

## Excel Solver Tutorial – Wilmington Custom Furniture

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(case originally developed by Barry Wray)

**Background:** Excel Solver can support business professionals with finding a solution to problems, such as: What product portfolio allows us to maximize profits; or: How should we deploy our delivery trucks such that operating costs are minimized?. The optimization problem is typically set up such that a target variable is either maximized (e.g., profits, cash flow) or minimized (e.g., costs, time), all while taking into account one or several conditions. The conditions, also called constraints, limit the feasible range of solutions and come in many forms. For example:

- Production volumes are limited by the number of machines and machine hours that a manufacturer has available.
- Production volumes are limited by the fact that staff can only work a certain number of hours per day; work after hours and on weekends requires overtime payment.
- Certain ratios need to be considered, such as: To produce one car, four tires are needed; Shoes always come in pairs of two; One shirt requires five buttons.
- The marketing department requires a certain set of products to be offered in the market, such as a ratio of 3:1 of football gear to sets of golf equipment.
- Limited shelf and warehouse space restricts the total number of products that can be displayed and offered in a store.
- Feasible solutions only include 'whole' integer numbers, for example, it is impossible to dispatch 1.5 delivery trucks, only 1 or 2 etc.

So, when using Excel Solver, the task is to find the solution that best achieves the objective while satisfying all of the relevant constraints. This problem of optimization under constraints falls in the general category of (linear) programming, and can be solved mathematically with methods, such as the Simplex Algorithm. Most likely, you will revisit this concept and learn more about it in a Supply Chain course, such as SCM 370. With Solver, Excel provides support primarily for the mathematical part of the problem. The decision maker prepares for the solution by developing a basic worksheet that includes all of the relevant calculations, and by configuring the Solver-tool, which includes setting up the objective, constraints, and solution method.

In this tutorial, we use the example of a custom furniture shop to explain (1) how to prepare a worksheet for the use of Excel Solver, (2) how to activate Solver in Excel, (3) how to configure and run Solver, and (4) how to interpret the results.

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## H.1 – Downloading the Starting Spreadsheet Template

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To start this tutorial, you will be given an Excel template with a basic setup for a Solver spreadsheet. After a brief introduction to the problem given and the file template you will learn

- (1) how to prepare a worksheet for the use of Excel Solver,
  - (2) how to create the optimal mix of products using Excel Solver,
  - (3) how to run Solver and generate a report,
  - (4) how to format the Solver report, and
  - (5) how to interpret the results.
- All Excel projects are graded with the help of a computer system (Entropy), which means that you must follow directions closely and place all formulas, headings etc. in the exact cells specified or the grading system will not find your work. Do not insert extra rows or columns!
  - **Do you own work, and do not share any files with others.**
    1. Download a starting template from Entropy as shown in Figure H-1. Go to <https://csbapp.uncw.edu/entropy> (or Google UNCW Entropy)
    2. Find the Upload files/download link in Entropy
    3. **Download the Template for the Excel Solver Tutorial (ILM Custom Furniture)** \*not shown below

### File Upload/Download

The following projects are available for upload/download

Assignment Name	Due	Due Time	Late Acceptance Until	File Type	Upload	Download
Project 7 - Excel Refresher	12/25/2020	11:59 PM	12/25/2020	XLSX	<a href="#">Upload Now</a>	<a href="#">Download Starting Template</a>
Project 8 - Scenario Tutorial	12/31/2020	11:59 PM	12/31/2020	XLSX	<a href="#">Upload Now</a>	<a href="#">Download Starting Template</a>

**Figure H-1: Entropy screen for Excel upload/download files**

4. Save the downloaded file to your “Documents” or “Downloads” folder. Do not open the spreadsheet in a browser
5. Rename the file **yourLastNameScenarioFurniture.xlsx** as in appleScenarioFurniture.xlsx
6. **Do not share this file with anyone else; it has been created just for you.**

## H.2 – Understanding the Worksheet

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**Purpose:** Using Excel Solver as a Decision Support System: Optimization under constraints.

To demonstrate the use of Excel Solver, we work on the following problem:

Wilmington Custom Furniture (WCF) produces three different products: chairs, tables, and cabinets. It is late Friday afternoon and WCF is trying to determine the production schedule for next week. In order to finalize this schedule, they must consider a few requirements that must be met.

- All three products are made from a special Cyprus wood found only around coastal North Carolina.
- WCF will have 300 linear feet of this special wood available next week.
- Each of the three products is hand-built by skilled craftsmen employed by WCF.
- According to the work schedule for next week, WCF will have a total of 300 labor hours available.
- After the products are manufactured, they must be stored in WCF's warehouse where they wait to be shipped to retail outlets at the end of the week.
- WCF has a total of 300 square feet available for furniture storage in the warehouse. Table H-1 lists the resources needed to make and store one unit of each product:

**Table H-1: Resource requirements for WCF's products**

	<b>Chair</b>	<b>Table</b>	<b>Cabinet</b>
Wood needed per unit (linear ft.)	5	12	12
Labor needed per unit (hours)	3	7	12
Storage space needed per unit (sq. ft.)	15	30	20

Since the goal of WCF's management is to maximize company profits, cost and revenue data also need to be included in the calculations. The key cost components include the following:

- Costs for wood per linear ft.: \$10.00
- Costs for labor per hour: \$40.00
- Costs for storage space per sq. ft.: \$5.00
- Fixed costs to operate the woodshop per day (mainly utilities): \$300

WCF sells its products to retailers at the following sales prices:

- Sales price per chair: \$255.00
- Sales price per table: \$900.00
- Sales price per cabinet: \$1,000.00

To calculate the company's bottom line, management needs to take into consideration an income tax rate of 30%. In addition, we also have to consider the following two conditions:

- First, a minimum of 2 units of each product have to be made every week for training purposes.
- Second, as a sales requirement, at least 4 times as many chairs as tables have to be produced, meaning the ratio of chairs to tables has to be 4 or more.
- Lastly, WCF is working under the assumption they can sell every chair, table, and cabinet they produce.

