"Techno-Economic Modelling In Telecommunications

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Department of Informatics and Telecommunications,

University of Athens, Greece

Course Title "Techno-Economics of Mobile Networks and the Internet"

Center for Communication, Media and Information Technologies (CMI) of Alborg University Copenhagen

The University

The University of Athens (www.uoa.gr) is the largest and oldest public educational institution in Greece. Being founded on 3 May of 1837, it was the first University not only in the newly-established Greek State but in all the Balkans and the Eastern Mediterranean in general.

Nowadays it consists of five (5) Faculties (Applied Sciences, Health Sciences, Law Economics & Political Sciences, Philosophy, Theology) which are divided into twenty-nine (29) departments with a total number of over 92.000 students.
The University staff includes 2500 Teaching and Research Staff members and 500 Administrative Staff. It provides more than 50 postgraduate programs leading to master diplomas. The University of Athens is a legal entity of public law. It has full administrative autonomy, but is subject to state supervision by the Ministry of Education, which also provides part of its funding.

The Department of Informatics and Telecommunications

- The **Department of Informatics and Telecommunications** (http://www.di.uoa.gr/) belongs to the Faculty of Applied Sciences and was founded in 1989 as a joint effort of the Departments of Physics and Mathematics.
- 41 full-time faculty members, about 20 permanent employees who belong to the Technical and Administrative personnel, and many research associates are presently employed by the Department. Most of the research associates are PhD candidates and postdoc researchers who are being supported by externally funded research and development (R&D) projects/programmes. More than 1200 undergraduate students, 200 postgraduate students and 100 PhD candidates are enrolled in the Department's programmes. It is divided in three divisions:
  - Computer Science,
  - Computer Engineering and
  - Communications and Signal Processing.

Postgraduate Studies

The Dept of Informatics and Telecommunications offers a postgraduate program that leads to MSc and PhD degrees.

The Department also participates in the following interdiciplinary postgraduate programmes:

- Electronics, Radiocommunications and Automation
- Specialization in Electronics and Radiocommunications
- Specialization in Electronic Automation
- Logic Algorithms and Computation
- Fundamental and Applied Cognitive Science
- Medical Informatics
- Microelectronics
- **Economics and Management of Telecommunication Networks**

(http://www.di.uoa.gr/en/postgrad.php)

Research Activities in University of Athens (our Group)

The team

3 faculty staff, 6 PhD senior researchers, 15 PhD students, 2 MSc students

- Wireless Communications (3G, LMDS, LBS)
- Optical Communications (Components Modeling, WDM, DWDM)
- Technoeconomic analysis
- Wireline technologies (xDSL)
- Integration of IP and Optical Networks
- Software Telecom – oriented SW
- TEconomic Tools
- Roadmapping Tools

Technoeconomic Activities

Our mission

- Conduct technoeconomic evaluations and formulate recommendations for telecommunication investment projects like:
  - Fibre access evolution
  - Next generation mobile networks and services
  - Broadband convergence
- Demand modelling for networks and technology
- Game theoretic analysis of networking

Current activities related to

- Analysis of FTTx deployment and FMC scenarios
- Demand and pricing models for networks and networking technology
- Technology roadmapping
- Market and Business models
- Economics of Home Networking

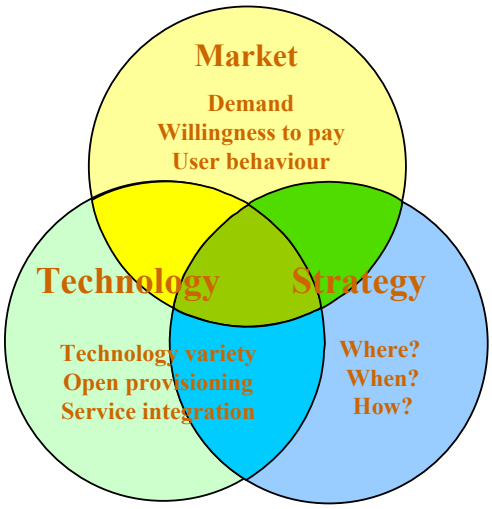
Working in the area since 1987

1. TITAN RACE 2087 - Tools for Introduction Scenario and Techno-economic Evaluation of Access Network
2. OPTIMUM AC226 - Optimised Network Architectures for Multimedia Services
3. TERA AC364 - Techno economics results from ACTS
4. TONIC IST-25172 - TechnO-ecoNomICs of IP optimised networks and services
5. Eurescom P901 - Extended investment analysis of telecommunications operator strategies
6. ECOSYS (Eureka/Celtic) – TechnoECOnomics of integrated SYStems and services
7. Several National TE projects related to public sector

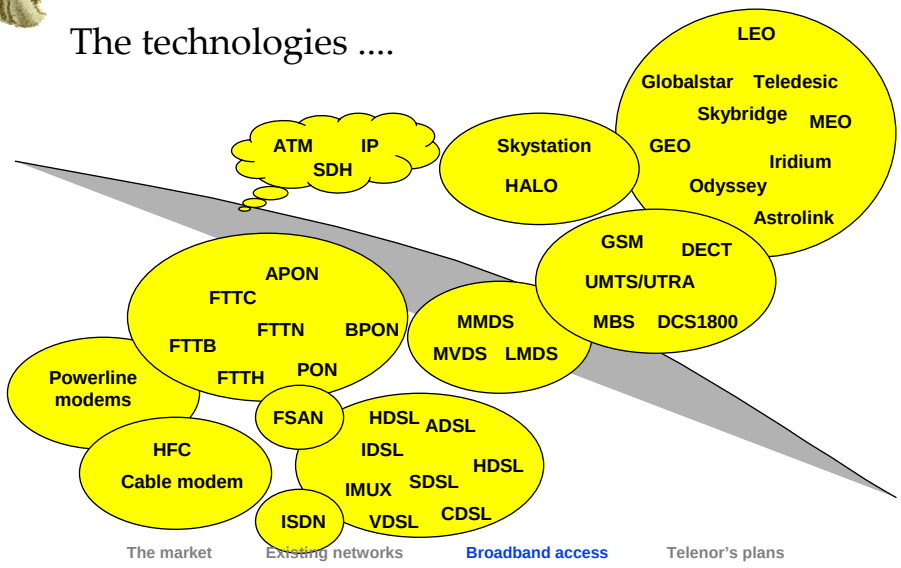
Featured publications from UoA Team

- D. Katsianis et al., "A Game Theory modeling approach for 3G Operators" NETNOMICS: Economic Research and Electronic Networking, online Sep 2008, ISSN 1385-9587 (Print) 1573-7071 (Online).
- J. Harno et al «Techno-Economic evaluation of 3G and beyond mobile business alternatives», NETNOMICS, online Oct 2008.
- Th. Rokkas et al. «Evaluation of FSO and FTTH technologies using techno-economic and risk analysis» Info, The journal of policy, regulation and strategy for telecommunications, information and media
- Th. Rokkas et al «Evaluation of FSO and FTTH technologies using techno-economic and risk analysis» Info, The journal of policy, regulation and strategy for telecommunications, information and media
- J. Harno, et al, "Alternatives for mobile operators in the competitive 3G and beyond business" Telecommunication Systems Journal (accepted for publication)
- D. Katsianis et al, "The economics of integration of DVB-S with terrestrial technologies and the role of dynamic bandwidth management", IJSC International Journal on Satellite Communications January 2007 (online) in press Volume 25, Issue 3 (May/June 2007).
- Th. Rokkas, et al., "Business Prospects of Wide-Scale Deployment of Free Space Optical Technology as a Last-Mile Solution: A Techno-Economic Evaluation, OSA/JON Journal of Optical Networking, Vol. 6, Issue 7, pp. 860-870 (2007)
- B. T. Olsen *et al*, "Technoeconomic Evaluation of the Major Telecommunication Investment Options for European Players", IEEE Network, vol. 20, no 4, July 2006.
- Th. Monath, Ph. Cadro, D. Varoutas and D. Katsianis, "Economics of fixed broadband access network strategies" IEEE Communication, Sep 2003.
- D. Varoutas *et al,* "Business opportunities for UMTS-WLAN networks" Annals of Telecommunications Vol. 58, n°3-4, March-April 2003
- D. Katsianis *et al,* "The financial perspective of the mobile networks in Europe", IEEE Personal Communications, Dec 2001, pp 58-64.

The challenge

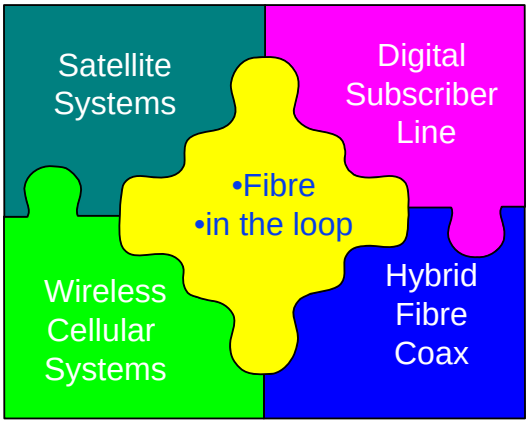


The technologies ....

