PPSDM Jakarta, Oct. 31st, 2017

Company decision-making for geothermal projects

(GEOCAP course 1.07)

Topic: Uncertainty modelling

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Public document (GEOCAP-2016-REP-TNO-1.07-xx)

Contents (Tuesday)

- Uncertainty modelling:
  - **Why?**
  - **Continuous uncertainties (Monte Carlo)**
  - **Discrete uncertainties (scenario / decision trees)**
- Dealing with uncertainty (1)
  - **Sensitivity analysis using multi-parameter variations (Monte Carlo)**
  - **Distributions of input parameters**
  - **Correlations between input parameters**
  - **Spreadsheet exercise using Crystal Ball**
- Dealing with uncertainty (2)
  - **Sensitivity analysis using simplified partial derivatives (spider, tornado diagrams)**
  - **Exercise (spider diagram)**

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Probabilistic modelling

- Key issue is: what information do we need to make optimal investment decisions?
  - Well defined project description (+ alternatives)
  - Projected cashflow for each decision alternative + uncertainties
  - Quantified uncertainties can be translated into risk and opportunities

- E&P data normally carry major uncertainties
  - Subsurface unknown / poorly known
  - Many parameters that have strong impact on decision criteria are very uncertain
    - Both income (e.g. production, oil price) and expenses (capex, opex)

- Deterministic methods will therefore always be wrong (by definition)
  - **"I'd rather be approximately right than precisely wrong" (*J.M. Keynes*)**

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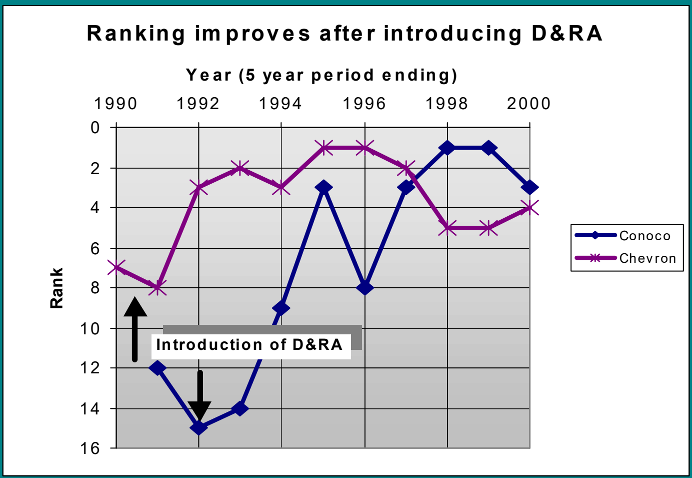
Applying full uncertainty analysis improves company performance



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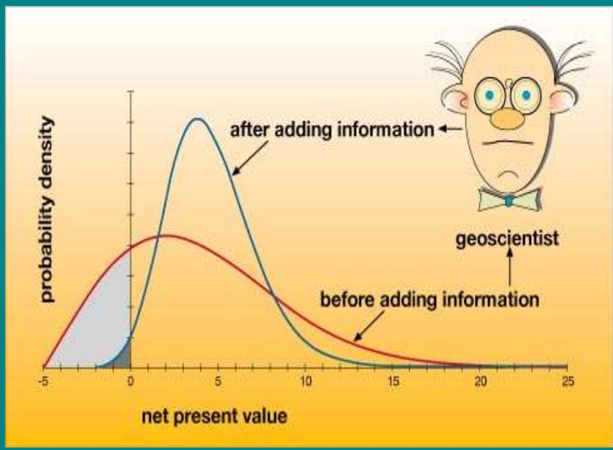
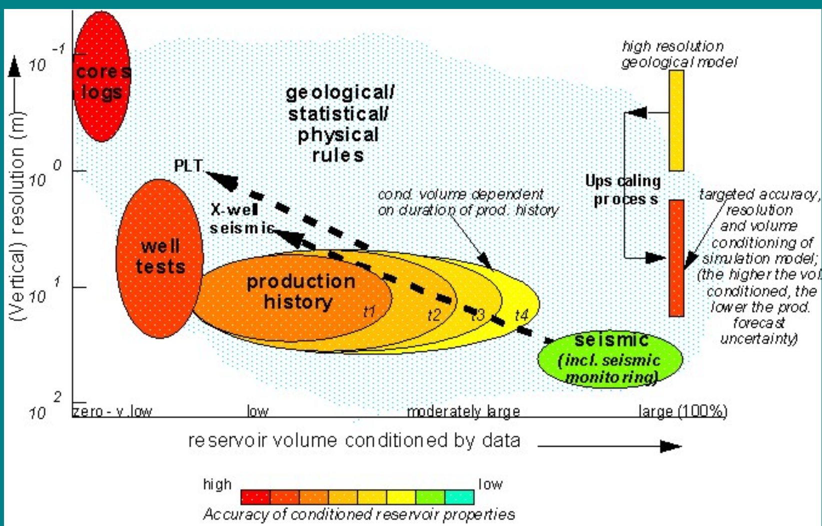
The task of all staff supporting GTE decision making is to

1. Correctly quantify, using the available models, the uncertainty in the KPIs
2. Create and evaluate decision options to <u>mitigate the downside</u> (e.g. by acquiring new information and/or designing flexibility options)
3. Create and evaluate decision options to <u>chase the upside</u> (e.g. by acquiring new information and/or designing flexibility options)



Data accuracy of productive system is quite limited → large technical risks



Deterministic vs. probabilistic modelling

- Probabilistic analysis still not standard in E&P industry, despite evidence that deterministic practice invites bias and underestimation of risks (poor quality decisions). Causes:
  - **Conservatism in E&P industry**
  - **People dislike statistical analysis (black box)**
  - **SEC + reserves estimation**
- Pros of probabilistic modelling :
  - **Better control of risk-mitigating measures**
  - **Better control of business opportunities and VoI**
  - **Better relationship with decision making**
- Cons of probabilistic modelling :
  - **Can be cumbersome and computationally demanding**
  - **People struggle to know what to do with uncertainty:**
    - **Exploiting uncertainty!**

