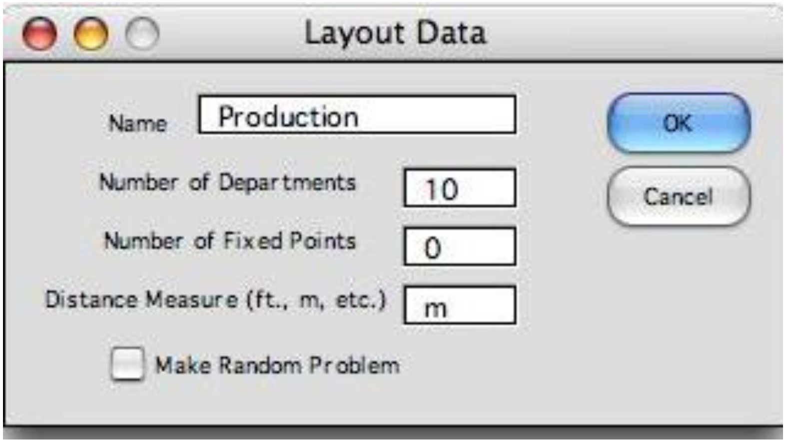
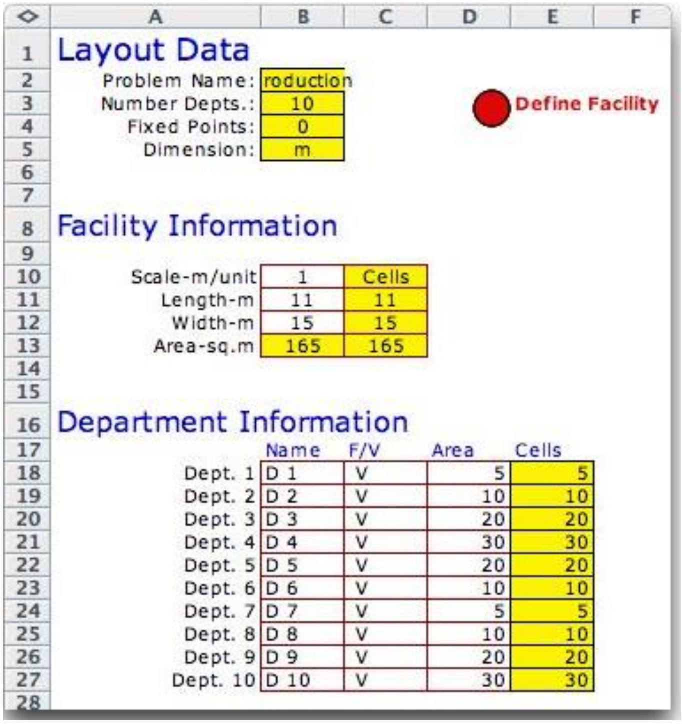
Facility Layout

Creating a New Layout

To create a new layout, select the **New Layout** Option from the **Facility Layout** menu. The dialog box below is presented. Provide the *Name* of the project, the *number of departments*, *number of fixed points* and the *distance measure*. When the *Make Random Problem* box is checked, random interdepartmental flows are provided. We will discuss the purpose of the fixed point parameter on page 23.



Pressing **OK** results in the *Layout Data* worksheet shown below. The data for the example is already filled in. The user should enter the facility *length* and *width* measured in the specified distance measure (meters in this case). The distance measure is converted into cells using the scale factor. The program limits the maximum facility dimensions to 50 cells wide by 100 cells long. When one of the specified plant dimension exceeds the limit, a scale factor greater than 1 must be entered to convert the distance measure to a cell measure. A scale factor greater than 1 reduces the size of the facility and results in quicker solution times.



Cells colored yellow should not be changed. They contain either formulas or quantities fixed by the program. The name defining the problem is reflected in the worksheet name and the named ranges on the worksheet so the name in cell B2 should not be changed. The number of departments is also fixed. The data cells with white backgrounds can be changed.

The department data is entered below row 16 of the worksheet.

Column B	holds the names of the departments.
Column C	holds the letters F or V. The letter F (fixed) means the department is fixed in location or sequence, and the letter V (variable) means the department location or sequence may be varied in the search for the optimum.
Column D	holds the department area expressed in square meters for the example.
Column E	holds the area expressed in cells. Since the example uses a scale factor of 1, the two measures are the same.

Departments labeled with an F in column C are fixed in sequence or location depending on the solution method chosen.

For the *Sequence* solution method, fixed departments retain their index provided in the *Initial Sequence*. Their locations may vary for different sequences when the variable departments have different areas.

For the *Traditional* solution method, fixed departments retain their locations provided in the *Initial Layout*.

The flow data is placed below the department data. This matrix is commonly called the *From-To Matrix*. A cell (*i*, *j*) holds the flow from department *i* to department *j*. The example flows were randomly generated by the program.

Flow Matrix

FROM \ TO	D 1	D 2	D 3	D 4	D 5	D 6	D 7	D 8	D 9	D 10
D 1				16						
D 2							11		16	
D 3	15	16		14	12		13	12		
D 4		18			13				16	
D 5						19		12		17
D 6		15	16	15			13	13		
D 7		16			16	14		13		
D 8			16			12				17
D 9		13	13		19	12				13
D 10	13	17				13	11	18		

Below the flow data, a matrix is provided to hold the material handling costs between departments. The default entries are 1 to indicate that all interdepartmental flows have the same cost, but these numbers can be changed to reflect different handling equipment, lot sizes and other factors.

Cost Matrix

FROM \ TO	D 1	D 2	D 3	D 4	D 5	D 6	D 7	D 8	D 9	D 10
D 1	1	1	1	1	1	1	1	1	1	1
D 2	1	1	1	1	1	1	1	1	1	1
D 3	1	1	1	1	1	1	1	1	1	1
D 4	1	1	1	1	1	1	1	1	1	1
D 5	1	1	1	1	1	1	1	1	1	1
D 6	1	1	1	1	1	1	1	1	1	1
D 7	1	1	1	1	1	1	1	1	1	1
D 8	1	1	1	1	1	1	1	1	1	1
D 9	1	1	1	1	1	1	1	1	1	1
D 10	1	1	1	1	1	1	1	1	1	1

When the data is ready, the button at the top of the page creates a second worksheet that holds the actual facility layout.

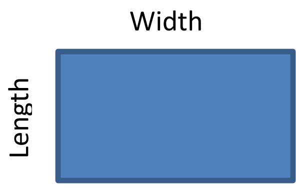
Defining the Facility

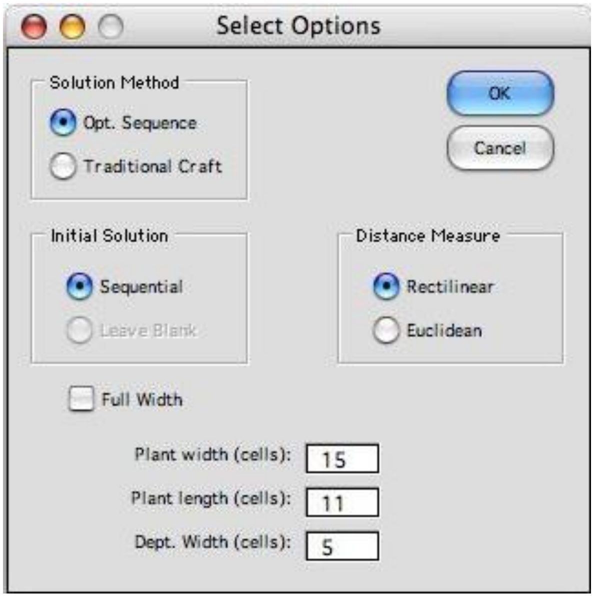
The button on the Layout Data worksheet 

presents the dialog box shown below with which the various solution options are selected.

The distance between two departments is the distance between their respective centroids. When material movement is parallel to the length and width boundaries of the plant, it is reasonable to use the *Rectilinear* measure. When the movement is via straight lines between the two centroids, the *Euclidean* measure is appropriate.

Two solution options are available, the *Optimum Sequence* method and the *Traditional Craft*. The length and width of the plant and the aisle width are set in the fields at the bottom.





The facility layout worksheet has various parameters and options listed at the top of the page as illustrated below.

At the top of the page in column B we see the name, number of departments, length and width of the facility, total area and the cost for the current layout. We hope to find a layout that minimizes the cost in cell B8. Column E holds parameters that are described subsequently.

Starting in row 11, a row is provided for each department.

Column A	holds the department name
column B	holds its color
column C	holds the area defined on the Layout Data worksheet
column D	holds the area defined for the department on the current layout
Columns E and F	hold the computed centroids of the department. For this example, we are using an *Aisle* layout.
Column G	shows the sequence number of the department.

The ranges shown in green hold numbers computed by the program.

Facility Layout

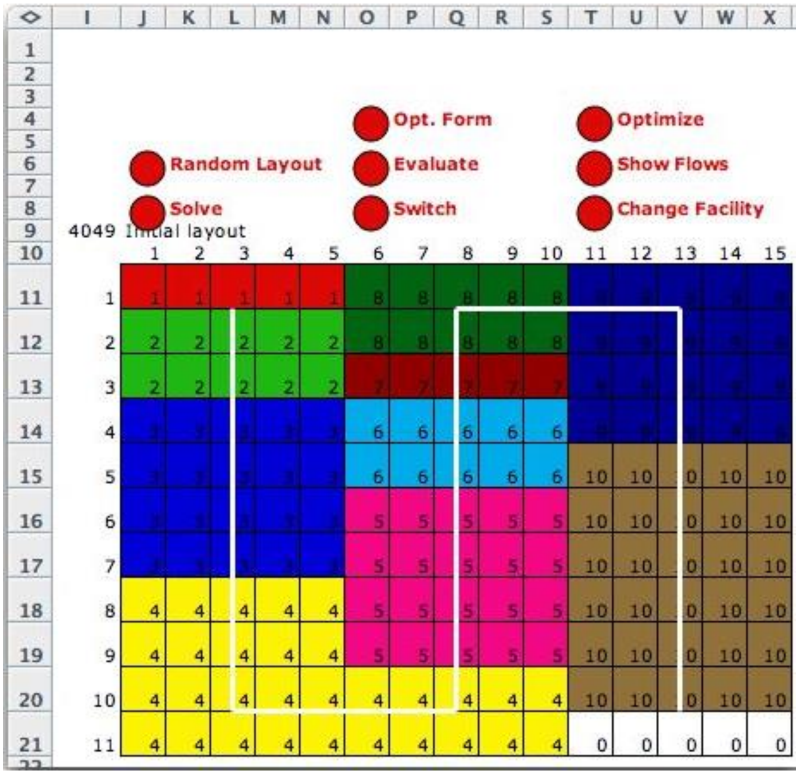
Problem Name:	Production	Method:	Sequence
Number Depts.:	10	Layout:	Aisle
Length(cells):	11	Fill Departments:	No
Width(cells):	15	Measure:	Rectilinear
Area (cells):	165	Number Aisles:	3
Cost:	4049	Dept. Width:	5

Department	Color	Area-required	Area-defined	x-centroid	y-centroid	Sequence
D 1	1	5	5	2.5	0.5	1
D 2	2	10	10	2.5	2	2
D 3	3	20	20	2.5	5	3
D 4	4	30	30	4.16666651	9.33333302	4
D 5	5	20	20	7.5	7	5
D 6	6	10	10	7.5	4	6
D 7	7	5	5	7.5	2.5	7
D 8	8	10	10	7.5	1	8
D 9	9	20	20	12.5	2	9
D 10	10	30	30	12.5	7	10

When the *Sequential* button is selected for the initial solution, a layout is automatically generated with the departments listed in numerical order in column G. This is the default initial sequence, but the numbers in this column can be changed to accommodate a user-supplied initial sequence. This is important if some departments are given a fixed index in the sequence.

