Practical steps in techno-economic evaluation of network deployment planning
part 1: methodology overview

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The telecom market is very competitive

- Technical superiority is not a guarantee for market success
- Additional requirements are
  - Understanding the market
  - estimating expected costs and revenues

![Diagram showing the relationships between government, vendors, customers, liberalization, globalization, technology push, and market pull.](image)
Network planning problem contains many subproblems

- Between which nodes to install a direct line?
- What will the user expect? What is needed to keep him satisfied?
- Which technology to use?
- How to route the traffic?
- In which layer to provide protection?
- Expected number of users?
- How much capacity on each line?
- Where to install network nodes?

Multiple subproblems Classification needed…

Time scale dictates classification

- **STP**
  - operational
  - weeks
  - Planning horizon: low
  - Uncertainty of planning environment: local
  - Geographical scope of planning decisions: minor
  - Relative influence of individual decisions on cash flows: e.g., configuration, monitoring

- **MTP**
  - tactical
  - months … 1 year
  - intermediate
  - subnetwork
  - medium
  - e.g., dimensioning, routing

- **LTP**
  - strategic
  - up to 5 years
  - high
  - network-wide
  - major
  - e.g., network topology, technology choice
Strategic network planning process

Total traffic demand

Customer demand

Network deployment plan

Which investments should be made at which points in time?

Old technology

New technology

Network planning

Equipment cost

Equipment cost

Existing network

Technical constraints

Physical constraints

Before the break
- Overview different steps
- Models to be used

After the break
- Reference case
- Tools demo

Goal of this tutorial
General methodology overview

Methodology

Scope
Refine
Model
Evaluate
Practical steps in techno-economic evaluation of network deployment planning

**SCOPE**
Step 1: Scope the problem

Collect input
all available data relevant for the project
Target area input

- Geographic / demographic / economic
  - Area type
  - Population density
  - Level of education
  - Income

- Legal
  - Right of Way
  - Licenses
  - Competition regulation

- Infrastructure
  - Existing networks / equipment
  - Reuse of locations (poles, buildings)

Market input

- Roles
  - What?
  - E.g. Building network, maintenance, etc.

- Actors
  - Who?
  - E.g. Customers, network operators, content providers

⇒ Input for business modeling analysis

- Users
  - E.g. Residential, commercial, industrial

- Services
  - E.g. Triple play, bandwidths, mobility, etc.
Technology input

- **State-of-the-art**
  - Available technology standards with their pros and cons
  - Commercial products ready for deployment
  - Technical specifications

- **Costs**
  - Cost figures for the different technologies
  - E.g. equipment costs, installation costs, operational costs, etc.

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Subdivide the problem in order to define the scope more clearly

![Diagram showing subdivide problem with areas, users/services, actors, technology, costs/revenues, and scope]

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p. 15

p. 16
Subdivide the problem to reduce complexity

**Goal:** split a complex problem logically into several smaller (manageable) subproblems

**But, it can be hard to ...**
- integrate calculations
  - Combination of optima ≠ Overall optimum
- see influences from one part on the others (e.g. CapEx and OpEx interaction, etc.)

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Subdivide areas

- Impossible to rollout the target area at once
  - *Due to practical limitations*
    - Time constraints
    - Resources (mostly manpower)
    - Legal permissions
  - Careful selection of rollout sequence
    - Type of network
    - Potential rollout speed
- Cherry picking!
Cherry picking

Finding those areas with the highest return on investment

- Clustering of information based on:
  - Distance
  - Market potential
    - Type of building (high vs. low buildings)
    - User density (urban vs. rural)
    - Social status
    - Employment degree
    - Residential and commercial density
  - Optimal utilization of equipment
    - E.g. FTTH: central office, street cabinet, fibers per cable
    - E.g. wireless: central office, base station

Different algorithms exist for this problem

Subdivide users / services

- Define some typical user and service types
  - Users
    - Residential vs. industrial
    - Frequent vs. occasional
  - Services
    - Data vs. triple play
    - Fixed vs. nomadic vs. mobile
Roles and actors for a wireless network

Scope

Subdivide problem

Actors

Site provis. Licensing Repair Content
Internet Conn. Backhaul Conn.