In the remainder of the tutorial, we develop answers to the following questions:

- Question 1: What is the optimal number of units of each product that maximizes the profits for the week, while satisfying the various constraints?
- Question 2: Does it make economic sense to hire more people?
- Question 3: Does it make economic sense to expand the warehouse?

**Reviewing the Worksheet:**

Before we begin, let's review the starter-file that you downloaded from Entropy. Note the five parts of the worksheet:

1. Place your name in Cell B2.
2. **Part 1: Changing Variable Cells (Decision Variables):** Highlighted in yellow are the decision variables that the solution of the problem is based upon. We don't know yet what the optimal solution will be, so we start out by putting a value of 1 in cells B5, B6 and B7. Once we run Solver, the system replaces our starting values with the correct values that optimize the solution and suggest to the decision maker how many units of each product to produce.
3. **Part 2: Objective (Target Variable):** Highlighted in green, B10 is the main dependent variable, the target that we are trying to optimize by using Solver. In our case, the target is income after taxes, which we intend to maximize. For convenience purposes, the value in Cell B10 is copied from the bottom of the spreadsheet. We enter =B79, so once we are finished with the income statement, the result will appear right at the beginning of the spreadsheet (right now, it should show a value of 0).
4. **Part 3: Constants:** The various constants have been described above and have already been filled into your starter file. They remain unchanged, at least for the time being, but will be referenced throughout parts 4 and 5 of the worksheet. In addition, they will be used to set up the Solver.
5. Compare parts 1 to 3 with the screenshot shown in Figure H-2:

	A	B
1	<b>Wilmington Custom Furniture</b>	
2	Solver Case Developed by:	
3		
4	<b>1. Changing Variable Cells (Decision Variables)</b>	
5	Number of Chairs	1.00
6	Number of Tables	1.00
7	Number of Cabinets	1.00
8		
9	<b>2. Objective (Target/Dependent Variable)</b>	
10	Income after taxes	
11		
12	<b>3. Constants</b>	
13	Wood needed per chair (linear ft)	5.00
14	Wood needed per table (linear ft)	12.00
15	Wood needed per cabinet (linear ft)	12.00
16	Wood available (linear ft)	300.00
17	Costs for wood per linear ft	\$ 10.00
18		
19	Labor needed per chair (hours)	3.00
20	Labor needed per table (hours)	7.00
21	Labor needed per cabinet (hours)	12.00
22	Labor available (hours)	300.00
23	Costs for labor per hour	\$ 40.00
24		
25	Storage space needed per chair (sq. ft.)	15.00
26	Storage space needed per table (sq. ft.)	30.00
27	Storage space needed per cabinet (sq. ft.)	20.00
28	Storage space available (sq. ft.)	300.00
29	Costs for storage space per sq. ft.	\$ 5.00
30		
31	Fixed costs per day (heating/cooling etc.)	\$ 300.00
32		
33	Sales price per chair	\$ 255.00
34	Sales price per table	\$ 900.00
35	Sales price per cabinet	\$ 1,000.00
36		
37	Minimum units for each product	2
38	Income tax rate	30%
39	Minimum ratio chairs per table	4

Figure H-2: Parts 1 to 3 of the Worksheet

**Part 4: Calculations**, and **Part 5: Income Statement** contain the various formulas that are needed to determine the target variable (Part 2). They are explained in more detail below.

**Good to know:** As we work our way through the worksheet, we enter various formulas (esp. in parts 4 and 5 below). However, unless we select a cell directly, only the resulting values are displayed in the spreadsheet, but not the actual formulas. Sometimes, this makes it difficult to understand what is going on in the spreadsheet and how the various formulas and cells relate with each other. **To review the formulas in a worksheet all at once click Ctrl and `** (apostrophe, top left on the keyboard). Click Ctrl and ` again to return to the original view.

### H.3 – Entering Formulas in Section 4

We start the calculations by determining how much we need of each of the resources wood, labor, and storage space. Then we determine costs and revenues for each product. Lastly, we determine the ratio of chairs to tables that we need for one of the Solver constraints.

6. **Row 42:** To calculate the wood needed for all chairs (linear ft.), we multiply the wood needed for one chair (B13) with the number of chairs that we plan to produce (B5).

In B42, enter  $=B5*B13$  --- NOT A SUM.

7. **Rows 43 and 44:** To calculate the wood needed for all tables and cabinets, we can copy the formula in B42 by dragging on the small square that appears when the cell (B42) is selected (Figure H3). Once the cursor changes its shape into a plus-sign when hovering over the small square at the lower right of B42, press the left mouse button, and with the mouse button pressed, drag the mouse to B44. Then release and check the formulas that have just created.

	A	B
39	Minimum ratio chairs per table	4
40		
41	<b>4. Calculations</b>	
42	Wood needed for all chairs (linear ft)	500
43	Wood needed for all tables (linear ft)	
44	Wood needed for all cabinets (linear ft)	
45	Wood needed for all products (linear ft)	

**Figure H-3: To copy the formula in B42 down into B43 and B44, drag on the small square that appears in the bottom right-hand corner of B42 (indicated by the circle)**

After copying the formula in B42 to B43 and B44, cell B43 should now have  $=B6*B14$  and B44 should have  $=B7*B15$ .

**Good to know (but you do *not* need to do this right now):** When you dragged the formula down from B42 to B44, the cell references in your formula (e.g., B5) changed (e.g., to B6 and B7). This is the case because we have been using what is called **relative references** in our formula. Relative references adjust according to their relative position, meaning the references move with the formula that is copied. This is often intended and comes in very handy like in our case, but not always.