The *Leave Blank* option is available only with traditional craft. Here the layout is left blank initially and the user must manually define the department locations in the layout. The layout is immediately to the right of this data on the worksheet.

The initial layout for the example was generated with the default sequence using an Aisle layout and is shown below.



The layout starts in cell J11. The number of colored cells to the right of J11 is the width of the facility and the number of colored cells below J11 is its length. The locations of the departments are specified by department indices or colors. The initial layout can be entered manually or automatically. It is most convenient to use an automatic *Aisle* layout. The aisles are indicated by the white lines running through the centers of the departments.

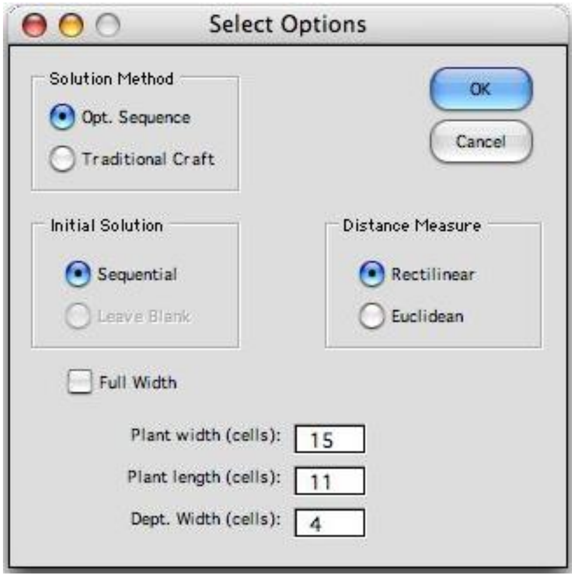
The aisle layout is determined by the department width, which for the example is equal to 5, and the sequence of departments. For the example, we have chosen the sequence as the department indices. The first department in the sequence starts in cell J11 and is assigned cells to the right until the department area is completely defined or the department width is reached. For the example, department 1 requires all five cells. The second department is placed below the first, using as many rows as necessary to enter the entire area. We continue to add departments until the entire length of the facility is used. Then the departments are placed at the bottom of aisle 2. In the example, department 4 uses both aisles 1 and 2. The layout continues up aisle 2 until the top is reached for department 8. Then the layout proceeds down aisle 3 until all departments are placed. For the example, five cells remain unused. The white lines on the layout show the serpentine nature of this layout procedure.

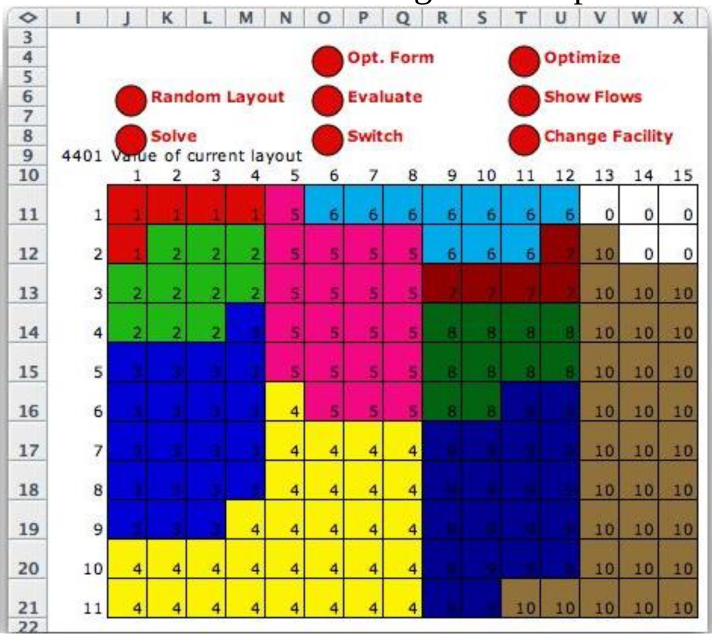
Change Facility:

To illustrate the effect of a different department width we click 

button. The dialog below is presented. Any of the options may be changed. In this case, we change the depth to 4.

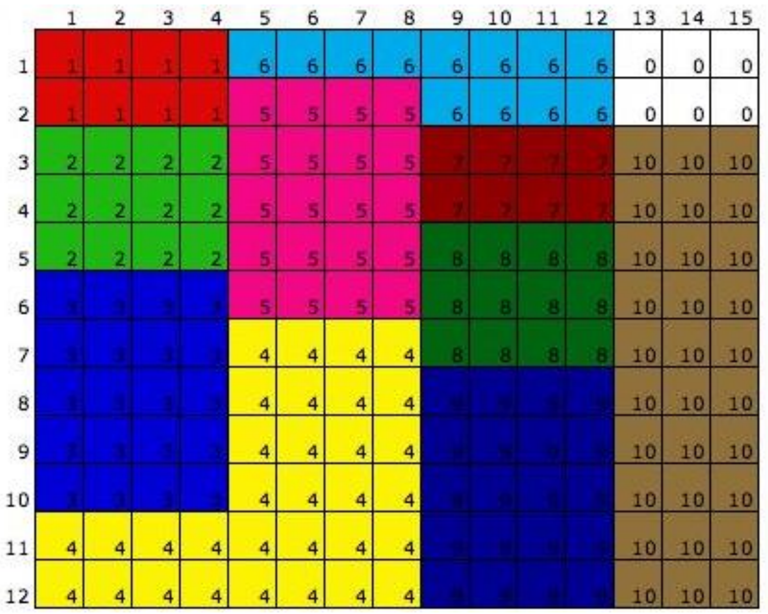
Because the department areas are not multiples of 4, the layout becomes more irregular. This affects that accuracy of distance measurements since department centroids are no longer in the center of rectangular departments.





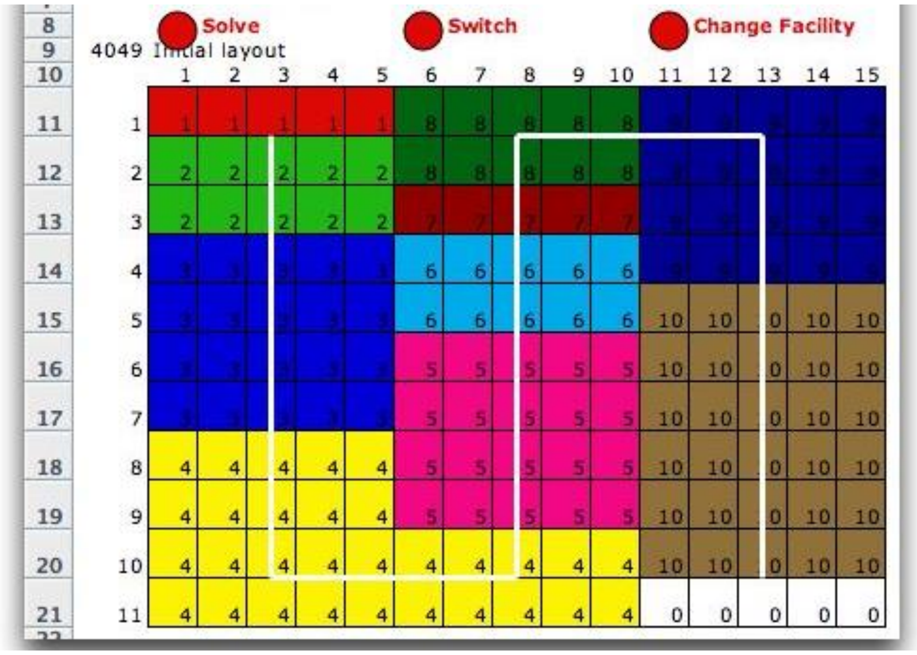
An alternative layout that more nearly maintains rectangular departments is obtained when the *Full Width* box is checked. The result for the example is shown below. For this option, departments are increased in area so that they fill an integral number of rows of the layout. Note that the area of department 1 has increased from 5 to 8. Of course, when department areas are increased, it may be necessary to increase the size of the facility. This is the case for the example where it is necessary to increase the length of the facility to 12 so that the larger departments can be accommodated.

The next step is to search for the optimum layout. We consider first the *Optimum Sequence* method and then the *Traditional Craft* method.



Optimum Sequence Method

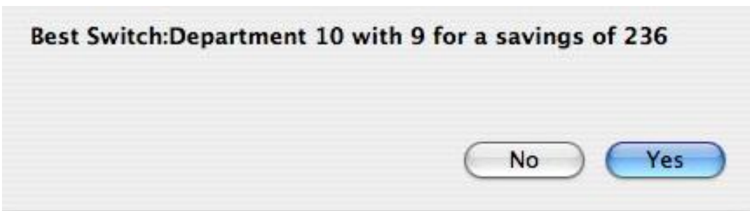
The sequential layout is defined by the department width and the sequence used to layout the departments along the aisles of the facility. The *optimum sequence* method of <u>solution starts with an arbitrary اعتباطى initial sequential solution and tries to improve the layout by switching two departments in the sequence</u>. At each step, the method computes the cost changes for all possible switches of two departments and chooses the most effective pair. The two departments are switched in the sequence and the method repeats. The process STOPS when no switch results in a reduced cost. To illustrate we start with the departments sequenced in order of department index as below.



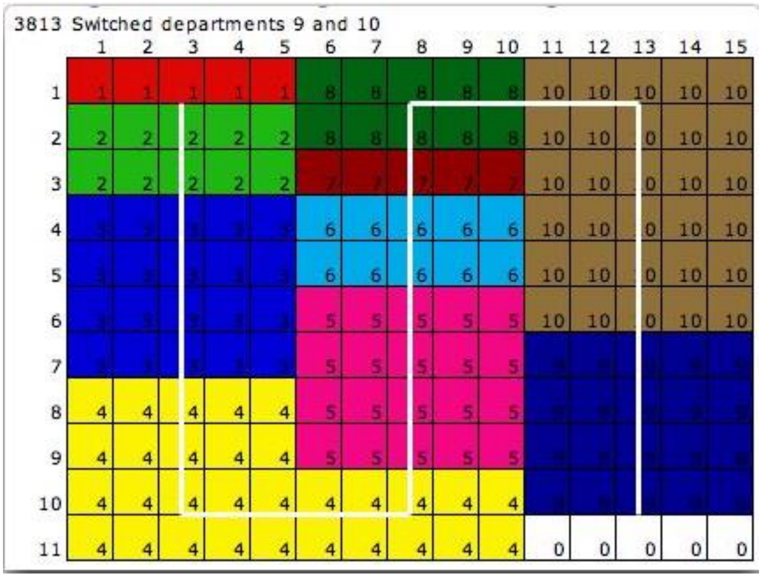
Clicking the 

button presents the dialog below.

