WE
DEMOCRATIZE
ANALYTICS

FRONTLINE solvers

EXCEL USERS
WEB USERS
DEVELOPERS

*Data Visualization * Data Mining * Simulation / Risk Analysis * Decision Trees * Conventional / Stochastic Optimization*

Optimization

Using Analytic Solver Platform

REVIEW BASED ON
MANAGEMENT SCIENCE

FrontlineSolvers

What We'll Cover Today

- Introduction
  - Frontline Systems
  - Session I beta training program goals
  - Overview of Analytic Solver Platform (ASP)
  - Linearity and convexity
- Model building
- Guided Mode
- Reports
- Parametric optimization

Frontline Systems Inc.

- Software Products for:
  - Conventional and Stochastic Optimization
  - Simulation/Risk Analysis
  - Data Mining and Visualization
- 26 Years in Business (Founded 1988)
- 7,000 Companies as Customers:
  - Commercial
  - Academic
  - Software vendors
- 500,000 Users

Lecturer

Sima Maleki

PhD - Industrial and Systems Engineering (Operations Research) - the University of Tennessee

Frontline Systems Consulting Lead and Modeling Specialist

Experience-

Network design, supply chain simulation and optimization, facility location, 3D layout optimization, scheduling, and "lean healthcare" resource utilization.

Session I Online Beta Training Goals

To familiarize you with the following concepts:

- Importance of model structure: linearity and convexity
- Building models in Excel using ASP
- Using the ASP Guided Mode to analyze and solve the model
- Reviewing the reports
- Using parametric optimization technique

To empower you to achieve success

- State of the art tools
- Online educational training
- User guides and video demos

Business Analytics Techniques

Descriptive Analytics

- Analyze what has happened
- Business intelligence queries/reports
- Data visualization
- Data transformation

Predictive Analytics

- Use data to segment or classify customers
- Use data to predict future behavior
- Data mining
- Forecasting

Prescriptive Analytics

- Determine the best course of action to take
- Optimization
- Simulation
- Decision analysis

Problem Solving Process

- It is increasingly important to efficiently use limited resources.
- Optimization can often improve efficiency with no capital investment.

Typical Optimization Applications

Industry

- Energy
- Chemical
- Manufacturing
- Transportation
- Finance
- Agriculture
- Health
- Mining
- Defense
- Forestry

Functional Area

- Staff planning
- Scheduling
- Routing
- Blending
- Capacity planning
- Media planning
- Supply chain
    - Inventory optimization
    - Vendor selection
- Portfolio optimization
- Product mix

Frontline Solvers Optimization Software

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Brief Overview of Analytic Solver Platform (ASP)

Ribbon

Gateway to Analytic Solver Platform's graphical user interface.

- **Model:** to display the Task Pane, defining dimensional models.
- **Optimization Model:** to set up optimization models.
- **Simulation Model:** to set up simulation models.
- **Parameter:** to run multiple optimizations or simulations.
- **Solve Action:** to solve optimization or simulation model.
- **Analysis:** to analyze the results, create reports and charts.

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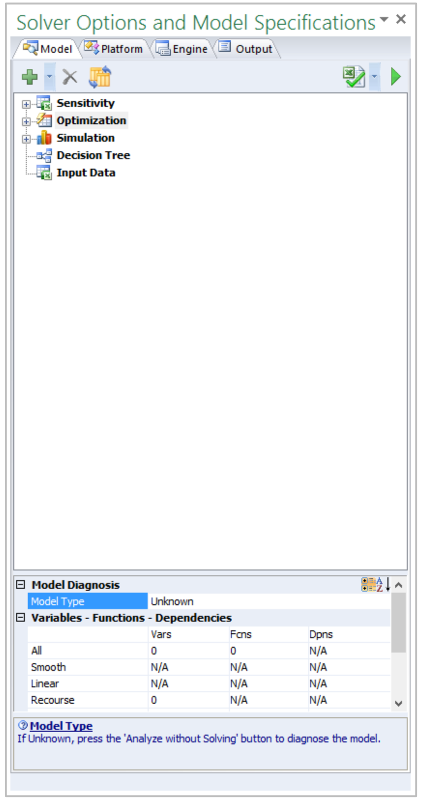
Brief Overview of Analytic Solver Platform (ASP)

Ribbon

- **Tools:** to create decision trees, fit distributions, examine simulation or optimization results.
- **Options:** to set options for optimization, simulation, charts and graphs.
- **Help:** to display online Help, use Live Chat, control Guided Mode, open examples or an online tutorial, access User and Reference Guides, and check the license status.

Brief Overview of ASP



Task Pane

- **Model button:** to display or hide the Task Pane.
- **Model tab:** to view the model in outline form, see results of model diagnosis, and optionally edit model elements in place.
- **Platform tab:** to view or change Platform options.
- **Engine tab:** to select a Solver Engine and set its options.
- **Output tab:** to view a log of solution messages, or a chart of the objective values.

Example – Problem Definition

- A company manufactures and sells two models of hot tubs: the Aqua-Spa and the Hydro-Lux.
  - Aqua-Spa – needs 9 hours of labor, 12 feet of tubing, and 1 pump and generates $350 profit.
  - Hydro-Lux – needs 6 hours of labor, 16 feet of tubing, and 1 pump and generates $300 profit.
  - Company expects to have 200 pumps, 1,566 labor hours, 2,880 feet of tubing.
- Managerial decision: how many Aqua-Spas and Hydro-Luxes should be produced to maximize the profit during the next production cycle?

