IEOR E4650 Business Analytics

Session 20: Salesforce Analytics and Optimization

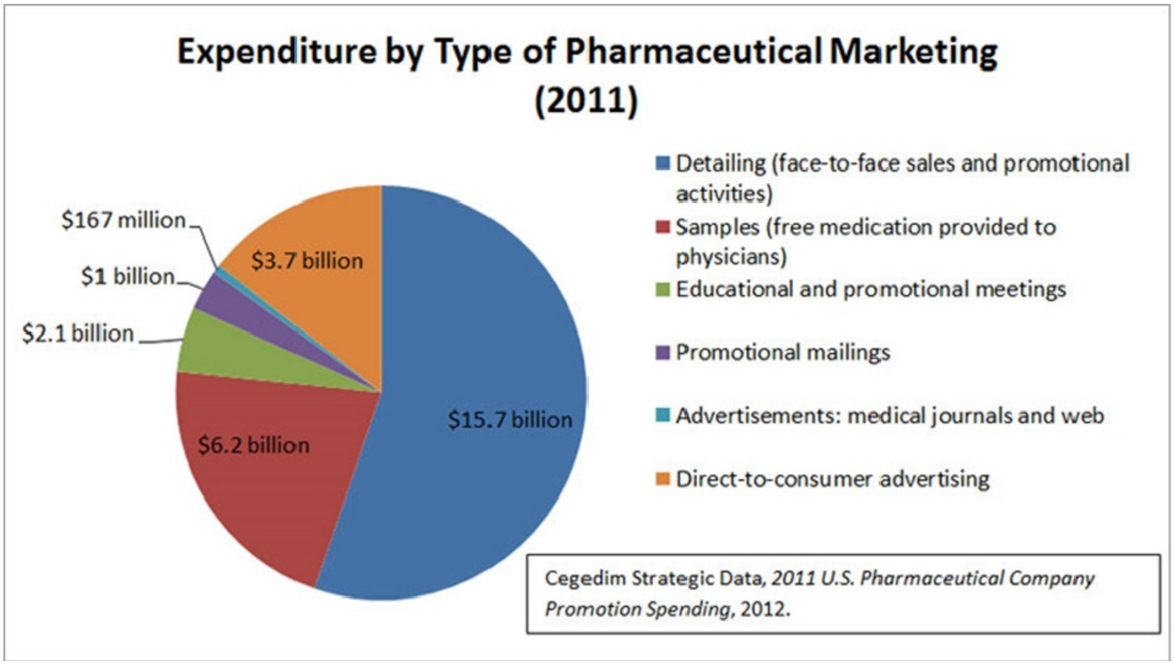
Spring 2018

Prof. Adam Elmachtoub

Outline

- Pharmaceutical Detailing
  - Problem formulation: objective and constraints
  - Finding an optimal solution
  - Sensitivity Analysis
- Supplier Optimization
- Pricing Example
- Sensitivity Analysis for Nonlinear Optimization

Pharmaceutical Detailing



Data Sources

- Two main sources
  - Pharmacy sales records (prescription drug monitoring)
  - AMA Physician Master File (600,000 US doctors)
- Consolidated and sold by third party vendors (e.g., Solucient Claims Data Warehouse)
- Data
  - Patient (ID)
  - Prescribing physician
  - Dosage
  - Date
- Allows for detailed tracking of physician-patient prescription histories
- Pharmaceutical companies track detailing visits and performance measures

The Analytic Opportunity

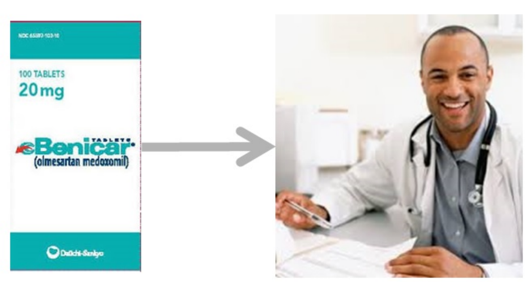
Utilize prescription data to make direct marketing of drugs more effective

- Which doctors should we target for in-person detailing?
- How often should we visit them?
- Should we provide samples? How many?
- Which drugs should we promote on each visit?
- Other marketing efforts (lunch & learn, conferences, webinar)

XGen: Pre-Class Exercise

Consider

- One brand (anti-platelet)
- One time period (week)
- Sample problem
  - 20 physicians of different types
  - 5 sales agents to dispatch



Question: Where to send each sales agent to maximize expected payoff?