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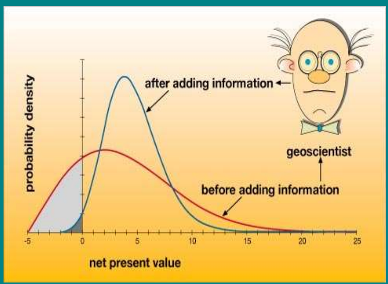
Using "Risk-tolerance" as optimization constraint

- Project Risk = $\int_{-\infty}^{WACC} IRR * \text{pdf}(IRR)\, d(IRR)$
  - **i.e. cum. prob. x average IRR, if it is <WACC**
- Project Risk = $\int_{-\infty}^{0} NPV * \text{pdf}(NPV)\, d(NPV)$
  - **i.e. cum. prob. x average NPV, if it is <0**



- The decision-maker should then specify his/her risk-tolerance: for the project in question, and given other (portfolio) considerations, which cumprob x average NPV, i.e. if it is <0, am I prepared to accept?
  - **Risk-tolerance criterion can then be used as optimisation constraint to cut out bad decision-alternatives**

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Random number Generators

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Monte Carlo sampling, Random number Generators

- RNG randomly samples a real number between [0;1]
  - How does pdf of RNG look like?
  - Stepwise process of sampling from a pdf:
    1. Convert pdf to cum-pdf
    2. Use RNG to randomly sample on Y-axis (0-100%)
    3. Look up associated value on X-axis
    4. Store X-value
    5. Repeat this for all other pdf's
    6. Using model, compute stochastic realisation of full model output
    7. Repeat steps 2-6 *n* times (e.g. 1000) & construct histograms
- Danger of bad RNGs: repeating cycles

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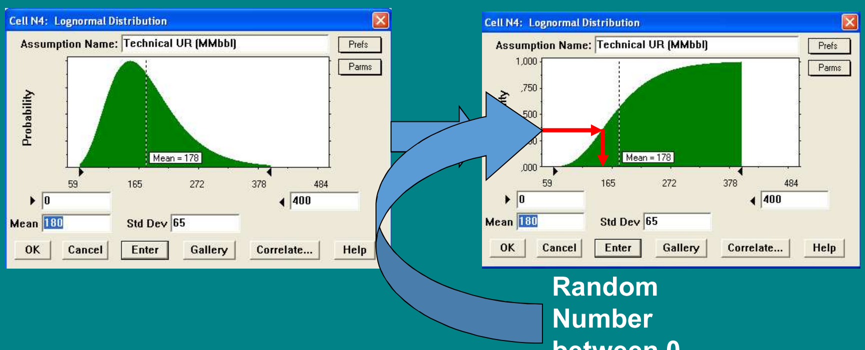
Using RNG to sample from pdf



Random Number between 0 and 1

Repeat sampling *n* times
Do this for each stochastic variable
Per set of stochastic variables compute model output realisation
Construct histogram of model output

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Linear Congruental Generators (LCG)

LCG:

- X(i+1) = (aX(i) + b) mod m
- a, b, m integer constants
- X(1) is the seed
- The generated numbers X(2), X(3),… lie between 0 and m-1

- Shortcoming:
  k-tuples (x(i),x(i+1),…,x(i+k)) fall on a finite number ($<(k!m)^{1/k}$), of parallel hyperplanes (Marsaglia (1968))

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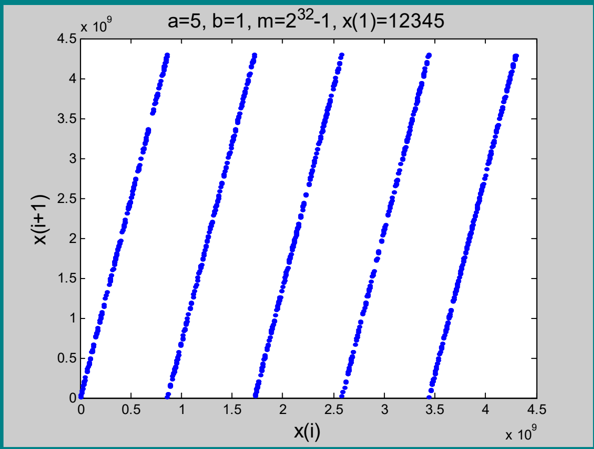
Example 1



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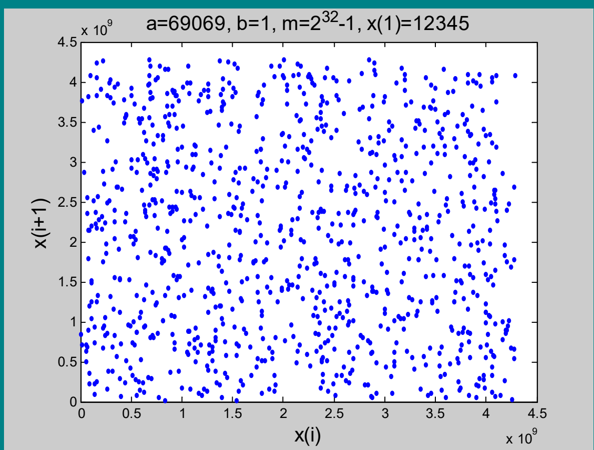
Example 2



