Excel Solver Tutorial

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1 Introduction

This tutorial will introduce you to some essential features of Excel and its plug-in, Solver, that we will be using throughout ENGR62 to solve linear programs (LPs). You will learn how to:

- represent LPs in an Excel worksheet,
- use the matrix functions SUMPRODUCT and MMULT,
- set up an LP in Solver, and
- generate various outputs from Solver.

This quarter you will see many applications of Solver in class demonstrations and homework assignments. Keep this tutorial document as a reference as you review the class demos and as you formulate LPs in your homeworks. For additional Excel/Solver assistance, try consulting the Excel Help files or numerous online resources or also on Piazza.

2 Installing Solver

Although the general concept behind using solver in different operating systems is the same, there are different ways to obtain the Solver add-in in different operating systems. Before going through the instructions, we remind you that you can download excel through https://uit.stanford.edu/software/officethis website. If you are all the university main computer clusters are equipped with Excel which has Solver already built in. If you have any troubles with Solver on your machine and you are short in time, please use these machines. Here is a quick installation guide for Windows, Mac and Linux.

Windows

1. Open Excel and go to `File` → `Options`.
2. In the `Options` dialog, select `Add-Ins` from the left sidebar.
3. At the bottom of the window, in the `Manage` box, select `Excel Add-ins` and click `Go`.
4. In the `Add-Ins Available` list, check the box next to `Solver Add-In` and click `OK`.
5. You will find the `Solver` button in the `Data` tab in the `Analysis` group.

Mac

1. Open Excel and go to `Tools` → `Excel Add-Ins`.

2. In the `Add-Ins Available` box, check the `Solver Add-In` box and click `OK`.

3. The `Solver` button will appear on the `Data` tab.

Linux

If your machine's OS is Linux, you can install LibreOffice (or OpenOffice) from http://www.libreoffice.orghere. After installing, use LibreOffice Calc, which has a built-in solver. For more details, refer to LibreOffice's documentation https://help.libreoffice.org/6.1/en-US/text/scalc/01/solver.html.

3 Setting Up Linear Programs In Excel

Linear programs (LPs) can take many forms. In this class we will often be dealing with LPs that can be represented mathematically as

$$\begin{array}{rl} \text{maximize} & c^T x \\ \text{subject to} & \text{Ax} \leq \text{b} \end{array}$$

$$A = \begin{bmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{bmatrix}$$

where the matrices A, b, and c comprise the problem data. Our goal is to maximize the value of the objective function, $c^T x$, by choosing an appropriate vector of decision variables, x. The matrices A and b specify a set of linear inequality constraints that reflect the requirements of the problem.

Entering Matrices into Excel

It is easy to display the components of an LP in their natural way in Excel, i.e., as a range of cells. For example, if A is a 5 * 3 matrix, then each element of A can be entered into its corresponding cell in a 5 * 3 range of cells. Identify ranges of cells to contain the data matrices A, b, and c and enter them into the Excel worksheet. Do the same for the decision variables, x. To keep your worksheet organized, you might consider arranging the matrices as shown below. You are also encouraged to use labels and text to document your work.

Naming Matrices in Excel

Excel allows you to name ranges of cells in the worksheet. This feature is especially convenient for doing matrix calculations and for setting up LPs in Solver. To name a range of cells, select the range and enter its name in the Name Box adjacent to the Formula Bar. Try using this method to give names to the data matrices A, b, and c and to the decision variables, x. For more detailed information, you can check https://support.office.com/en-us/article/define-and-use-names-in-formulas-4d0f13ac-53b7-422e-afd2-abd7ff379c64this video.

Matrix Calculations: SUMPRODUCT and MMULT

We will frequently use the SUMPRODUCT and MMULT commands in Excel.

- `SUMPRODUCT(range1, range2)`: Computes the sum of the products of corresponding elements.

- `MMULT(range1, range2)`: Performs matrix multiplication.

The arguments of SUMPRODUCT and MMULT can be either ranges of cells or range names. It is more concise and descriptive to use names. For a pair of ranges named S and T, entering SUMPRODUCT(S,T) into the Formula Bar returns $\sum_{i,j} s_{ij}t_{ij}$ i.e., the sum of the products of corresponding elements of S and T. Entering MMULT(S,T) into the Formula Bar returns the matrix whose i, jth element is $\sum_k s_{ik}t_{kj}$, i.e.,normal matrix multiplication. SUMPRODUCT(S,T) will return an error unless S and T have the same dimensions. Similarly, MMULT(S,T) will return an error unless the number of columns of S equals the number of rows

of T. If you need to take the transpose of a matrix, use the TRANSPOSE function.
Important note: If a matrix function returns a matrix larger than a single element, you must first use the mouse to select the cells that will contain the result, then type the matrix function into the Formula Bar, and finally type ENTER to evaluate the matrix function. For example, if S and T are 3 * 5 and 5 * 4 matrices, respectively, then the result of MMULT(S,T) will be a 3 * 4 matrix. To perform this calculation and display the result in the worksheet, first highlight a 3 * 4 range of cells, type MMULT(S,T) into the Formula Bar, then type ENTER to display the result in the highlighted area.
With regard to LPs, two of the most important matrix calculations are computing the objective function value, $c^T x$, and the constraint function, Ax. The objective function value $c^T x$ is the scalar product of two vectors, and so can be computed using either SUMPRODUCT(c,x) (as long as c and x are both either row or column vectors) or MMULT(cT,x) (The MMULT command shown here assumes that the objective function, c, has been entered as a row matrix and named cT. Of course, how you issue matrix function commands in Excel will depend on how you entered the data into your worksheet. If you entered c as a column, then you would compute $c^T x$ as MMULT(TRANSPOSE(c),x)). The constraint function Ax is a matrix, so MMULT(A,x) must be used.
Select ranges of cells to contain $c^T x$ and Ax and compute their values using the Excel matrix functions. As the following section will make clear, it is helpful to give these ranges names such as $c^T x$ or OF for $c^T x$, and Ax for Ax. Also remember that neither SUMPRODUCT nor MMULT will work properly if either of the two arguments are empty. For this reason, you must provide dummy values–such as zeros–for the decision variables, x.