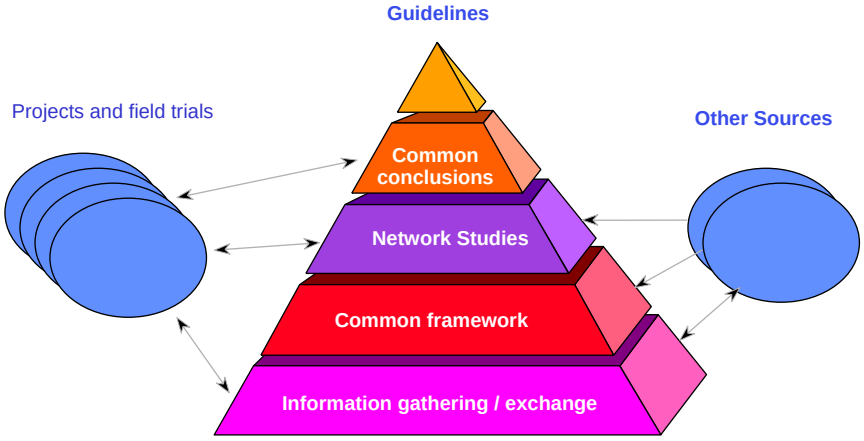


The market | Existing networks | **Broadband access** | Telenor's plans

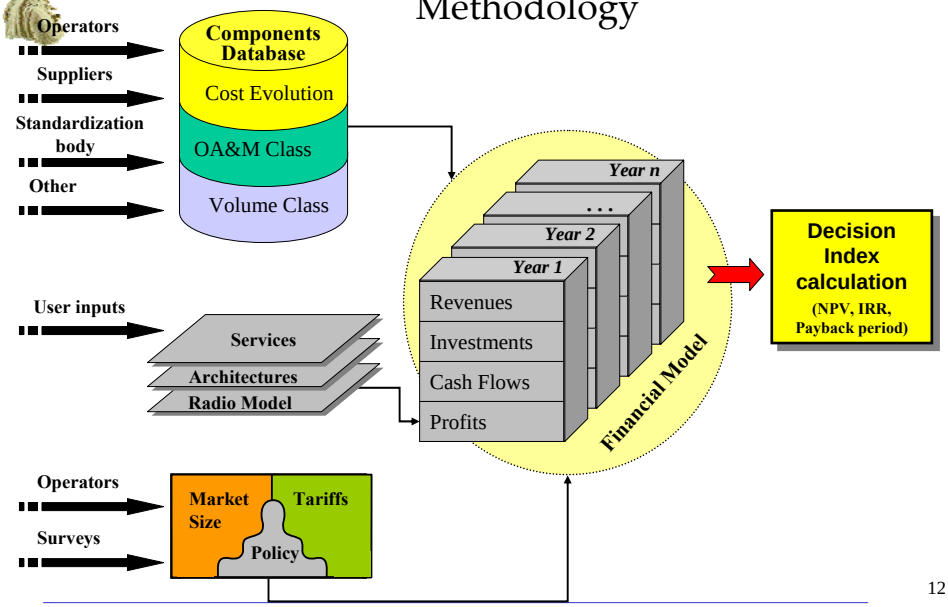
A wide range of alternatives for interactive broadband access



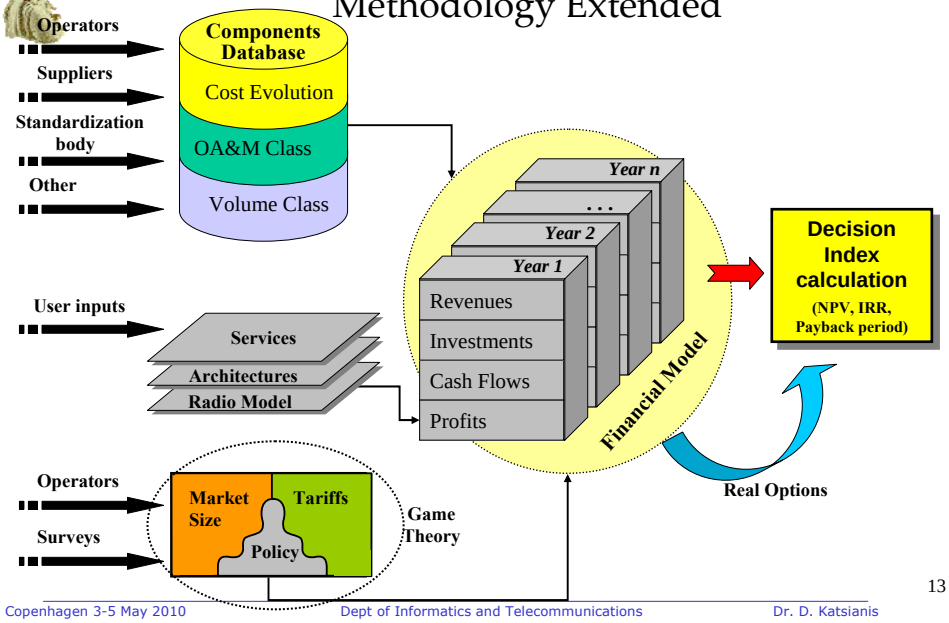
Consolidation of Results and Guidelines for deployment scenarios



Methodology



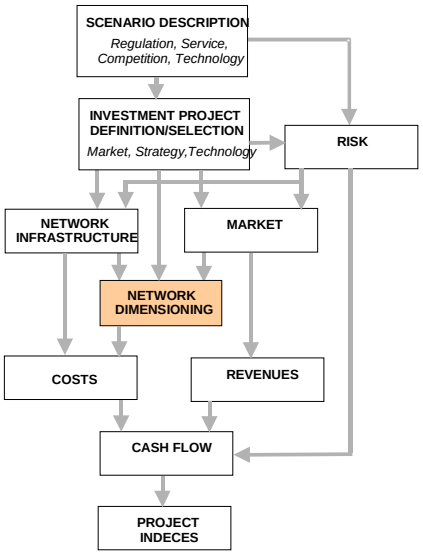
Methodology Extended



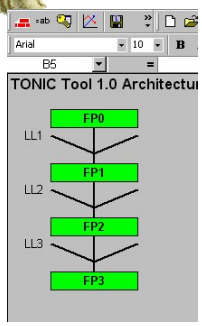
Steps in Network Evaluation

- Definition of service basket
- Network scenarios
- First Simulations – Main Financial results
- Sensitivity and Risk Analysis
- Evaluation Recommendation and Guidelines

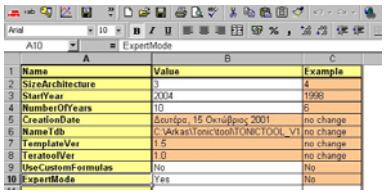
Modeling the Steps in Business evaluation



Techoeconomic Tool



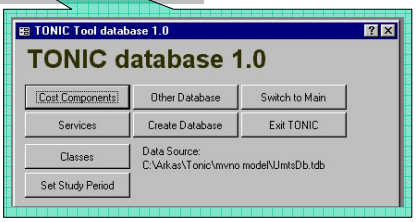
- Based on Office platform
  - Excel & Access
- Automatic sensitivity analysis
- Compatibility with Risk Analysis Tool(s)



	Name	Value	Example
2	SizeArchitecture	3	4
3	StartYear	2004	1998
4	NumberOfYears	10	6
5	CreationDate	Δευτέρα, 15 Οκτώβριος 2001	no change
6	NameTdb	C:\Arkas\Tonic\tonic\TONICTOOL_V1	no change
7	TemplateVer	1.5	no change
8	TeratoolVer	1.0	no change
9	UseCustomFormulas	No	No
10	ExpertMode	Yes	No

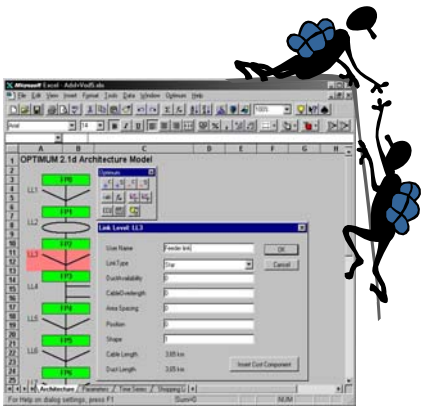
The TE tool & its database

Component	Auto Update	Level	ItemType	M_Rate	M_Hours	WriteOff	ReferencePrice	Referer
GPRS_and_UMTS_DNS	1	FP1	Material/Electronics	0,08	0	5	15.000	
GPRS_and_UMTS_Firewall	1	FP1	Material/Electronics	0,08	0	5	70.000	
GPRS_Charging_gw	1	FP1	Material/Electronics	0,08	0	5	380.000	
Middleware	1	FP1	Material/Electronics	0,05	0	5	15	
UMTS_Billing_system	1	FP1	Material/Electronics	0,05	0	5	6.000.000	
UMTS_Call_Processing_Serv	1	FP1	Material/Electronics	0,05	0	5	2.000.000	
UMTS_HSS	1	FP1	Material/Electronics	0,05	0	5	2.000.000	
UMTS_MediaGateway_circuit	1	FP1	Material/Electronics	0,05	0	5	600.000	
UMTS_MediaGateway_ip_mu	1	FP1	Material/Electronics	0,05	0	5	2.100.000	
UMTS_MSC_Server	1	FP1	Material/Electronics	0,05	0	5	1.800.000	
UMTS_MSC_upgrade	1	FP1	Material/Electronics	0,05	0	10	200.000	
UMTS_OMC	1	FP1	Material/Electronics	0,08	0	10	7.000.000	
Authentication Server	1	FP0	Material/Electronics	0,05	0	5	500.000	
GPRS_and_UMTS_GGSN_S	1	FP0	Material/Electronics	0,08	0	5	1.300.000	
UMTS_CAMEL_Server	1	FP0	Material/Electronics	0,08	0	10	3.600.000	
UMTS_GMSC_Server	1	FP0	Material/Electronics	0,08	0	5	1.800.000	
UMTS_HLR/AuC	1	FP0	Material/Electronics	0,08	0	5	1.090.000	