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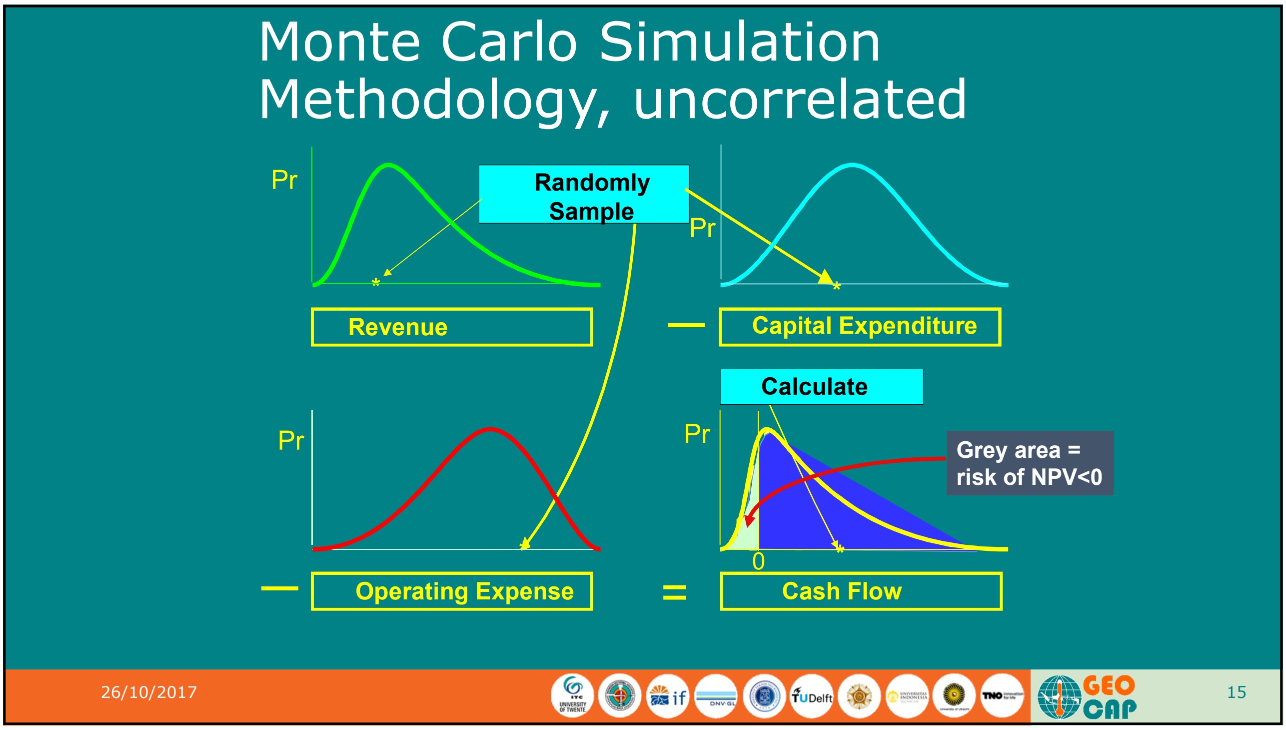
Monte Carlo Simulation Methodology, uncorrelated
Pr
Randomly Sample
Pr
Revenue
—
Capital Expenditure
Calculate
Pr
Pr
Grey area = risk of NPV<0
0
—
Operating Expense
=
Cash Flow
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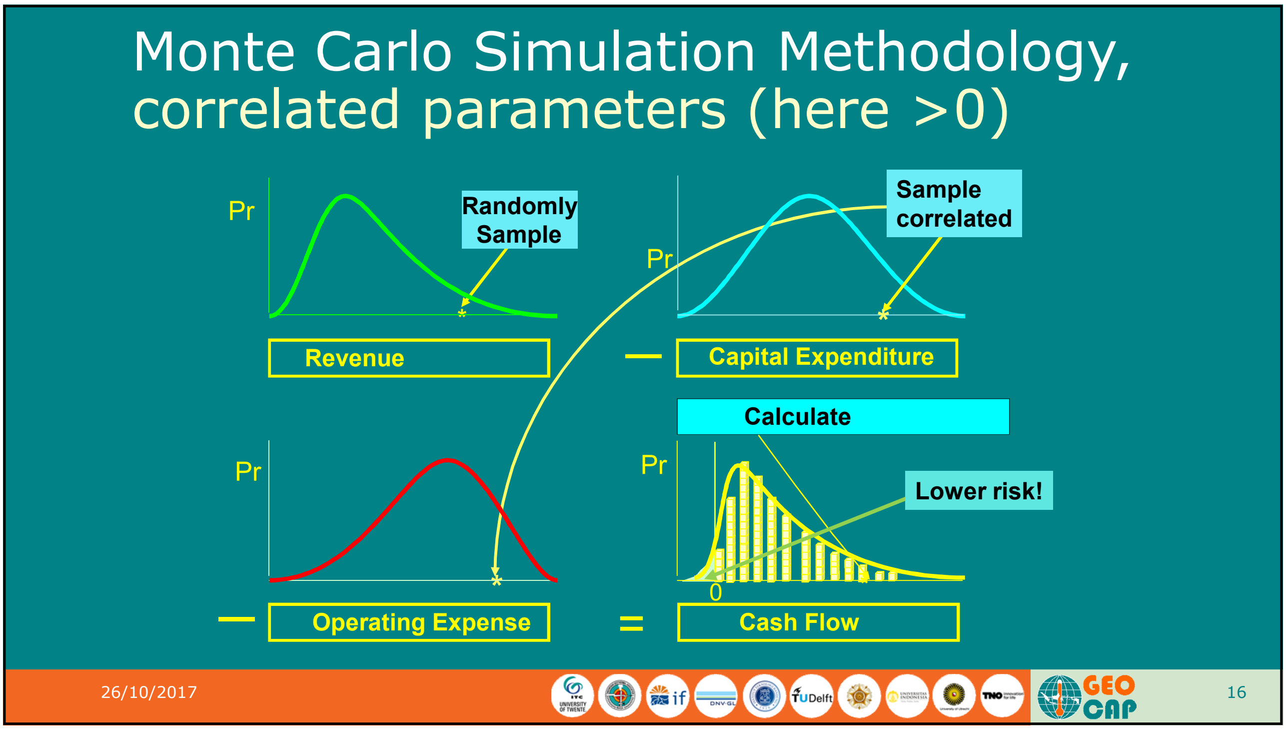
Monte Carlo Simulation Methodology, correlated parameters (here >0)
Pr
Randomly Sample
Sample correlated
Pr
Revenue
—
Capital Expenditure
Calculate
Pr
Pr
Lower risk!
0
—
Operating Expense
=
Cash Flow
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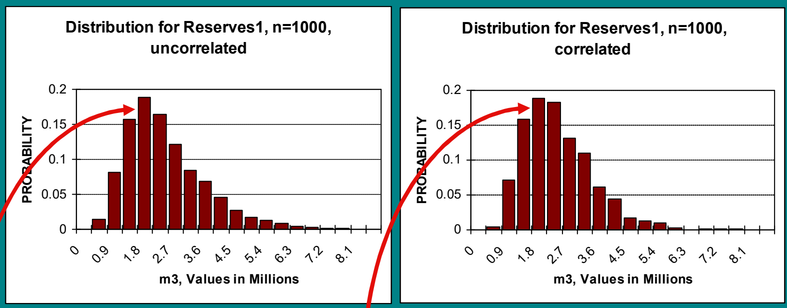
Effect of parameter correlations on output distribution