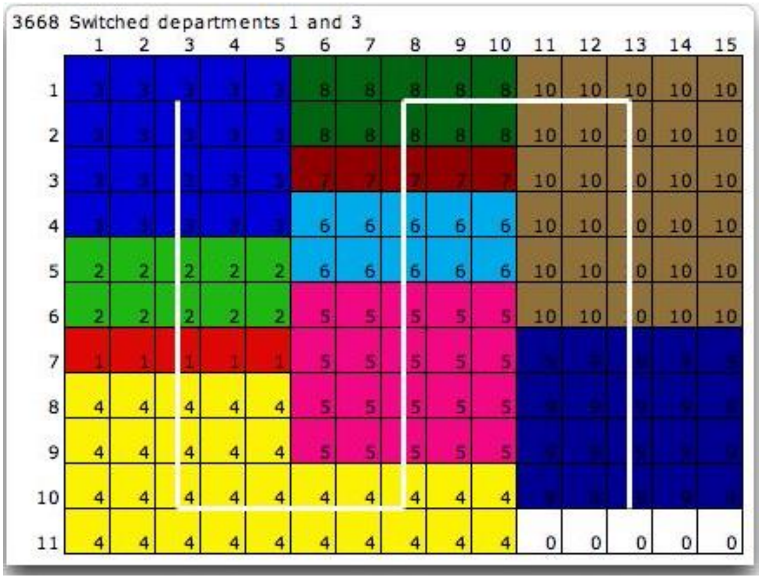
Starting from the initial sequence, the program finds the best switch and presents its conclusion below.



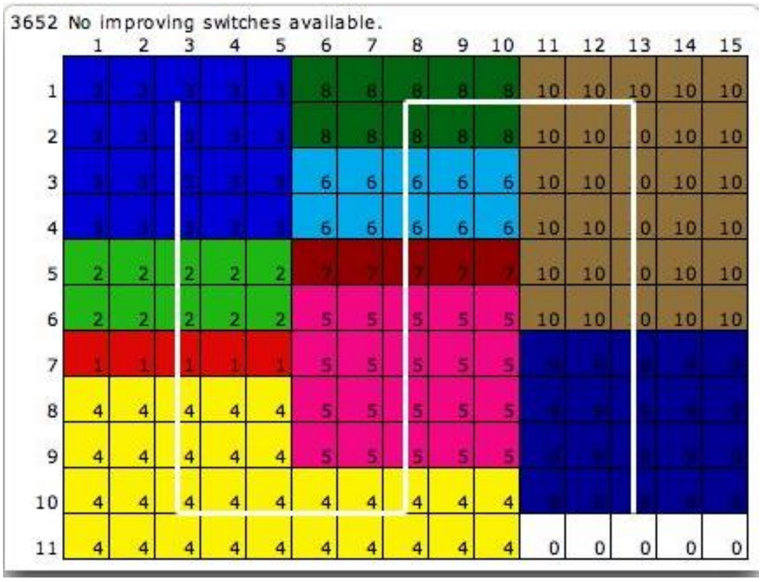
Clicking *Yes* causes the change in layout. Notice that departments 9 and 10 are switched in sequence and in location.



The next best switch is departments 1 and 3. Notice that the change in sequence affects the relative locations of the departments switched. When the departments are of different size, the locations of all departments between are also adjusted.

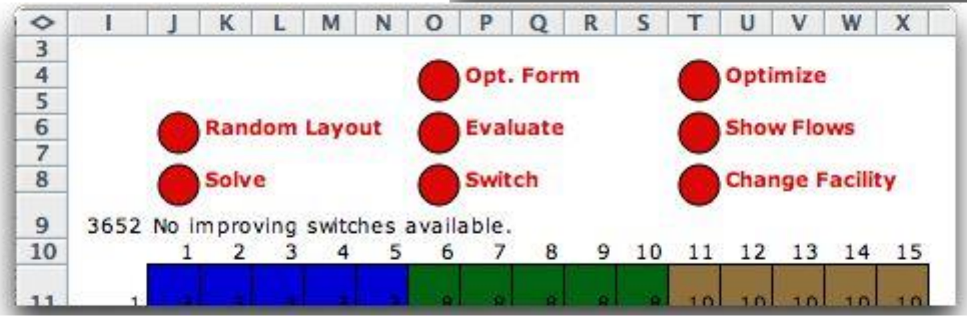


We restarted the process with the initial sequence and chose the *Do Not Stop* option. The process stopped with no further improvement after one additional switch of departments 6 and 7. The result is shown.



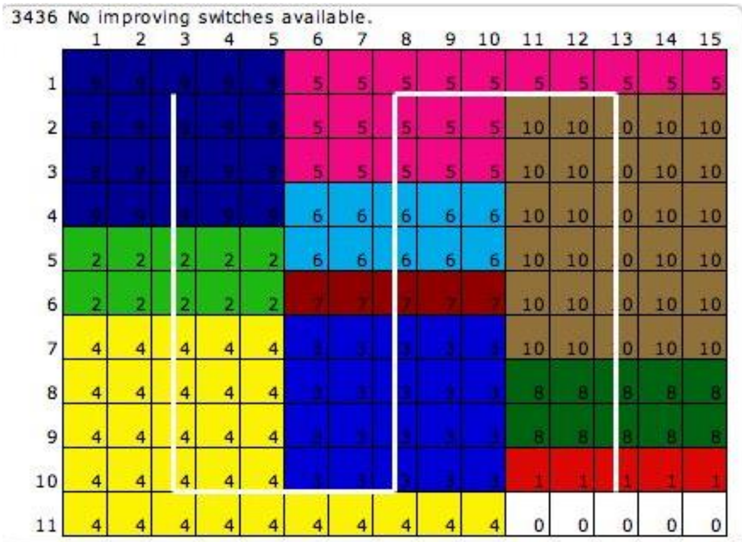
To the right of the layout appears a summary of the switches made during the process.

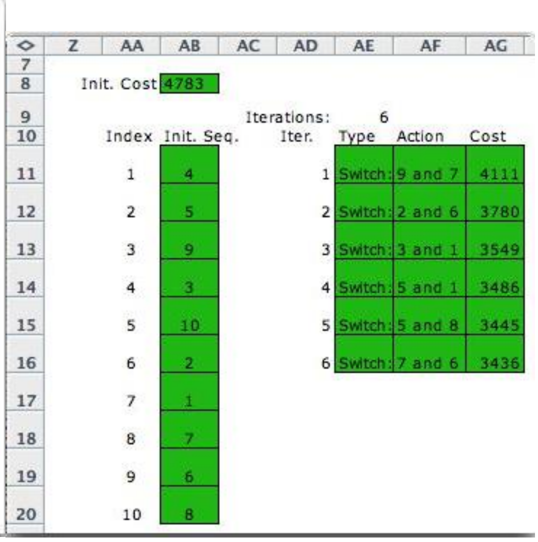
Above the layout there are several additional buttons. The Random Layout button generates a random sequence of departments and places them on the layout. Since the switch heuristic does not guarantee optimality, <u>it is useful to start at several different solutions and select the best.</u>



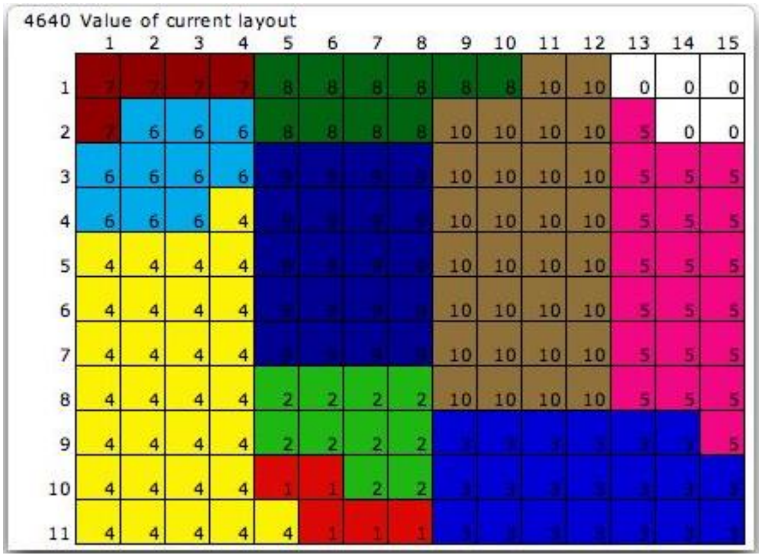
The Evaluate button evaluates the current sequence placed in column G of the worksheet. The user can manually change the sequence. The Switch button allows the user to force the program to switch two departments. The Show Flows button draws lines between centroids to show the flows.

For the example we generated a random sequence using the Random Layout button and performed the switch procedure until no improvement was possible. The resulting layout is shown below with the summary results. Note that this layout is much different that the one previously discovered. Its cost is slightly larger than before.

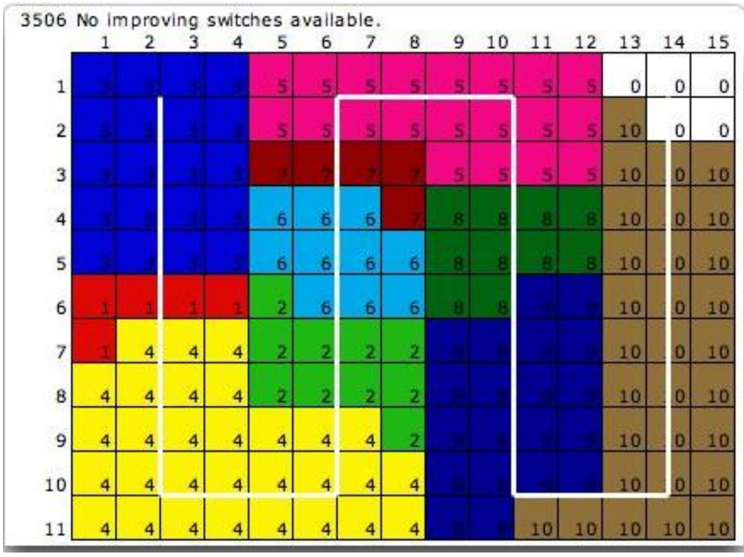




We initiated the layout with a department width of 4 with the resultant sequential layout as below.



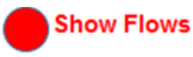
After a sequence of switches we obtain the final layout shown with its summary below.