Bug

There is a sporadic bug in Excel's Solver where the right-hand side (RHS) of constraints that depend on variables may cause issues. To avoid this, ensure that the RHS of a constraint does not depend on any variables.

4 Using Solver

Setting up the LP in Solver

When all of the LP components have been entered into the worksheet and given names, bring up Solver using the Data → Solver... menu. There are four main elements of the Solver dialog box:

- **Set Objective:** The objective contains the quantity you wish to optimize the objective function value. To specify the Objective, either click on the cell with the mouse or type in the name of the cell containing the objective function value (e.g., OF or cTx).
- **To:** This specifies the direction of the optimization. Click on either of the "Max" or "Min" radio buttons.
- **By Changing Variable Cells:** Select the decision variables. Recall that our goal is to optimize the value of the objective function by choosing an appropriate vector of decision variables. Therefore we will allow Excel to change the decision variables, x. In the "By Changing Variable Cells:" field, either select the range of decision variables using the mouse or type in the name of the range (e.g., x).
- **Subject to the Constraints:** Define the constraints by selecting ranges for $Ax \leq b$. For some versions of solvers, the right hand side of a constraint must be a constant scalar, vector or matrix, and everything that depends on the decision variables must be on the left. Just follow this convention to be safe. Make sure that the RHS of a constraint does not depend on any variables.

Since we will be dealing primarily with linear programs in this class, select Simplex LP from Select a Solving method to force Excel to use a method for solving LPs known as the Simplex algorithm, which we will discuss in some detail later in the course. It is important to select Simplex LP, or else you may end up with inappropriate outputs. Once the LP has been properly set up in the Solver dialog box, press the Solve button to run Solver.

Solver Output Options

Pressing the Solve button runs Solver. Depending on the size of the LP, it may take some time for Solver to get ready. If Solver reaches a solution, a new dialog box will appear and prompt you to either Keep solver solution or Restore original values. At this point you may also choose to see a number of output reports. The Answer report provides a summary of the optimal decision variable values, binding and non-binding constraints, and the optimal objective function value. The Sensitivity report provides information describing the sensitivity of the optimal solution to perturbations in the problem data. This report will become important during our study of linear programming duality.

A Note About Submission

Solving an LP in Excel can sometimes take up a lot of worksheet space, especially if there are many variables or constraints. For each excel problem you solve, you should submit image/PDF of the (1) Solver box, (2) Answer report, (3) Main sheet with the formulas showing. There should also be some description of the linear program formulation either in the excel sheet or in your HW answers. See https://canvas.stanford.edu/courses/115098/files/folder/6-%20Extra%20Files?preview=5802080here for more explanation.

5 An Example

Consider the following linear program:

$$\begin{aligned}
&\text{maximize } 50x_1 + 30x_2 + 25x_3 + 30x_4 \\
\text{subject to}& \\
&2x_1 + 2.5x_2 + 3x_3 + 1.8x_4 \leq 800 \\
&1.2x_1 + 1x_2 + 2x_3 + 0.8x_4 \leq 400 \\
&1.5x_1 + 1.2x_2 + 1.5x_3 + 0.8x_4 \leq 380 \\
&x_2 \geq 50 \\
&x_3 \geq 30 \\
&x_1, x_2, x_3, x_4 \geq 0
\end{aligned}$$

This problem can easily be represented as an LP of the form :

$$\begin{aligned}
&\text{maximize } c^T x \\
&\text{subject to } Ax \leq b \\
&\qquad x \geq 0
\end{aligned}$$

where data matrices A, b and c^T are

$$A = \begin{bmatrix} 2 & 2.5 & 3 & 1.8 \\ 1.2 & 1 & 2 & 0.8 \\ 1.5 & 1.2 & 1.5 & 0.8 \\ 0 & -1 & 0 & 0 \\ 0 & 0 & -1 & 0 \end{bmatrix}$$

$$b = \begin{bmatrix} 800 \\ 400 \\ 380 \\ -50 \\ -30 \end{bmatrix}$$

$$c^T = \begin{bmatrix} 50 & 30 & 25 & 30 \end{bmatrix}$$

Note that two of the inequality constraints have been reversed to become "$\leq$" constraints. In an Excel worksheet, identify ranges of cells to accommodate A, b, c^T , and x, and name the ranges appropriately. In this example we will assume these ranges have been named A, b, cT , and x, respectively. Initialize the vector of decision variables x with some dummy values such as zeros. Select a position for the objective function, define it using the function MMULT(cT,x), and name it cTx, say. Similarly, define the constraint function Ax using MMULT(A,x) and name the result Ax (Remember that since Ax is a 5*1 matrix, you will first have to highlight a 5*1 range of cells and press CTRL SHIFT ENTER to evaluate MMULT(A,x)). Open Solver from the Tools → Solver... menu. Enter the following information into the dialog box:

- Set Objective: cTx
- To: check "Max" radio button
- By Changing Variable Cells: x
- Subject to the Constraints: $Ax \leq b$ and $x \geq 0$

Press Solve. Generate Answer and Sensitivity reports, and examine your solution. We will also provide the excel file for this example on Canvas.