- Mean=2641
- Mode=2465
- Stdev=1172
- Min=563
- Max=7928

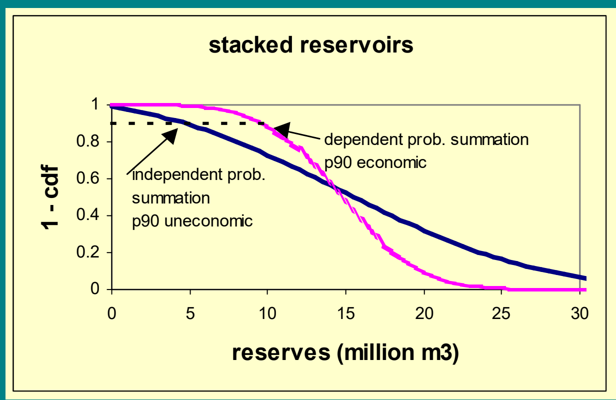
- Mean=2599
- Mode=1932
- Stdev=1038
- Min=621
- Max=7777

Negative correlation

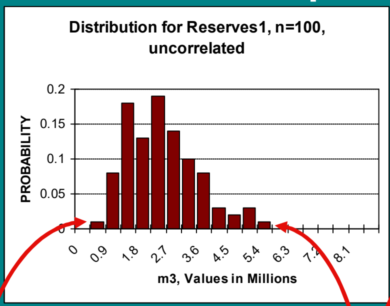
Note difference in the two "most likely" models!

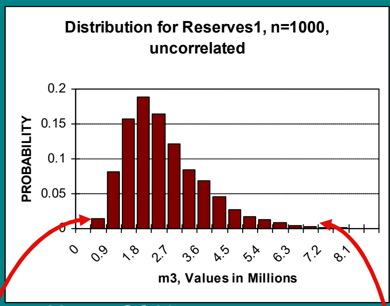
Static earth model : probabilistic summation of dependent units

- Dependencies poorly known
- Updating schemes / look-backs needed
- Shape of curve is function of dependencies
- "Proved" volumes (P90) can be economic / non-economic depending on dependencies modelled!



Effect of number of Monte Carlo samples on output distribution





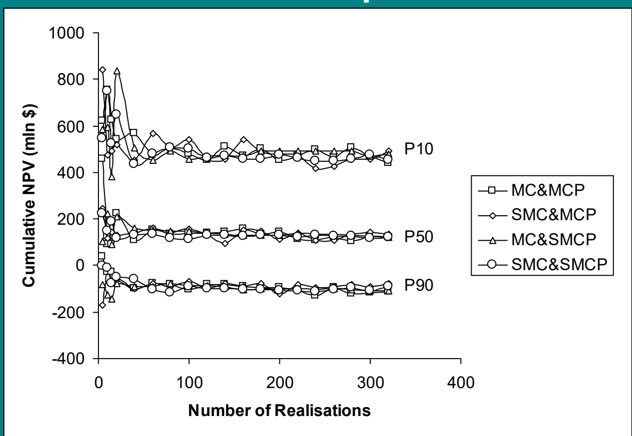
- Mean=2612
- Mode=2211
- Stdev=1038
- Min=842
- Max=5518

Range increased

- Mean=2641
- Mode=2465
- Stdev=1172
- Min=563
- Max=7928

Note difference in mode, and in upside & downside

Estimation of P10 – P50 – P90 values as a function of sample size



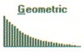
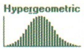
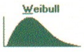
Example - MC, SMC refer to Monte-Carlo or MC-stratified sampling.
MCP, SMCP refer to Monte-Carlo propagation and stratified MC-propagation.

Crystal Ball introduction + exercise

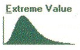
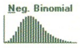
Less common distributions (1)

Distribution	Conditions	Applications	Examples
Custom	• Very flexible distribution, used to represent a situation you cannot describe with other distribution types • Can be either continuous or discrete or a combination of both • Used to input an entire set of data points from a range of cells		
Less commonly used distributions are listed below and on the back side of the card.			
Binomial	• For each trial, only 2 outcomes are possible; usually, success or failure • The trials are independent • The probability is the same from trial to trial	Describes the number of times an event occurs in a fixed number of trials, also used for Boolean logic (true/false or on/off).	Number of heads in 10 flips of a coin, likelihood of success or failure
Poisson	• Number of possible occurrences is not limited • Occurrences are independent • Average number of occurrences is the same from unit to unit	Describes the number of times an event occurs in a given interval (usually time).	Number of telephone calls per minute, number of defects per 100 square yards of material

Less common distributions (2)

Exponential 	• The distribution describes the time between occurrences • Distribution is not affected by previous events	Describes events that recur randomly.	Time between incoming phone calls, time between customer arrivals
Geometric 	• Number of trials is not fixed • Trials continue until the first success • Probability of success is the same from trial to trial	Describes the number of trials until the first successful occurrence.	Number of times you spin a roulette wheel before you win, how many wells to drill before you hit oil
Hypergeometric 	• Total number of items (population) is fixed • Sample size (number of trials) is a portion of the population • Probability of success changes after each trial	Describes the number of times an event occurs in a fixed number of trials, but trials are dependent on previous results.	Chance of a picked part being defective when selected from a box (without replacing picked parts to the box for the next trial)
Weibull 	This flexible distribution can assume the properties of other distributions. When shape parameters equal 1, it is identical to Exponential. When equal to 2, it is identical to the Rayleigh.	Fatigue and failure tests or other physical quantities.	Failure time in a reliability study, breaking strength of a material in a control test
Beta 	• Range is between 0 and a positive value • Shape can be specified with two positive values, alpha and beta	Represents variability over a fixed range, describes empirical data.	Representing the reliability of a company's devices

