Accuracy of Economic Estimation and Sensitivity Analysis by Monte Carlo Simulation

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since 1997	Cologne University of Applied Sciences, Chemical Reaction Engineering and Process Simulation Polymer Engineering, PET Synthesis and Recycling Cost Engineering PET and Chemical Engineering Consulting
1993-1997	John Brown Deutsche Engineering GmbH, Process Engineer and Head of R&D PET Synthesis, Processing and Recycling
1989-1993	Doctorate, Dr.-Ing., "About the Reduction of Diesel Engine Emissions" Technical University of Clausthal, Germany
1983-1989	Study, Process Engineering, Chemical Reaction Engineering Technical University of Clausthal, Germany

Sensitivity Analysis by Monte Carlo Simulation - Agenda

Cost Estimation - All Engineering is Cost Engineering

- Cost estimators in the process industry
  - are often senior industrial chemists or chemical engineers
  - estimate fixed capital investment and production cost
  - for feasibility studies, in process development, for budget authorization
  - in early stages of a project
  - no time and no resources for rigorous engineering
  - applying rules of thumb, heuristics, and "crystall ball methods"

- Core competences of cost estimators
  - can handle cost estimation techniques
  - can estimate cost basing on vague and incomplete data sets
  - have overview over different plant types and their cost structures
  - have good market knowledge and feeling
  - have basic knowledge in statistics
  - have gut feeling for economy and the respective characteristic factors
  - are in contact to other cost engineering professionals

Economy of a Chemical Product - Key Parameters

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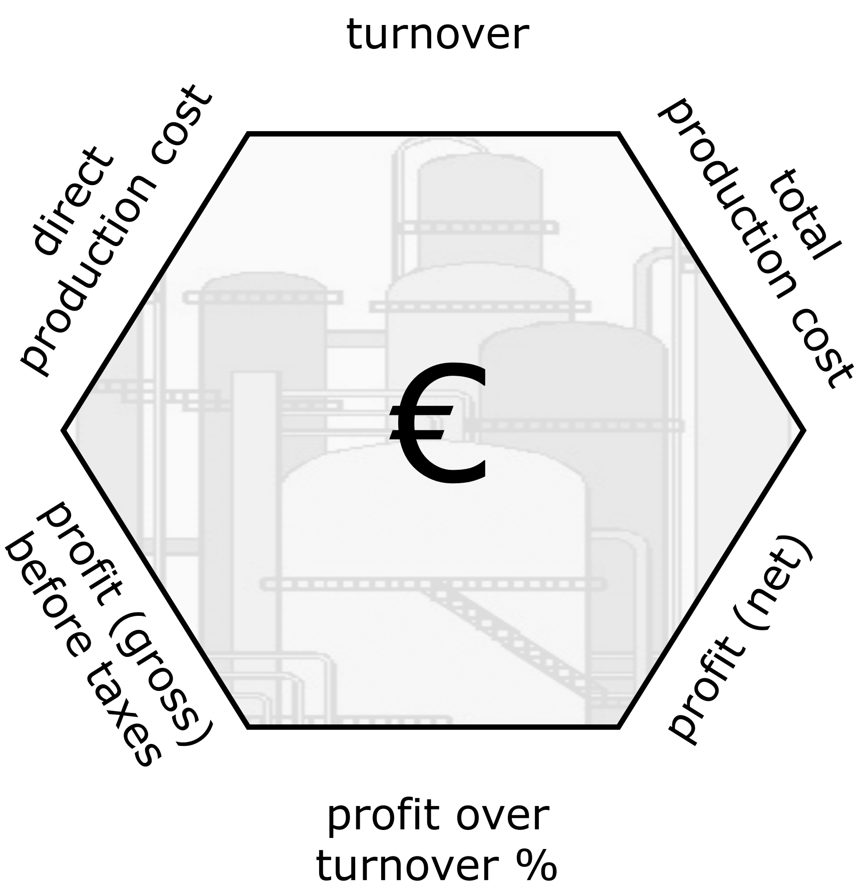

investors rate of return

reflux of capital = profit + depreciation

discounted cash flow rate of return

reflux of capital over fixed capital investment

break even point of percentaged installed capacity

maximum percentaged price reduction

payback period

Cost Estimation Methods

Mass and number approach

- Calculate mass
- Count control loops
- Count pipes
- Calculate space
- Count enigneering hours
- ....

± 15 - 20%

Module method

- "Package Units‟
- Reactors
- Columns
- Crystallizers
- Dryer
- ....

Percent of delivered-equipment cost approach

- Apparatus, process machinery
- Instrumentation and controls
- Piping
- Buildings
- Engineering
- ....