Roles and actors for a wireless network

Scope

Subdivide problem

Actors

Local Government National Regulator Network Operator Content Provider
Site provis. Licensing Repair Content
ISP Internet Conn. Backhaul Conn.

p. 21

p. 22
Roles and actors for a wireless network

Subdividing technologies

 FIXED
- FTTH
  Home run fiber
  Active star
  Passive (PON)
- xDSL
- Docsis
- EPON
- GPON
 WIRELESS
- WiMAX
  Fixed WiMAX
  Mobile WiMAX
- WiFi
- 3G
Subdividing technologies

- **Wireless (coverage)**
  - Local hotspots
  - Full outdoor coverage
  - Full indoor coverage
- **Pylons**
- **Wireless (installation)**
  - Buildings
  - Street lampposts

Subdivide costs / revenues

- A logical division of the total costs
  - Lifecycle
    - Installation
    - Running
    - Teardown
  - CapEx vs. OpEx
  - Network vs. services
### Costs

<table>
<thead>
<tr>
<th>CapEx (depreciated)</th>
<th>OpEx</th>
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</thead>
<tbody>
<tr>
<td>Land, buildings</td>
<td>Power consumption</td>
</tr>
<tr>
<td>Passive infrastructure</td>
<td>Floor space</td>
</tr>
<tr>
<td>Equipment</td>
<td>equipment driven</td>
</tr>
<tr>
<td>Network deployment</td>
<td>Maintenance</td>
</tr>
<tr>
<td>...</td>
<td>Repair</td>
</tr>
</tbody>
</table>

**Scope**

**Subdivide problem**

**Costs/ revenues**

*Standard: eTOM*

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### Direct versus indirect costs

**Direct costs**
- Equipment
- Powering
- Activities
- ...  

**Indirect costs**
- Environmental impact
  - CO2 emissions
- Impact on employment
  - ...

*Longer term impact*
Direct versus indirect revenues

- Direct revenues
  - From subscriptions
  - Business versus residential
  - ...

- Indirect revenues
  - Benefit for community
  - Attracting more SMEs to the city/region/...
  - Positive image building for communities
  - ...

Longer term impact

enhanced Telecom Operations Map

- Standardized by TMF: ITU-T M.3050
- AB process decomposition model
  - Process model, not state model!
  - Grouping
    - Vertical: purpose of the processes
    - Horizontal: where those processes are taking place
  - Decomposition: notional level 0 to maximum of 3 levels
    - NOT the goal to address detailed processes and procedures of an enterprise
- Out of scope
  - Rainy day scenarios
  - Dynamic aspects

p. 29

p. 30
Hierarchical process architecture

- Different level of processes
  - Level 0: business activities
  - Level 1: process groupings
  - Level 2: core processes
  - Level 3: business process flows
  - Level 4: operational process flows
  - Level 5: detailed process flows

enhanced Telecom Operations Map

Customer

- Strategy, Infrastructure & Product
  - Marketing & Offer Management
  - Service Development & Management
  - Resource Development & Management (Application, Computing and Network)
  - Supply Chain Development & Management

Operations
- Operations
  - Enterprise & Enabling
  - Enterprise Risk Management
  - Enterprise Performance Management
  - Human Resources Management

- Fulfillment
- Assurance
- Billing

- Customer Relationship Management
- Service Management & Operations
- Resource Management & Operations (Application, Computing and Network)
- Supplier/Partner Relationship Management
eTOM OPS: level 0, 1, 2 processes

Scope

Subdivide problem

Costs/revenues

p. 33

eTOM SIP: level 0, 1, 2 processes

Scope

Subdivide problem

Costs/revenues

p. 34
eTOM EM: level 0, 1, 2 processes

Process input required before actual modeling starts
Different user adoption models exist
Cumulative market share: S-shaped curve

Adoption forecasting formula

\[ S(t) = m \cdot \frac{1 - e^{-(p+q)t}}{1 + \frac{q}{p} e^{-(p+q)t}} \]

- \( m \) = market potential
- \( p \) = innovation coefficient
- \( q \) = imitation coefficient
**Gompertz Adoption forecasting formula**

\[ S(t) = m \cdot e^{-b(t-a)} \]

- \( m \) = market potential
- \( a \) = inflection point (at 37% adoption)
- \( b \) = slope impacting factor

**Fisher-Pry Adoption forecasting formula**

\[ S(t) = m \cdot \frac{1}{1 + e^{-b(t-a)}} \]

- \( m \) = market potential
- \( a \) = inflection point (at 50% adoption)
- \( b \) = slope impacting factor
Fitting to the data points and choosing the best model

According to the reliability of the model
And to the reliability of the forecasts

What happens when delaying the rollout

Delay = 10y
We expect a less than linear increase in delay (e.g. word of mouth, technical evolution, etc.)