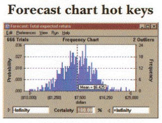
Less common distributions (3)

Gamma 	• The possible occurrences in any unit of measurement is not limited • The occurrences are independent • The average number of occurrences is constant from unit to unit	Applied for physical quantities, such as the time between events when the event process is not completely random.	Demand for expected number of units sold during lead time, meteorological processes (pollutant concentrations)
Logistic 	Conditions and parameters are complex. See: Fishman, G. *Springer Series in Operations Research*. NY: Springer-Verlag, 1996.	Describes growth.	Growth of a population as a function of time, some chemical reactions
Pareto 	Conditions and parameters are complex. See: Fishman, G. *Springer Series in Operations Research*. NY: Springer-Verlag, 1996.	Analyzes other distributions associated with empirical phenomena.	Investigating distributions associated with city population sizes, size of companies, stock price fluctuations
Extreme Value 	Conditions and parameters are complex. See: Castillo, Enrique. *Extreme Value Theory in Engineering*. London: Academic Press, 1988.	Describes largest value of a response over time or the breaking strength of materials.	Largest flood flows, rainfall, and earthquakes, aircraft loads and tolerances
Neg. Binomial 	• Number of trials is not fixed • Trials continue to the r th success (trials never less than r) • Probability of success is the same from trial to trial	Models the distribution of the number of trials or failures until the r th successful occurrence.	Number of sales calls before you close 10 orders

Crystal Ball

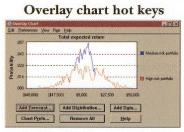
Chart Hot Keys

Forecast chart hot keys



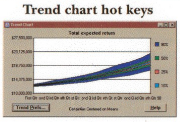
d - change distribution display type
g - change number of groups
l - turn grid lines on/off
m - turn mean line on/off
t - change chart type
<spacebar> - switch views

Overlay chart hot keys



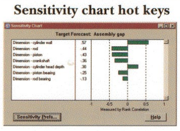
d - change distribution display type
g - change number of groups
t - change chart type
l- turn grid lines on/off
n - turn legend on/off
i - view difference

Trend chart hot keys



f - forecast names horizontal/vertical
d - change placement of bands
l - change grid lines
v - change axis end point values

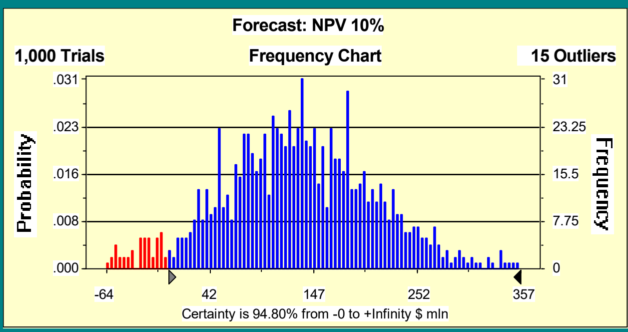
Sensitivity chart hot keys



t - sensitivity measurement method
d - change type of data to include
g - cut off value, on or off
h - cut off count, on or off

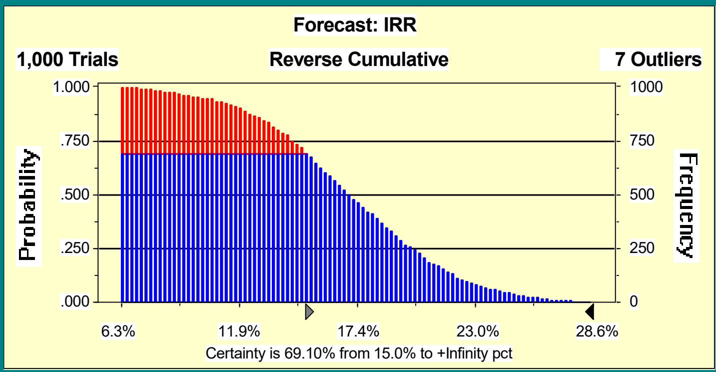
Define and select	
Define assumption	alt-c, a
Define decision	alt-c, d
Define forecast	alt-c, f
Select all assumptions	alt-c, m
Select all decisions	alt-c, i
Select all forecasts	alt-c, r
Select some	alt-c, s
Edit	
Freeze assumptions	alt-c, z
Copy data	alt-c, c
Paste data	alt-c, p
Clear data	alt-c, e
Cell preferences	alt-c, l
Run	
Run, run	alt-u, u
Run, continue	alt-u, u
Stop	alt-u, o
Reset	alt-u, e
Single step	alt-u, s
Run preferences	alt-u, p
Close Crystal Ball	alt-u, c
Data/Results	
Forecast windows	alt-u, f
Open overlay chart	alt-u, l
Open trend chart	alt-u, t
Open sensitivity chart	alt-u, n
Create report	alt-u, r
Extract data	alt-u, d
Save run	alt-u, v

Introduction Crystal Ball - KPI1 (NPV)



- The NPV distribution shows that there is a 5.2% probability that the 10% NPV will be negative under the assumptions used; on the other hand NPV's in excess of $300 mln cannot be excluded.

Introduction Crystal Ball - KPI2 (IRR)



- The expectation curve for IRR indicates a range between 6% and 29%. There is a 31% probability that the IRR will be less than 15%, an important message for companies with this IRR yardstick.

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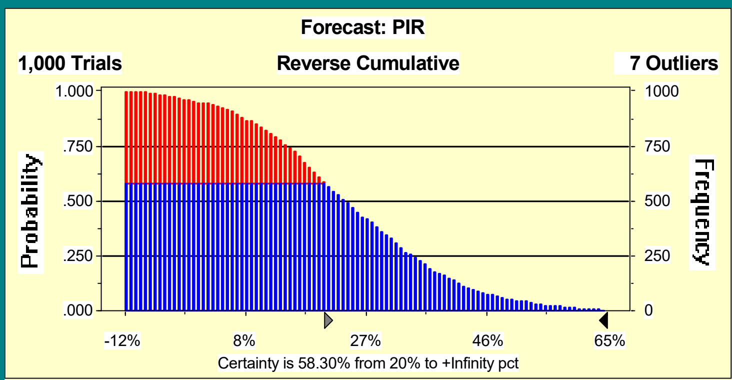
Introduction Crystal Ball - KPI3



- The expectation curve for PIR extends between –12% and 65%. For companies with a 20% PIR yardstick, there is a 42% chance that this would not be met.