A Predictive Model of Conversion

Estimate from past data Logistic Regression parameters

$$\text{Probability that agent } i \text{ converts doctor } j = \frac{e^{w_{ij}}}{1 + e^{w_{ij}}}$$

where

$$w_{ij} = -3.07 - 0.18\, CARD(j) + 0.05\, XGen\%(j) + 0.42\, SER(i) + 0.17\, F2F(i,j)$$

Variables:

- CARD - indicator if physician is a cardiologist (CARD=1) or a primary care physician (CARD=0).
- XGen% - measure of the % of the physicians' patients who are currently being precribed other XGen therapies.
- SER - Sales Effectiveness Ratio (SER), measure of relative effectiveness of a sales representative in converting physicians to a new drug;
- F2F - indicator of whether the specific sales representative had a prior successful face-to-face relationship with a given physician. (physician-sales rep interaction variable)

From Conversion Probabilities to Payoffs

Expected payoff from allocating agent i to doctor j

$$Prob(i,j) \times Size(j) \times \$50$$

- $Prob(i,j)$ = prob. agent i converts doctor j
- $Size(j)$ = size of practice of doctor j
- expected payoff per patient = $\$50$

	Sale Rep				
Doctor	**1**	**2**	**3**	**4**	**5**
1	$ 6,326	$ 6,989	$ 5,232	$ 5,088	$ 6,288
2	$ 9,809	$ 9,247	$ 8,115	$ 7,892	$ 8,310
3	$ 7,870	$ 7,419	$ 6,511	$ 7,433	$ 7,824
4	$ 10,620	$ 10,027	$ 7,535	$ 7,330	$ 9,034
5	$ 6,141	$ 5,789	$ 5,962	$ 4,940	$ 5,202
6	$ 8,919	$ 9,841	$ 8,663	$ 7,194	$ 7,571
7	$ 8,273	$ 7,804	$ 6,858	$ 7,818	$ 8,224
8	$ 12,886	$ 12,156	$ 10,683	$ 12,179	$ 10,938
9	$ 3,139	$ 2,959	$ 3,048	$ 2,965	$ 2,659
10	$ 5,087	$ 4,799	$ 4,217	$ 4,808	$ 4,318
11	$ 7,496	$ 8,283	$ 6,200	$ 6,030	$ 6,350
12	$ 9,972	$ 8,050	$ 7,074	$ 8,065	$ 8,483
13	$ 6,436	$ 7,101	$ 5,336	$ 5,191	$ 5,463
14	$ 8,747	$ 9,652	$ 8,496	$ 7,055	$ 7,425
15	$ 5,845	$ 5,514	$ 5,677	$ 4,714	$ 5,811
16	$ 7,810	$ 7,367	$ 5,514	$ 5,363	$ 5,648
17	$ 2,081	$ 2,296	$ 2,021	$ 1,678	$ 1,766
18	$ 8,371	$ 6,757	$ 5,938	$ 5,777	$ 6,080
19	$ 9,334	$ 8,798	$ 7,721	$ 7,508	$ 7,907
20	$ 3,512	$ 3,313	$ 3,411	$ 3,319	$ 2,981

Determining a Sales Force Plan for XGen

- We need to determine an allocation of sales agents to doctors for the upcoming week

What are possible heuristics to do so?

Performance Evaluation of a Given Plan

Sale Rep

Doctor	1	2	3	4	5
1	$ 6,326	$ 6,989	$ 5,232	$ 5,088	$ 6,288
2	$ 9,809	$ 9,247	$ 8,115	$ 7,892	$ 8,310
3	$ 7,870	$ 7,419	$ 6,511	$ 7,433	$ 7,824
4	$ 10,620	$ 10,027	$ 7,535	$ 7,330	$ 9,034
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19	$ 9,334	$ 8,798	$ 7,721	$ 7,508	$ 7,907
20	$ 3,512	$ 3,313	$ 3,411	$ 3,319	$ 2,981

Profit 105,368 =SUMPRODUCT(C7:G26,J7:N26)

Sale Rep

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

An Optimization Model

- Decision variables: a numerical variable (or set of variables) that defines the decision/action to be optimized

- Constraints: conditions defining the allowable (feasible) values for the decision variables
    - business rules
    - physical constraints
    - financial constraints

- Objective: a function that measures the quality of the decision (i.e. how good or bad it is)
    - maximize the function (e.g., revenues)
    - minimize the function (e.g., costs)