If a reference is not supposed to change (e.g., the reference to cell B5 needs to stay B5, no matter where the formula is copied to), then we use what is called an **absolute reference**. An absolute reference is characterized by \$-signs, e.g., \$B\$5, that can be generated automatically as follows: Place your mouse over the cell that contains the reference that you want to become an absolute reference, then highlight the cell reference in the formula bar by using the left mouse button (Figure 6-3), and press the **function key F4**. The \$-signs appear automatically without having to be typed.

Again, as the instructions state on the previous page – you **DO NOT** need to change any references in B42 to B44 to absolute references. This information is provided here for concept review of the two types of references.

8. **Row 45: Wood needed for all products:** Now that we know the wood required to produce each of the three products, we can calculate the total wood needed. The easiest approach is to use a SUM-function: (in B45 enter =SUM(B42:B44)).
9. **Rows 47-55:** Calculate the needs for labor (hours) and storage space (sq. ft.) like the calculations of wood. When done, the number should match Figure H-4 below.

41	<b>4. Calculations</b>	
42	Wood needed for all chairs (linear ft)	5.00
43	Wood needed for all tables (linear ft)	12.00
44	Wood needed for all cabinets (linear ft)	12.00
45	Wood needed for all products (linear ft)	29.00
46		
47	Labor needed for all chairs (hours)	3.00
48	Labor needed for all tables (hours)	7.00
49	Labor needed for all cabinets (hours)	12.00
50	Labor needed for all products (hours)	22.00
51		
52	Storage space needed for all chairs (sq. ft.)	15.00
53	Storage space needed for all tables (sq. ft.)	30.00
54	Storage space needed for all cabinets (sq. ft.)	20.00
55	Storage space needed for all products (sq. ft.)	65.00
56		

**Figure H-4: Resources needed to produce 1 unit each of chairs, tables, and cabinets.**

10. **B57: Costs per chair:** To calculate the costs per chair, we need to add the three cost components: wood, labor, and storage space.

Specifically, we need to add the costs for wood, as linear ft. needed for one chair multiplied by the costs for one linear ft., plus the costs for labor, as hours of labor needed for one chair multiplied by the costs for one hour and plus the costs for storage, as square ft. needed for one chair multiplied by the costs for one sq. ft. So, we enter:

$$=(B13*B17)+(B19*B23)+(B25*B29)$$



11. **B58: Costs for all chairs:** In order to obtain the costs for all chairs to be produced in a week, we multiply the costs required to produce one chair with the total number of chairs that we plan to produce:

=B5\*B57

12. **B59: Revenues for all chairs:** Since we know the sales price for one chair (B33), we can determine the revenues for all chairs by multiplying it with the number of chairs that we plan to produce (and assume to sell) that week:

=B5\*B33

13. **B61 to B67:** Calculate the costs and revenues for the other two products tables and cabinets similar to the calculations for the chairs. When done, the number should match Figure H-5.

57	Costs per chair	\$	245.00
58	Costs for all chairs	\$	245.00
59	Revenues from all chairs	\$	255.00
60			
61	Costs per table	\$	550.00
62	Costs for all tables	\$	550.00
63	Revenues from all tables	\$	900.00
64			
65	Costs per cabinet	\$	700.00
66	Costs for all cabinets	\$	700.00
67	Revenues from all cabinets	\$	1,000.00

**Figure H-5: Costs and Revenues as a result of producing 1 unit each of chairs, tables, and cabinets.**

14. **B69: Ratio Chairs/Tables:** The last formula in the Calculations section is the ratio of chairs to tables. Obviously, we need to divide the number of chairs that we plan to produce by the number of tables (=B5/B6).

However, in cases where B5, the number of tables is set to zero, this formula results in an error message (#DIV/0!), which can confuse the user and cause other problems. So, we need to address this issue. Luckily, since Office 2007, Excel contains a neat function, IFERROR, that we can apply here.

=IFERROR(value, value\_if\_error) returns one value when there is no error, and another value or a message when the formula produces an error. So, in our case, we enter:

=IFERROR(B5/B6,0)

This gives us the ratio of chairs to tables that we want, unless the number for tables is 0, in which case an error message is generated (Division by zero), which is then converted into the value of 0. Please note that mathematically speaking, 0 is not the correct solution of a division by zero, but it is workable for our purposes.

### Part 5: Income Statement

Now, we have all the necessary numbers to determine costs, revenues, and income before and after taxes for the week. We start with the total costs:

15. **B72: Variable costs for all products:** The variable costs include everything associated with the number of products that we plan to make. You should add the costs of chairs, tables and cabinets (think cells B58, B62 and B66)
16. **B73: Fixed costs per week (5 days):** In addition to variable costs that are required to make the products, we also incur fixed costs, such as expenses for heating and cooling that are independent of production volumes. In the constant section (Part 3), we have a value listed that indicates fixed costs per day (B31), so assuming that a regular week consists of 5 working days, we determine the fixed costs as:

=B31\*5

17. **B74: All costs:** To calculate all costs, build the sum of variable and fixed costs:
18. **B76: Revenues from all sales:** To determine the revenues from all sales, we add the revenues for each of the three products, chairs, tables and cabinets, similar for what you did for the costs.

=SUM(B59,B63,B67)

19. **B77: Income before taxes:** All revenues minus all costs result in the income that is subject to taxes:
20. **B78: Income tax expense:** Since we know the income that is subject to taxes (B77) as well as the income tax rate (B38), we can calculate the income tax expense as  $B77 * B38$ . However, the rule in our situation is that we don't get a tax refund (i.e., there can be no negative tax values) in years that we don't make a profit, meaning there are no taxes when our income is negative. So, we need to use the IF-function to ensure that our income tax expense is calculated only when our profits are greater than 0. Otherwise our tax expense should be set to 0.