± 20-25%

Accuracy of Cost Estimation vs. Project Progress

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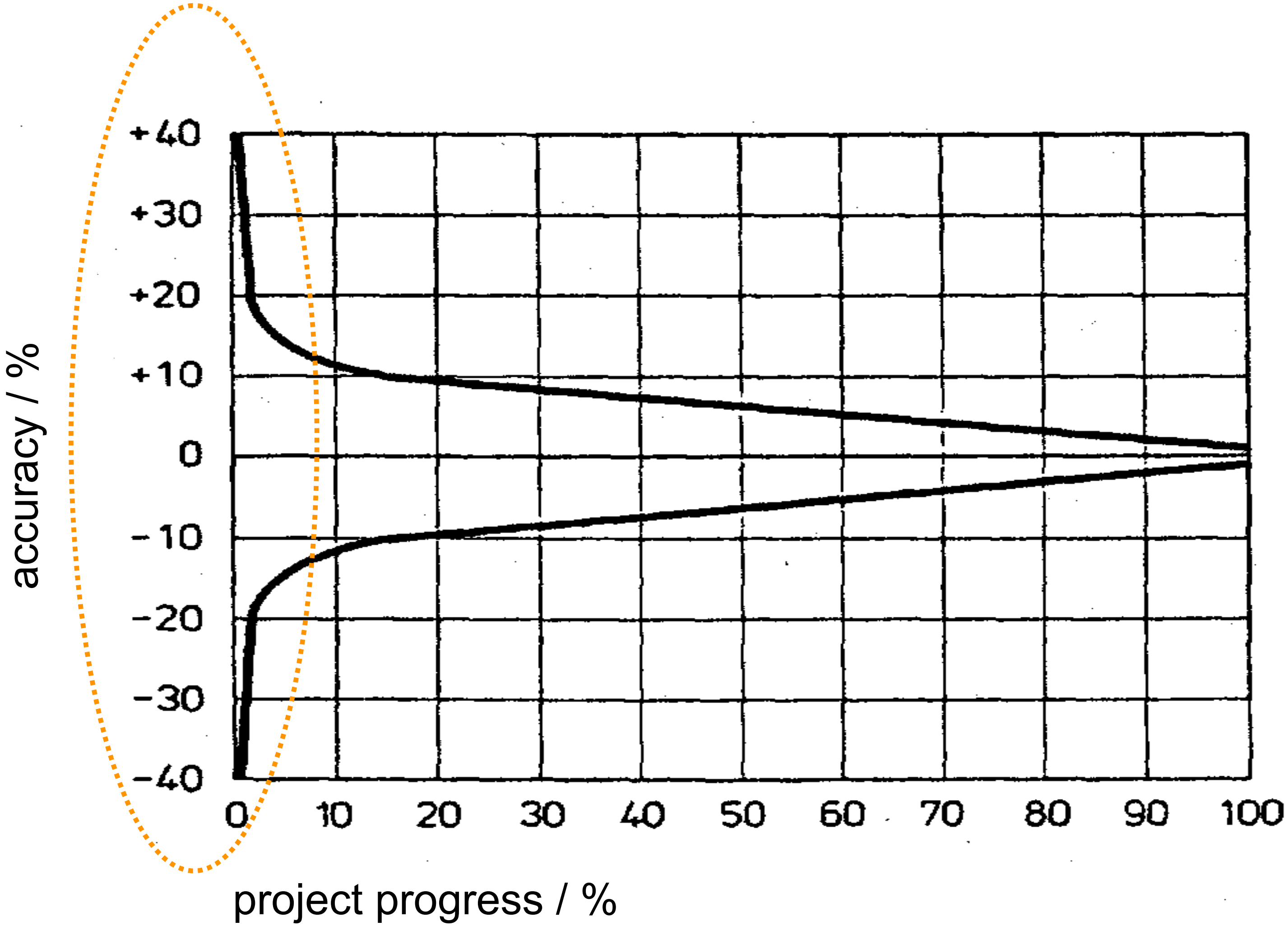


Capital Cost Estimates and Accuracy

	Types of Capital Cost Estimates	Accuracy
1	Order-of-Magnitude Estimate based on similar previous cost data	> ± 30 %
2	**Study Estimate** based on knowledge of major items of equipment	± **30 %**
3	**Preliminary Estimate** based on sufficient data to permit the estimate to be budgeted	± **20 %**
4	Definitive Estimate based on almost complete data, but before completion of drawings and specifications - basic engineering done	± 10 %
5	Detailed Estimate based on complete engineering drawings, specifications, and site surveys, P&IDs and plant layout; detailed engineering done	± 5 %

Revised Lang Factors

Type of Plant	Fixed-capital investment	Total capital investment
Solids processing[1]	4.0	4.7
Solids/fluids processing[2]	4.3	5.0
Fluids processing[3]	5.0	6.0

Examples:

[1] Ore dressing

[2] Terephthalic acid via p-xylene

[3] Distillation at refinery

Peters, M.S.; Timmerhaus, K.D.; West, R.E.: Plant Design and economics for Chemical Engineers, Mc.Graw-Hill (2003)