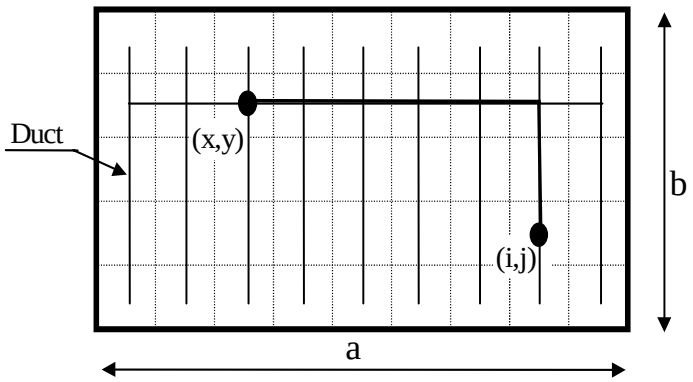
Cost data-base

- Cost parameters
  - P(0)
  - $n_r(0)$
  - ΔT
  - K
- Maintenance parameters
  - MTTR
  - MTBR
  - Maintenance Class
  - Labor cost/hour
- Depreciation
  - Write off class
- Uncertainty Classes



Geometrical model

Ducts and an example cable route within the basic TITAN model area.



Cable length in the geometrical model

a is the length of the model area
b is the width of the model area
x is the length co-ordinate of distribution point, x ∈ [0,a-1]
y is the width co-ordinate of distribution point, y ∈ [0,b-1]

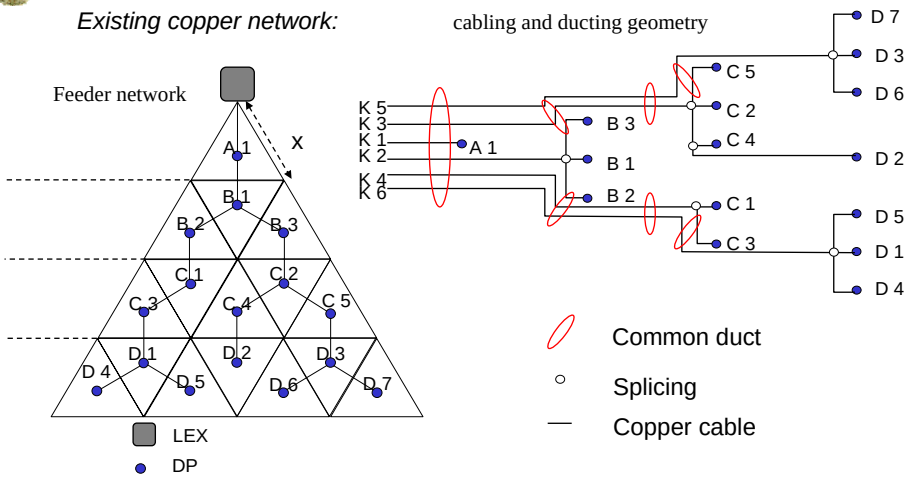
Example:
Total duct lengths:
$l_d = a\,(b-1)$

The total cable length in case of a star topology:

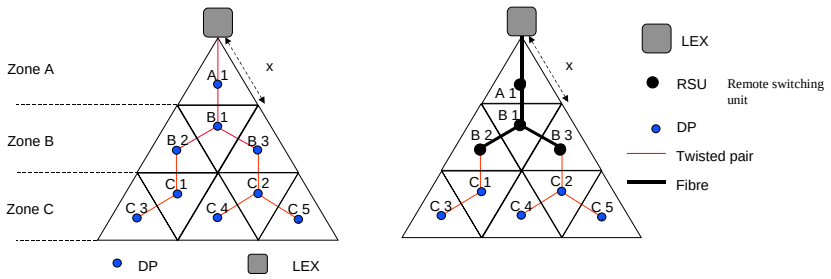
$$l_c(a,b,x,y) = \frac{a}{2}\cdot\left[(b-y-1)^2 + y^2 + b - 1\right] + \frac{b}{2}\cdot\left[(a-x-1)^2 + x^2 + a - 1\right]$$

Feeder network

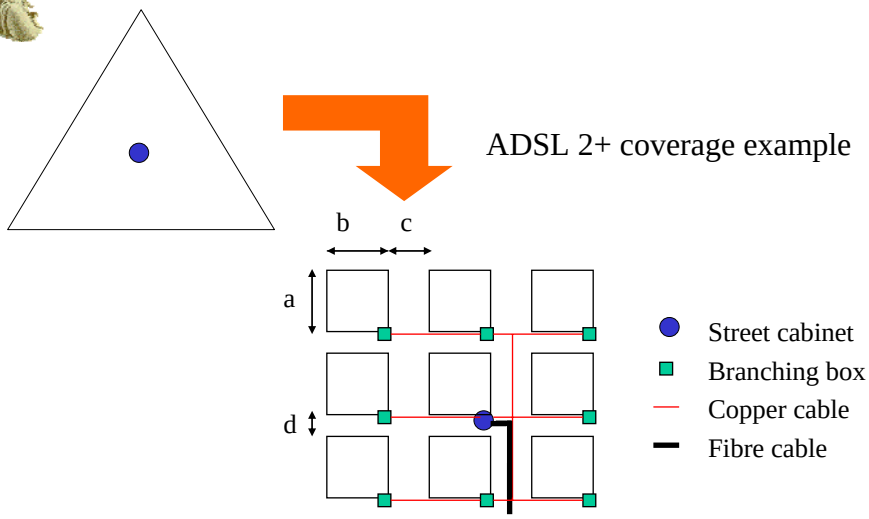
Existing copper network:



Upgrade FTTCab



Distribution network + Geometrical Model

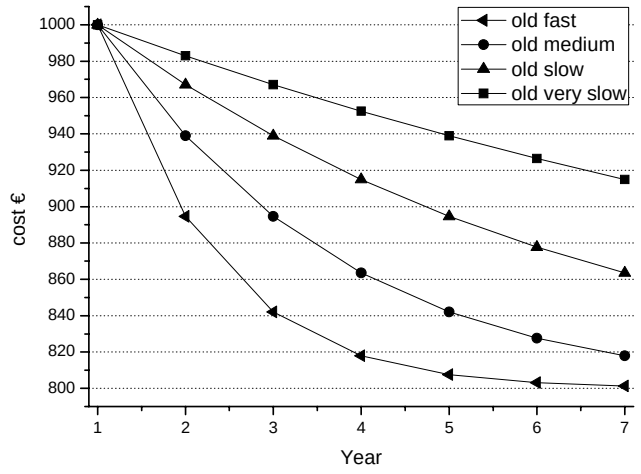


Cost model

- P(0), the price in the reference year 0
- $n_r(0)$, the relative accumulated volume in year 0,
- ΔT , the time for the accumulated volume to grow from 10 % to 90 %,
- K , the learning curve coefficient.

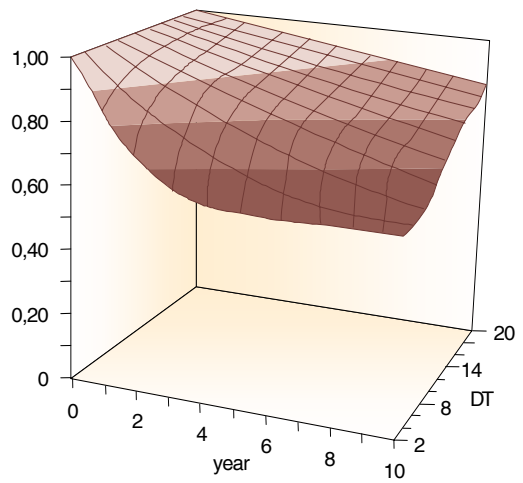
$$P(t) = P(0) \cdot \left[n_r(0)^{-1} \cdot \left(1 + e^{\left\{ \ln\left[n_r(0)^{-1} - 1 \right] - \left[\frac{2 \cdot \ln 9}{\Delta T} \right] \cdot t \right\}} \right)^{-1} \right]^{\log_2 \cdot K}$$