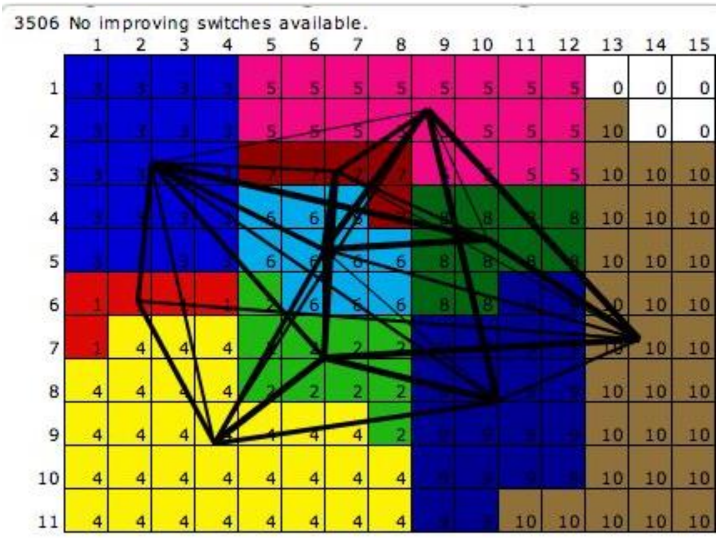


Init. Cost 4640

Iterations: 6

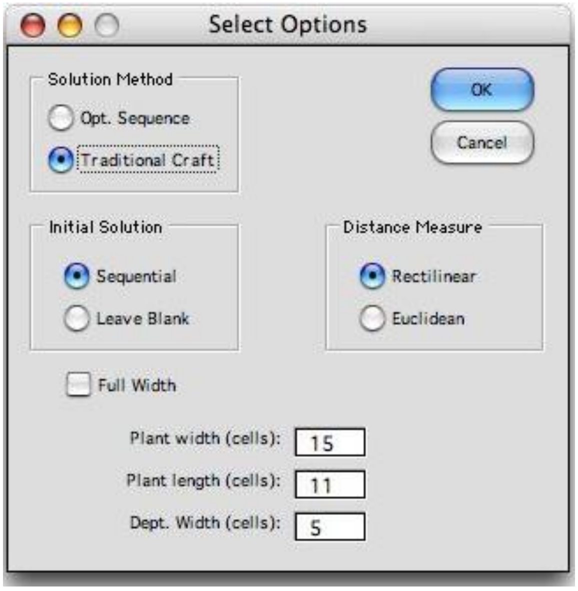
Index	Init. Seq.	Iter.	Type	Action	Cost
1	4	1	Switch:	3 and 9	4262
2	5	2	Switch:	3 and 7	4073
3	9	3	Switch:	1 and 6	3746
4	3	4	Switch:	2 and 6	3615
5	10	5	Switch:	5 and 10	3517
6	2	6	Switch:	5 and 8	3506
7	1				
8	7				
9	6				
10	8				

Clicking the  button shows the flow lines between departmental centroids. The thickness of a line shows the relative magnitude of the flow-cost between two of the departments. Four different thickness are used with a thin line indicating a relative small flow-cost between two departments and a thick line indicating a large flow-cost.



The sequential layout can be easily automatically generated. The sequential layout method quickly finds good layouts for alternative facility designs. The *Traditional Craft* method is an alternative.

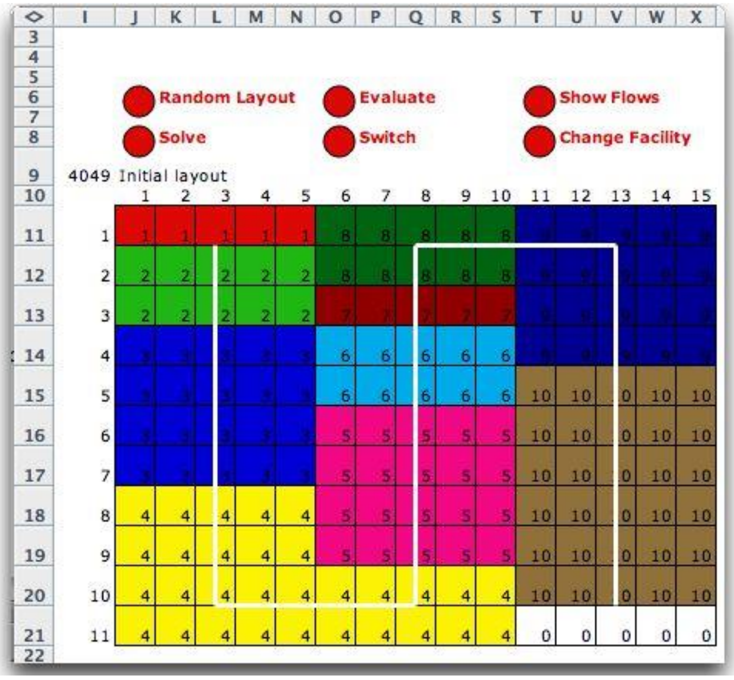
2. Traditional CRAFT Method



To create a worksheet for the ***Traditional Craft*** option, click that button on the *Options* dialog Define Facility. The most convenient way to initialize the layout is with a ***sequential*** layout. Otherwise, click the ***Leave Blank*** button.

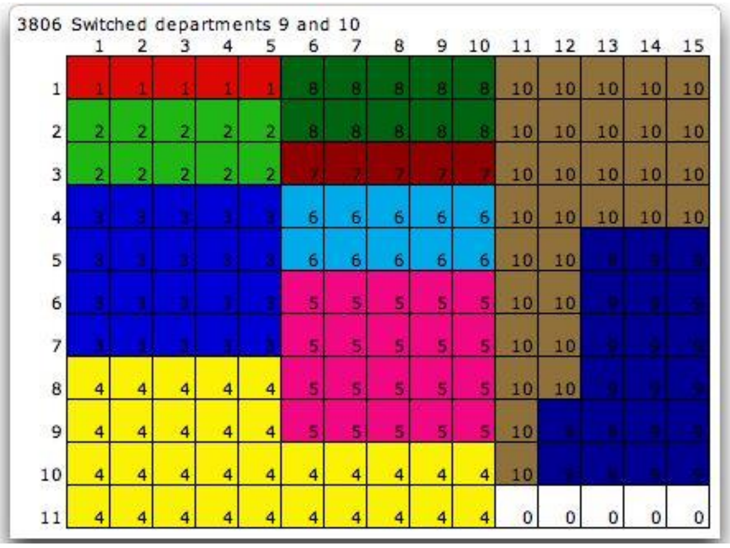
2.1 Sequential Initial Solution

To illustrate the CRAFT method we start with a **sequential** layout with the departments sequenced in order of department index as below. The CRAFT method is not limited to this kind of initial solution, but it is convenient since the process is automatic.



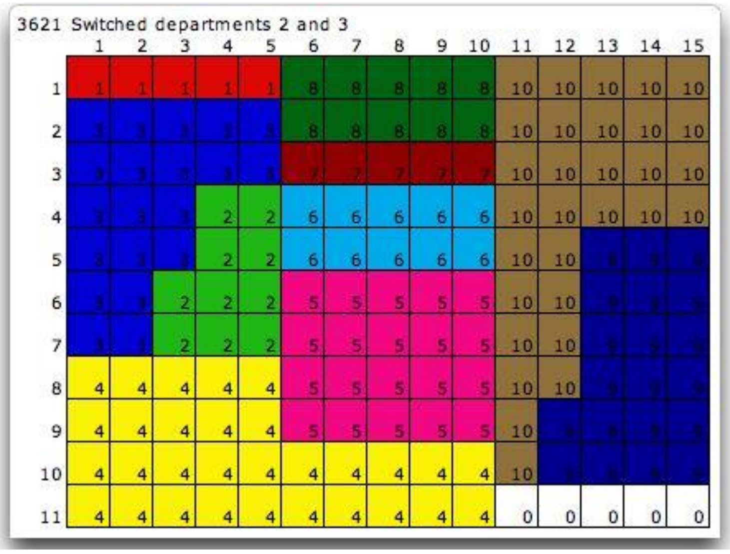
Similar to the sequential method, the CRAFT method also investigates departments for switching. Candidates for switching are pairs of departments that have the same area or pairs of departments that are adjacent in the layout. For example, consider the feasible switches that involve department 6 in the layout above. Departments 2 and 8 have the same area, so the pairs (2, 6) and (6, 8) are feasible. Departments that are adjacent to 6 are departments 3, 5, 7, 9 and 10, so the pairs involving these departments and department 6 are feasible.

To evaluate the effect of switching the two departments, the CRAFT method assumes that the centroids of the two departments are switched and computes the resultant cost savings. When the two departments are the same size, this evaluation is accurate. When the departments have different sizes, the centroids of the departments do not exactly switch locations. In this case the evaluation may be not be accurate and a switch that looks promising may actually increase the cost of the layout. The CRAFT method implemented by this add-in terminates if this occurs.

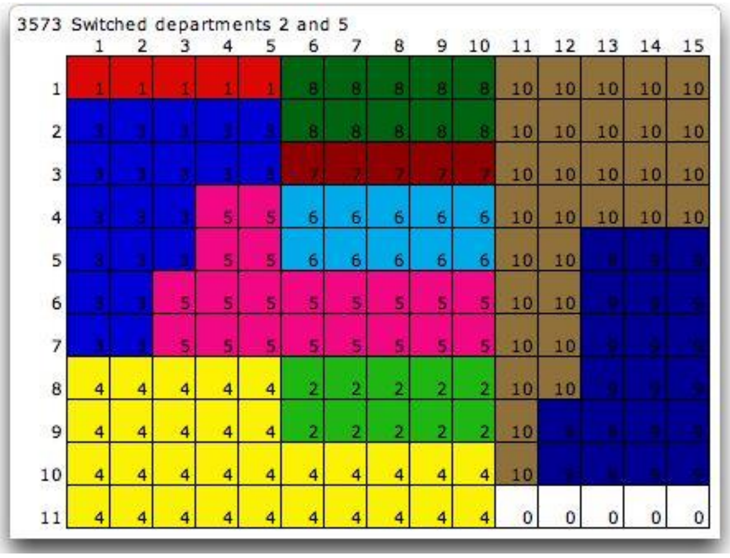


For the example, the best feasible pair is 9 and 10. Since the two departments are different sizes, there are many alternatives for arranging the cells of the smaller sized department 9 into the larger area formerly holding department 10. The program has an algorithm for choosing the arrangement that results in the layout below. Although one might question the logic of this arrangement, it is difficult to program an algorithm that always makes the most reasonable assignment. The user can adjust the assignment of cells by changing cell indices, but this is a manual operation.

The next iteration interchanges departments 2 and 3.