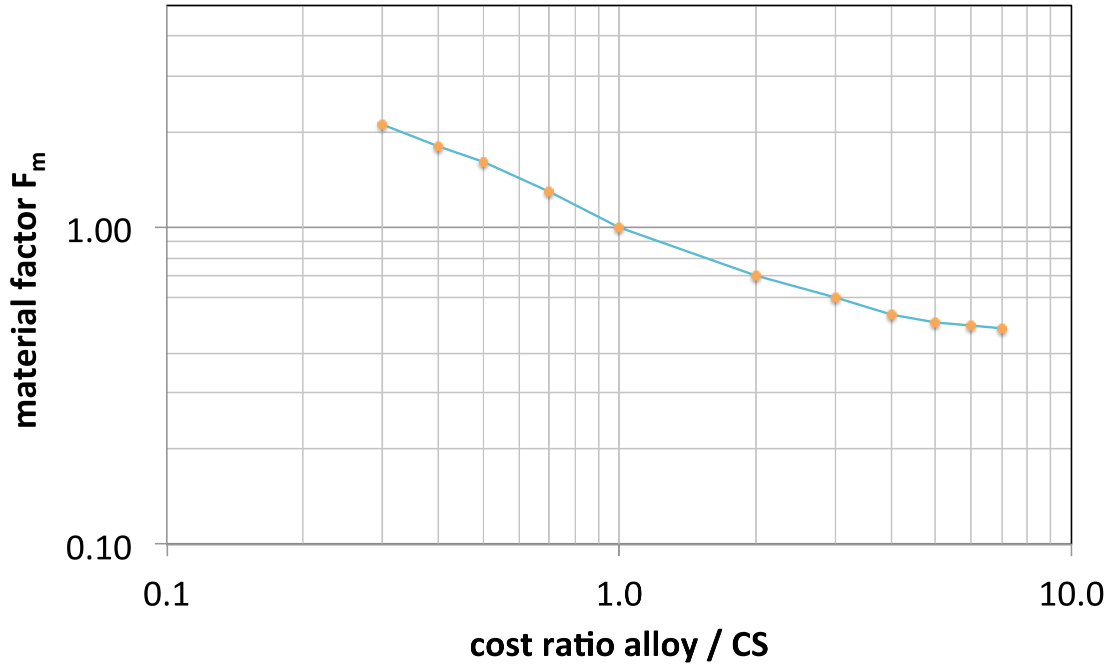
Application of Lang Factors

$$\text{Capital cost} = \text{Lang factor} \cdot F_m \cdot F_i \cdot F_p \sum(\text{Equipment cost})$$

F_m = Material adjustment factors = f(ratio alloy / CS); range: 2.0 ... 0.4

F_i = Instrumentation factor
local controls: 1.15
typical bulk chemical process: 1.35
extensive controls: 1.55

F_P = Place factor (in 1996)
USA: 1.0
PR China: 0.97
Germany: 1.05
Saudi Arabia: 1.3



Hand Factors - Individual Factors (up-dated 1992)

Equipment	Multiplier
• Fractionating column shells	4.0
• Fractionating column trays	2.5
• Pressure vessels	3.5
• Heat exchangers	3.5
• Fired heaters	2.5
• Pumps	4.0
• Compressors	3.0
• Instruments	3.5

applied to delivered cost of equipment

Humphreys, K. K, Project and Cost Engineers' Handbook, Marcel Dekker (2005)

$$\text{Capital cost} = F_i \cdot F_b \cdot F_p \sum \left(\text{Equipment cost} \cdot \text{Hand factor} \cdot F_m\right)$$

F_b = Building factor

Type of Plant	New Plant / New site	New Unit at existing site	Expansion at existing site
Solids processing	1.68	1.25	1.15
Solids and fluids processing	1.47	1.29	1.07
Fluids processing	1.45	1.11	1.06

Brown, T.: Engineering Economics and Economic Design for Chemical Engineers, CRC Press (2007)