Effect of ΔT for given $nr(0)$=0.5 for a component with initially cost 1000€

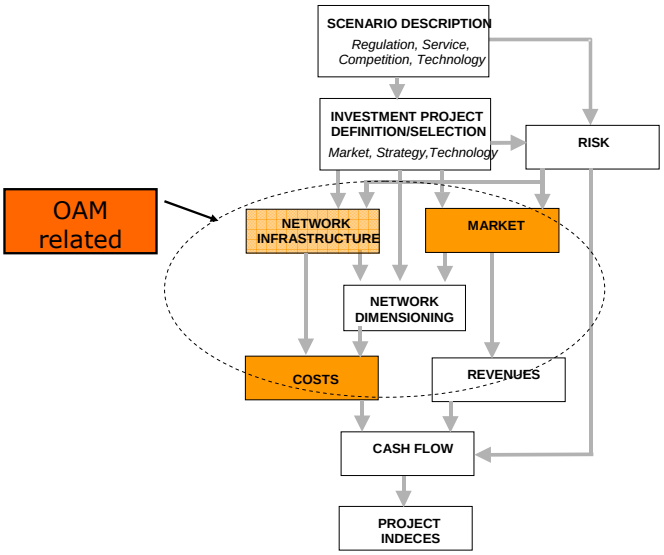


Relative cost evolution as a function of Δ T

with $n_r(0)$=0.001



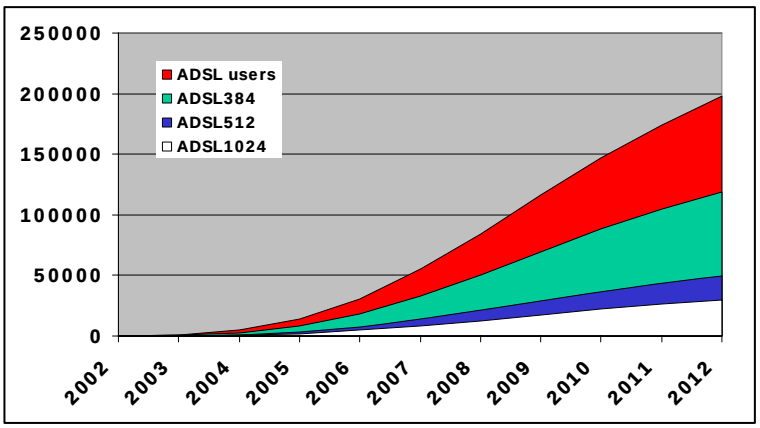
Operational Cost in TE Modeling



Main OPEX elements (check Annex)

1. Maintenance of equipment and components
2. Equipment and software licenses, Maintenance outsourcing
3. Sales and marketing, Customer acquisition
4. Customer provisioning
5. Customer care
6. Charging and billing
7. Service management
8. Network management
9. Product/platform development
10. Rental of physical network resources
11. Roaming
12. Interconnection
13. Yearly cost of radio spectrum licenses
14. Regulation
15. Content

Example Demand



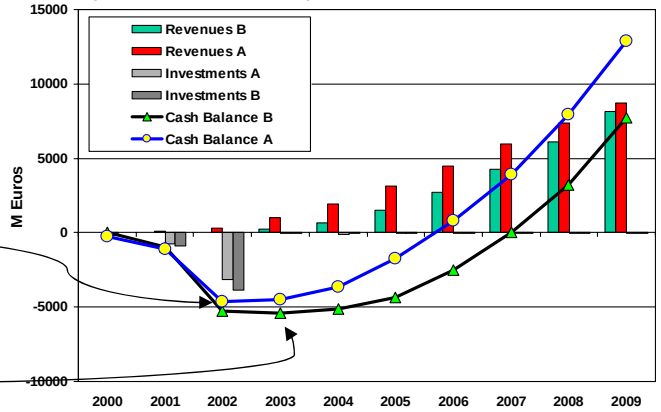
Financial Results

	Case A	*Case B*
Net present value	4960 MEuros	1992 MEuros
Internal rate of return	28.8%	17.5%
Payback period	6.7 years	8 years

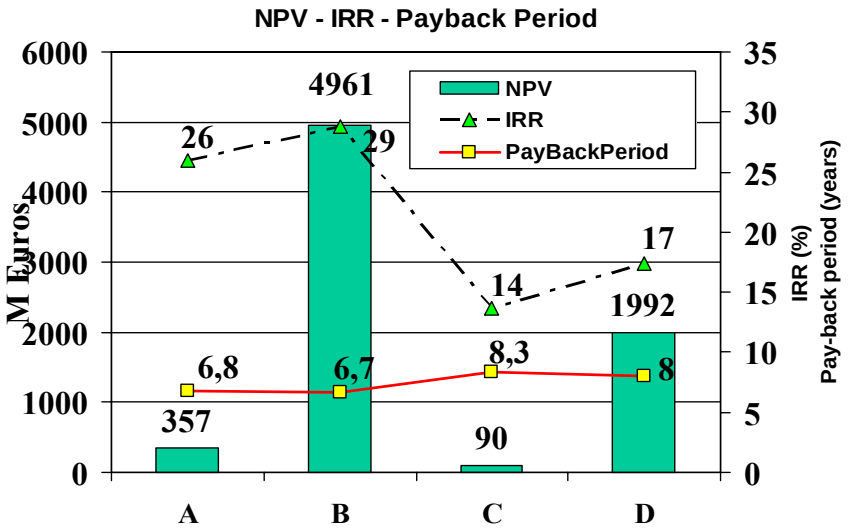
Maximum Finance need

4600 MEuros

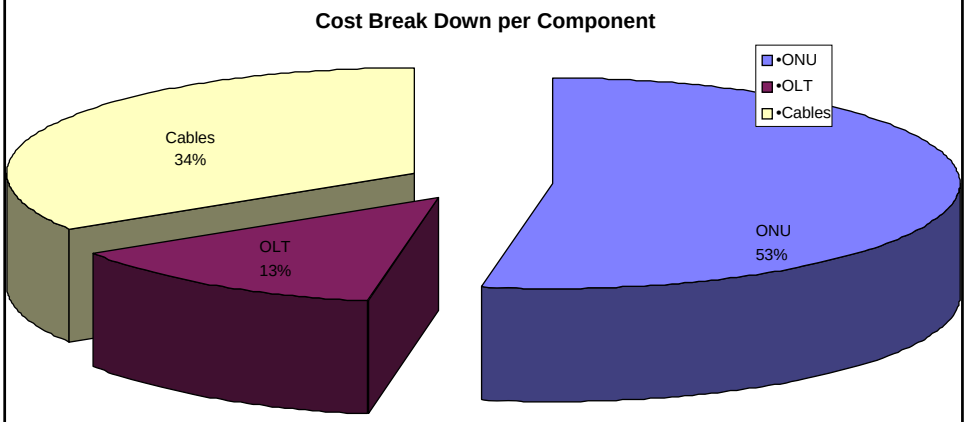
5400 MEuros



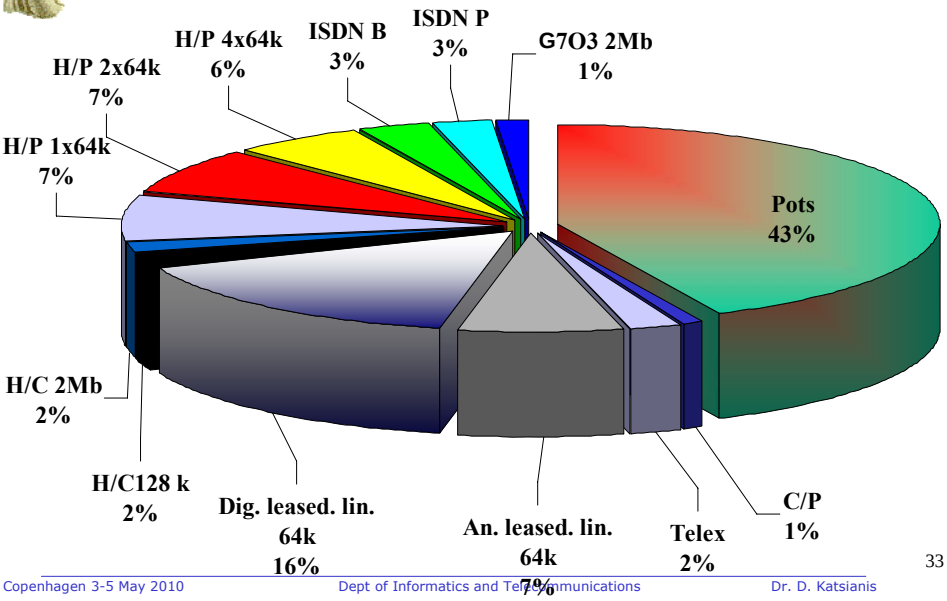
NPV - IRR - Payback Period



Cost Breakdown



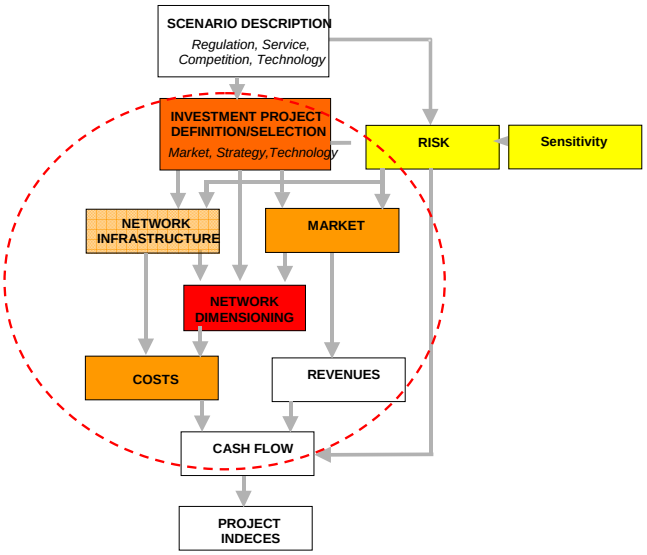
Revenues stream



Main Financial Results

- Net Present Value, NPV
- Internal Rate of Return, IRR
- Payback Period
- Financial indicators
  - Investments
  - Running Costs
  - Revenues
  - Cash Flows
  - Depreciation
  - Profits
  - Taxes
  - Retained Cash Flows
  - Cash Balance
  - Rest Value

Risk Analysys in TE Modelling



Sensitivity Analysis

- What if…?
- Approach
  - select the most critical input parameters
  - establish boundaries for their variation with a « 95% confidence interval »
- Results
  - impact on NPV
    - at boundary input parameter values: new NPV
    - sensitivity factor: how NPV varies (slope at base value)
  - impact on IRR
    - at boundary input parameter values: new IRR
    - sensitivity factor: slope at base value, although variation usually non linear

What is uncertainty (modelling)?