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Crystal Ball volumetrics

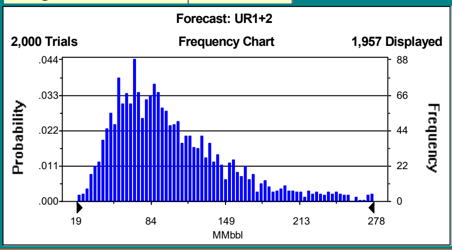
Uncorrelated *versus* *Correlated*

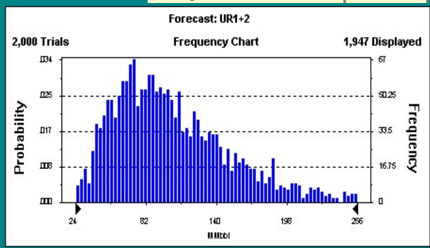
Statistics	UR1
Trials	2000
Mean	77.64
Median	64.73
Mode	---
Standard Deviation	52.44
Variance	2,749.83
Skewness	2.21
Kurtosis	12.09
Coeff. of Variability	0.68
Range Minimum	8.64
Range Maximum	549.58
Range Width	540.94

Correlations:

- GRV1 | GRV2 = 0.75
- NTG1 | Por1 <0
- NTG1 | Sat1 <0
- NTG2 | Por2 <0
- NTG2 | Sat2 <0

Statistics	UR1+2
Trials	2000
Mean	109
Median	96
Mode	---
Standard Deviation	59
Variance	3490
Skewness	1.96
Kurtosis	10.67
Coeff. of Variability	0.54
Range Minimum	23
Range Maximum	662
Range Width	639





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Crystal Ball exercise
volumetrics with and without
correlations

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Sensitivity Analysis

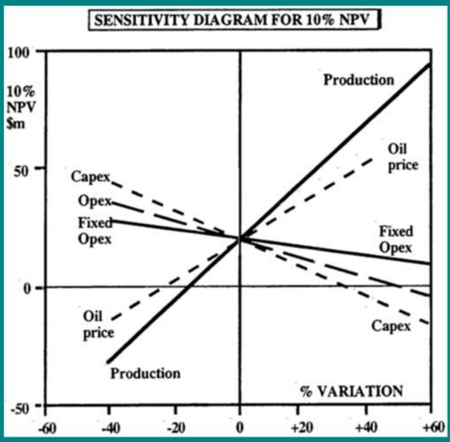
Sensitivity Analysis (SA)

- Should always be part of decision analysis
- Permutation of (series of) uncertain input parameter(s) to study impact on end-result (e.g. economic indicator, decision criterion)
- Derivative analysis
- Normally, this analysis is limited to a single-point, linearised partial derivative
- Examples: tornado chart, spider chart

- More sophisticated methods exist
  - **Sampling**
  - **Multi-variate SA**
  - **mapping of Jacobean**

Sensitivity analysis (deterministic)

- Reference is "base case" or "most likely case"
- Vary input parameters one by one by a certain relative amount
- Study impact on Key performance indicators of project
- Use this to understand risks of project and to design risk mitigating measures



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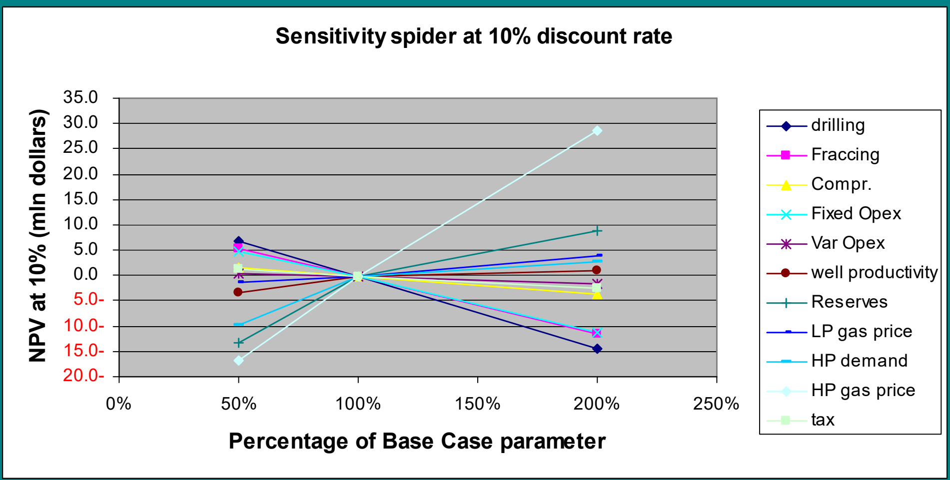
Spider chart (deterministic SA)



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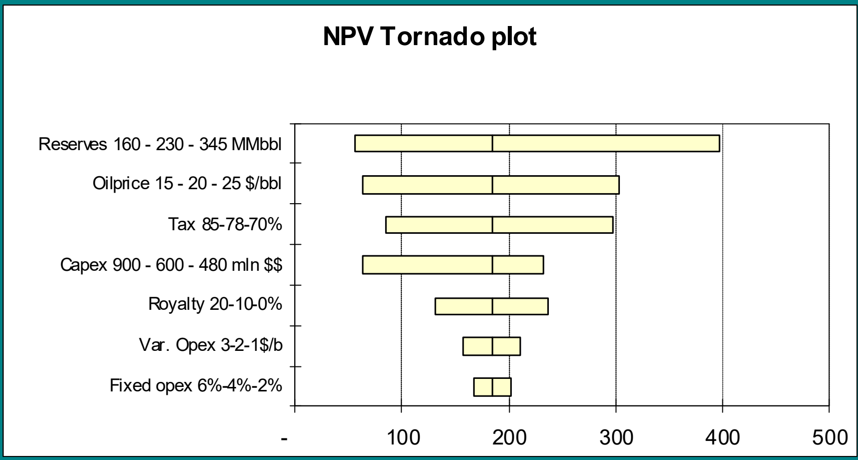
Tornado chart (1) – deterministic SA