We expect a stronger take-up
Influence of momentary influences
(e.g. analog switch-off)

![Graph showing normal adoption of ADSL, 802.11b and VDSL, 802.11g with Analog switch-off push adoption in one year to the full market-potential]

Analog switch-off might push adoption in one year to the full market-potential

![Graph showing normal adoption of ADSL, VDSL, and FTTH with Analog switch-off push adoption in one year to the full market-potential]

Scope
Process
User adoption

User adoption

Normal Adoption: e.g. ADSL, 802.11b
Normal Adoption: e.g. VDSL, 802.11g

Analog Switch-off: e.g. ADSL
Analog Switch-off: e.g. VDSL, FTTH


Adoption

0% 10% 20% 30% 40% 50% 60% 70% 80% 90% 100%

Adoption

0% 10% 20% 30% 40% 50% 60% 70% 80% 90% 100%

Scope
Process
User adoption

User adoption

Normal Adoption: e.g. ADSL, 802.11b
Normal Adoption: e.g. VDSL, 802.11g

Analog Switch-off: e.g. ADSL
Analog Switch-off: e.g. VDSL, FTTH


Adoption

0% 10% 20% 30% 40% 50% 60% 70% 80% 90% 100%

Adoption

0% 10% 20% 30% 40% 50% 60% 70% 80% 90% 100%
Existing site locations for mobile/wireless networks

- Operational sites
- Sites under construction
- Construction permit requested

Source: http://www.sites.bipt.be/

p. 49

Detailed infrastructure information for mobile/wireless networks

Source: http://www.sites.bipt.be/

p. 50
Processed information map for mobile/wireless networks

Antenna locations for Brussels

Extra info per antenna:
Location, operators, types, height, power, tilt, etc.

Practical steps in techno-economic evaluation of network deployment planning

MODEL
Step 2: Model costs and revenues

Model infrastructure and processes using appropriate level of detail
Increasing level of detail

- Increase of focus
  - On the most important points
  - By detailing one part at a time

- Reducing size and complexity
  - Calculations
  - Covered area or customer base

- Zoom in on most important part
  - By further subdividing this part
  - By detailing the calculation of this part

Level of detail in the different models
Fractional cost modeling

![Cost structure diagram]

For a 10% penetration rate (subscribers / homes passed).

Source: Orange – from FTTH pilot to pre-rollout in France

Function of driver cost modeling

Examples of drivers:
- Installation length (50€/m)
- Customer base (1k €/cust)
...
→ Combinations possible
Wireless network dimensioning

Cell size calculation

- Link budget calculation
  (BS & CPE specs / antenna heights / margins / type of area / buildings)

- User density & service req.
  (required bandwidth)

- Propagation models
  (E.g. Free space, Erceg, Hata …)

  PHYSICAL RANGE

  SERVICE RANGE

  CELL SIZES

Methodology

1. Map (& reduce) all site-information (e.g. on grid)
2. Calculate range for each site installation
3. Select optimal sites for required coverage
4. Analyze the regions of overlap
Wireless network dimensioning
Existing GSM operator in Brussels

Original coverage

GSM: 71.4% cov., 409 ant.
3G: 36.9% cov., 193 ant.

Optimized solution

GSM: 96.6% cov., 367 ant.
3G: 87.7% cov., 584 ant.

Wireless network dimensioning
Greenfield dimensioning in Brussels

New GSM operator

96.8% coverage
177 antennas

New 3G operator

91.61% coverage
419 antennas
Wireless network exposure taking regulation into account

Antenna power is set above its maximum for some locations → Exceeding exposure limits

Wireless network dimensioning Bill of material

- # sites
- # base stations
- # antennas
- # sectors
- Shelter
- Backhaul connection equipment
Process based cost modeling

- Two calculation methods
  - Activity based costing (ABC)
  - Simulation based costing

Standards: BPMN, XPDL

BPMN: graphical format

- Business Process Modeling Notation
  - a standardized graphical notation for drawing business processes in a workflow
  - developed by Business Process Management Initiative (BPMI)
  - now being maintained by the Object Management Group since the two organizations merged in 2005
Core BPMN Elements

Activities from Complete BPMN Elements
Events from Complete BPMN Elements

- Start
- Intermediate
- End

Event Types:
- Message
- Timer
- Error
- Cancel
- Compensation
- Rule
- Link
- Terminate
- Multiple