Products	Aqua-Spa	Hydro-Lux	Total Availability
Labor Hours	9	6	1566
Tubing Material	12	16	2880
Pump	1	1	200
Profit Margin	350	300	Maximization

Examples of Variables, Constraints, and Objective

Portfolio optimization

- Variables: amounts invested in different assets
- Constraints: budget, max. or min. investment per asset, minimum return
- Objective: overall risk or return variance

Power generation

- Variables: number of generating units, output rate, height of reservoir, …
- Constraints: demand, generator limit
- Objective: operating, fuel cost, power consumption

Process manufacturing

- Variables: raw materials allocated to production processes
- Constraints: max. or min. outputs, blend specifications
- Objective: profit or cost of final products

Mathematical Optimization

- Mathematical optimization problem

$$Maximize/Minimize\ f_0(x)$$
$$Subject\ to\ f_i(x) \leq b_i, \qquad i = 1, \dots, m$$
$$h_i(x) = 0, \qquad i = m+1, \dots, M$$

- **Decision variables:** $x = (x_1, \dots, x_n)$:
- **Objective function:** f_0
- **Constraint functions:** f_i and h_i for $i = 1, \dots, M$
- **Feasible solution:** x that satisfies all the constraints.
- **Optimal solution:** x^* that has the largest/smallest value of f_0 among all possible x that satisfy the constraints.

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Example – Problem Formulation

- Decision variables: number of Aqua-Spas X_1 Hydro-Luxes X_2
- Objective function to max. profit: $Max\ 350X_1 + 300X_2$
- Constraints:

Total available labor hours: $9X_1 + 6\ X_2 \leq 1566$

Total available Tubing Material: $12X_1 + 16X_2 \leq 2880$

Total pumps: $1X_1 + 1\ X_2 \leq 200$

Bounds on variables: $X_1, \quad X_2 \geq 0$

Products	Aqua-Spa	Hydro-Lux	Total Availability
Labor Hours	9	6	1566
Tubing Material	12	16	2880
Pump	1	1	200
Profit Margin	350	300	Maximization

Example – Spreadsheet Implementation

- Decision variables: number of Aqua-Spas X_1 Hydro-Luxes X_2
  - Spreadsheet Cells: $\boldsymbol{B3}$ $\boldsymbol{C3}$

- Objective function to max. profit: $Max\ 350X_1 + 300X_2$
  - Spreadsheet Cell: $\mathbf{E4} = \mathbf{B4} * \mathbf{B3} + \mathbf{C4} * \mathbf{C3} = \mathbf{SUMPRODUCT}(\mathbf{B4}{:}\,\mathbf{C4}, \mathbf{B3}{:}\,\mathbf{C3})$

Model Structure Matters!

- Frontline Solvers can optimize any optimization model defined in Excel, however **speed** and **solution** quality depend heavily on the **formulas** you use.
- This is intrinsic; independent of any optimization software.
- A linear model will solve quickly, to large scale, and yields a proven optimal solution.
- A model with IF or LOOKUP functions will solve many times more slowly, cannot be very large scale, and yields only a "better" solution.
- Feasibility or infeasibility can be proven only for convex models.

Linear, Non-Linear, Non-Smooth

Linear: =SUM(A1:A10)