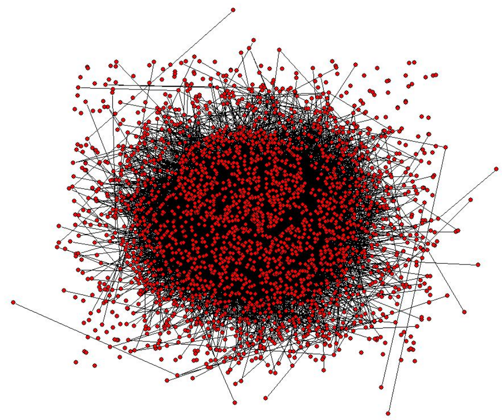
Optimization Model for XGen

- Decision variables: there are $5 \times 20 = 100$ decision variables:
    - $x_{i,j} = 1$ if agent i is assigned to doctor j, 0 otherwise
- Constraints:
    - each doctor can only receive at most one visit
    - agents 1 and 2 can visit at most two doctors and agents 3, 4 and 5 can visit at most three doctors
- Objective: maximize the expected profit

sum over all agents i and doctors j: $x_{i,j} \times \text{Payoff}(i,j)$

Capturing Value Through Optimization

Identify the best choice from an enormous universe of alternatives



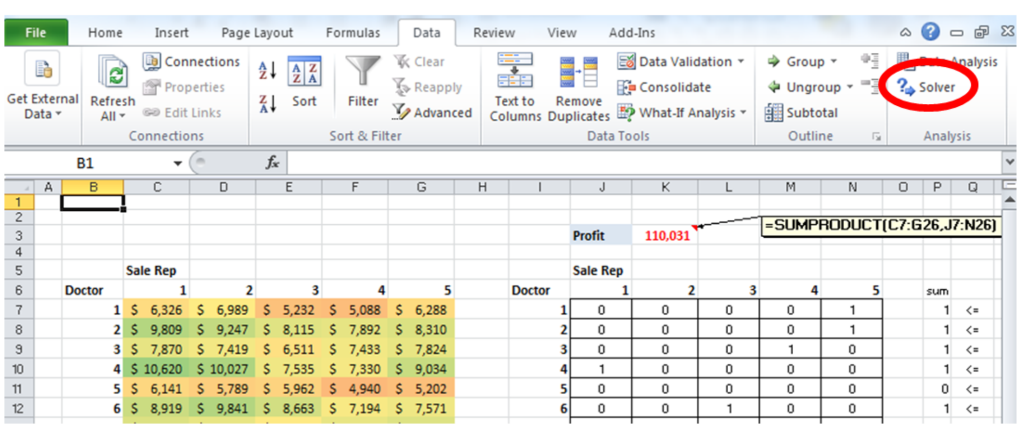
Example: Pharma problem with 5 sales agents and 20 doctors. How many possibilities?

$2^{100} = (1,048,576)^5 \approx 10^{30}$ (ignoring constraints)

The Solver Optimization Add-in

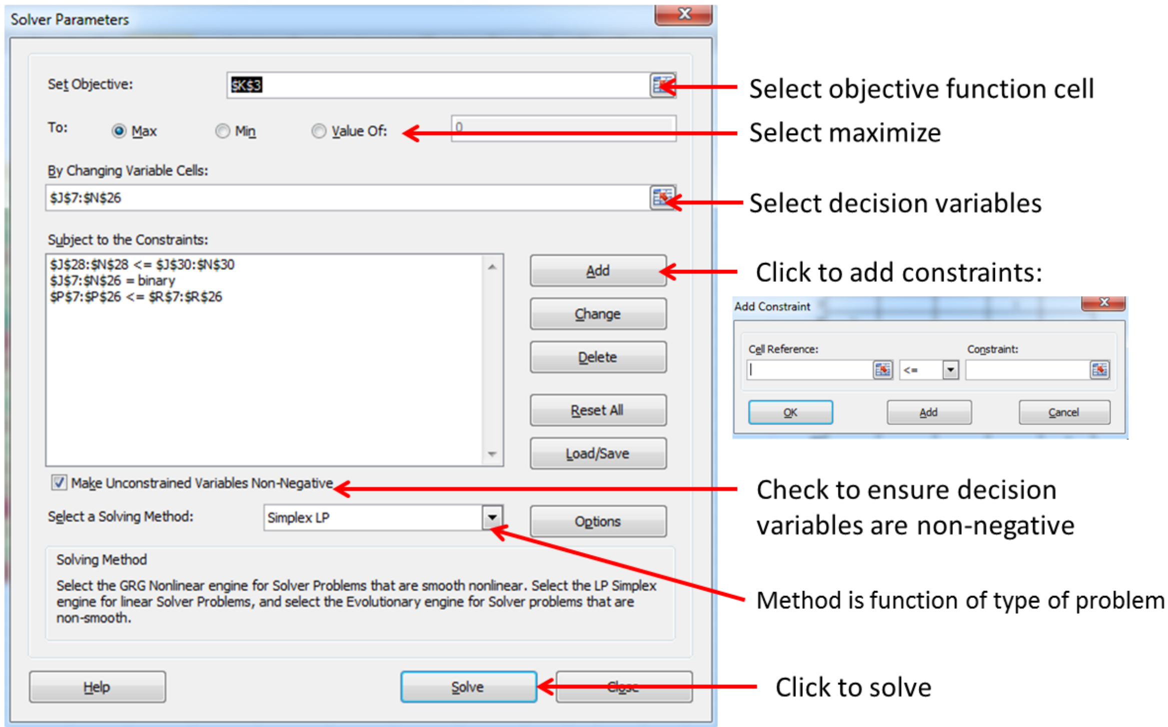
In Excel, a pre-loaded add-in allows to solve optimization problems