Gateways from Complete BPMN Elements

- Exclusive Decision/Merge (XOR)
  - Data-Based
    - Name
  - Event-Based
- Inclusive Decision/Merge (OR)
- Complex Decision/Merge
- Parallel Fork/Join (AND)
Connections from Complete BPMN Elements

Artifacts from Complete BPMN Elements
Pools from Complete BPMN Elements

<table>
<thead>
<tr>
<th>Pool</th>
<th></th>
<th></th>
<th></th>
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<tbody>
<tr>
<td>Name</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lanes (within a Pool)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Name</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

XPDL: textual format

- XML Process Definition Language
  - XML schema
  - declarative part of workflow
- Format to interchange Business Process definitions between different workflow tools
  - exchange the process design
  - both the graphics and the semantics
    - contains coordinates -> saves graphical representation
- Standardized by the Workflow Management Coalition (WfMC)
- [http://www.wfmc.org/standards/xpdl.htm](http://www.wfmc.org/standards/xpdl.htm)
Activity-based costing

1. time frame
2. costs (actions)
3. probabilities (questions)
4. entire process cost

\[ \text{costA1} + p \cdot \text{costA2} + (1-p) \cdot \text{costA3} + \text{costA4} \]

5. total OpEx cost for network scenario

Define cost of an action

- Straightforward approach:
  \[ \text{cost of action} = \text{time needed to perform action} \times \text{wages of person taking care of it (incl. taxes)} \]

- Several employee categories involved, with wages
  - administrative personnel
  - technicians
  - engineers
  - sales people

- Total cost of personnel
  \[ = \text{wages} + \text{training} + \text{tools and transport} \]
  \[ = \text{wages} \times (1 + \text{weight factor}) \]
  weight factor per category:
  e.g. technicians need more tools than administrative personnel

p. 75

p. 76
Simulation based costing
Example: repair process simulation

Model + simulation

Manpower

Max
Average

Where will the input come from?

Top-down
Bottom-up

Approach
**Modeling approach**

**Top-Down**
- Ledger
- Costs
- Service/resource usage
- Cost per service

**Bottom-Up**
- Costs
- Service/resource usage
- Network Dimensioning
- Service Demand

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**Both approaches example for a wireless network rollout**

**BOTTOM UP**
- Greenfield Installation
- Dimensioning
  - Antennas, Housing, Operations, …

**TOP DOWN**
- Extrapolation
  - From cost and size experience
- Extending the Installation

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p. 79

p. 80
Approach versus level of detail

Level of detail
- Fractional
- Function of driver
- Dedicated dimensioning

Approach
- Top-down
- Bottom-up

Infrastructure
- Processes

Model revenues in a similar way as costs

Model
- Revenues
Direct revenues

Figure 14: Telecom services revenues in EU-25, 2001-2005

Revenue allocation for extraction of input revenues

Examples:
1. Average revenue per user
2. Average minutes per user
   1. National / International
   2. to mobile / to fixed
   3. etc.

Source: IDATE from national regulation authorities
Direct revenues

- Estimate revenues by using "simple" formulae
- Example

Subscribers x (subscription rate)
Subscribers x (avg. number of VoD / subs.)
Advertisement revenues

Revenues for IPTV service

Pricing
Practical steps in techno-economic evaluation of network deployment planning

**EVALUATE**

**Step 3: Evaluate the project**

- **Scope**
- **Model**
- **Refine**

- **Evaluate**
  - Value network analysis
  - Investment analysis

p. 88
Present value of future cash flows

\[ C = \frac{F}{(1+i)^n} \]

where
- \( C \) = current value
- \( F \) = future expense
- \( r \) = rate of return (discount rate)
- \( n \) = years into the future

Current value of 100 euro to be spent in the future

<table>
<thead>
<tr>
<th>Year</th>
<th>Value</th>
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<tbody>
<tr>
<td>Now</td>
<td>100</td>
</tr>
<tr>
<td>Year 1</td>
<td>110.5</td>
</tr>
<tr>
<td>Year 2</td>
<td>122.05</td>
</tr>
<tr>
<td>Year 3</td>
<td>134.28</td>
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<tr>
<td>Year 4</td>
<td>147.75</td>
</tr>
<tr>
<td>Year 5</td>
<td>162.47</td>
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</table>