As you have learned earlier in earlier assignments, the IF-function [=IF(logical\_test,value\_if\_true,\_value\_if\_false)] consists of three parts:

- First, we enter a logical test, which is a statement that needs to result in either TRUE or FALSE. Our logical test is the question of whether income before taxes is greater than zero:  $B77 > 0$ .
- Second, we enter the value of the cell (B78) in case the logical test results in TRUE. That value is the tax expense calculated as income before taxes times the tax rate:  $B77 * B38$
- Third, we enter the value of the cell (B78) in case the logical test results in FALSE. That value is 0 in our worksheet. So, the entire formula for the income tax expense reads:

=IF(B77>0,B77\*B38,0)

21. **B79: Income after taxes:** Lastly, we deduct the income tax expense from the income before taxes, which gives us the income after taxes. This is our result value that we are most interested in (and that we want to maximize by using Solver):
22. **B10: Income after taxes:** Have B10 = B79, as we will use this cell in the Solver Component
23. Save your work and compare your income statement with Figure H-6:

69	Ratio Chairs/Tables		1.00
70			
71	<b>5. Income statement</b>		
72	Variable costs for all products	\$	1,495.00
73	Fixed costs per week (5 days)	\$	1,500.00
74	All costs	\$	2,995.00
75			
76	Revenues from all sales	\$	2,155.00
77	Income before taxes	\$	(840.00)
78	Income tax expense	\$	-
79	Income after taxes	\$	(840.00)

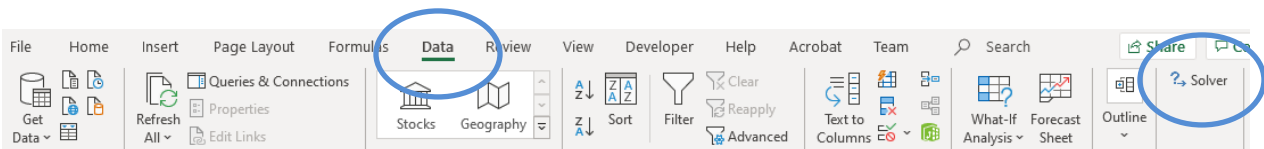
**Figure H-6: Income statement for a production of 1 unit each of chairs, tables, and cabinets**

**Note:** The income before taxes is negative right now, which leads to an income tax expense of 0 because of the IF-statement. This result is due to the fact that the minimal production volumes of 1 chair, table and cabinet each are not yet sufficient to offset the fixed costs per week. Once our production volumes increase, the results will become positive.

## H.4 – Solver as a Decision Support Tool

### H.4.1 – Activating Excel Solver

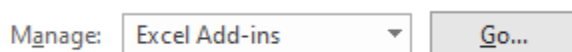
Excel Solver comes with the Excel-software but it is not generally installed for the default installation of Excel. You can check if Solver has been activated by selecting Data from the menu on the top of your Excel window. If activated, Solver should appear in the Analysis group to the very right of your window:



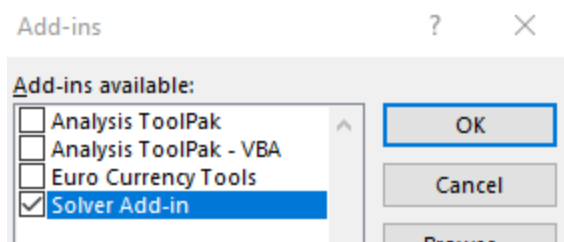
**Figure H-7: Once activated, the Solver icon appears to the very right in the Data menu**

24. If Solver does not appear it needs to be activated as follows:

- Select **File** from the top menu
- In the **lower** left part of the window that appears, click on **Options**
- In the **left** part of the window that appears next, click on **Add-ins**
- In the **lower** part of the window that appears, find the **pull-down menu next to Manage**
- Open the pull-down menu next to **Manage**, select **Excel Add-Ins**, then click on **Go**



**Figure H-8: Finding the 'Excel Add-ins' menu as part of the total Add-In' Menu**



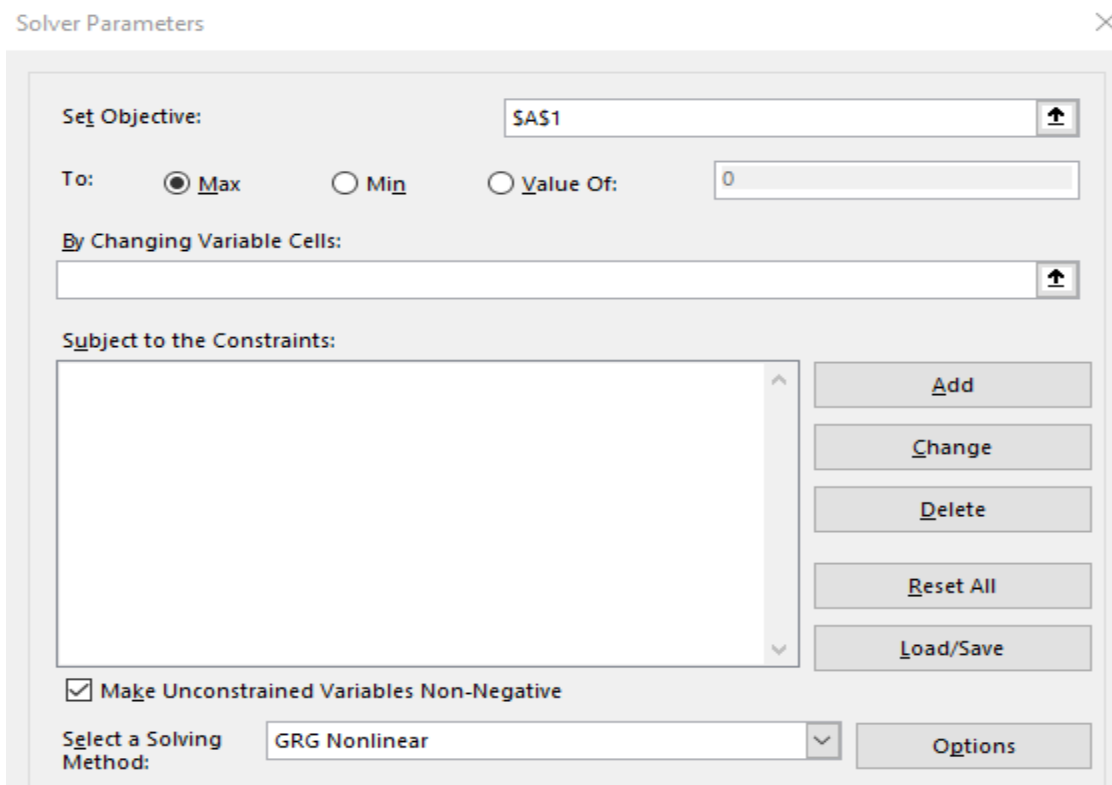
**Figure H-9: Selecting the Solver Add-in**