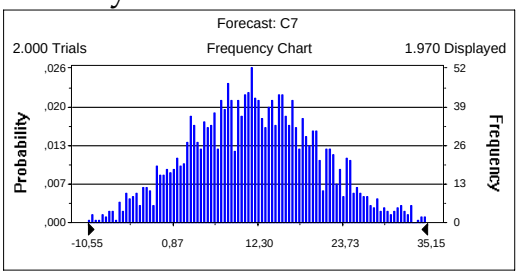
- It's Essential to distinguish between variation, "true" uncertainty and decision/strategic variables
- Variation:
  - Variation depends on the details of gathered data e.g. geographic and demographic characteristics, existing market figures, …
- True uncertainty:
  - Future penetration, market share evolution, cost evolution, technology development, …
- Decision variables:
  - Variables that are under some control of the company e.g. coverage, timing of investment, service mix and time of launch, pricing variables, …

Modelling uncertainty

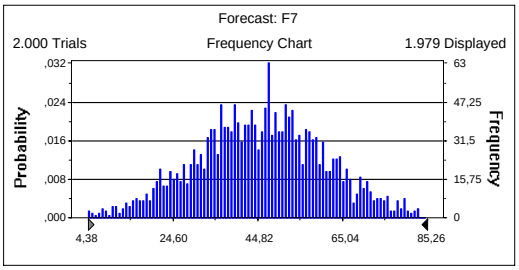
- Define probability density functions (pdf) given a set of parameters e.g. expected value, confidence interval, maximum and minimum values
  - Choice of pdf can be difficult to justify when no historical value is available
  - Confidence interval or percentiles are more intuitive metrics than the standard deviation

Uncertainity and Risk

- **Project A**
  - Mean 11,58
  - σ=9,06

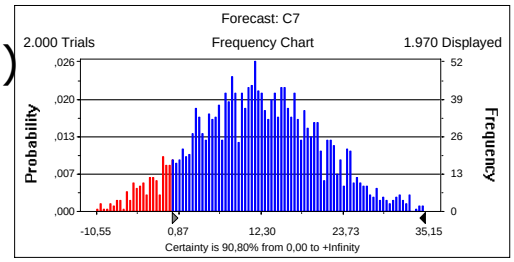


- **Project B**
  - Mean 45,36
  - σ=15,98

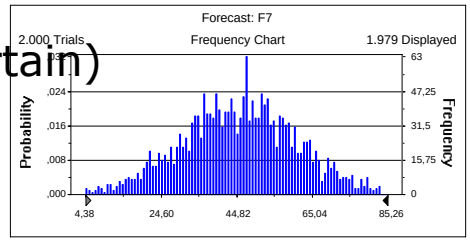


Uncertainity and Risk

- **Project A (Risk)**
  - Mean 11,58
  - σ=9,06
  - 9,2% perc<=0



- **Project B (uncertain)**
  - Mean 45,36
  - σ=15,98
  - 5% perc=22
  - 95% perc =75



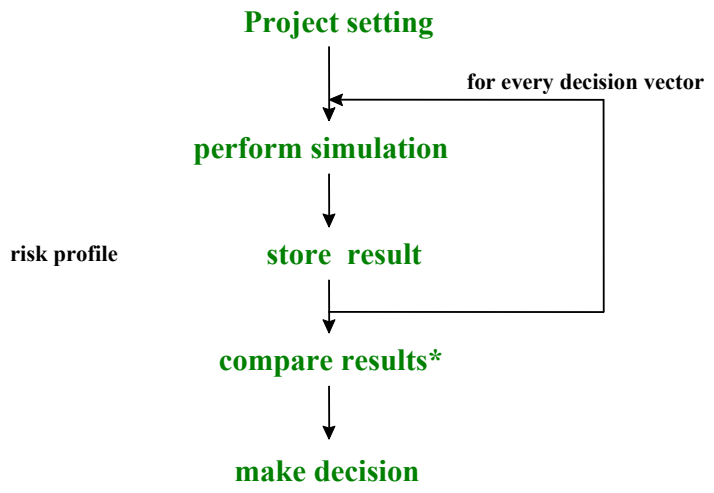
Possible -> Probable

- What is Possible?
- What is Probable?

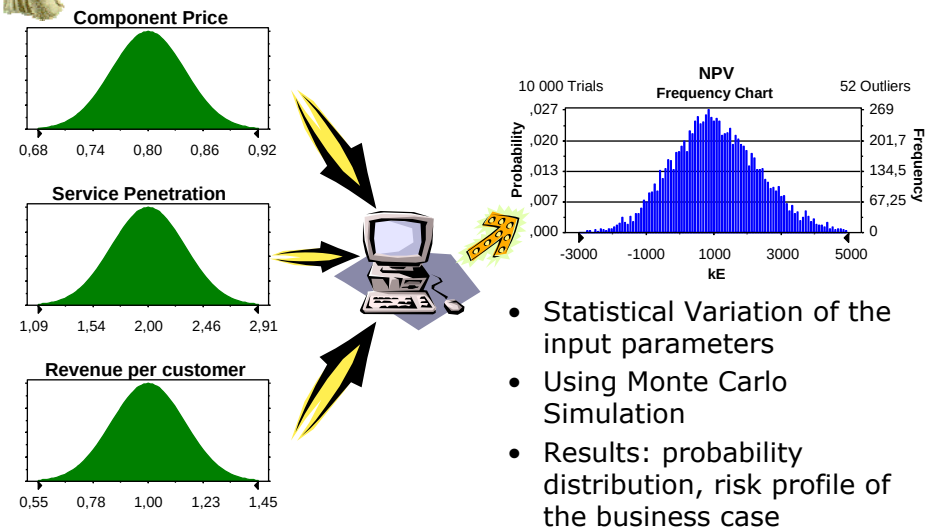
Risk Analysis

- **Input:**
  - **Uncertainty in market parameters**
    - **Market size**
    - **Market share**
    - **Broadband services characteristics**
  - **Uncertainty in Cost parameters**
    - **Cost units**
    - **Cost evolution**
    - **Area characteristics**
- **Outputs:**
  - **Probability measures for a reduced set of parameters**

Method

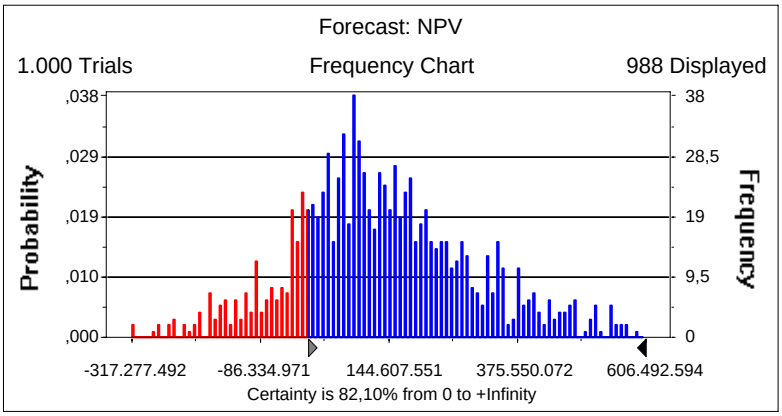


Risk Analysis



- Statistical Variation of the input parameters
- Using Monte Carlo Simulation
- Results: probability distribution, risk profile of the business case
- Extended basis for investment decisions

Risk Analysis - NPV



Requirements for a T-E study

- Services Scenarios
  - Dimensioning
- Commercial Network Architectures .
  - For selected services
  - Database construction
  - Serving areas
- T-E Model Constructions
  - Study period (years?)
- Potential market
- Market Shares (e.g number of operators)
- Pricing
- **Runs- Results**
- **Sensitivity and Risk Analysis**
- **Evaluation of the results – Recommendation and Guidelines - Commercial viability**

Time for Questions & Answers

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EURO 2004

Annex I

Main OPEX elements
http://www.optcomm.di.uoa.gr/ecosys/
(ECOSYS project, deliverable 6,2005)

Main OPEX elements

1. Maintenance of equipment and components
2. Equipment and software licenses, Maintenance outsourcing
3. Sales and marketing, Customer acquisition
4. Customer provisioning
5. Customer care
6. Charging and billing
7. Service management
8. Network management
9. Product/platform development
10. Rental of physical network resources
11. Roaming
12. Interconnection
13. Yearly cost of radio spectrum licenses
14. Regulation
15. Content

Maintenance of equipment and components (1)

- Includes all the recurrent costs that are periodically necessary for undisturbed network and service operation.
- Includes both preventive maintenance and reparation
- Reinvestment due to outdated equipment is treated as CAPEX. Reinvestment means a change to a newer version of equipment, usually with higher functionality.
- Decommissioning cost (removing of old equipment) might be counted as OPEX or be included to CAPEX.