Estimation of Fixed-Capital by Percent of Delivered-Equipment Cost

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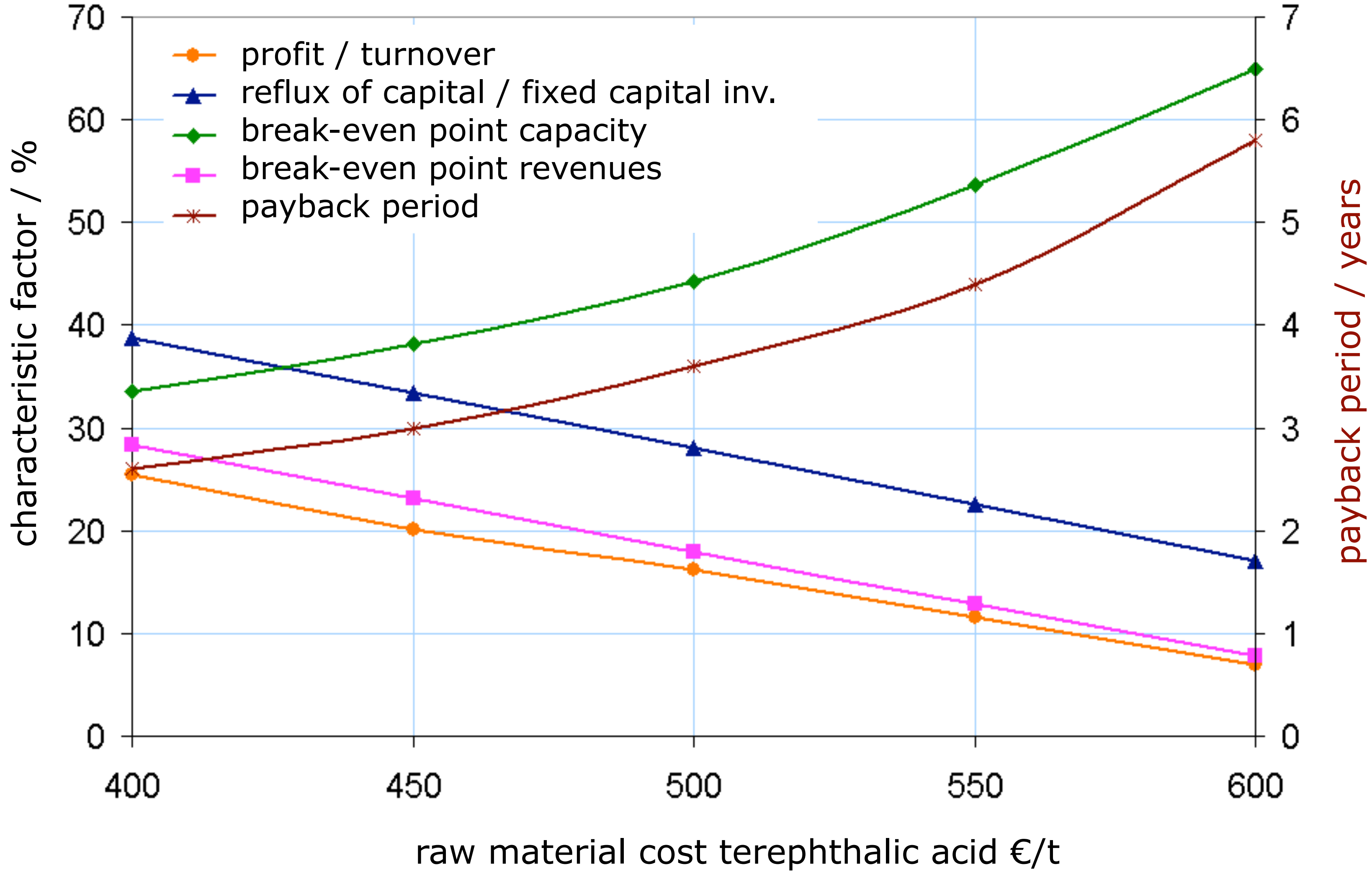
Plant type, processing:	**Solids**	**Solids/Fluids**	**Fluids**
Direct costs	Ratio factors / %		
Purchased equipment	100	100	100
Purchased-equipment installation	45	39	47
Instrumentation and controls (installed)	18	26	36
Piping (installed)	16	31	68
Electrical systems (installed)	10	10	11
Building (including services)	25	29	18
Yard improvements	15	12	10
Service facilities (installed)	40	55	70
Total direct plant cost	269	302	360
Indirects costs			
Engineering and supervision	33	32	33
Construction expenses	39	34	41
Legal expenses	4	4	4
Contractors's fee	17	19	22
Contingency	35	37	44
Total indirect plant cost	128	126	144
Fixed capital investment	397	428	504
Working capital (15 % total capital invest)	70	75	89
Total capital investment	467	503	593

existing site, necessary land is available, investments ranging from under 1 Mio € to over 100 Mio €