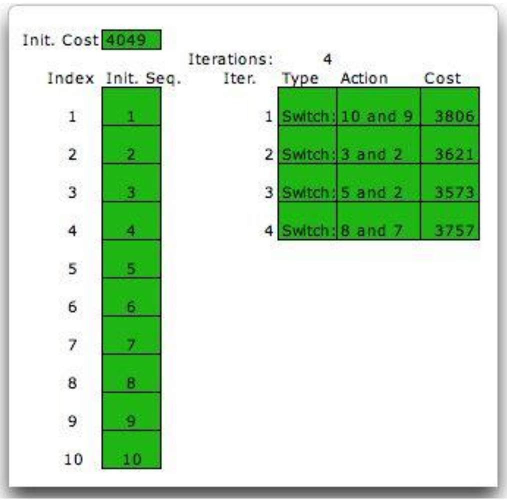
The next iteration interchanges departments 2 and 5. Note that this change causes department 5 to overlap two widths of the formerly sequential layout. Although we started with a sequential layout, the CRAFT method does not consider department widths in its algorithms. We have erased the lines representing aisles, because no aisles are implied by the CRAFT layout.



3573 Switched departments 2 and 5

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	1	1	1	1	1	8	8	8	8	8	10	10	10	10	10
2	3	3	3	3	3	8	8	8	8	8	10	10	10	10	10
3	3	3	3	3	3	7	7	7	7	7	10	10	10	10	10
4	3	3	3	5	5	6	6	6	6	6	10	10	10	10	10
5	3	3	3	5	5	6	6	6	6	6	10	10	9	9	9
6	3	3	5	5	5	5	5	5	5	5	10	10	9	9	9
7	3	3	5	5	5	5	5	5	5	5	10	10	9	9	9
8	4	4	4	4	4	2	2	2	2	2	10	10	9	9	9
9	4	4	4	4	4	2	2	2	2	2	10	9	9	9	9
10	4	4	4	4	4	4	4	4	4	4	10	9	9	9	9
11	4	4	4	4	4	4	4	4	4	4	0	0	0	0	0

The program next determines that if the centroids of departments 7 and 8 are switched, the cost of the layout will be reduced. When the switch is actually made, the cost increases. The add-in recovers the solution before the switch and terminates. The summary of the CRAFT process is shown.



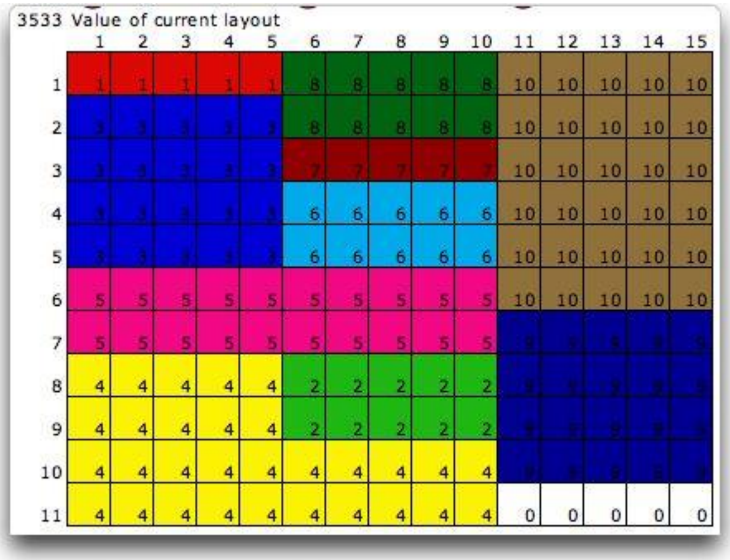
Init. Cost 4049

Iterations: 4

Index	Init. Seq.
1	1
2	2
3	3
4	4
5	5
6	6
7	7
8	8
9	9
10	10

Iter.	Type	Action	Cost
1	Switch:	10 and 9	3806
2	Switch:	3 and 2	3621
3	Switch:	5 and 2	3573
4	Switch:	8 and 7	3757

We rearranged some of the cells <u>manually</u> to obtain more regular departments. The results have a lower cost than the final solution obtained by the algorithm. This solution could not have been obtained with the sequential method because department 5 spans two widths of 5 cells each.

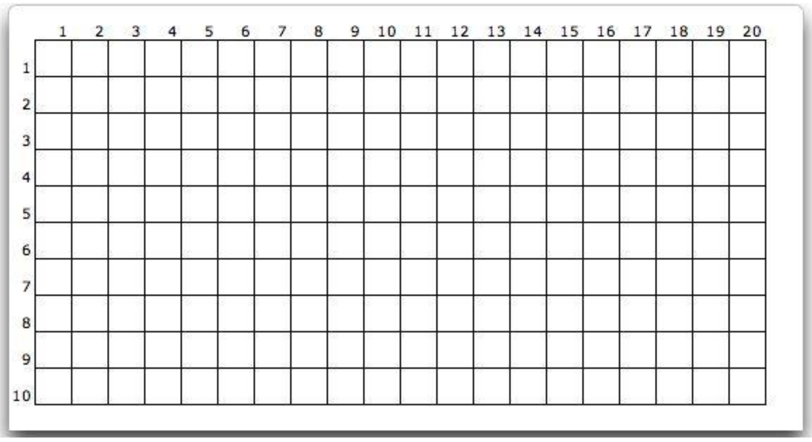


3533 Value of current layout

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	1	1	1	1	1	8	8	8	8	8	10	10	10	10	10
2	3	3	3	3	3	8	8	8	8	8	10	10	10	10	10
3	3	3	3	3	3	7	7	7	7	7	10	10	10	10	10
4	3	3	3	3	3	6	6	6	6	6	10	10	10	10	10
5	3	3	3	3	3	6	6	6	6	6	10	10	10	10	10
6	5	5	5	5	5	5	5	5	5	5	10	10	10	10	10
7	5	5	5	5	5	5	5	5	5	5	9	9	9	9	9
8	4	4	4	4	4	2	2	2	2	2	9	9	9	9	9
9	4	4	4	4	4	2	2	2	2	2	9	9	9	9	9
10	4	4	4	4	4	4	4	4	4	4	9	9	9	9	9
11	4	4	4	4	4	4	4	4	4	4	0	0	0	0	0

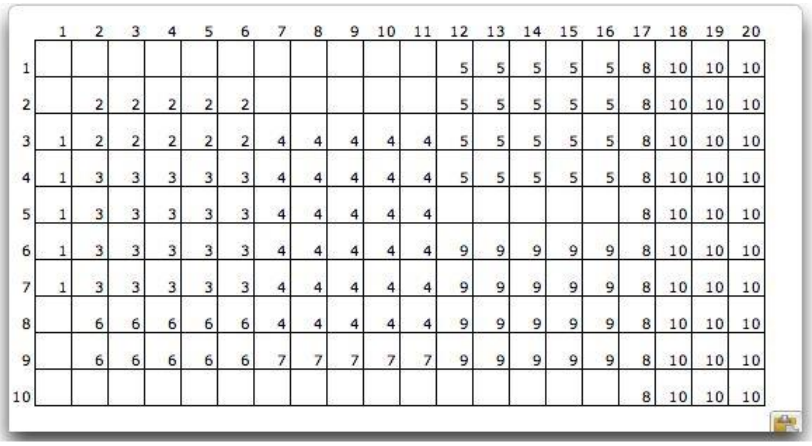
2.2 Blank Initial Solution

The CRAFT method is not restricted to initial layouts obtained by the sequential method. By choosing ***Blank*** on the dialog, a blank layout is presented.



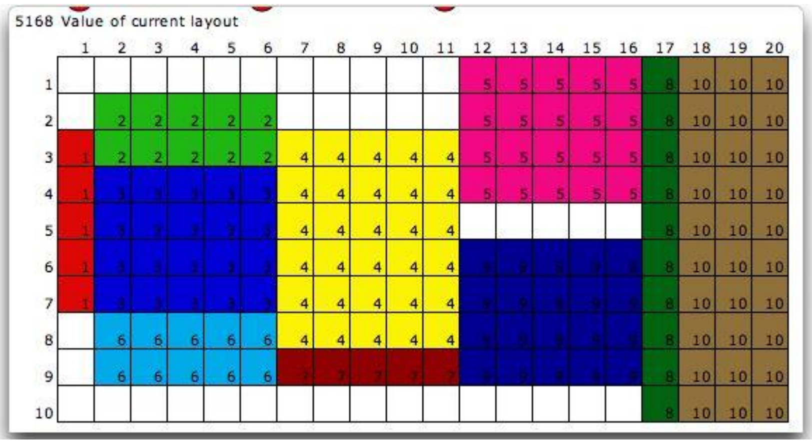
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1																				
2																				
3																				
4																				
5																				
6																				
7																				
8																				
9																				
10																				

An initial layout is constructed by placing numbers or colors on the layout. One possible initial layout is below.



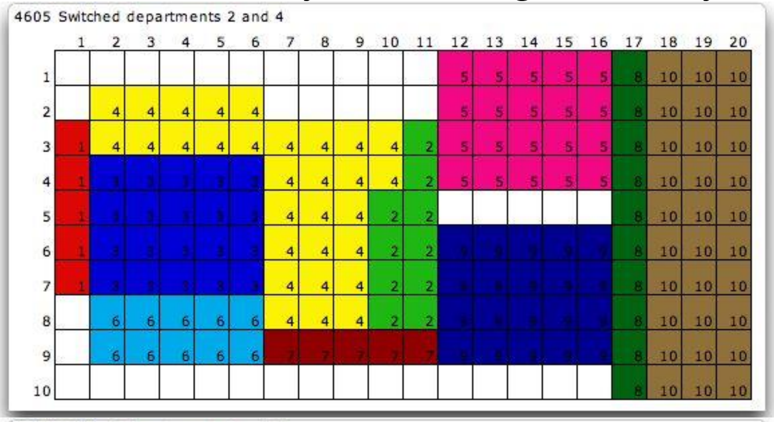
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1												5	5	5	5	5	8	10	10	10
2		2	2	2	2	2						5	5	5	5	5	8	10	10	10
3	1	2	2	2	2	2	4	4	4	4	4	5	5	5	5	5	8	10	10	10
4	1	3	3	3	3	3	4	4	4	4	4	5	5	5	5	5	8	10	10	10
5	1	3	3	3	3	3	4	4	4	4	4						8	10	10	10
6	1	3	3	3	3	3	4	4	4	4	4	9	9	9	9	9	8	10	10	10
7	1	3	3	3	3	3	4	4	4	4	4	9	9	9	9	9	8	10	10	10
8		6	6	6	6	6	4	4	4	4	4	9	9	9	9	9	8	10	10	10
9		6	6	6	6	6	7	7	7	7	7	9	9	9	9	9	8	10	10	10
10																	8	10	10	10

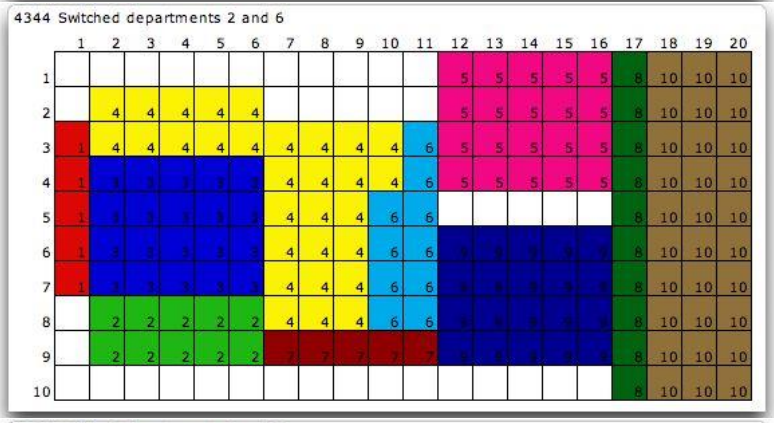
The blank spaces might represent the actual building shape or unusable portions of the facility. Pressing the ***Evaluate*** button, colors the cells and evaluates the layout.