- f. In the window that appears mark the checkbox next to **Solver**, then click on **OK**
- g. In the top-bar menu (Data tab) verify that you now have the option of Solver (all the way to the right, see Figure H-7)

## H.4.2 – Configuring Solver

We are now ready to configure and run Solver to work on **Question 1: What is the optimal number of units of each product that maximizes the profits for the week, while satisfying the various constraints?**

25. To **start Excel Solver**, select **Data** from your top menu; then click on **Solver** in the Analysis group that should now be visible all the way to the top right part of your window. The window that is launched should look like Figure H-10. Solver is ready to be configured and run.



**Figure H-10: Initial Solver configuration window**

26. The first step is to **set the objective**, in other words select the target variable. As mentioned earlier, our target variable is Income after Taxes (which is just another expression for profits). So, we enter **B10** into the box after **Set Objective**.

**Good to know:** To avoid typing you can also place your cursor into the box after Set Objective, then select cell B10 by clicking on it in the worksheet. The value of B10 is then entered automatically into the Solver configuration window.

27. Now, we have a choice of direction: we can either **maximize or minimize the target variable**. As is typically the case with profits, we try to maximize, so make sure that **Max** is selected.
28. Next, we indicate the **Changing Variable Cells**. These are the cells that Solver will vary in order to find the optimal solution. As outlined above, our changing variable cells are the volumes of the three products that we are trying to determine. These cells are highlighted in yellow on our spreadsheet. We enter **B5:B7** into the box below **By Changing Variable Cells**.
29. At last, we are ready to **enter the constraints** that need to be satisfied while trying to optimize the target variable.

Each constraint consists of three components:

- a. The first component is a **Cell Reference**, which is the part of the constraint that changes as the variable cells are being adjusted. For the first constraint, the cell reference is the total amount of wood that we need for production (B45)
- b. As the second component we need an **Operator** that links cell reference with the constraint. Our operator is  $\leq$  because we have an upper limit for the wood that we can use, so our cell reference needs to be less or equal to the upper limit.
- c. The third component is the **Constraint**, i.e., the limit that needs to be satisfied. In our case, the limit is the amount of wood available (B16), and in contrast to the cell reference, the constraint does not change.

So, to enter our first constraint click on **Add** next to the Constraints box, then enter **B45 as Cell Reference,  $\leq$  as Operator and B16 as Constraint** (Figure H-11):

The image shows the 'Add Constraint' dialog box. It has a title bar with 'Add Constraint' and a close button (X). The main area is divided into two sections: 'Cell Reference:' and 'Constraint:'. Under 'Cell Reference:', there is a text box containing 'B45' and a small upward-pointing arrow icon. Under 'Constraint:', there is a text box containing 'B16' and a small upward-pointing arrow icon. Between these two text boxes is a dropdown menu showing '<= >'. At the bottom of the dialog, there are three buttons: 'OK', 'Add', and 'Cancel'.

**Figure H-11: First constraint (We cannot use more wood then we receive each week)**

30. Click on **Add** and enter the second and third **constraints for the limited amounts of labor hours and storage space** in a similar way. After each constraint click the Add-button for a new empty form.
31. The **fourth through sixth constraints** request that we produce at least 2 units of each product. We can actually summarize the three constraints into one entry by entering B5:B7 as the cell reference (Figure H-12):

The screenshot shows the 'Add Constraint' dialog box. The 'Cell Reference' field is set to 'B5:B7'. The operator dropdown is set to '>='. The 'Constraint' field is set to 'B37'. The 'OK' button is highlighted with a blue border.

**Figure H-12: Three constraints summarized in one entry**

32. Constraint five requests that the planned **ratio of chairs/table** (B69) be greater than or equal to the limit outlined in the constants part (B39).

Lastly, we have three constraints that are intended to ensure that we only produce “whole” products and not, say  $\frac{1}{2}$  of a chair. These constraints are called integer constraints and are entered as follows Enter **B5:B7 as Cell References** (or put your mouse into the box and then highlight B5:B7 in the spreadsheet) – Figure H-13. Then select **int** from the pull-down menu as the **operator**. The **Constraint** will automatically be set to **integer**. After the last constraint is complete, click the **OK-button**.

The screenshot shows the 'Add Constraint' dialog box. The 'Cell Reference' field is set to 'B5:B7'. The operator dropdown is set to 'int'. The 'Constraint' field is set to 'integer'. The 'OK' button is highlighted with a blue border.

**Figure H-13: Integer-Constraint**

The final set of constraints should look like the following screenshot (Figure H-14):

Solver Parameters

Set Objective:

To:  Max  Min  Value Of:

By Changing Variable Cells:

Subject to the Constraints:

- \$B\$45 <= \$B\$16
- \$B\$50 <= \$B\$22
- \$B\$55 <= \$B\$28
- \$B\$5:\$B\$7 = integer
- \$B\$5:\$B\$7 >= \$B\$37
- \$B\$69 >= \$B\$39

Buttons: Add, Change, Delete

**Figure H-14: All constraints have been added**

Use the **Change**-button to edit any of the constraints in case there is an error, **Add** to include another constraint, and **Delete** if there is one too many.