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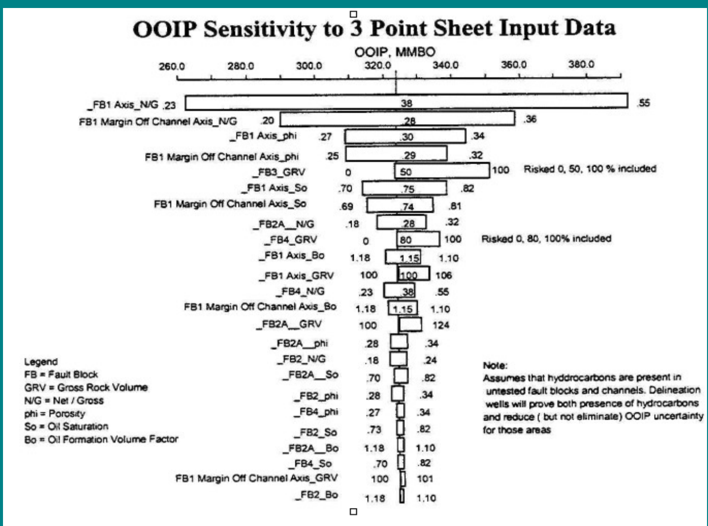
Tornado chart (2) – deterministic SA



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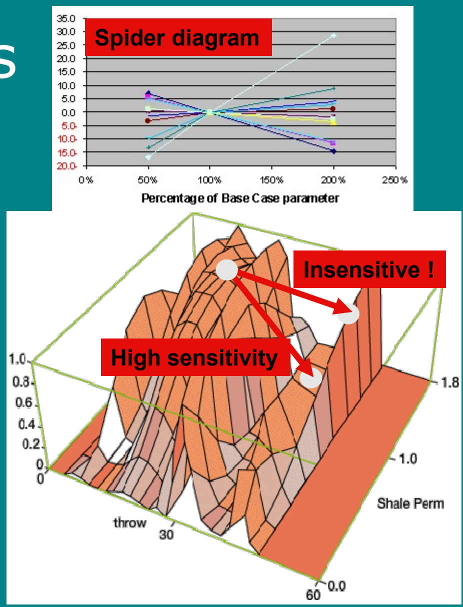
Sensitivity analysis

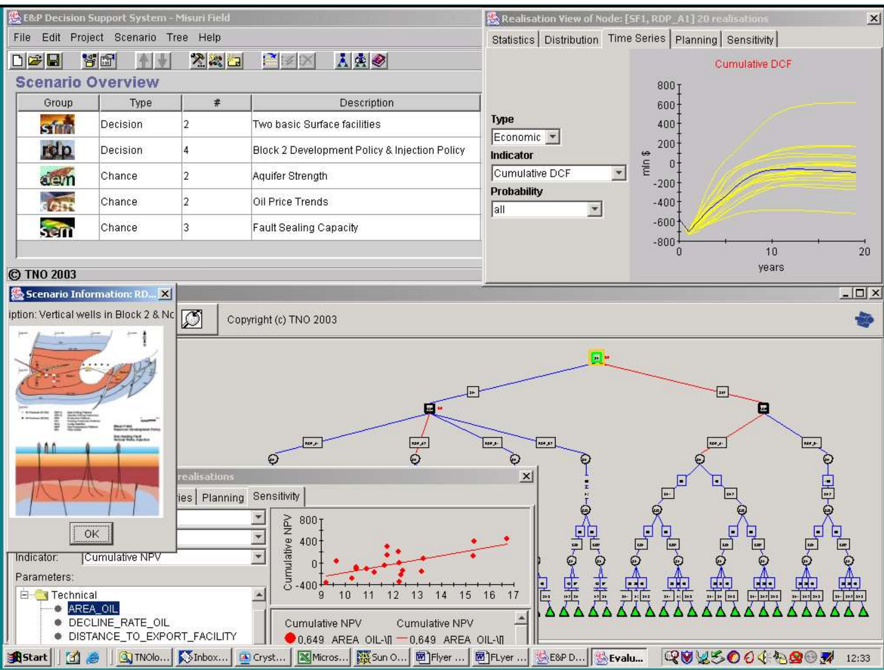
- Beware of complex response surfaces (normal!)
- Standard method: tornado, spider, BUT
- What does a single-point, linearized partial derivative mean on a complex surface?



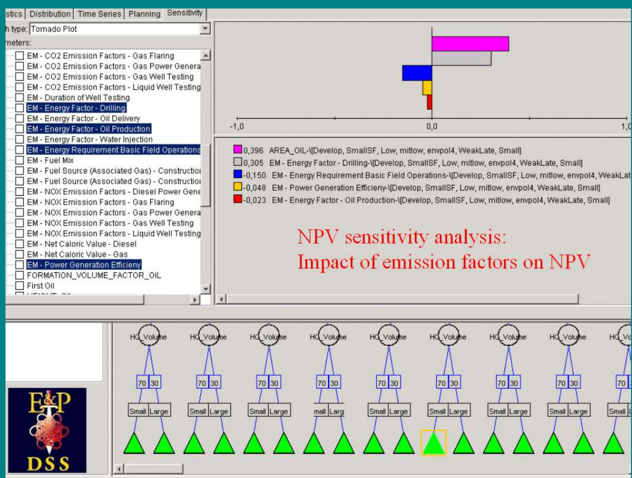
Sensitivity Analysis - probabilistic

- All MonteCarlo samples used: "multi-variate SA"
- All samples plotted in XY-graph
  - X = Input parameter studied (e.g. porosity)
  - Y = Output parameter studied (e.g. NPV)
- Correlation coefficient and tangent of regression line reported as sensitivity