Sequential Variation of Input Parameters - Monomer Cost PET



Sequential Variation of Input Parameters - Product Cost PET

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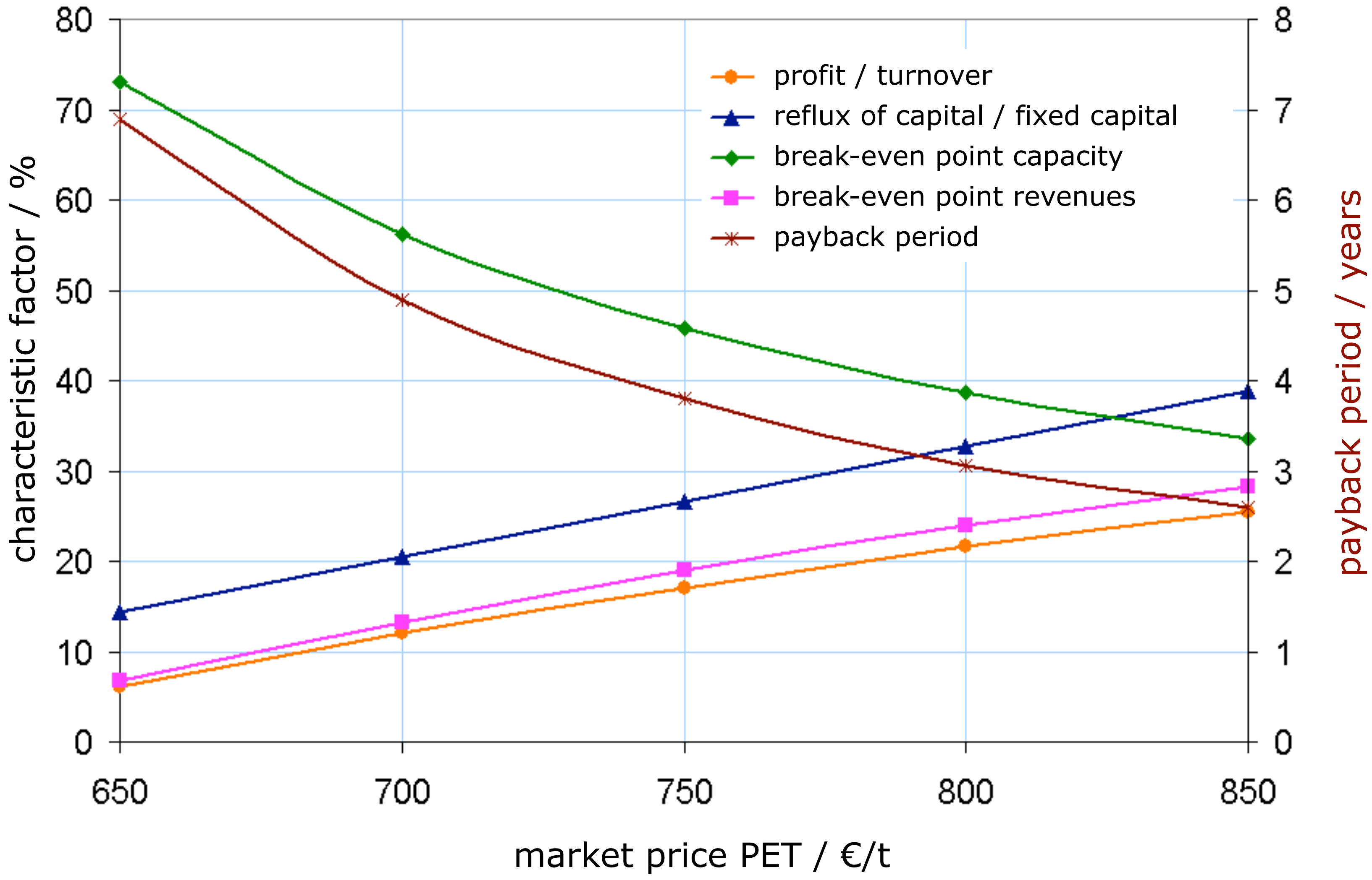
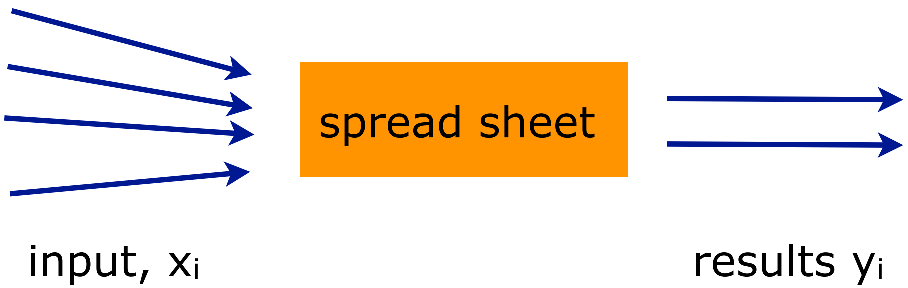
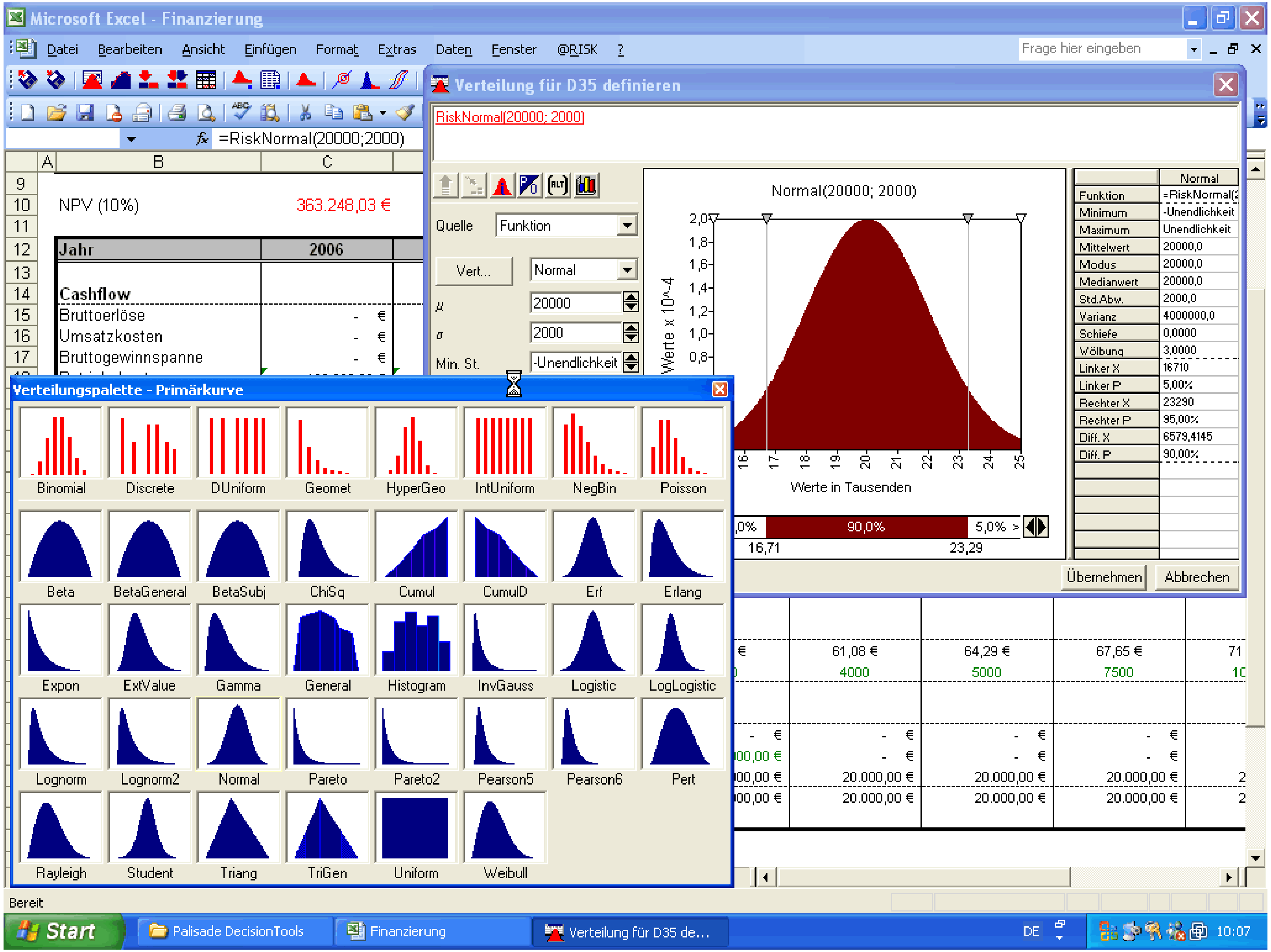