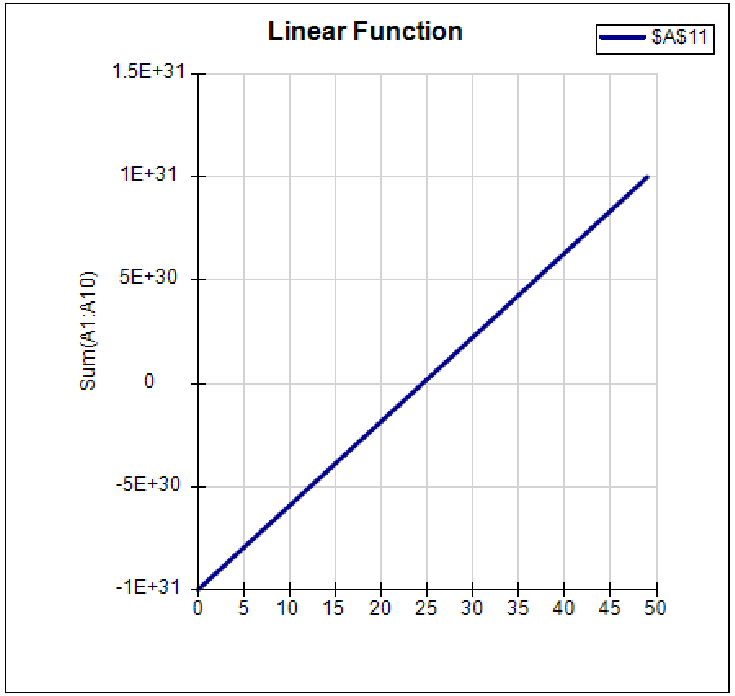
Easiest/Fastest

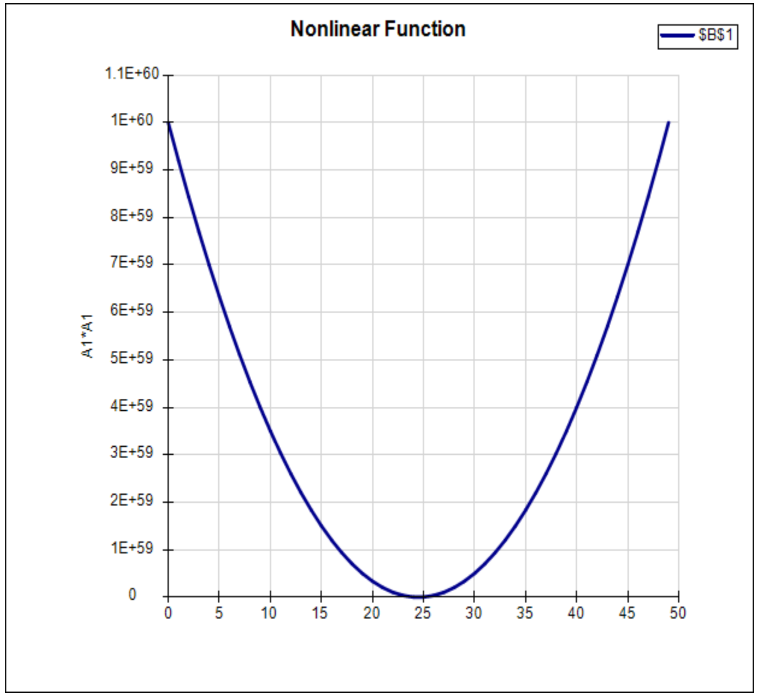
Non-linear: =A1*A1

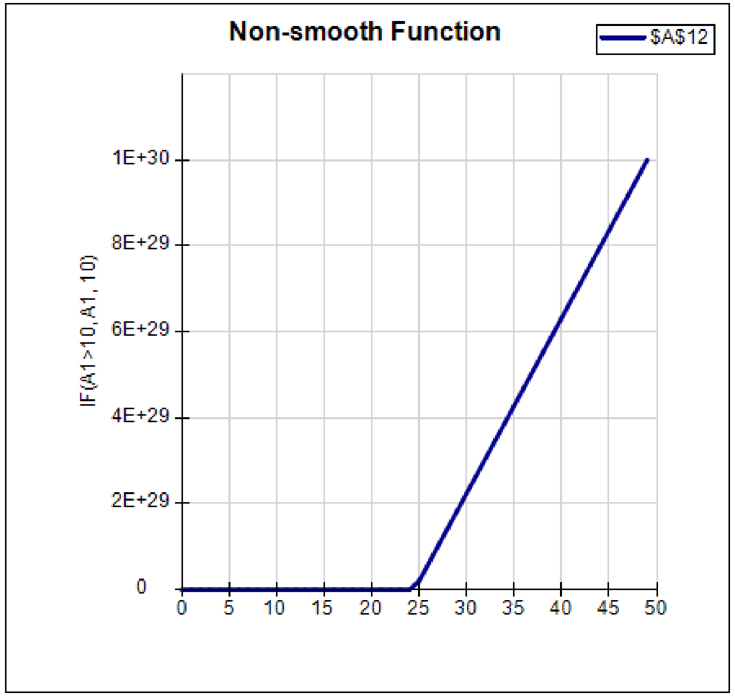
Slower

Non-smooth: =IF(A1>25, A1, 0)

Hardest/Slowest

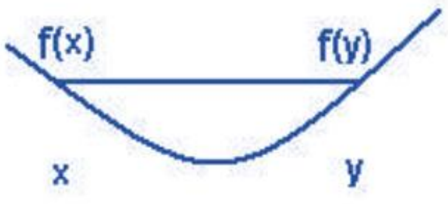




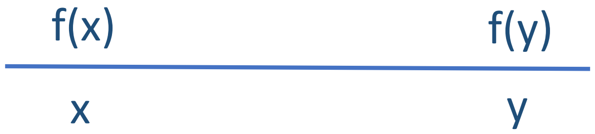


Beyond Linearity: Convexity

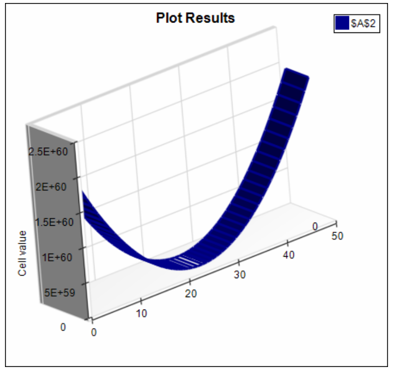
- The key property of functions of the variables that makes a problem “easy” or “hard” to solve is *convexity*.



- Geometrically, a function is *convex* if, at any two points x and y, the line drawn from x to y (called the *chord* from x to y) lies *on or above* the function.



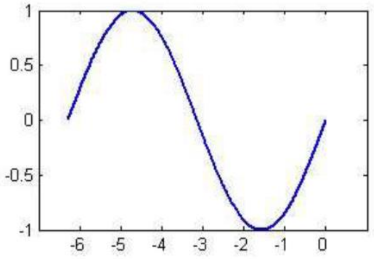
- All linear functions are convex. The *chord* from x to y lies on the function.



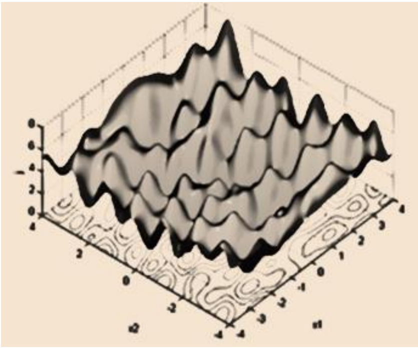
- In a minimization problem, if all constraints and objective are convex you can be confident of finding a globally optimal solution even if the problem is very large.

Non-Convexity

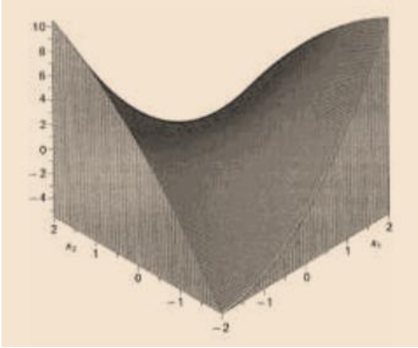
- A non-convex function "curves up and down." SIN(C1) Combinations of non-convex functions create complex shapes that are expensive to search.



- Non-convex functions can have multiple locally optimal solutions, making it difficult to find the globally optimal solution.
  - A compromise is to seek a "good," but not a proven optimal solution.



- Even one non-convex function makes the whole model non-convex, and therefore much harder to solve.