Maintenance cost example

- M1 - Represents the cost of repair parts. This component is driven by the investments.
- M2 - Represents the cost of repair work.

$$M_i = (M_1 + M_2)_i$$
$$= \frac{V_{i-1} + V_i}{2} \cdot \left(P_i \cdot R_{class} + P_l \cdot \frac{MTTR}{MTBR} \right)$$

V_i is the equipment volume in year I

- P_i is the price of cost item in year i
- R_{class} is the maintenance cost percentage (to be defined)

P_l is the cost of one working hour

MTTR is the mean time to repair for the cost item in question (to be defined)

MTBR is the mean time between failures for the cost item in question (to be defined)

Equipment and software licenses, maintenance outsourcing (2)

- This includes e.g. yearly expenses from the operator to the equipment provider after buying the equipment (maintenance agreement and periodic licence costs).
- Annual fees and/or Upgrades based on:
  - Working time for upgrade (upgrade time)
  - Frequency of upgrades (FOU)
  - Number of network elements to visit
- Software maintenance cost = annual cost (driver: customers, nodes, traffic etc) and/or
- Software maintenance cost = upgrade time * working time costs * FOU * number of network elements to visit

Sales and marketing, Customer acquisition (3)

- This element is intended to cover both retail and wholesale businesses.
  - Marketing, Advertising, Campaigns
    - very case dependent
      - wholesale for a few customer vs. retail for mass market
    - Consists of the
      - manpower costs - marketing staff working for the relevant case times the average manpower cost
      - costs o buying media time for advertising.
    - Marketing cost = cost per potential customer * size of potential customer base
    - Relevant to Customer acquisition cost vs Churn rate
  - SLA (Service level agreement) negotiation
    - depend on the length of preparation and negotiation and manpower cost.
  - Subsidisation (provisions to e.g. handset vendors)
    - Subsidisation cost = number of new (subsidized) customers * subsidy cost per customer

Customer provisioning (4)

- Customer registration
- Installation and reinstallation (by churn) of customer
- Activation of customers devices
- Provisioning includes also initial service configuration, disconnecting a customer, deleting data from customer base etc.
- The average installation/reinstallation cost can have some learning effects i.e. reduce over time because of economies of scale.
  - E.g Provisioning cost = (customers_year_end – customers_year_begin + churned customers) * provisioning cost of one customer
  - Provisioning of one customer might be

$$P(t) = n(t)^{-\alpha} \cdot P_0$$

Customer care (5)

- Customer service, handling of complaints etc
- Help desk operation
- CRM (customer relationship management) operation
- May often be outsourced, can be based on personal and/or IT-systems.
- E.g. Customer care cost = average number of customers per year * customer care personnel per customer * yearly manpower cost

Charging and billing (6)

- Data collection, etc.
- Charging
- Billing
- Accounting and controlling (regular reporting to the higher level management)
- Charging and billing cost = average number of customers per year * unit cost(t)
- unit cost(t) ->(price per customer)

Service management (7)

- Product management (responsible person)
- Supervision and monitoring of services and quality
- SLA management

- Cost = management cost for service1 + management cost for service2 + …etc

Network management (8)

- Faults, Configuration, Accounting, Performance, and Security management (FCAPS)
- Supervision and control of network elements
- Operation Support Systems (OSS) operation
- Network management cost = F(number of personnel, number of network management systems, number of network elements)

Product/platform development (9)

- Network planning
- Service design and development
- SLA design
- Product/platform development cost = F(number of engineers, number of services, complexity of existing and new services)

Rental of physical network resources (10)

These elements are very relevant to service providers or virtual operators that do not own network platforms, or infrastructure, but rent it from others. Also traditional operators often have to pay for some of these.

- LLU (local loop unbundling)
- Wholesale (e.g. DSL access)
- Leased lines
- Dark fiber
- Co-location, hosting
- Mast for base stations
- Mobile access
- SAN (Storage area network)

- Dependent
  - Number of customer (LLU Buldings, ADSL Wholesale)
  - Traffic (leased lines)
  - Number of sites (mast for base stations)

Roaming (11)

- Roaming agreement and settlement cost:
  - The cost incurred in negotiating and managing the roaming agreements and financial settlements.
- Global roaming test:
  - The cost incurred in conducting interoperability tests for roaming across multiple networks and technologies.
- VHE (Virtual home environment) maintenance:
  - The cost incurred for the maintenance of the VHE, essential for providing the same personalized profile across multiple networks and terminals for an inbound subscriber.
- Roaming costs = cost per inbound subscriber * total number of inbound subscriber + cost per outbound subscriber * total number of outbound subscribers

Interconnection (12)

- The interconnection costs include mainly termination charges levied by a network operator responsible for completing a call or session originated in another network.
- The main driver is interconnecting traffic volumes
- Interconnection costs = (cost per traffic unit) * (total inbound traffic – total outbound traffic)
- Prices are often different in different directions (e.g. in incumbent/non-incumbent case). Interconnection costs can also vary based on geographical location such as national and international connections.

Radio spectrum licenses (13)

- Yearly cost for frequency licenses for UMTS, WiMAX etc
- Some regulatory regimes allow the possibility of leasing the spectrum owned by an operator to a third party.
  - e.g.the leasing of spectrum by an MVNO from a network operator could be possible. Here, the spectrum leasing cost incurred by an MVNO is considered as an OPEX whereas the cost incurred by the network operator in purchasing that license is considered as CAPEX
- yearly fixed fee or fee for the entire duration of license.

Regulation (14)

- Cost for collecting information and reporting to the regulator
- Additional cost due to the impact of changes in regulatory decisions
- Fines based on regulator decisions
- E.g personnel costs involved in regulatory reporting and information collection as well as the costs involved in complying with the regulatory decisions.

Content (15)

- This is the cost in purchasing licenses from a third party (content owner) for content distribution.
  - number of licenses and number of users of the content
- Includes also other payments to a third party
  - maintenance of content distribution and rights management systems.

Company specific OPEX elements

- General management of the company
- Research &Development
- Law department
- Economy department
- Human resources (HR)
- General IT support

Annex II

Risk Analysis

Elnegaard N. K., et al. "Analysing the Impact of Forecast Uncertainties in Broadband Access Rollouts by the Use of Risk Analysis" *Telektronikk(100) no 4, 2004, pp 157-167*

Possible -> Probable

- What is Possible?
- What is Probable?

Alternative parameter sets

- Mean and standard deviation
- Percentiles
- Mode (most expected value)and lower/higher percentile
- …

Probability distributions (pdf)

- Continuous distributions:
  - Normal
  - Lognormal
  - Beta
  - Gamma
  - Uniform
  - Exponential
- Discrete distrubutions
  - Binomial
  - Hypergeometric
  - Poisson
  - Geometric

Beta distribution – characteristics

Definition:

$$p(x) = \frac{1}{\mathrm{B}(\mu,\nu)} x^{\mu-1}(1-x)^{\nu-1}, \ \mathrm{B}(\mu,\nu) = \frac{\Gamma(\mu)\Gamma(\nu)}{\Gamma(\mu+\nu)}, \ x \in [0;1]$$

Most expected value (mode), X_M :

$$\frac{dp(x)}{dx} = 0 \Rightarrow x = X_{\mathrm{M}} = \frac{\mu-1}{\mu+\nu-1}$$

$$\mathrm{Y}_{\mathrm{M}} = (b-a)\frac{\mu-1}{\mu+\nu-1} + a$$

Calculating parameters of a pdf: Beta

Example – 90% confidence interval defined:

$$= \frac{\mu(Y_M - a) + 2Y_M - (b + a)}{Y_M - a}$$

$$\int_{X_{\text{conf, L}}}^{X_{\text{conf, H}}} p(x)dx = \int_0^{X_{\text{conf, H}}} p(x)dx - \int_0^{X_{\text{conf, L}}} p(x)dx$$
$$= \tilde{\mathrm{B}}(\mu, \nu, X_{\text{conf, H}}) - \tilde{\mathrm{B}}(\mu, \nu, X_{\text{conf, L}})$$
$$= \tilde{\mathrm{B}}(\mu, g(\mu), X_{\text{conf, H}}) - \tilde{\mathrm{B}}(\mu, g(\mu), X_{\text{conf, L}}) = 0.90$$

where

$$\nu = g(\mu) = \frac{\mu(1 - X_M) + 2X_M - 1}{X_M}$$

μ and thereby also ν are found by using Solver
Cumulative Beta-distribution is a built-in function in Excel