- Software Crystal Ball or @Risk (Excel extension)
- All input parameters with defined distribution function, e.g.: uniform, triangle, normal ...
- Simultaneous variation of input parameters
- Repeated calculation of spread sheet (1,000 times, 10,000 times,...)
- Output of calculation results given by distribution functions, with most probable result and e.g. 90 % probability that the result falls within a certain range
- Tornado-Analysis: Graphical representation of regression sensitivities



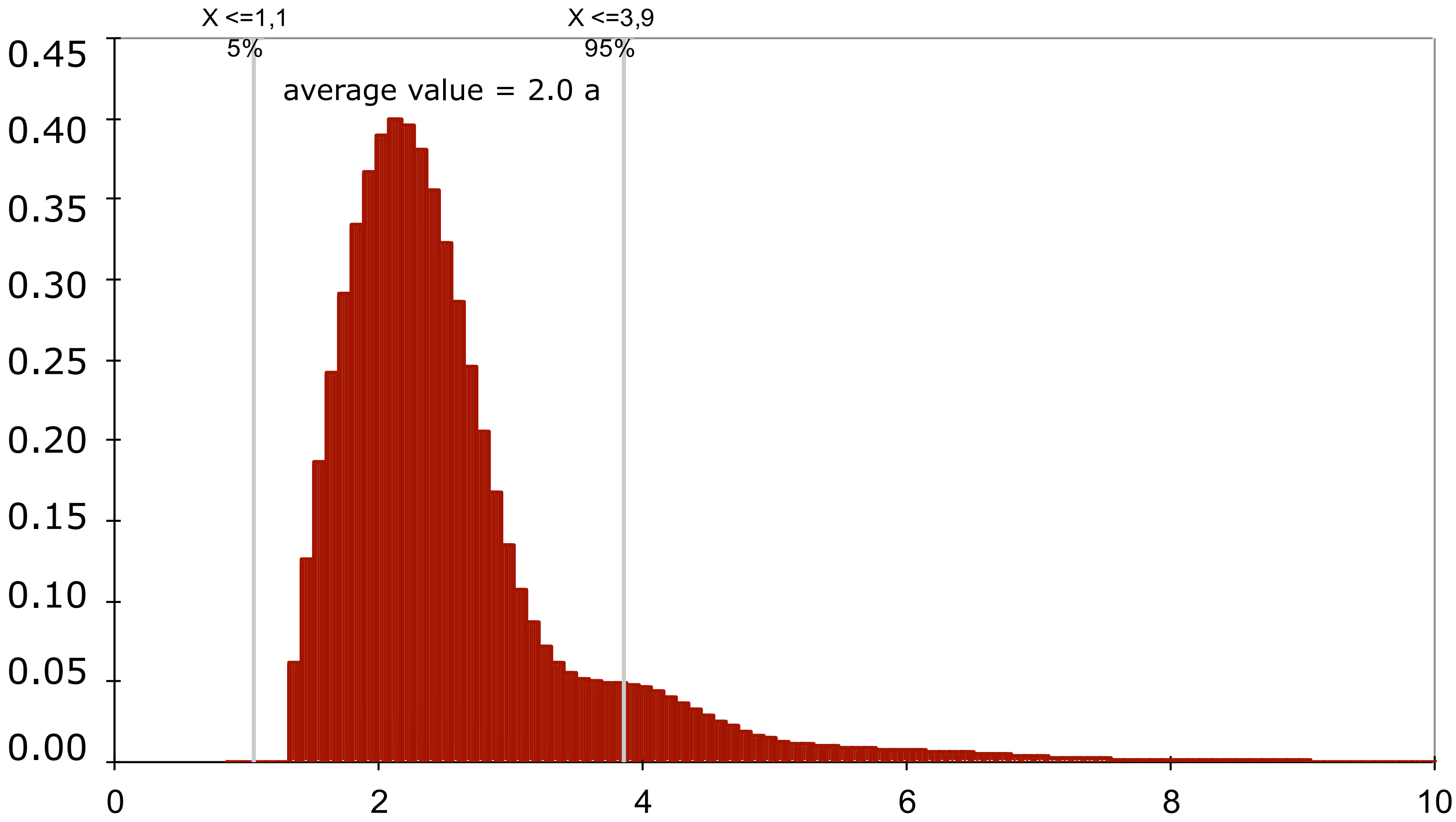
John William Waterhouse - The Crystal Ball