33. It is possible that the solving method is set to Simplex LP by default, which would be fine for our purposes if we had not used any IF-functions in our worksheet. With the use of IF and IFERROR, however, our problem has become non-linear from Solver's perspective, which is why we need to select **GRG Nonlinear** as the **Solving Method**.

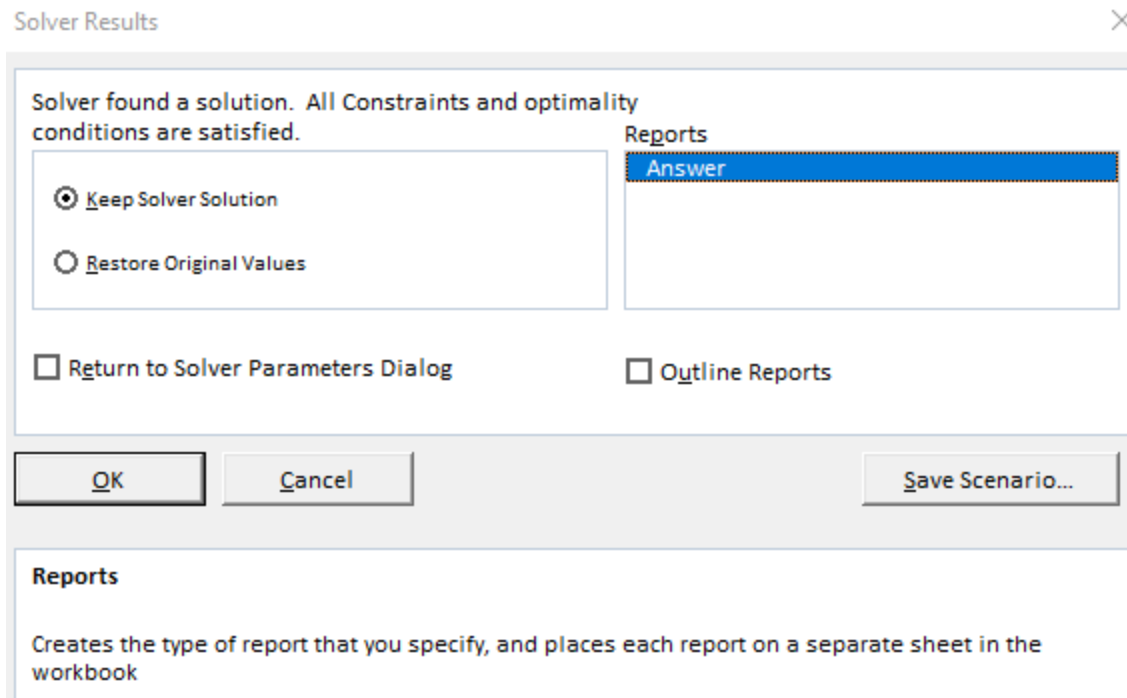
Select a Solving Method:  Options

**Figure H-15: Selecting a Solving Method**

34. Now, that we have configured the Solver tool, we are ready to run it by pressing the **Solve**-button. After a few moments during which the computer processes the various calculations, a window should appear stating that a solution has been found.

**Note:** In case that no solution is found and an error message appears, carefully check the Solver set-up, including all constraints (operators!), objective (target cell, max/min!), optimization method (GRC Non-Linear!), and changing variable cells. Also, check the worksheet itself for any possible errors that might have been overlooked..

In the window that appears when a solution has been found we select "**Keep Solver Solution**" and also highlight on "**Answer**" under Reports, as indicated in Figure H-16:



**Figure H-16: Select Keep Solver Solution and Answer Report**

35. Finally click, **OK** (ensure the Answer option under reports is highlighted)
36. As soon as we click the OK-button, two things happen:
  - a. First, the **values in the Sheet 1 worksheet change** to reflect the solution that has been found, and, thus, provide the answer to our Question 1. We note in particular the new values of the Variable Cells (B5:B7) where we now see the suggested production volumes for the three products, and also the Result Variable (B10) that indicates the expected income after taxes.
  - b. Second, at the bottom of our screen, we notice that a **new worksheet has been added**, named **Answer Report 1**. This new worksheet contains important information about the Solver configuration as well as the solution in the three parts Objective Cell, Variable Cells, and Constraints (Figure H-17); and therefore also helps us to answer our question.



A	B	C	D	E	F	G
1	Microsoft Excel 16.0 Answer Report					
2	Worksheet: [SolverTutorial.xlsx]Sheet1					
3	Report Created: 12/31/2020 10:11:34 AM					
4	Result: Solver found a solution. All Constraints and optimality conditions are satisfied.					
5	Solver Engine					
6	Engine: GRG Nonlinear					
7	Solution Time: 0.047 Seconds.					
8	Iterations: 5 Subproblems: 0					
9	Solver Options					
10	Max Time Unlimited, Iterations Unlimited, Precision 0.000001, Use Automatic Scaling					
11	Convergence 0.0001, Population Size 100, Random Seed 0, Derivatives Forward, Require Bounds					
12	Max Subproblems Unlimited, Max Integer Sols Unlimited, Integer Tolerance 1%, Assume NonNegative					
13						
14	Objective Cell (Max)					
15	Cell	Name	Original Value	Final Value		
16	\$B\$10	Income after taxes	\$ (840.00)	\$ 756.00		
17						
18						
19	Variable Cells					
20	Cell	Name	Original Value	Final Value	Integer	
21	\$B\$5	Number of Chairs	1.00	8.00	Integer	
22	\$B\$6	Number of Tables	1.00	2.00	Integer	
23	\$B\$7	Number of Cabinets	1.00	6.00	Integer	
24						
25						
26	Constraints					
27	Cell	Name	Cell Value	Formula	Status	Slack
28	\$B\$45	Wood needed for all products (linear ft)	136.00	\$B\$45<=\$B\$16	Not Binding	164
29	\$B\$50	Labor needed for all products (hours)	110.00	\$B\$50<=\$B\$22	Not Binding	190
30	\$B\$55	Storage space needed for all products (sq. ft.)	300.00	\$B\$55<=\$B\$28	Binding	0
31	\$B\$69	Ratio Chairs/Tables	4.00	\$B\$69>=\$B\$39	Binding	0.00
32	\$B\$5	Number of Chairs	8.00	\$B\$5>=\$B\$37	Not Binding	6.00
33	\$B\$6	Number of Tables	2.00	\$B\$6>=\$B\$37	Binding	0.00
34	\$B\$7	Number of Cabinets	6.00	\$B\$7>=\$B\$37	Not Binding	4.00
35	\$B\$5:\$B\$7=Integer					