Can be found under the "Data" tab, in the "Analysis" category



Note: if it does not appear there, you should simply activate the pre-loaded add-in (see appendix for instructions on how to do so)

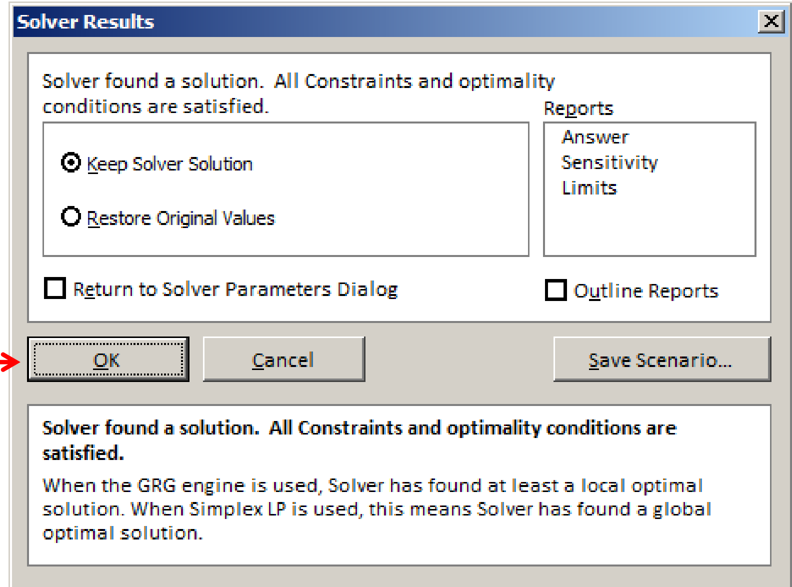
The Solver Optimization Add-in



The Solver Optimization Add-in: Solving method

- If the objective and the constraints are linear, one should use the simplex LP method
- If the objective or the constraints are nonlinear, one should use the GRG non-linear method
- If you have any doubt, you can start with the simplex LP method, and then move on to the GRG non-linear method if solver sends back an error message
- In general, constraints may be written in different forms. To the extent that these can be expressed in a linear fashion, one should do so as linear problems are easier to solve

Successful Execution



Click OK

The Optimized Model

Profit: 110,031 =SUMPRODUCT(C7:G26,J7:N26)

Sale Rep

Doctor	1	2	3	4	5
1	$ 6,326	$ 6,989	$ 5,232	$ 5,088	$ 6,288
2	$ 9,809	$ 9,247	$ 8,115	$ 7,892	$ 8,310
3	$ 7,870	$ 7,419	$ 6,511	$ 7,433	$ 7,824
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20	$ 3,512	$ 3,313	$ 3,411	$ 3,319	$ 2,981

Sale Rep

Doctor	1	2	3	4	5	sum		
1	0	0	0	0	1	1	<=	1
2	0	0	0	0	1	1	<=	1
3	0	0	0	1	0	1	<=	1
4	1	0	0	0	0	1	<=	1
5	0	0	0	0	0	0	<=	1
6	0	0	1	0	0	1	<=	1
7	0	0	0	1	0	1	<=	1
8	0	0	0	1	0	1	<=	1
9	0	0	0	0	0	0	<=	1
10	0	0	0	0	0	0	<=	1
11	0	1	0	0	0	1	<=	1
12	0	0	0	0	1	1	<=	1
13	0	0	0	0	0	0	<=	1
14	0	0	1	0	0	1	<=	1
15	0	0	0	0	0	0	<=	1
16	0	1	0	0	0	1	<=	1
17	0	0	0	0	0	0	<=	1
18	1	0	0	0	0	1	<=	1
19	0	0	1	0	0	1	<=	1
20	0	0	0	0	0	0	<=	1
sum	2	2	3	3	3			
	<=	<=	<=	<=	<=			
	2	2	3	3	3			

Optimal allocation yields an expected profit of $110,031!