Excel Extension Program @Risk - Distribution Functions



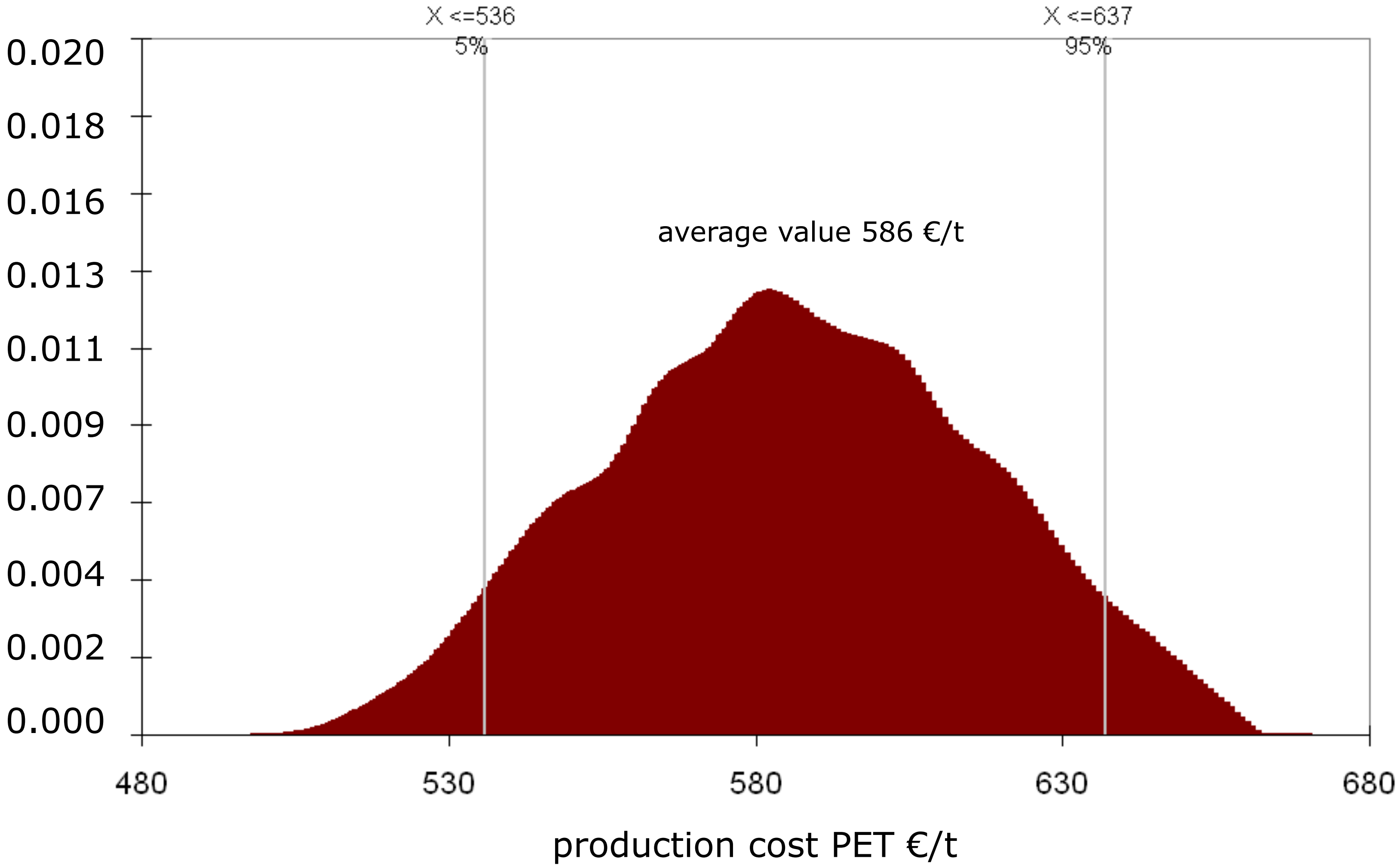
PET Production - Payback Period of a Plant for PET Production