**Figure H-17: Answer Report 1** (contains all constraints)

We have now found the **Answer to Question 1**: What is the optimal number of units of each product that maximizes the profits for the week, while satisfying the various constraints.

**Producing 8 chairs, 2 tables and 6 cabinets maximizes the profits for the week at \$756 while satisfying all of the constraints.**

The constraints are listed in the lower part of the Answer Report.

37. Please, save your work now, and upload the file to Entropy. Verify your upload.

## H.5 – Interpreting the Results (check with instructor)

The remainder of this tutorial is intended as a follow-up exercise to help deepen your understanding about decision making and the support that Solver can provide to decision makers.

As for most decision support systems, the computer is not meant to replace but instead support the decision maker with finding and implementing a good (possibly even optimal) solution to the problem at hand. In order to do that, we take a close look at the computer-generated solution and interpret the findings beyond the suggested optimum.

38. In the lower part of the Answer Report, there are some useful clues to get started. Note that in the constraints part (Row 26 and below), there is a **column (F) that reads “Binding” or “Not Binding” for each of the constraints**. This information indicates which of the constraints that we entered into the Solver tool actually limit the solution that was found.

When looking through the constraints, we notice that **three constraints are binding**, namely the constraints concerning the Storage Space Needed for all Products, Ratio of Chairs/Tables and the Number of Tables to be produced.

39. **All other constraints are not binding**, and for those constraints, the right-most column (G) indicates how much **slack** we have before each of the constraints starts to limit our solution.

For example, we see from the value in D29 that we plan to use 110 hours of labor, which is in fact 190 hour less than our constraint of 300 hours. In other words, the slack, as indicated in G28, is 110, which provides us with the answer to **Question 2: Does it make economic sense to hire more people?** At this point, **the answer clearly is No**. Actually we should have a discussion on how to keep the current employees busy. Note that the slack (values in Column G) for all constraints that are binding is 0.

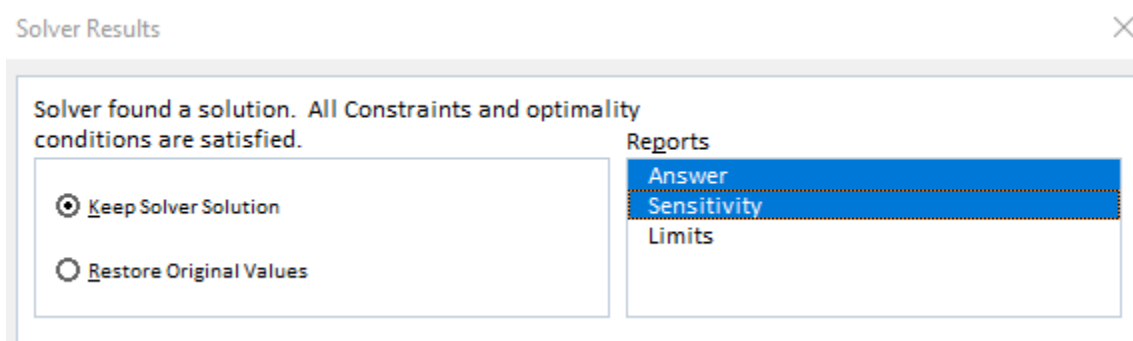
40. At this point, we cannot yet answer Question 3: Does it make economic sense expand the warehouse?

While we can see from the Answer Report that the lack of storage space indeed limits our result because it is a binding constraint, we cannot tell how much our objective (=Income after Taxes) would improve if we expanded the warehouse to add more storage space. This information is important, given that adding storage space is costly.

A **Sensitivity Report** can help us answer Question 3 by telling us exactly how much our objective variable would improve if we relaxed the constraint on the storage space (or any other binding constraint).

41. To obtain a Sensitivity Report, **the integer-constraints have to be deleted** because this type of report requires a continuous set of input variables, which is a Solver-Requirement. Go back to the main worksheet Sheet1, then launch Solver (**Data – Solver**).

Select the **Integer Constraints (B5:B7=integer)**, then press **Delete** and **Solve** to run Solver one more time. The window that appears once a solution is found now offers us three different reports. Please, select the first two options, **Answer and Sensitivity** then click OK (Figure H-18):



**Figure H-18: Report choices after running Solver without integer-constraints**

42. Once we click the OK-Button, two additional worksheets are created, namely Answer Report 2 (Figure H-19) and Sensitivity Report 1 (Figure H-20).