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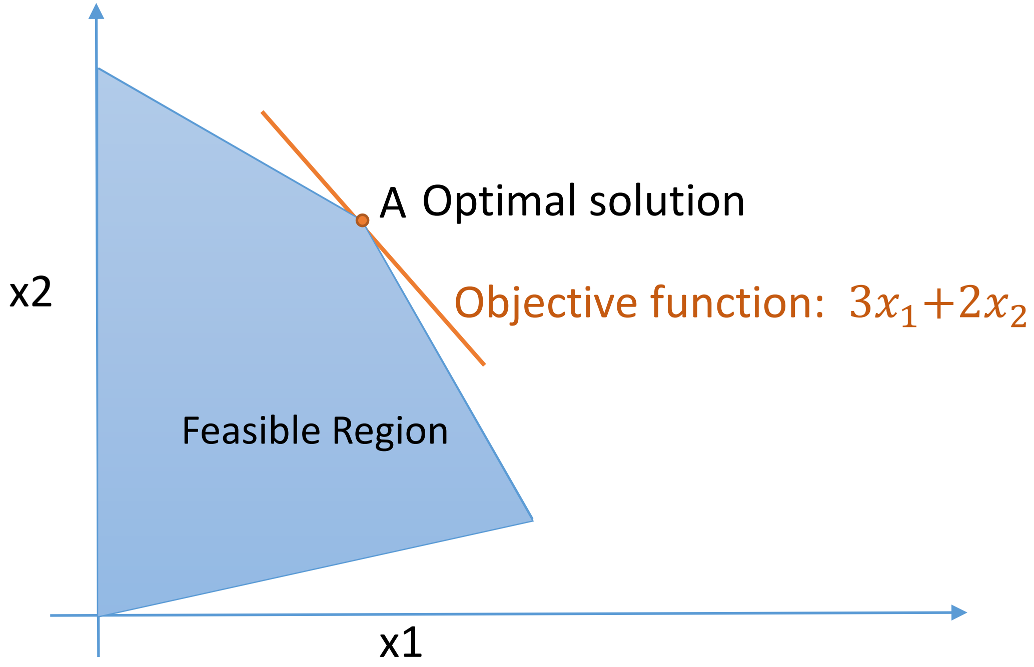
Linear Models: Easy to solve

- Linear constraints intersect to form a ***convex*** region.
- Optimal solution always lies on the boundary of the feasible region.



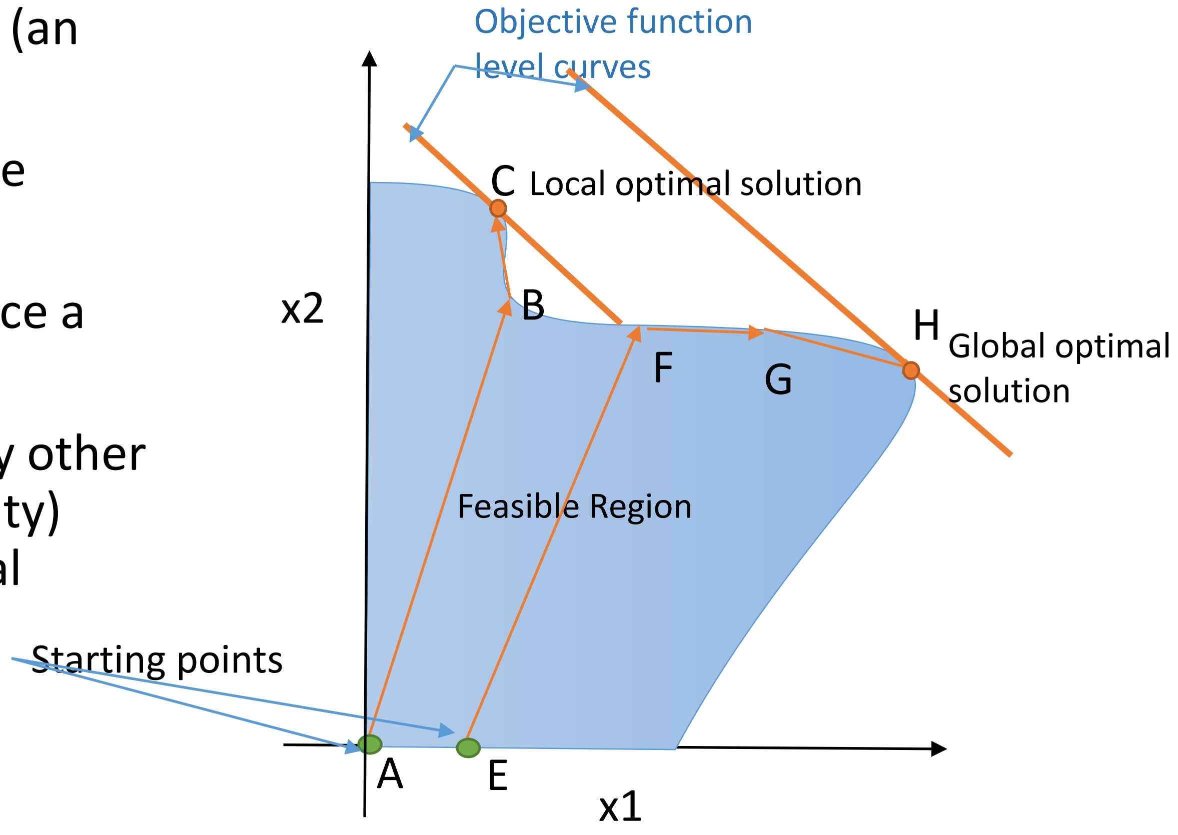
Max $3x_1+2x_2$

Subject to

$$x_1+x_2 \leq 4,$$
$$2x_1+x_2 \leq 5,$$
$$-x_1+4x_2 \geq 2$$
$$x_1, x_2 \geq 0.$$