Optimization Results

What can happen when solving an optimization problem?

- Algorithm returns a feasible, optimal solution
  - Note: there can be multiple optimal solutions
  - But all optimal solutions have the same objective function value
- Algorithm cannot find a feasible solution
  - The model has conflicting constraints
  - For example, if we added the constraint that the total number of doctors visited is greater than 15
- Algorithm does not converge
  - One may have forgotten constraints; without those constraints, one could generate infinite revenues
  - Computational time limits reached

Sensitivity Report for Xgen

Constraints

Cell	Name	Final Value	Shadow Price	Constraint R.H. Side	Allowable Increase	Allowable Decrease
J28	Sale Rep	2	7656.754512	2	0	0
K28		2	7140.554179	2	1	0
L28		3	5962.312868	3	1	0
M28		3	5750.256938	3	1	0
N28		3	6157.975082	3	0	0
P7		1	129.8537232	1	0	0
P8		1	2152.427754	1	0	0
P9		1	1683.06722	1	0	1
P10		1	2963.1708	1	0	0
P11		0	0	1	1E+30	1
P12		1	2700.466201	1	0	1
P13		1	2068.160489	1	0	1
P14		1	6428.777138	1	0	1
P15		0	0	1	1E+30	1
P16		0	0	1	1E+30	1
P17		1	1141.966837	1	0	1
P18		1	2324.56871	1	0	0
P19		0	0	1	1E+30	1
P20		1	2533.359972	1	0	1
P21		0	0	1	1E+30	1
P22		1	226.2919631	1	0	1
P23		0	0	1	1E+30	1
P24		1	714.5762889	1	0	0
P25		1	1758.190893	1	0	1
P26		0	0	1	1E+30	1

- What happens if Sales Rep 2 makes one more visit?
- What happens if Doctor 3 retires?
- There are a lot of zeros in the allowable increase/decrease columns since this is a degenerate LP!
- Need to resolve to answer other what-if questions.

Implementation at a Major Pharmaceutical Company

Source: Awi Federgruen

The implemented model uses:

- 10 brands, 5 regions
- 4 physician tiers, 4 specialties
- 10 marketing instruments
- 48 monthly time periods
- Tens of thousands of constraints
- Hundreds of thousands variables

Solved in under 5 minutes on a PC

Supplier Optimization

- A plane manufacturer relies on suppliers to obtain steel
- There are three kinds of steel: carbon, alloy, and stainless
- The manufacturer needs 2000 tons of carbon steel, 1700 tons of alloy steel, and 1300 tons of stainless steel each month
- There are 3 different suppliers to choose from, each having different capabilities and costs, located in Germany, Russia, and Ukraine
- Real instances have hundreds of products and suppliers!

Supplier Capabilities

- There is a minimum number of tons that need to be ordered each month in order to keep suppliers in business
- There is a maximum number of tons that can be ordered from each supplier corresponding to their capacity

Supplier	Minimum	Maximum
Germany	750	1000
Russia	2000	3000
Ukraine	1500	2000

All numbers are in tons/month

Supplier Costs

- Each supplier has a different cost for producing each type of steel

Supplier	Carbon	Alloy	Stainless
Germany	500	600	650
Russia	400	600	500
Ukraine	450	500	475

All numbers are in $/month

What is the cheapest way to meet the manufacturer's needs from his suppliers?

Optimization Model for Manufacturer

- Decision variables: there are $3 \times 3 = 9$ decision variables:
  - $x_{i,j}$ how much supplier i supplies of steel type j
- Constraints:
  - The total steel supplied from each supplier is in between the minimum and maximum
  - The total type of each steel supplied meets the minimum requirements by the manufacturer.
- Objective: maximize the expected profit

sum over all suppliers i and steel types j: $\quad x_{i,j} \times \text{Cost}(i,j)$

Optimal Solution

Supplier	Carbon	Alloy	Stainless
Germany	0	750	0
Russia	2000	0	250
Ukraine	0	950	1050

Supplier	Minimum	Supplied	Maximum
Germany	750	750	1000
Russia	2000	2250	3000
Ukraine	1500	2000	2000