Ref. Elnegaard N. K., et al. "Analysing the Impact of Forecast Uncertainties in Broadband Access Rollouts by the Use of Risk Analysis" Telektronikk(100) no 4, 2004, pp 157-167

Transformation of a random variable

Given a random variable with mode, minimum, maximum and confidence interval:

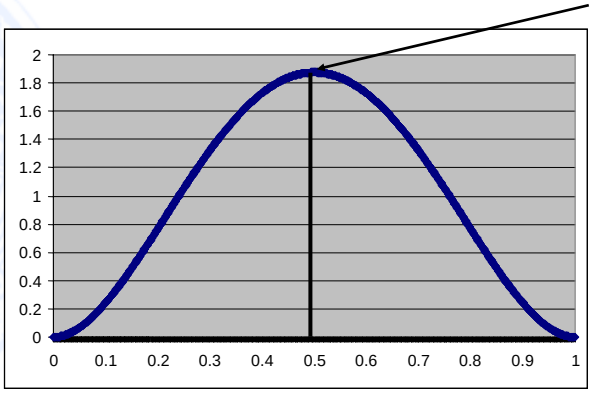
$$Y_{\min} < Y_{\text{conf, L}} < Y_M < Y_{\text{conf, H}} < Y_{\max}$$

Find the parameters of the Beta-distributed variable X :

$$Y = (Y_{\max} - Y_{\min})X + Y_{\min} \Leftrightarrow$$
$$X = \frac{Y - Y_{\min}}{Y_{\max} - Y_{\min}}$$

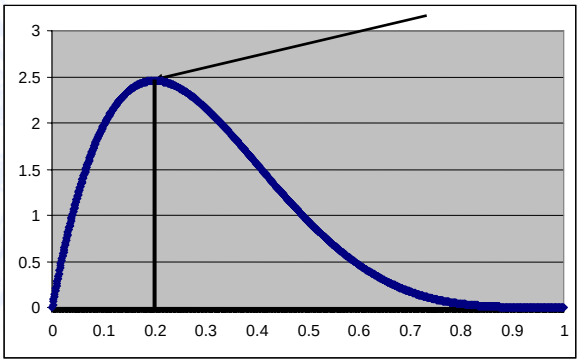
Beta distribution: $\mu = 3$, $\nu = 3$

$X_M = 0.5$



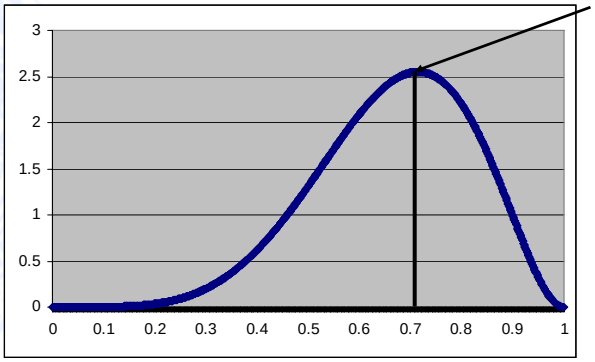
Beta distribution: $\mu = 2$, $\nu = 5$

$X_M = 0.2$

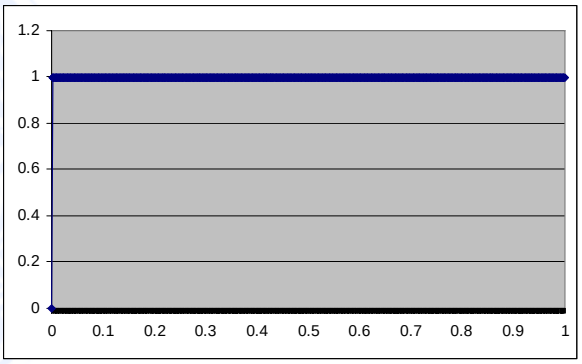


Beta distribution: $\mu = 6$, $\nu = 3$

$X_M = 5/7 \sim 0.714$



Beta distribution: $\mu = 1$, $\nu = 1$



Lognormal distribution characteristics

- Definition:

$$p(x) = \frac{1}{\sqrt{2\pi}\sigma_{\text{Log}} x} \exp\left\{ \frac{-\left(\ln(x) - \mu_{\text{Log}}\right)^2}{2\sigma_{\text{Log}}^2} \right\}$$

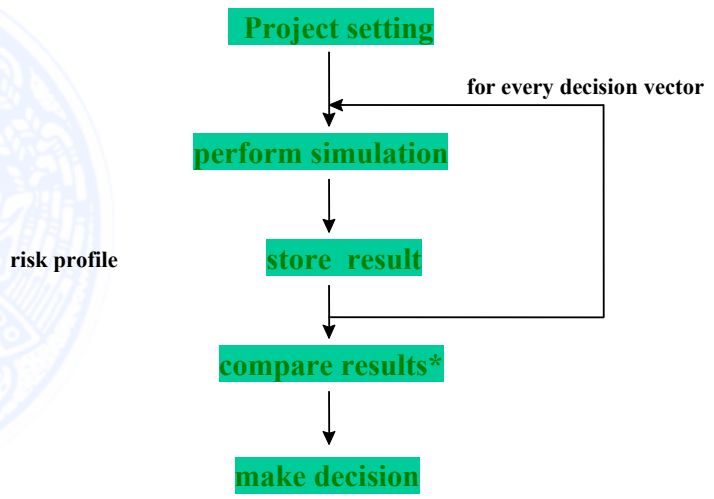
- Most expected value (mode), X_M :

$$\frac{dp(x)}{dx} = 0 \Rightarrow x_M = \exp\left\{\mu_{\text{Log}} - \sigma_{\text{Log}}^2\right\}$$

- Mean and variance:

$$\mu = \exp\left\{\mu_{\text{Log}} + \frac{\sigma_{\text{Log}}^2}{2}\right\}, \quad \sigma^2 = \exp\left\{2\mu_{\text{Log}} + \sigma_{\text{Log}}^2\right\}\left[\exp\left\{\sigma_{\text{Log}}^2\right\} - 1\right]$$

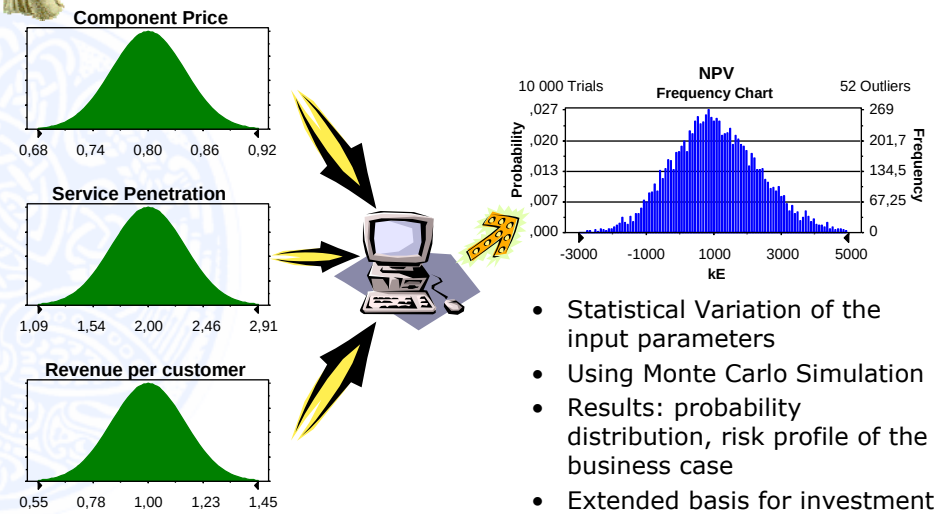
Method



Monte Carlo Simulation in Crystal Ball

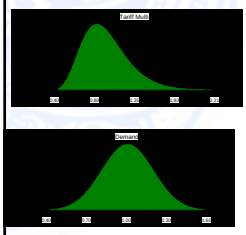
- A number of uncertainty variables are selected and defined by probability distributions
- Forecast functions are defined such as NPV
  - IRR generally not recommended (!)
- A predefined number of runs in the simulation is carried out – in each run a new random number is picked from each distribution
- Complete statistics on forecast functions are generated
- Ranking of uncertainty variables with respect to rank correlation with forecasts