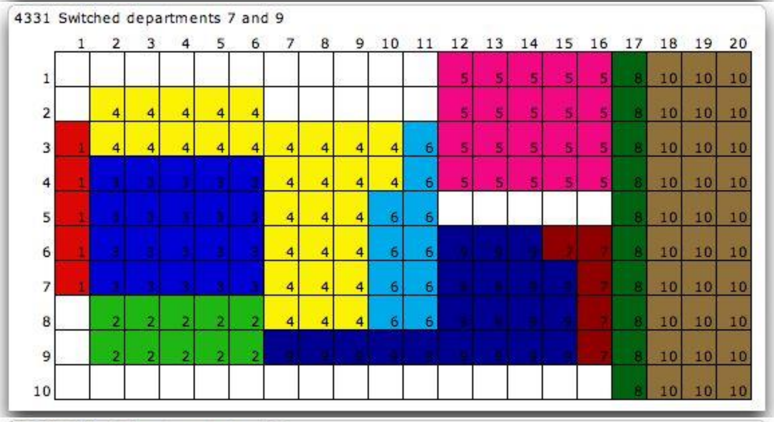


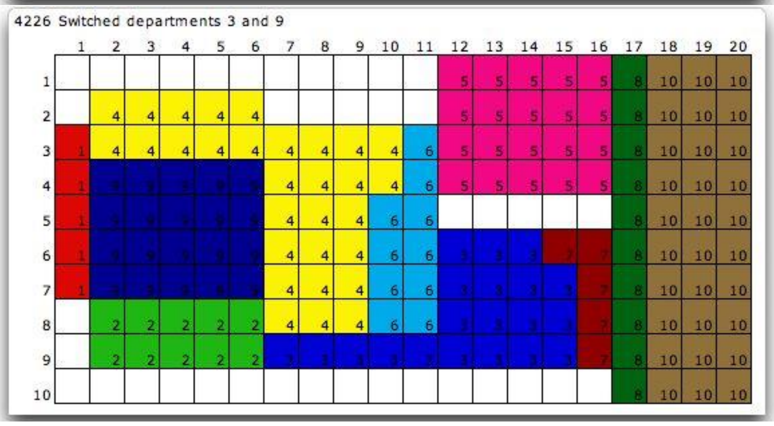
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1												5	5	5	5	5	8	10	10	10
2		2	2	2	2	2						5	5	5	5	5	8	10	10	10
3	1	2	2	2	2	2	4	4	4	4	4	5	5	5	5	5	8	10	10	10
4	1	3	3	3	3	3	4	4	4	4	4	5	5	5	5	5	8	10	10	10
5	1	3	3	3	3	3	4	4	4	4	4						8	10	10	10
6	1	3	3	3	3	3	4	4	4	4	4	9	9	9	9	9	8	10	10	10
7	1	3	3	3	3	3	4	4	4	4	4	9	9	9	9	9	8	10	10	10
8		6	6	6	6	6	4	4	4	4	4	9	9	9	9	9	8	10	10	10
9		6	6	6	6	6	7	7	7	7	7	9	9	9	9	9	8	10	10	10
10																	8	10	10	10

The iterations of CRAFT are shown by the following series of layouts.









The last switch is hard to see because 3 and 9 are similar shades of blue. The method terminates when a proposed switch of departments 6 and 9 is unsuccessful in improving the solution.

The CRAFT method only uses the cells defined by the initial layout. Thus cells can be designated as unused by simply leaving them blank. The procedure will never use them.

Fixed Points

It is often true that department flow also passes to or from fixed points in the facility. For example, the facility probably includes one or more loading or shipping docks. Raw materials arrive at some docks while finished goods leave at others. Workers may travel between departments and fixed points within the facility, such as restrooms or tool cribs.

We have included five fixed points in the facility considered previously. The data for the fixed points appears to the right of the interdepartmental flow data. The x-proportion and y-proportion tell where the fixed point is located relative to the width and length of the facility. When the proportions are (0, 0), the point is at the upper-left corner of the facility. When the proportions are (1, 1), the point is at the lower-right corner of the facility. Proportions (0.5, 0.5) places the point in the center of the facility area. We have entered data for flows between departments and fixed points as below.

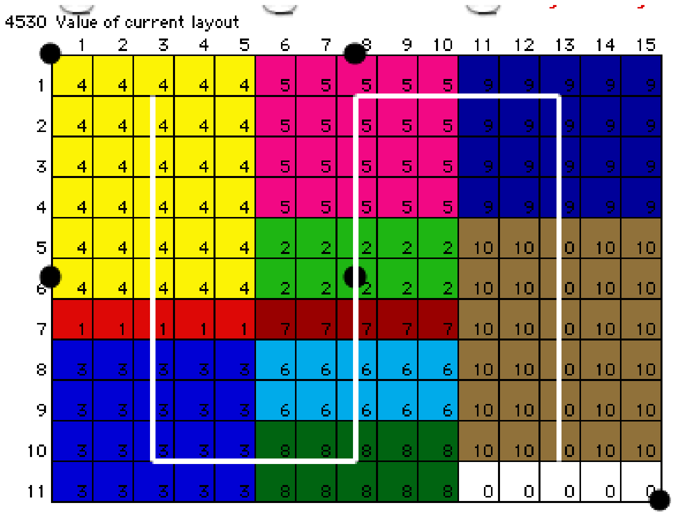
Fixed Points

	D 9	D 10		1	2	3	4	5
31			x-Prop.	0	1	0.5	0.5	0
32			y-Prop.	0	1	0.5	0	0.5
33				20				
34	16					10		
35						12		
36	16					13		
37		17				14	20	
38						15		20
39						14		
40		17				13		
41		13				12		
42					20	10		

Fixed Point Costs

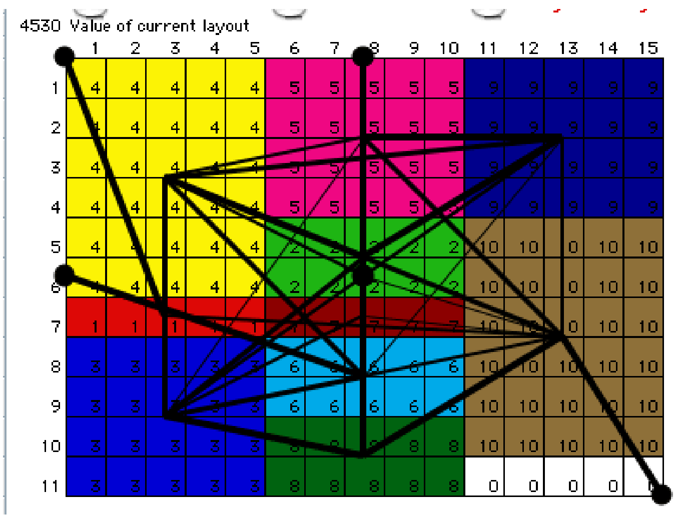
	D 9	D 10	1	2	3	4	5
48	1	1	1	1	1	1	1
49	1	1	1	1	1	1	1
50	1	1	1	1	1	1	1
51	1	1	1	1	1	1	1
52	1	1	1	1	1	1	1
53	1	1	1	1	1	1	1
54	1	1	1	1	1	1	1
55	1	1	1	1	1	1	1
56	1	1	1	1	1	1	1
57	1	1	1	1	1	1	1

In diagrams showing the layout, the fixed points are shown as black dots.



The cost of flow to the fixed points is considered during the optimization. The solution for the example is shown below with the flow-cost lines superimposed.

As many as 50 fixed points may be included in the facility.



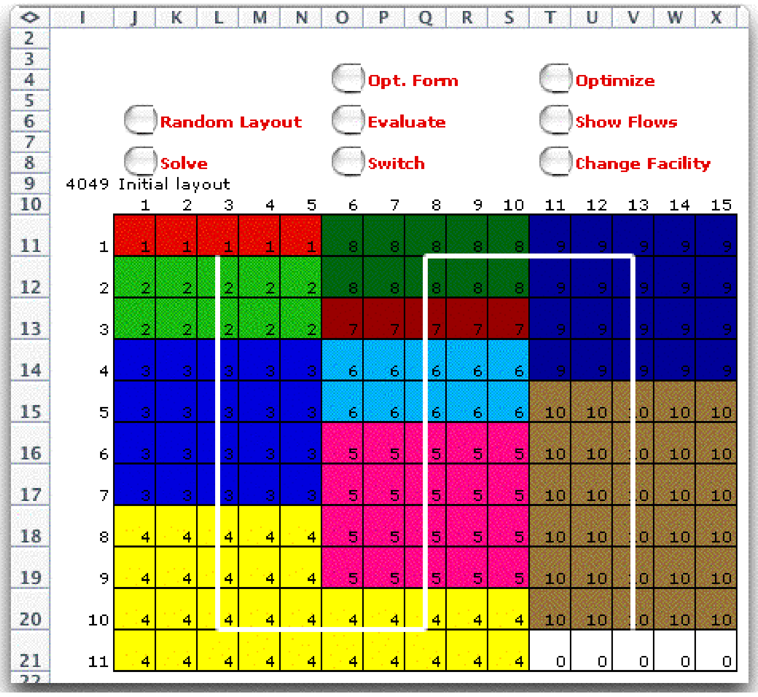
-Layout Buttons

When a workbook is opened on a computer different than the one in which it was created, the buttons on the worksheets are not linked to the Layout Add-in. Selecting the Layout Buttons menu items, recreates the buttons and links them to the resident add-in.

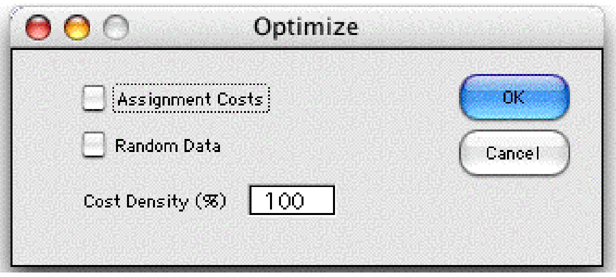
Optimize

For more extensive searches for the optimum of a sequential layout we use the capabilities of the *Optimize* add-in. To use the methods described on this page the *Optimize* add-in must be installed. When the sequential layout worksheet is created, two additional buttons are placed above the graphical display of the layout. The *Optimize Form* button, shown in column O of the figure below, constructs a form used for the combinatorial search process and creates the necessary links between the form and the layout data. The *Optimize* button, in column T, calls the dialog that sets the parameters for a combinatorial search and initiates the search.