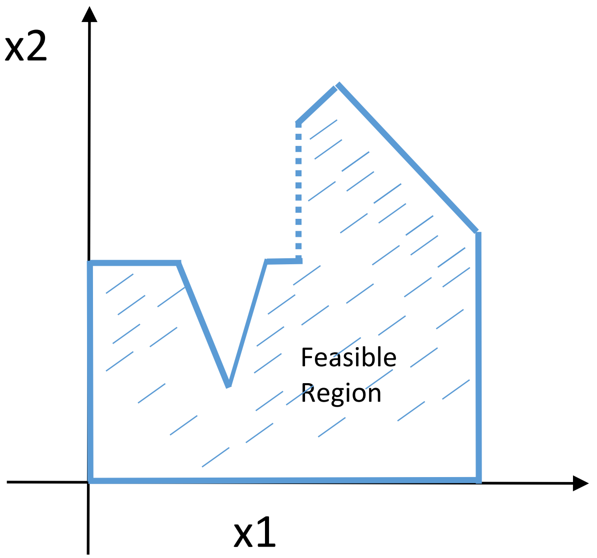
Non-Linear Models: Harder to Solve

- NLP algorithms begin at a starting point (an initial feasible solution).
- Moves in the direction that improves the objective function.
- If there is no feasible direction to produce a better objective function value, it stops.
- A local optimal solution (better than any other feasible solutions in its immediate vicinity) might be found instead of global optimal solution.



Non-Smooth Models: Hardest to Solve

- For a non-smooth model, you should expect only a “good,” not an optimal solution.
- A systematic search would take exponentially long.
- Evolutionary algorithm relies on random sampling.
  - Maintains a *population* of candidate solutions.
  - Makes random changes and combines elements of existing solutions to create a new solution.
  - Performs a *selection* process.
  - Stops and returns a solution when certain heuristic rules indicate that further progress is unlikely or when it exceeds a limit on computing time.
- http://xefer.com/maze-generator



Recap – Optimization Solutions

- Optimal solution – a feasible solution where the objective function reaches its maximum (or minimum) value.
  - Globally optimal solution is one where there are no other feasible solutions with better objective function values.
  - A locally optimal solution is one where there are no other feasible solutions “in the vicinity” with better objective function values.
- The kind of solution the Solver can find depends the **formulas you use** and the Solver Engine you choose.
  - Smooth convex: expect a globally optimal solution.
  - Smooth non-convex: usually expect a locally optimal solution.
  - Non-smooth: expect to settle for a “good” solution that may or may not be optimal.

Formulas Determine Your Model’s Structure

- SUM and SUMPRODUCT are common in linear models.
- IF and LOOKUP functions can be non-smooth/non-convex.
- ASP can automatically find “problem” formulas in your model.
- IF functions can sometimes be used:
  - A1 is a decision variable, B1 is a constant parameter
  - =IF(A1>10, A1,2*A1) is non-smooth
  - =IF(B1>10, A1, 2*A1) is linear

Model Building in a Spreadsheet

Using Analytic Solver Platform

Models in Excel Spreadsheets

- A well-designed, well documented, and accurate spreadsheet model is a valuable tool in decision making.
- To build an optimization model in Excel, start with a what-if model, with input cells for decision variables.
  - Create Excel formulas, copy them across cell ranges, …
  - Use Excel's *array* formulas, and Excel functions that return array results.
  - Use Excel's rich facilities to access data in external text files, Web pages, and relational databases to populate the model.

Setting Up a Model in ASP as an Excel Spreadsheet

- Organize the data for the model on the spreadsheet.
- Reserve a cell to hold the value of each decision variable.
- Pick a cell to represent the objective function, and enter a formula that calculates the objective function value in this cell.
- Pick other cells and use them to enter the formulas that calculate the left-hand sides of the constraints.
- The constraint right-hand sides can be entered as numbers in other cells, or entered directly in the Solver’s Add Constraint dialog.
- Best practice: use constants for constraint right-hand sides.

Example – Spreadsheet Implementation

- Decision variables: number of Aqua-Spas X_1 → $\boldsymbol{B3}$, Hydro-Luxes X_2 → $\boldsymbol{C3}$
  - Spreadsheet Cells: $\boldsymbol{B3}$, $\boldsymbol{C3}$

- Objective function to max. profit: $Max\ 350X_1 + 300X_2$
  - Spreadsheet Cell: $\mathbf{E4} = \mathbf{B4} * \mathbf{B3} + \mathbf{C4} * \mathbf{C3} = \mathbf{SumProduct(B4{:}\,C4, B3{:}\,C3)}$

Products	Aqua-Spa	Hydro-Lux	Total Availability
Labor Hours	B8 = 9	C8 = 6	E8 = 1566
Tubing	B9 = 12	C9 = 16	E9 = 2880
Pump	B10 = 1	C10 = 1	E10 = 200
Profit Margin	B4 = 350	C4 = 300	Maximization

	A	B	C	D	E
1					
2		Aqua-Spa	Hydro-Lux		
3	Number to Make				Total Profit
4	Unit Profit Margin in $	350	300		
5					
6					
7	Constraints			Used	Available
8	Labor Required	9	6		1566
9	Tubing Required	12	16		2880
10	Pumps Required	1	1		200

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Example – Spreadsheet Implementation

- Constraints:

Total available labor hours: $9\ X_1 + 6\ X_2 \leq 1566$

- *Formula for Cell D8* = ***B3*B8+C3*C8*** Or ***SUMPRODUCT(B3:C3,B8:C8)***

Total available Tubing Material: $12X_1 + 16X_2 \leq 2880$

- *Formula for Cell D9* = ***B3*B9+C3*C9*** Or ***SUMPRODUCT(B3:C3,B9:C9)***

Total pumps: $1X_1 + 1\ X_2 \leq 200$

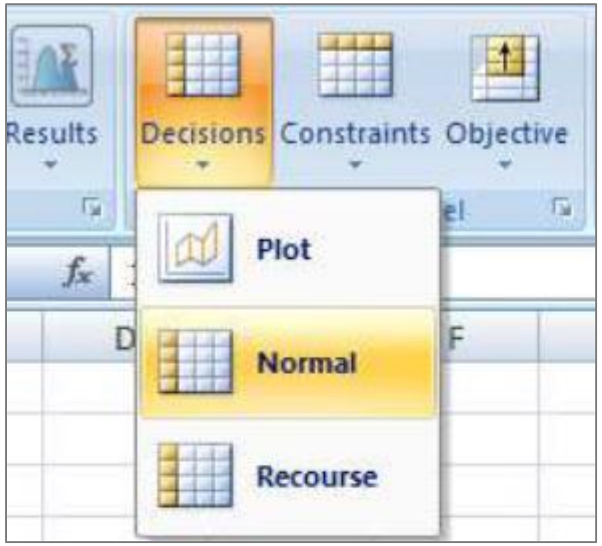
- *Formula for Cell D10* = ***B3*B10+C3*C10*** Or ***SUMPRODUCT(B3:C3,B10:C10)***

Bounds on variables $X_1, \quad X_2 \geq 0$

Products	Aqua-Spa	Hydro-Lux	Total Availability
Labor Hours	B8 = 9	C8 = 6	E8 = 1566
Tubing	B9 = 12	C9 = 16	E9 = 2880
Pump	B10 = 1	C10 = 1	E10 = 200
Profit Margin	B4 = 350	C4 = 300	Maximization

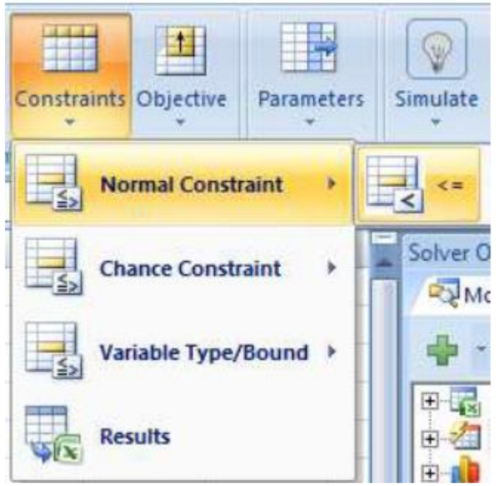
Summary – Setting Up a Model in ASP as an Excel Spreadsheet

- Use mouse to select the cell range on the worksheet. Then click the **Decisions** button and click **Normal** to define the cell range as normal decision variables.



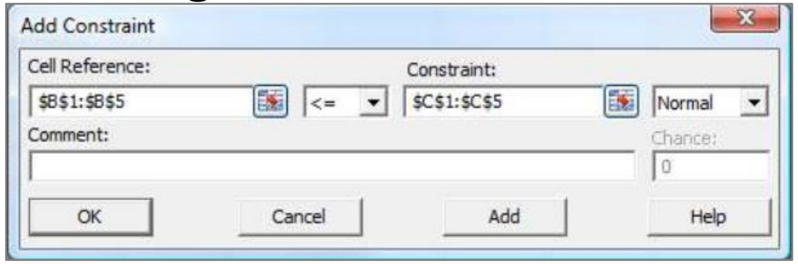
- Use the mouse to select the objective cell on the worksheet. Then click the **Objective** button (min or max).

- To define the **constraints**, use mouse to select the range on the worksheet. Then click the **Constraints** button, and click **Normal Constraint** (<=, > = , or =)

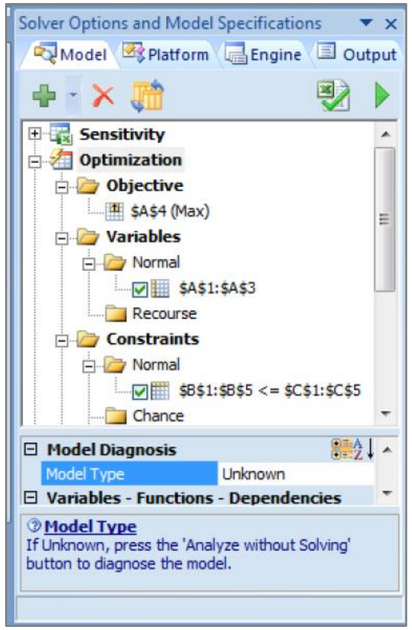


Summary – Setting Up a Model in ASP as an Excel Spreadsheet

- Complete the Add Constraint dialog.

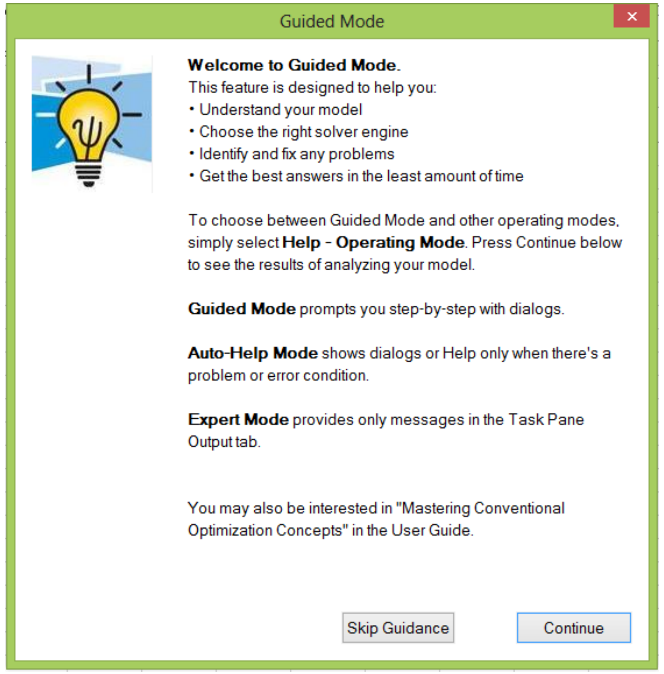


- The Task Pane Model tab now shows all the elements of the optimization model just defined in outline form.