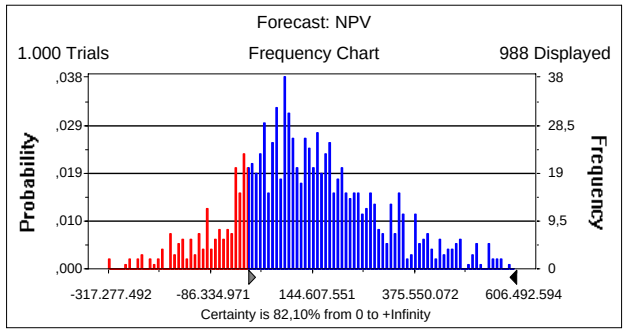
Risk Analysis



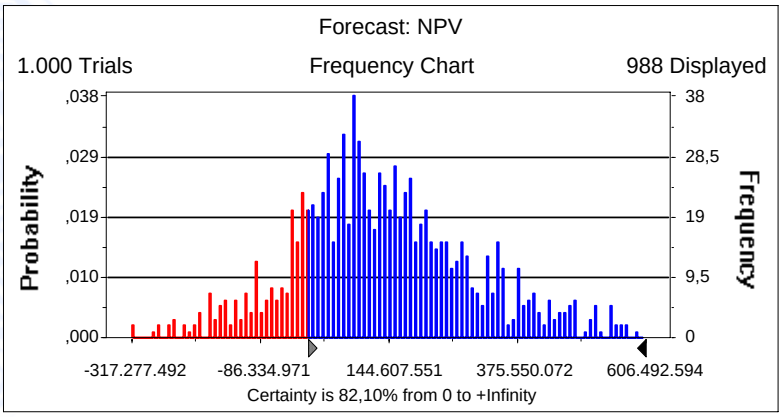
- Statistical Variation of the input parameters
- Using Monte Carlo Simulation
- Results: probability distribution, risk profile of the business case
- Extended basis for investment decisions

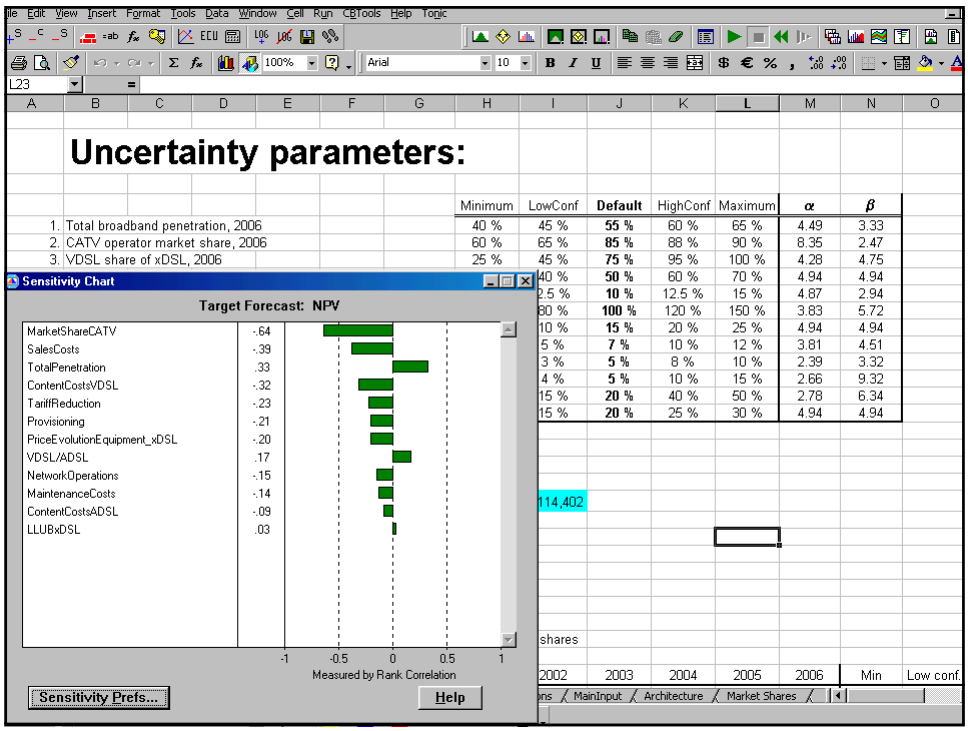
Risk Analysis (probable)

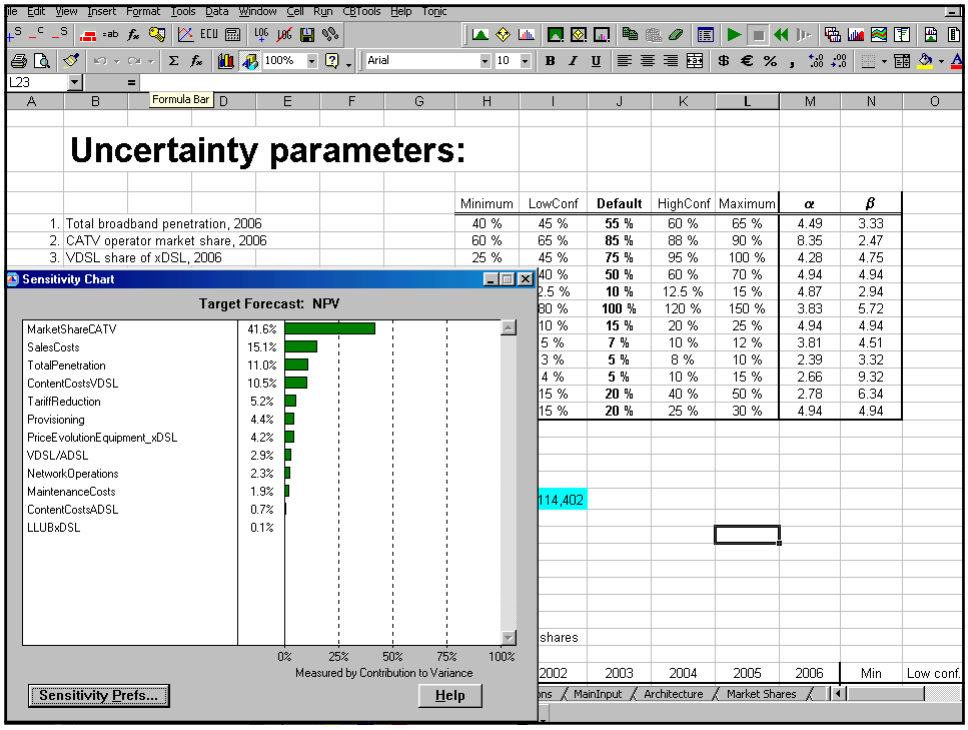




Risk Analysis - NPV




Uncertainty parameters:
Minimum LowConf Default HighConf Maximum α β
1. Total broadband penetration, 2006 40 % 45 % 55 % 60 % 65 % 4.49 3.33
2. CATV operator market share, 2006 60 % 65 % 85 % 88 % 90 % 8.35 2.47
3. VDSL share of xDSL, 2006 25 % 45 % 75 % 95 % 100 % 4.28 4.75
Sensitivity Chart
Target Forecast: NPV
MarketShareCATV -.64
SalesCosts -.39
TotalPenetration .33
ContentCostsVDSL -.32
TariffReduction -.23
Provisioning -.21
PriceEvolutionEquipment_xDSL -.20
VDSL/ADSL .17
NetworkOperations -.15
MaintenanceCosts -.14
ContentCostsADSL -.09
LLUBxDSL .03
-1 -0.5 0 0.5 1
Measured by Rank Correlation
Sensitivity Prefs...
Help
114,402
shares
2002 2003 2004 2005 2006 Min Low conf.
MainInput Architecture Market Shares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Sensitivity Chart
Target Forecast: NPV
MarketShareCATV 41.6%
SalesCosts 15.1%
TotalPenetration 11.0%
ContentCostsVDSL 10.5%
TariffReduction 5.2%
Provisioning 4.4%
PriceEvolutionEquipment_xDSL 4.2%
VDSL/ADSL 2.9%
NetworkOperations 2.3%
MaintenanceCosts 1.9%
ContentCostsADSL 0.7%
LLUBxDSL 0.1%
0% 25% 50% 75% 100%
Measured by Contribution to Variance
Sensitivity Prefs...
Help
114,402
shares
2002 2003 2004 2005 2006 Min Low conf.
MainInput Architecture Market Shares

Penetration-Forecast

Example – asymmetric S-curve:

$$S(t) = \frac{M}{(1+\exp(\alpha+\beta t))^{\gamma}}$$

Given: penetration at T_1 and T_2, M and γ. Find β and α

Ex.: uncertainty defined as the uncertainty in $S(T_2)$

$$\beta = \frac{1}{T_2 - T_1} \ln\left[\frac{\left(\frac{M}{S(T_2)}\right)^{1/\gamma} - 1}{\left(\frac{M}{S(T_1)}\right)^{1/\gamma} - 1}\right]$$

Evaluation of the MC methodology -1

- 88Low-cost and easy-to-use commercial software e.g. Crystal Ball®
- All well-known as well as customized probability distributions for modelling uncertainty variables available in the menue
- Some software packages distinguish between uncertainty variables and decision variables e.g. Crystal Ball®
- Automised sensitivity analysis of many variables which change simultaneously
- Correlation can be taken into account
- Probability of events can be measured as e.g P(NPV>0)

Evaluation of the MC methodology - 2

- In practical life, suitable distributions may be very difficult to justify – particularly if no historical data is available
- Flexibility is not catered for as in option pricing and decision tree methodologies
- Correlations between variables difficult to justify
- Should be used with care: two many variables increases calculation time and the model may become too complex to understand and explain

Literature Reviews

- Broadband Access Networks Introduction strategies and techno-economic evaluation Edited by L.A. IMS Published within the Telecommunications Technology And Applications Series by Chapman & Hall 1998 ISBN 0 412 82820 0
- http://www.decisioneering.com
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- Elnegaard N. K., et al. "Analysing the Impact of Forecast Uncertainties in Broadband Access Rollouts by the Use of Risk Analysis" *Telektronikk(100) no 4, 2004, pp 157-167*