We use the example described earlier for illustration. The initial layout below has the departments sequenced in numerical order.



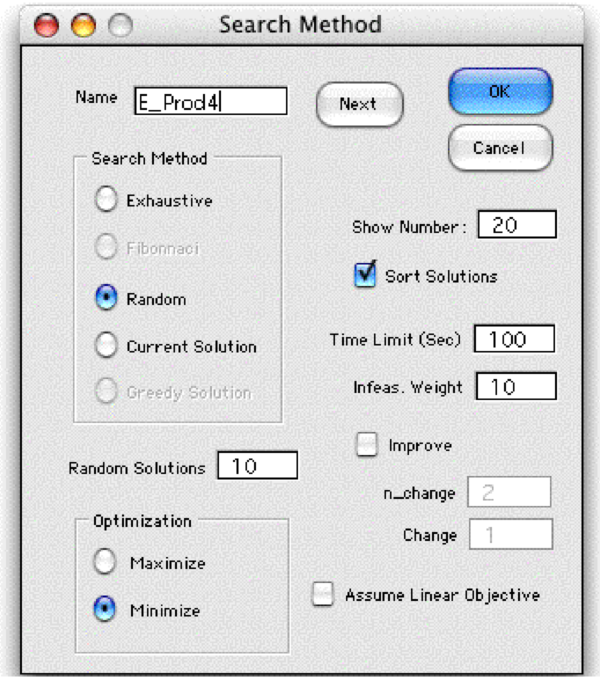
Clicking the *Optimize Form* button brings a dialog that controls whether the model includes assignment costs and restrictions or not. For this example we choose to not include the assignment costs and illustrate the other option later.



Clicking the OK button creates the form shown below at the right of the layout. The form shows the initial permutation describing the layout. Rows 3 through 5 hold information used by the search procedure. Cell AL has a link to Cell B8, where the computed value of the layout is calculated. The range of cells AJ8 through AS8 are manipulated by the search algorithms. They are linked by Excel formulas to the range G11 through G20, the cells that define the sequence for the Layout add-in. The cells in row 10 are constructed by the Optimize add-in but are not used when assignment costs are not considered. The *Feasibility* conditions defined by cells AN3 and AN4 are not used for the example.

	AI	AJ	AK	AL	AM	AN	AO	AP	AQ	AR	AS
1											
2	**Optimize**			Objective		Feasible					
3	Name	E_Prod4	Dir.	Min	State	TRUE					
4	Search Method	Current	Value	4049	Value	0					
5	Problem	Permute	Algorith	layout.x	la!eval_layoutcomb						
6	Variables	1	2	3	4	5	6	7	8	9	10
7	Name	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10
8	Permutation	1	2	3	4	5	6	7	8	9	10
9											
10	Obj. Terms	0	0	0	0	0	0	0	0	0	0

Clicking the *Optimize* button presents the *Search* dialog with various options for searching for the optimum permutation and the associated layout. For the illustration we have chosen to randomly generate 10 permutations or layout sequences. Notice that the form does not allow a *Greedy* solution. We have disabled this button because the algorithm of the *Optimize* add-in used for the greedy solution of permutations does not work for the layout application.



The *Optimize* add-in generates 10 random permutations and the *Layout* add-in evaluates them. The best of the 10 are placed on the combinatorial form. The 10 solutions appear to the right of this display (shown below the form on this page).

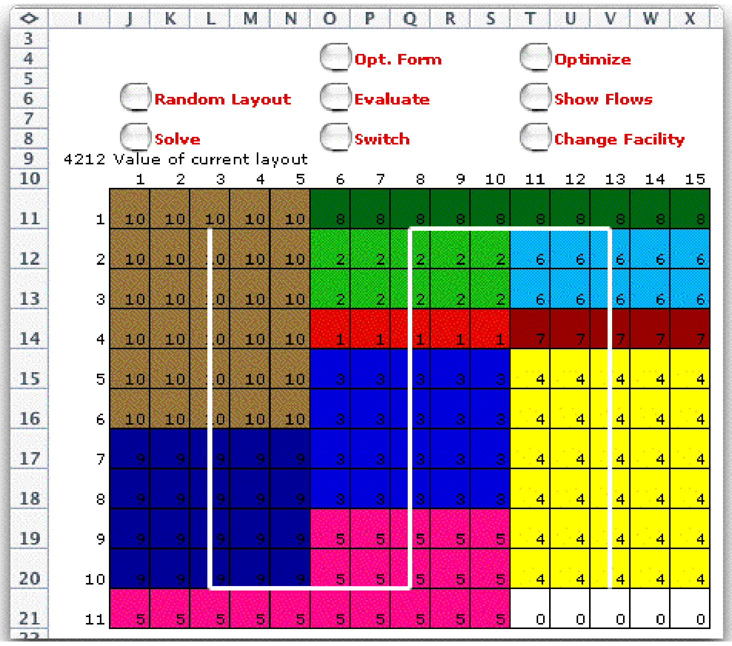
	AI	AJ	AK	AL	AM	AN	AO	AP	AQ	AR	AS
1											
2	**Optimize**			Objective		Feasible					
3	Name	E_Prod4	Dir.	Min	State	TRUE					
4	Search Method	Random	Value	4212	Value	0					
5	Problem	Permute	Algorith	layout.x	la!eval_layoutcomb						
6	Variables	1	2	3	4	5	6	7	8	9	10
7	Name	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10
8	Permutation	5	6	4	10	3	8	9	7	2	1
9											

Best Obj.: 4212 Best Found
Search time: 1 seconds
Runs: 11 Num.: 11 Imp.: 0
Complete: 100%
Stop Interval: 100

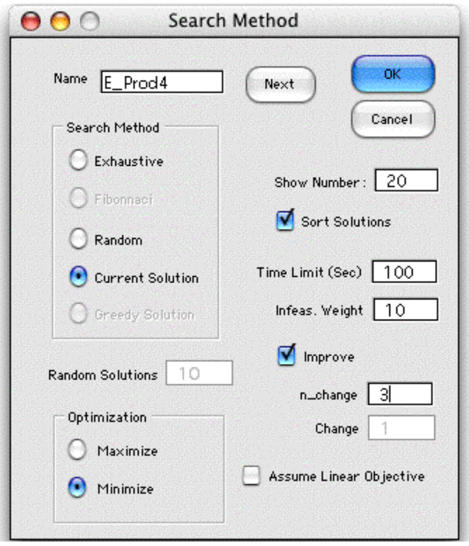
Sorted Feasible Solutions

Run	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	Obj.
10	5	6	4	10	3	8	9	7	2	1	4212
11	5	6	4	10	3	8	9	7	2	1	4212
4	1	6	8	2	7	10	4	9	3	5	4307
3	1	2	5	3	6	8	7	9	10	4	4482
8	9	8	10	3	2	7	5	1	4	6	4519
2	5	9	4	10	2	7	8	3	1	6	4550
7	2	5	4	9	3	8	7	10	6	1	4557
5	1	6	3	4	9	10	7	8	5	2	4701
9	8	7	4	6	1	3	5	9	2	10	4918
6	4	1	7	8	5	3	10	6	9	2	4951
1	2	8	10	7	3	5	6	1	4	9	5120

The layout associated with the best of the solutions is shown below. It happens that this solution is not as good as the initial solution.



We continue in our search for the optimum by starting from the best random result and choosing the improvement option that tries all 2 and 3-change variations of the layout. The process first tries all 2-change variations and whenever a change results an improvement, the two permutation positions are switched in value. The process continues until no 2-change switch results in improvement, then all 3-change switches are evaluated. The program terminates when a complete run through the changes results in no improvement.



The results are shown below. The layout measure has been improved, but there is no guarantee that the solution is optimal. Along with the results, the improving solutions encountered during the search are listed starting in column AU. The best solution is repeated as run 381. The time required for the 381 evaluations was 28 seconds on the author's computer. Each evaluation requires a call to the subroutine *eval_layoutcomb* in the *Layout* add-in. Each evaluation requires significant computation effort.

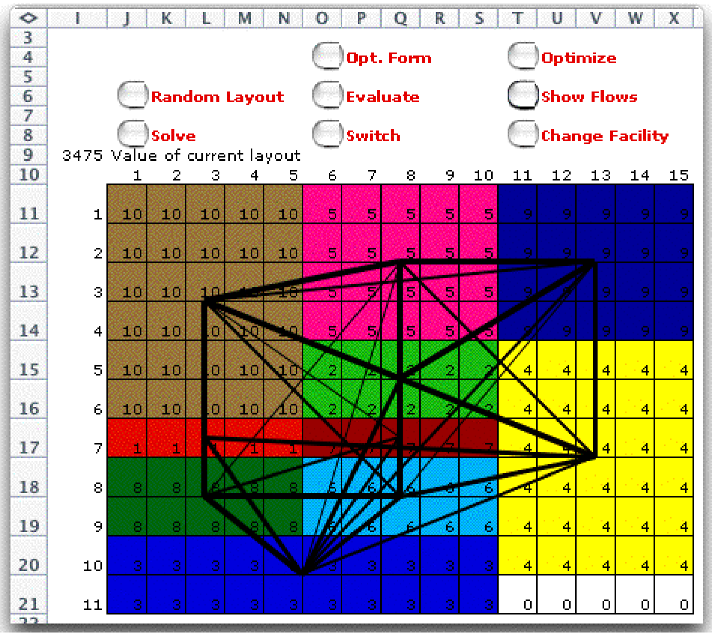
	AI	AJ	AK	AL	AM	AN	AO	AP	AQ	AR	AS
1											
2	**Optimize**			Objective		Feasible					
3	Name	E_Prod4	Dir.	Min	State	TRUE					
4	Search Method	Current	Value	3475	Value	0					
5	Problem	Permute	Algorith	layout.xla!eval_layoutcomb							
6	Variables	1	2	3	4	5	6	7	8	9	10
7	Name	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10
8	Permutation	2	7	4	10	8	5	6	3	9	1

Best Obj.: 3475 Current Sol. with Improvements
Search time: 28 seconds
Runs: 381 Enum.: 2 Imp.: 379
Complete: 100%
Stop Interval: 100

Sorted Feasible Solutions

Run	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	Obj.
60	2	7	4	10	8	5	6	3	9	1	3475
381	2	7	4	10	8	5	6	3	9	1	3475
35	2	8	4	10	7	5	6	3	9	1	3615
23	2	8	4	10	3	5	6	7	9	1	3627
22	2	8	6	10	3	5	4	7	9	1	3859
15	2	8	5	10	3	6	4	7	9	1	3862
12	2	6	5	10	3	8	4	7	9	1	3960
10	2	5	6	10	3	8	4	7	9	1	4017
8	9	5	6	10	3	8	4	7	2	1	4083
4	4	5	6	10	3	8	9	7	2	1	4122
3	6	5	4	10	3	8	9	7	2	1	4195
1	5	6	4	10	3	8	9	7	2	1	4212