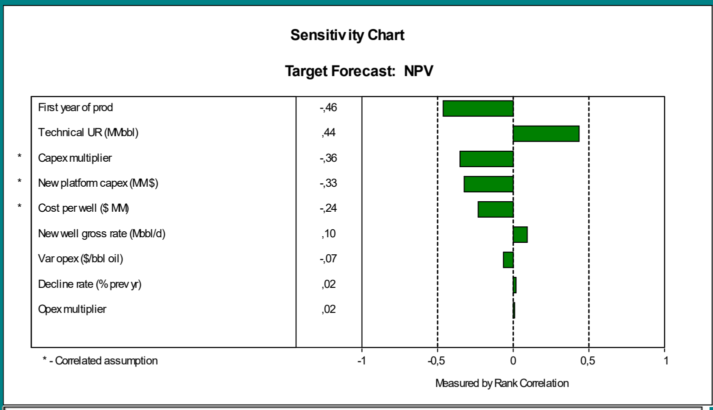
- For a given output parameter (e.g. NPV), this can be done for various input parameters.
  - Parameters can be ranked according to sensitivity
    - Probabilistic Tornado chart: either positive or negative correlation
    - No plus or minus around a base case (there is no base case!)
  - Ranking can be done in various ways:
    - Correlation coefficient
    - Rank correlation (see Crystal Ball)
    - Contribution to variance (see Crystal Ball)



Probabilistic NPV sensitivity analysis for emission factors



Probabilistic NPV sensitivity analysis Rank correlation (oil field development)



rank correlation

A method whereby Crystal Ball replaces assumption values with their ranking from lowest value to highest value using the integers 1 to N prior to computing the correlation coefficient. This method allows distribution types to be ignored when correlating assumptions.

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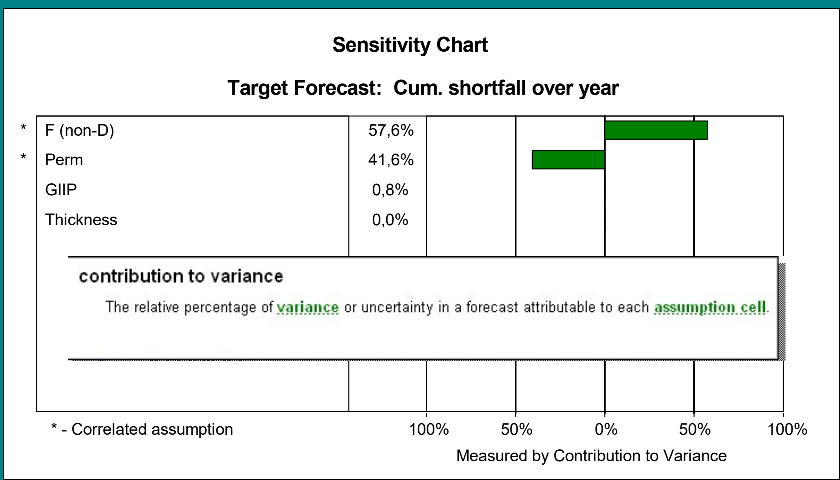
Probabilistic NPV sensitivity analysis: contribution to variance (Underground Gas Storage)



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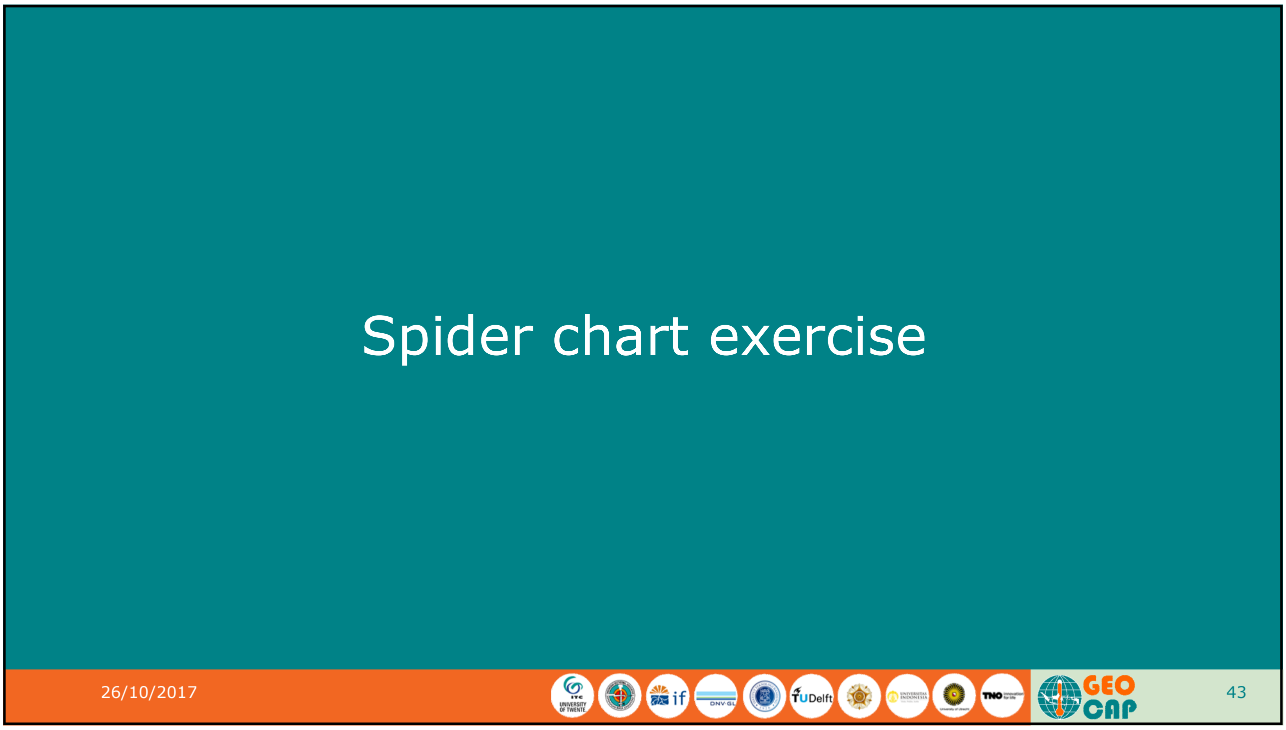
Spider chart exercise
26/10/2017
GEO
CAP
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