14	Objective Cell (Max)					
15	<b>Cell</b>	<b>Name</b>	<b>Original Value</b>	<b>Final Value</b>		
16	\$B\$10	Income after taxes	\$ 756.00	\$ 756.00		
17						
18						
19	Variable Cells					
20	<b>Cell</b>	<b>Name</b>	<b>Original Value</b>	<b>Final Value</b>	<b>Integer</b>	
21	\$B\$5	Number of Chairs	8.00	8.00	Contin	
22	\$B\$6	Number of Tables	2.00	2.00	Contin	
23	\$B\$7	Number of Cabinets	6.00	6.00	Contin	
24						
25						
26	Constraints					
27	<b>Cell</b>	<b>Name</b>	<b>Cell Value</b>	<b>Formula</b>	<b>Status</b>	<b>Slack</b>
28	\$B\$45	Wood needed for all products (linear ft)	136.00	\$B\$45<=\$B\$16	Not Binding	164
29	\$B\$50	Labor needed for all products (hours)	110.00	\$B\$50<=\$B\$22	Not Binding	190
30	\$B\$55	Storage space needed for all products (sq. ft.)	300.00	\$B\$55<=\$B\$28	Binding	0
31	\$B\$69	Ratio Chairs/Tables	4.00	\$B\$69>=\$B\$39	Binding	0.00
32	\$B\$5	Number of Chairs	8.00	\$B\$5>=\$B\$37	Not Binding	6.00
33	\$B\$6	Number of Tables	2.00	\$B\$6>=\$B\$37	Binding	0.00
34	\$B\$7	Number of Cabinets	6.00	\$B\$7>=\$B\$37	Not Binding	4.00
35						

**Figure H-19: Answer Report 2** (Integer-constraints eliminated)

The first thing we notice is that the results to our problem have not changed:

- Comparing D16 to E16, we note that the expected Income after Taxes is still \$756
- Comparing the Original Values to the Final Values in the Variable Cell Report in Figure H-19, the recommendation still is to produce 8 chairs, 2 tables and 6 cabinets

Please, note that this result is not very common. Typically, we'd expect fractions for the variable cells, such as "8.5 chairs", "1.79 tables" as a result of relaxing the integer constraints.

The new Answer Report tells us in F28:F34 that we have still three constraints that are binding, namely the constraints regarding storage space, ratio of chairs to tables, and number of tables.

43. In order to finally find an answer to our Question 3, we take a look at the Sensitivity Report (Figure H-20):

1 Microsoft Excel 16.0 Sensitivity Report					
2 Worksheet: [SolverTutorialJudithExtra.xlsx]Sheet1					
3 Report Created: 12/31/2020 10:17:21 AM					
4					
5					
6 Variable Cells					
7				Final	Reduced
8	Cell	Name	Value	Value	Gradient
9	\$B\$5	Number of Chairs	8	8	0
10	\$B\$6	Number of Tables	2	2	-671.9987681
11	\$B\$7	Number of Cabinets	6	6	0
12					
13 Constraints					
14				Final	Lagrange
15	Cell	Name	Value	Value	Multiplier
16	\$B\$45	Wood needed for all products (linear ft)	136	136	0
17	\$B\$50	Labor needed for all products (hours)	110	110	0
18	\$B\$55	Storage space needed for all products (sq. ft.)	300	300	10.49999959
19	\$B\$69	Ratio Chairs/Tables	4	4	-300.9999924

Figure H-20: Sensitivity Report 1 (Integer-constraints eliminated)

The part that is most interesting in the Sensitivity Report is Column E, in particular, Cell E18, where we find something called the Lagrange Multiplier.

Cell E18 shows a value of about 10.5. This is the amount that our target variable (income after taxes) would increase if we relaxed the associated constraint by one unit. In other words, one additional square foot of storage space would provide us with an extra income after taxes of \$10.50.

At this point, the decision maker needs to know how much it costs to add one (or more) additional sq. ft. of storage space. If the answer to that question is \$10.50 or less, then an expansion of the warehouse should be considered. So, the answer to **Question 3: Does it make economic sense to expand the warehouse?** is: **Expanding the warehouse and adding storage space makes economic sense as long as the costs for doing so are less than \$10.50 per square foot.**

Similarly, the negative value in E19 tells us that our income after taxes would *decrease* by \$301 if we increased the Ratio of Tables/Chairs by 1 (i.e., require 5 chairs to be produced per table).

Conversely, our result would *increase* by \$378 if we decreased this ratio by one (i.e., require only 3 chairs to be produced per table). So, the sensitivity report tells us that the ratio-requirement also has a noticeable economic impact on our results, which decision makers may want to discuss at some point.

44. Save your file, upload to Entropy and verify your upload.

## Appendix 1.1 Uploading a file to Entropy that is stored on your machine.

1. **Make sure your Excel file is closed. Excel should not be open when you upload it to Entropy.**
2. Open a web browser.
3. Go to Entropy (<https://csbapp.uncw.edu/Entropy/>). Enter your Entropy UserID and Password and select the appropriate class.
4. Click the **Upload Assignment** option.

### Your Progress

[Check Progress](#)

[Upload Assignment / Download Starting Template](#)

**Figure Appendix-1: Entropy, starting the process to upload an assignment**

5. Find the correct assignment name you wish to upload (**will not be Excel Refresher**). This will vary based on your instructor. Check your documents, downloads or recent folder for your xlsx file.
6. Click **Upload Now** beside the appropriate assignment.

### File Upload/Download

The following projects are available for upload/download

Assignment Name	Due	Due Time	Late Acceptance Until	File Type	Upload	Download
Project 7 - Excel Refresher	12/25/2020	11:59 PM	12/25/2020	XLSX	<a href="#">Upload Now</a>	<a href="#">Download Starting Template</a>

**Figure Appendix-2: Entropy, upload an assignment**

7. Entropy will respond with a listing of all files uploaded and their date/time. *Should you upload a file to the same assignment more than once, it will list both uploads but only keep and grade the most recent upload.*

Assignment Name	Due Date	Upload Date	File Size	Unique Upload ID
Project 3 - Access Queries	09/10/2020 11:00 PM	09/11/2020 03:24 PM	950272	196972
Project 3 - Access Queries	09/10/2020 11:00 PM	09/11/2020 03:09 PM	819200	196973

**Figure Appendix-3: Summary of files uploaded**

8. Be sure to save a copy of your Excel file onto a permanent storage device. Recommended storage area would be your **OneDrive storage area** via your Email account.