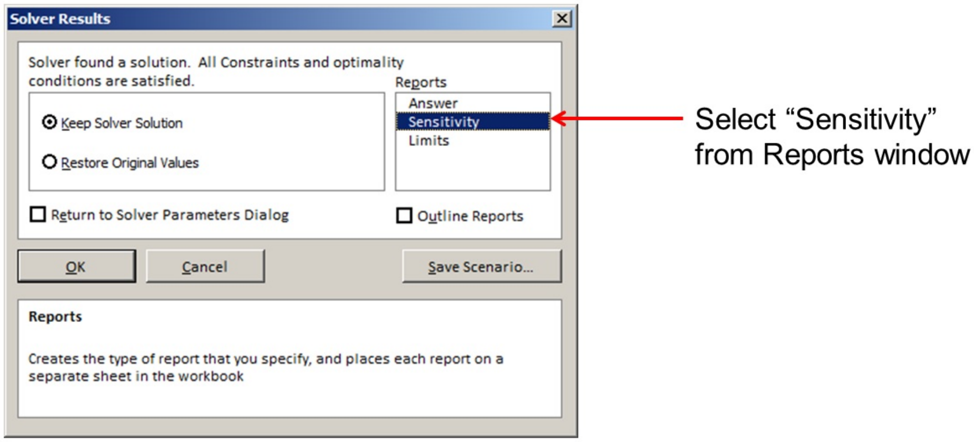
All numbers are in tons/month

What happens if Germany increases their maximum? Russia? Ukraine?

What happens if Germany increases their minimum? Russia? Ukraine?

The Sensitivity Report

In addition to finding optimal solutions, optimization algorithms provide important sensitivity information



The Sensitivity Report

Microsoft Excel 15.0 Sensitivity Report
Worksheet: [Supplier Optimization_after.xlsx]Sheet1
Report Created: 4/7/2016 1:33:40 AM

Variable Cells

Cell	Name	Final Value	Reduced Cost	Objective Coefficient	Allowable Increase	Allowable Decrease
C19	Germany Carbon	0	25	500	1E+30	25
D19	Germany Alloy	750	0	600	25	75
E19	Germany Stainless	0	75	650	1E+30	75
C20	Russia Carbon	2000	0	400	25	400
D20	Russia Alloy	0	75	600	1E+30	75
E20	Russia Stainless	250	0	500	75	25
C21	Ukraine Carbon	0	75	450	1E+30	75
D21	Ukraine Alloy	950	0	500	75	25
E21	Ukraine Stainless	1050	0	475	25	75

Constraints

Cell	Name	Final Value	Shadow Price	Constraint R.H. Side	Allowable Increase	Allowable Decrease
C25	Carbon	2000	400	2000	750	250
D25	Alloy	1700	525	1700	750	250
E25	Stainless	1300	500	1300	750	250
H19	Germany TOTAL SUPPLIED	750	0	1000	1E+30	250
H20	Russia TOTAL SUPPLIED	2250	0	3000	1E+30	750
H21	Ukraine TOTAL SUPPLIED	2000	-25	2000	250	500
H19	Germany TOTAL SUPPLIED	750	75	750	250	750
H20	Russia TOTAL SUPPLIED	2250	0	2000	250	1E+30
H21	Ukraine TOTAL SUPPLIED	2000	0	1500	500	1E+30

Interpreting the Report

- We focus only on Constraints table, ignore Variables table
- **Final Value** is the value of the left hand side of the constraint using the optimal solution
- **Constraint R.H. Side** is the right-hand side of the constraint
- **Shadow price** is how much the objective will *increase* if we increase the r.h. side by 1
- Shadow price is also how much the objective will *decrease* if we decrease the r.h. side by 1
- **Allowable increase and decrease** are the range of values for which the shadow prices are accurate

Sensitivity Questions

- What happens if we increase the minimum from Germany by 100? (obj. increase by 7500)
- What happens if we increase the minimum from Germany by 500? (infeasible)
- What happens if we increase the maximum from Russia by 50? (nothing)
- What happens if we decrease the maximum from Ukraine by 400? (obj. increase by 10,000)
- What happens if we decrease the maximum from Ukraine by 600? (don't know, out of range for allowable decrease)

Some useful comments

- When a constrain is not binding, i.e., the constraint is loose, then the shadow price is 0
- An allowable increase of 1E30 is basically infinity in computer speak
- An allowable increase (decrease) of 0 means that we can't rely on the shadow price, but it's probably a reasonable approximation for small increases (decreases)
- Can only do sensitivity analysis from report for one constraint at a time
- If you run into trouble, you can always resolve the optimization problem...