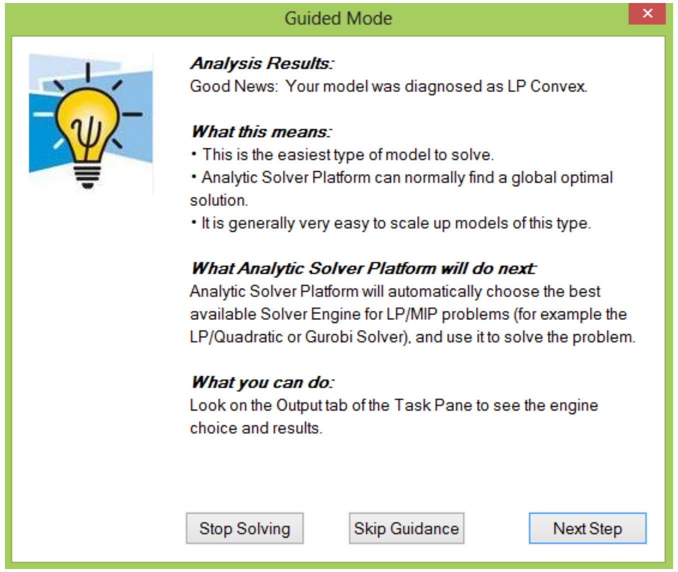
- Solve the model by clicking the **Optimize** button on the Ribbon, or by clicking the **green arrow** at the top right of the Task Pane.

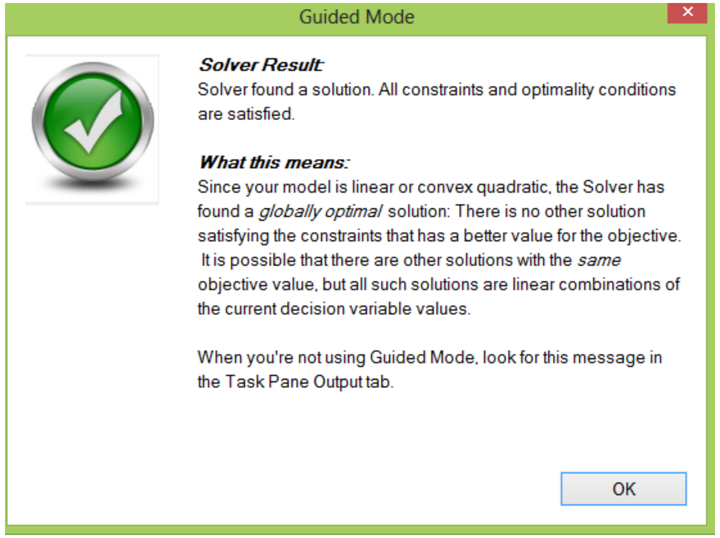
- Follow the Guided Mode step-by step help.



Summary – Setting Up a Model in ASP as an Excel Spreadsheet

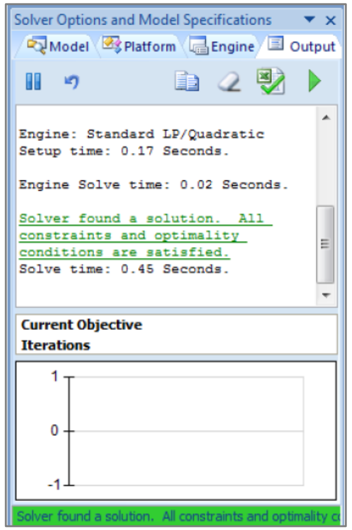
- Click on Continue and review the analysis results.





- Click on Next Step and review the Solver Results.

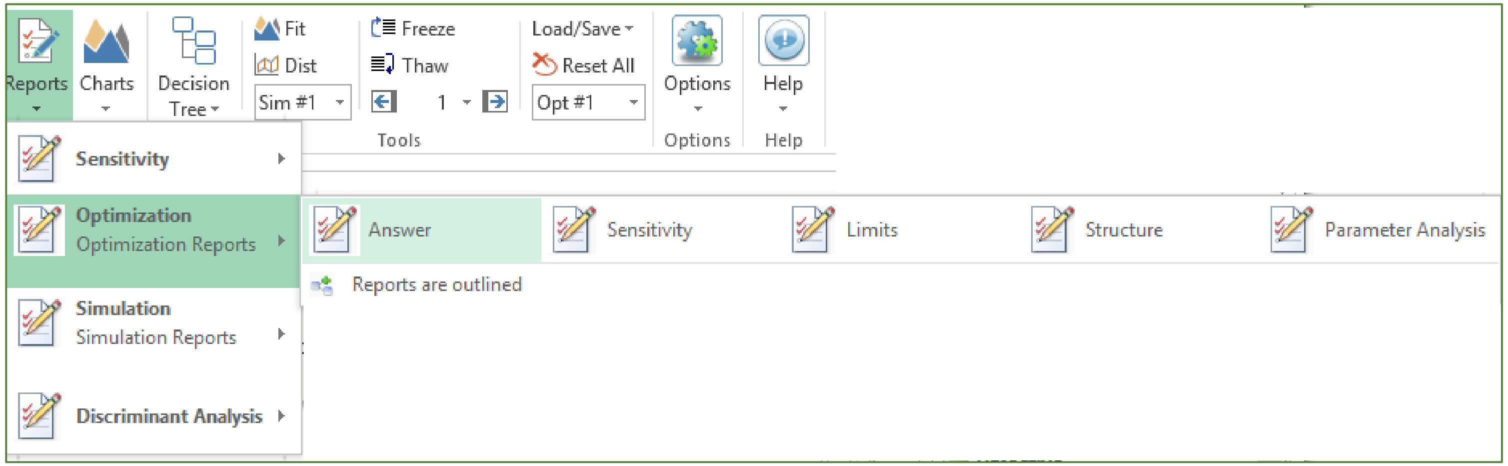
- Review the output tab.
- Click the underlined message in the log to open online Help to a full explanation of the message.