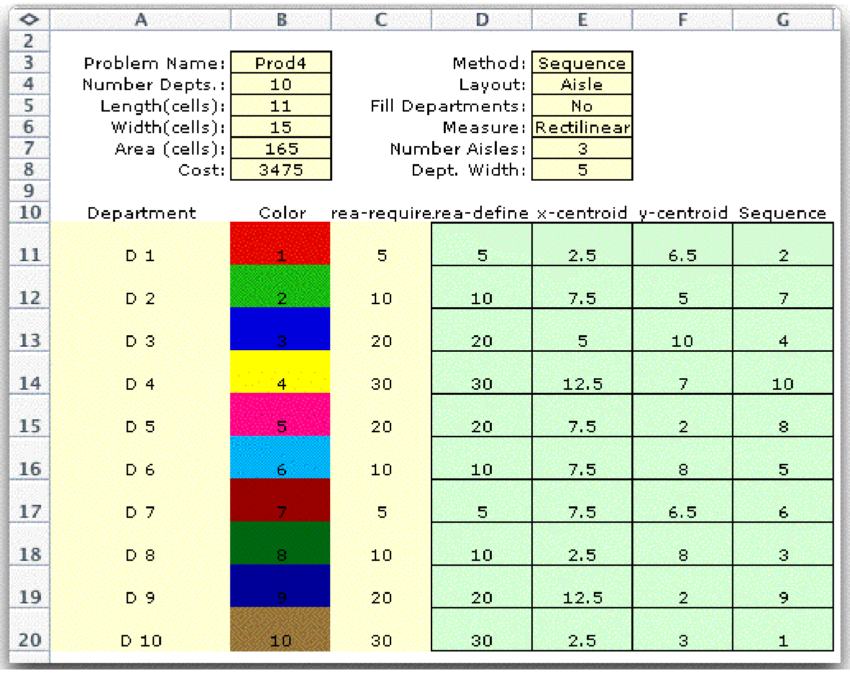
The final layout with the interdepartmental flows superimposed is shown below.



We see on the worksheet starting in column A, various quantities used in the evaluation. When the combinatorial search procedures are in control, the sequence defining the layout in column G is controlled by the the combinatorial algorithms. For example, cell G11 holds the formula

=AJ8

The value in cell AJ8 is the first element of the permutation. The other cells in column G are similarly linked to the combinatorial variables.



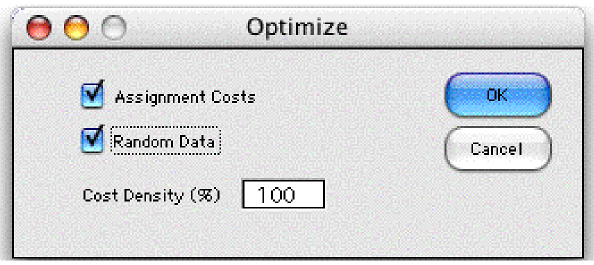
	A	B	C	D	E	F	G
2							
3	Problem Name:	Prod4		Method:	Sequence		
4	Number Depts.:	10		Layout:	Aisle		
5	Length(cells):	11		Fill Departments:	No		
6	Width(cells):	15		Measure:	Rectilinear		
7	Area (cells):	165		Number Aisles:	3		
8	Cost:	3475		Dept. Width:	5		
9							
10	Department	Color	rea-require	rea-define	x-centroid	y-centroid	Sequence
11	D 1	1	5	5	2.5	6.5	2
12	D 2	2	10	10	7.5	5	7
13	D 3	3	20	20	5	10	4
14	D 4	4	30	30	12.5	7	10
15	D 5	5	20	20	7.5	2	8
16	D 6	6	10	10	7.5	8	5
17	D 7	7	5	5	7.5	6.5	6
18	D 8	8	10	10	2.5	8	3
19	D 9	9	20	20	12.5	2	9
20	D 10	10	30	30	2.5	3	1

The combinatorial procedures of the Optimize add-in are much more powerful than the random search and 2-way switches available in the Layout add-in. There are limitations to the *Optimize* search however. Only the *Sequential* layout is defined by a permutation, so the option is not available for the *Traditional* layout.

The combinatorial form (cells AN3 and AN4) allows feasibility conditions on permutations. These are not used for the example, but the feasibility conditions might be useful for other layout applications.

Assignment Costs and Restrictions

Clicking the *Optimize Form* button brings a dialog that controls whether the model includes assignment costs and restrictions. We consider the same example as above, but decide to include assignment costs. The *Random data* button indicates whether the program is to provide random data for the costs. The *Cost Density* indicates the proportion of cells that are to contain numeric cost data. The alternative is for a cell to contain the string ***. This indicates that an assignment is not allowed.



The figure below shows the portion of the worksheet containing the combinatorial form after 10 random solutions were generated and the best of these improved with 2-change assignment swaps. The assignment cost matrix is labeled C(i, j). A component in column j and row i indicates the cost of assigning department j to sequence position i. To illustrate the possibly fixed assignments, disallowed assignments are indicated by *** in the associated cells. The example illustrates the case where department 1 is fixed as the first department in the sequence and department 10 is fixed as the last. Department 5 is required to have an even numbered position. Disallowed cells reduce the search effort because solutions that use disallowed cells are not enumerated.

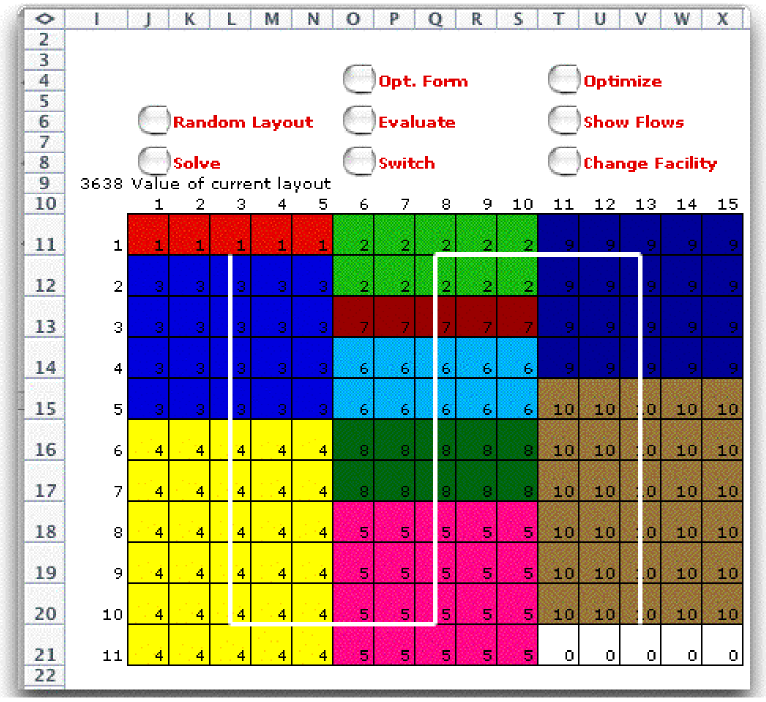
The assignment costs are computed in row 10 and the sum is added to the layout cost in cell AL5. The combinatorial optimization minimizes this sum.

	AI	AJ	AK	AL	AM	AN	AO	AP	AQ	AR	AS
1											
2	**Optimize**			Objective		Feasible					
3	Name	E_Prod5	Dir.	Min	State	TRUE					
4	Search Method	Current	Value	3811	Value	0					
5	Problem	Permute	Algorith	!eval_layoutcomb							
6	Variables	1	2	3	4	5	6	7	8	9	10
7	Name	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10
8	Permutation	1	8	2	3	4	6	7	5	9	10
9											
10	Obj. Terms	0	0	28	34	40	11	26	9	25	0
11											
12	C(i,j)	1	2	3	4	5	6	7	8	9	10
13	0	0	0	0	0	0	0	0	0	0	0
14	1	0	***	***	***	***	***	***	***	***	***
15	2	***	30	28	44	46	2	28	38	39	***
16	3	***	14	41	34	***	24	20	29	13	***
17	4	***	42	14	39	40	38	11	8	7	***
18	5	***	38	1	44	***	43	31	9	19	***
19	6	***	18	16	32	19	11	7	25	12	***
20	7	***	11	6	24	***	37	26	20	37	***
21	8	***	0	3	30	10	2	3	3	14	***
22	9	***	24	26	13	***	1	12	18	25	***
23	10	***	***	***	***	***	***	***	***	***	0

The form below shows several solutions found during the improvement process. Run 1 in row 17 holds the best solution obtained in 10 randomly generated solutions. During the improvement process only solutions that result in an improvement in the incumbent solution are included in the solutions presented. The best solution is solved as the final run, so two identical solutions appear at the top of the sorted list.

	AU	AV	AW	AX	AY	AZ	BA	BB	BC	BD	BE	BF	BG
1													
2	**Best Obj.:**	3811 Current Sol. with Improvements											
3	**Search time:**	5 seconds											
4	**Runs:**	76	Enum.:		2	Imp.:	74						
5	**Complete:**	100%											
6	**Stop Interval:**	10											
7													
8		**Sorted Feasible Solutions**											
9		Run	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	Obj.
10		43	1	8	2	3	4	6	7	5	9	10	3811
11		76	1	8	2	3	4	6	7	5	9	10	3811
12		21	1	8	2	9	4	6	7	5	3	10	3816
13		20	1	8	2	9	4	5	7	6	3	10	3914
14		18	1	8	2	9	4	7	5	6	3	10	3923
15		9	1	8	2	3	4	7	5	6	9	10	3948
16		8	1	8	3	2	4	7	5	6	9	10	4094
17		1	1	9	3	2	4	7	5	6	8	10	4128

The final layout is shown below.



It must be emphasized that the search processes provided by the *Optimize* add-in do not guarantee optimality. They do provide a method to find good solutions to hard problems. Using the random generation plus improvement options and few hours of computation time, one can probably find good answers to problems of moderate size.

The effort to evaluate an individual layout grows approximately as the square of the number of departments and linearly with the number of cells in the layout. The effort of generating random solutions is approximately linear with the number of solutions generated. The effort of one pass through the 2-change improvement process is approximately quadratic with the number of departments. The number of passes through the process is hard to estimate, but one would also expect that to grow with the number of departments. The number of solutions evaluated for exhaustive enumeration grows exponentially with the number of departments.

With these rough estimates, one could try exhaustive enumeration with up to 10 departments. From 10 -30 departments the various heuristics probably would yield results in reasonable time. With more than 30 departments, quadratic growth begins to become painful. With more than 30 departments, the cost of a commercial solver or programming a stand alone application in an efficient programming language is probably justified. The Excel worksheet can probably hold a problem with 100 departments, but computation would be painfully slow.