Optimal Pricing

A firm would like to set the price for two of its products. If the prices are p_1 and p_2, the demand (over a month) for product 1 is given by $d_1(p_1) = 100 \times e^{-0.5p_1}$ and the demand for product 2 by $d_2(p_2) = 200 \times e^{-p_2}$.

The firm wants to maximize its revenues while also ensuring that the total number of units sold (for both products) is at least 150.

- Formulate this as an optimization problem:
  - What are the decision variables?
  - What are the constraints?
  - What is the objective?
- Solve this problem using Solver
- What is the impact of having to increase the minimum to 151? 149?

The Sensitivity Report

Microsoft Excel 15.0 Sensitivity Report
Worksheet: [Pricing Optimization.xlsx]Sheet1
Report Created: 4/7/2016 2:26:01 AM

Variable Cells

Cell	Name	Final Value	Reduced Gradient
B3	p1	1.63643561	0
B4	p2	0.63602799	0

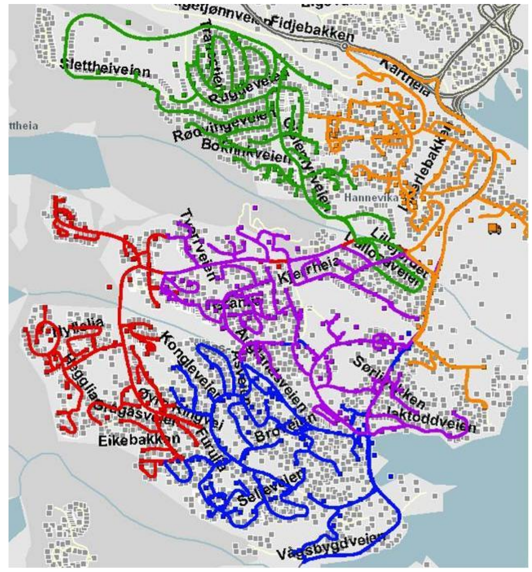
Constraints

Cell	Name	Final Value	Lagrange Multiplier
B9	Total demand	149.999929	-0.36397118

Interpreting the Report for Nonlinear Optimization

- **Final Value** is the value of the left hand side of the constraint using the optimal solution
- **Lagrange multiplier** is how much the objective will *approximately* increase if we increase the r.h. side by 1
- Lagrangian multiplier is also how much the objective will *approximately* decrease if we decrease the r.h. side by 1
- Lagrangian multiplier is similar interpretation to shadow price
- For nonlinear problems, the allowable range is 0. Only useful for considering small changes to the r.h. side!
- This DOES NOT work for discrete/integer/binary problems! (Only continuous problems)

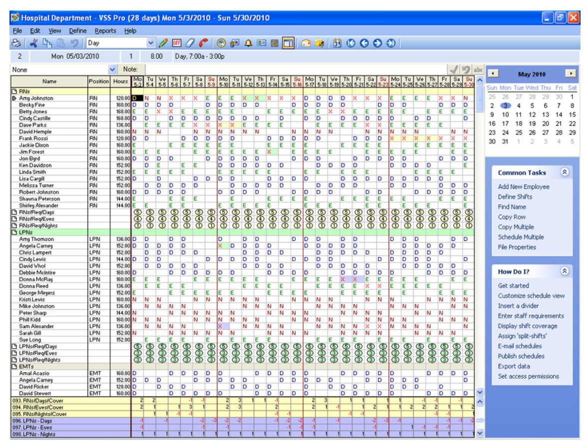
Applications of Optimization: Routing



Manage delivery systems (UPS, Fresh Direct)

- Decision variables: routes for each vehicle in the fleet
- Objective: minimize overall distance traveled (gas costs)
- Constraints: deliver items within the time frame promised

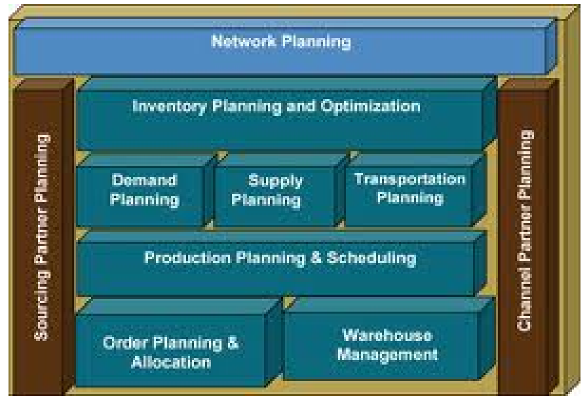
Applications of Optimization: Scheduling