Solver Reports

After **solving**, produce reports by selecting Reports – Optimization from the Ribbon.

- Answer, Sensitivity Reports
- Structure Report
- Solutions Report
- Scaling Report
- Population Report
- Linearity and Feasibility Reports
- Transformation Report

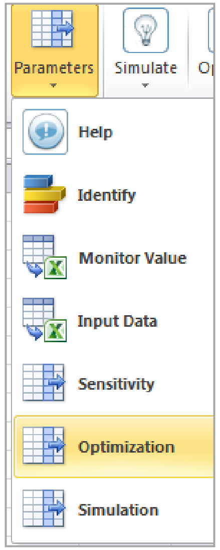


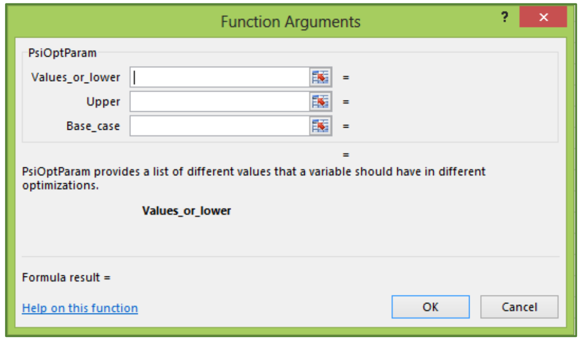
Parametric Optimization

- Often you want to solve a problem for various scenarios or cases.
- In each scenario, certain model parameters have different values.
- ASP lets you easily define optimization parameters, and run multiple optimizations in one “Solve”.
- Parameters are saved as =PsiOptParam() function calls.

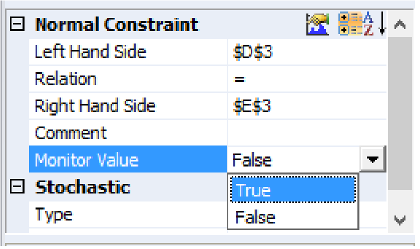
Summary – Parametric Optimization

- Select the cell, choose **Parameters - Optimization** from the Ribbon.
- Enter a lower and upper limit on values for the parameter, or a list of explicit values for the parameter.

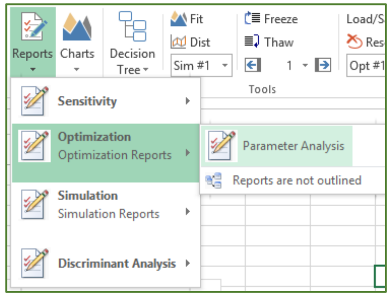




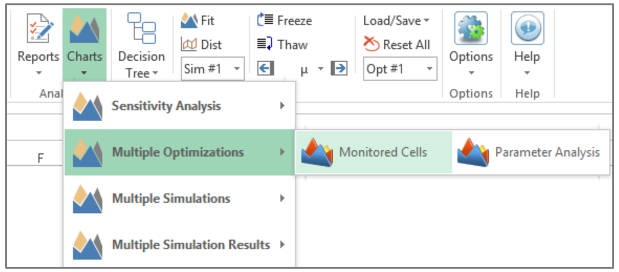
- Use PsiOptValue (cell, optimization #) to retrieve the specific value for a cell or function of an optimization.
- Track a constraint value by setting its Monitor property in the Task Pane.



- Select Reports – Optimization – Multiple Optimization



- Select Charts – Multiple Optimization.



Benefits of Optimization

- A good optimization model finds better combinations of values for the decision variables than you might find by manual what-if.
- Many of our customers have found better solutions for real industrial problems, **worth millions in savings**.
- Frontline’s Solvers offer powerful tools to help you get a better solution by diagnosing model structure and fixing problems, automatically selecting the Solver Engine, and providing updated information at each step.
  - Help – Operating Mode – Guided Mode.

Further Benefits of Modeling

- Building a model often reveals relationships and yields a greater understanding of the situation being modeled.
- Having built a model, it is possible to apply analytic methods to suggest courses of action that might not otherwise be apparent.
- Experimentation is possible with a model, whereas it is often not possible, or desirable, to experiment with the situation being modeled.
- Analytic Solver Platform is a complete toolset for descriptive, predictive and prescriptive analytics.

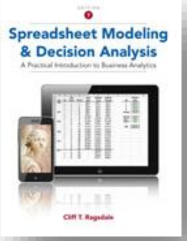
Contact Info

- Dr. Sima Maleki
- Best way to contact me: Consulting@Solver.com
- You may also download this presentation from our website.
- You can download a free trial version of Analytic Solver Platform at Solver.com.

References

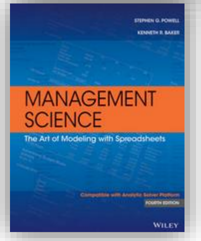
- **Spreadsheet Modeling and Decision Analysis: A Practical Introduction to Business Analytics, 7th Edition**

http://www.cengage.com/us/



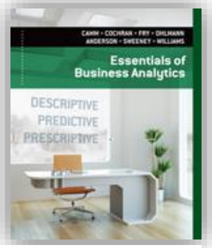
- **MANAGEMENT SCIENCE-The Art of Modeling with Spreadsheets, 4th Edition**

http://www.wiley.com/WileyCDA/WileyTitle/productCd-EHEP002883.html



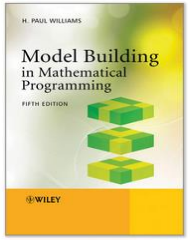
- **Essentials of Business Analytics, 1st Edition**

http://www.cengage.com/us/



- **Model Building in Mathematical Programming**

http://www.wiley.com/WileyCDA/WileyTitle/productCd-1118443330.html



Q & A

FRONTLINE solvers

Thank You!