Fixed capital investment, wages, raw material cost, product market price ± 20 %

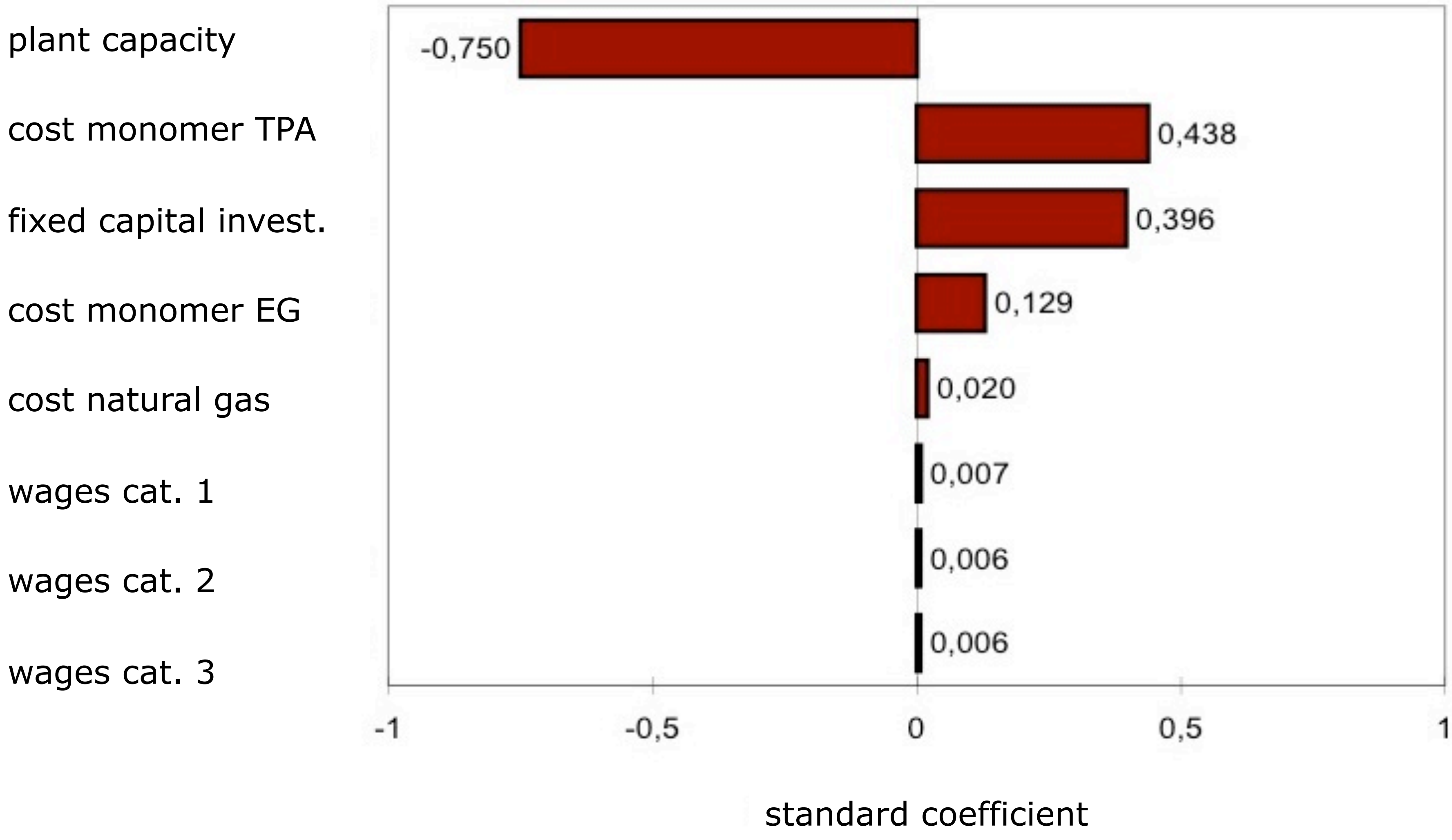


PET Production - Production Cost of PET

Fixed capital investment, wages, raw material cost, product market price ± 20 %



Tornado Analysis - Payback Period



Conclusions

- Accuracy of cost estimation of fixed capital investment in the process industry lies in the range of ± 20 -30 % if the "Percentage of Delivered-Equipment Cost" method is applied
- The more items are estimated by the "mass and number approach", the higher is the accuracy - if one is lucky and everything is done properly, an accuracy of ± 15 % can be achieved
- The Monte Carlo appraoch is an appropriate way to derive most probable results together with confidence intervalls for e.g. a 90 % chance that the result will fall within a certain range
- The Monte Carlo approach does not cover systematic errors
- The tornado analysis helps to identify the strongest correlation between single input parameters and the result of a cost estimation, e.g. payback period, fixed capital investment or production cost
- Most parameters in cost estimation show a non-linear effect on the respective characteristic factors