Workforce management (nurses, sales associates)

- Decision variables: one variable for each employee and hour of the day indicating whether the employee would work in that hour or not
- Objective: minimize labor costs
- Constraints: employees may only work 8 hour shifts, each time of the day has a minimum staffing level

Applications of Optimization: Supply Chain Management



Supply chain management

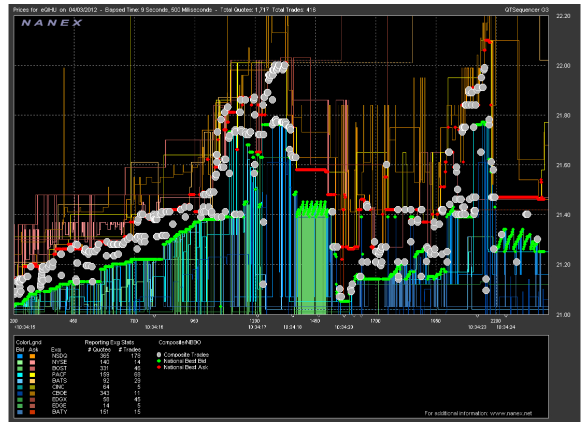
- Decision variables: quantities to order and times of reordering
- Objective: minimize inventory costs (fixed costs associated with ordering, variable costs associated with units received, holding costs / opportunity costs associated with storing the inventory)
- Constraints: storage capacity is limited, cash flow constraints, cannot sell more than what is demanded

Applications of Optimization: Media Planning

Media planning

- Decision variables: budget to allocate to different media
- Objective: maximize return on investment
- Constraints: ensure some exposure in all media, limited overall budget

Applications of Optimization: Finance



Portfolio optimization

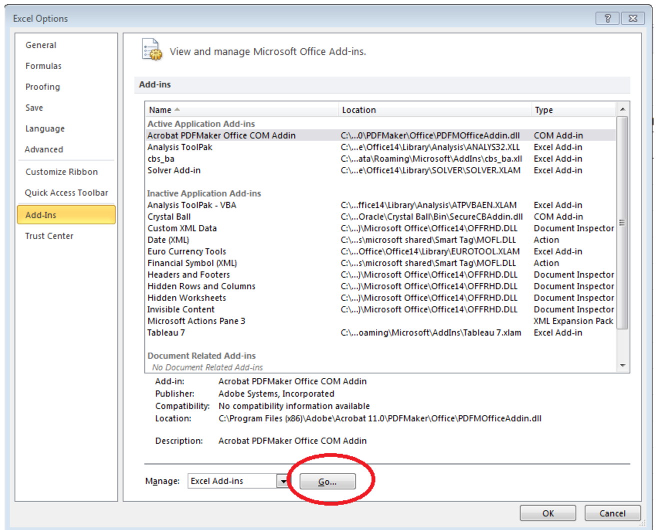
- Decision variables: amount to invest in each asset
- Objective: maximize returns
- Constraints: limit on risk, limits on the borrowing allowed

Summary

- Optimization: from predictions to better decisions
- Sensitivity Analysis can help us understand the value of trying to modify constraints, which can correspond to strategic business actions
- Linear optimization problems allow us to do a broad sensitivity analysis over allowable ranges
- Nonlinear optimization problems allows us to do approximate sensitivity analysis over a small range
- Next time we will look at optimization problems with more than one objective

Appendix: The Solver Optimization Add-in

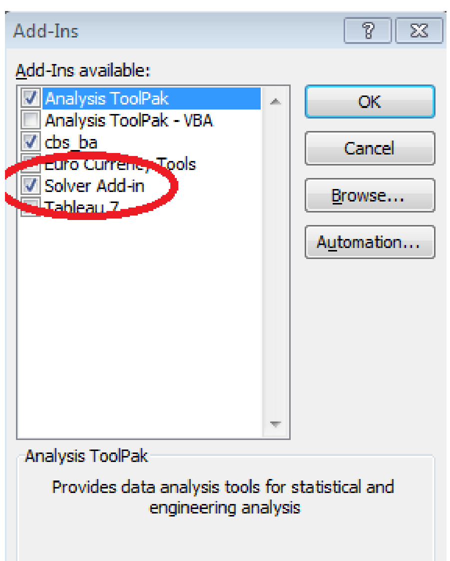
To activate the Solver Add-in, go to the “File” tab and select add-ins, this leads you to the following screen



Click at the bottom on the “Go...” button

The Solver Optimization Add-in

The screen below would the appear



Simply check the button in front of “Solver Add-in”
The Solver Add-in is now activated