Defining Rate of Return

Capital Asset Pricing Model (CAPM)

\[ E(R_i) = R_f + \beta_{im} (E(R_m) - R_f) \]

where
- \( E(R_i) \) = expected return on the capital asset
- \( R_f \) = risk-free rate of interest
- \( \beta_{im} \) = sensitivity of the asset returns to market returns
- \( R_m \) = expected return of the market
- \( E(R_m) - R_f \) = the market premium or risk premium

In telecom, rate of return varies between 10% and 20%
Investment decisions

Cash flows used:
- Incremental, operational, after taxes, economical lifetime

Initial investment: buy a machine
Annual revenue: sell produced goods
End of the project: resell the machine

Investment analysis for static case uses traditional techniques

Evaluate
- Payback
- ROI
- NPV
- IRR
**Payback time**

- Payback time = time needed to pay back initial investment

<table>
<thead>
<tr>
<th>Year</th>
<th>Amount</th>
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<tbody>
<tr>
<td>2004</td>
<td>-200</td>
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<tr>
<td>2005</td>
<td>+40</td>
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<tr>
<td>2006</td>
<td>+40</td>
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<tr>
<td>2007</td>
<td>+40</td>
</tr>
<tr>
<td>2008</td>
<td>+40</td>
</tr>
<tr>
<td>2009</td>
<td>+60</td>
</tr>
<tr>
<td>2010</td>
<td>+0</td>
</tr>
</tbody>
</table>

Payback time = 4.66 years

- **Obj.** Payback time <= Maximum accepted payback time
- Indicates risk: shorter payback time = smaller risk
- Easy to use
- Does not take into account CFs after payback period

**Return On Investment (ROI)**

- Return on investment = ROI = \[ \frac{\text{average future annual cash flow}}{\text{initial investment (average over economic lifetime of project)}} \]

- **Obj.** ROI >= minimum required ROI
- Takes into account CFs after payback time
- Takes into account size of the project (size of cash flows)
- Does not take into account timing of CFs
Net Present Value (NPV)

- Present value of all cash flows in the investment project, discounted using the minimum required return on investment

\[ NPV = \sum_{t=0}^{n} \frac{CF_t}{(1 + r)^t} \]

**Obj.**
- NPV \(\geq 0\)
- Takes into account all CFs
- Takes into account timing
- Takes into account size of the project (size of cash flows)

**-**
- Dependent on considered lifetime (t)
- Does not penalize huge intermediate losses

Internal Rate of Return (IRR)

- Internal rate of return = discount ratio for which present value of expenses equals present value of revenues

\[ \sum_{t=0}^{n} \frac{CF_t}{(1 + IRR)^t} = 0 \]

**Obj.**
- IRR \(\geq\) required minimum
- Takes into account all CFs
- Takes into account timing of CFs (time value)

**+**
- Does not take into account size of the project
- Problems
- Multiple rates of return in case CFs exhibits 2 changes of sign
- Mutually exclusive projects (NPV and IRR give opposite advice)

p. 95

p. 96
NPV compared to IRR

- Two mutually exclusive projects
  
<table>
<thead>
<tr>
<th>CF0</th>
<th>CF1</th>
<th>NPV (r=0)</th>
<th>IRR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small budget</td>
<td>-1 euro</td>
<td>1.5 euro</td>
<td>0.5 euro</td>
</tr>
<tr>
<td>Large budget</td>
<td>-10 euro</td>
<td>11 euro</td>
<td>1 euro</td>
</tr>
</tbody>
</table>

- NPV ≠ IRR

- Explanation: incremental IRR
  - small budget project is beneficial
  - beneficial to invest additionally?

<table>
<thead>
<tr>
<th>CF0</th>
<th>CF1</th>
<th>NPV (r=0)</th>
<th>IRR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Large budget instead of small budget</td>
<td>-10 – (-1) = -9 euro</td>
<td>11-1.5 = 9.5 euro</td>
<td>0.5 euro</td>
</tr>
</tbody>
</table>

⇒ follow NPV

Comparing two projects using multiple methods

- Payback period
- NPV at y7 & y10
- Lifetime important
**Value network analysis**

adds quantitative results to business model

- **Basic model with a lot of cash flows between actors**
- Suited for successful business cases, but can be very risky for projects requiring high investments

**Integrator model**

- Integrator makes deals with a lot of actors in the field
- Project lead by the integrator who shares in the profits

**Consortium model**

- A lot of costs can be saved
- Negotiation needed for revenue allocation, depending on the considered investment efforts from each party
Value network analysis for a wireless network

Cost savings + revenue sharing ⇒ BC changes!

Local Government

National Regulator

Network Operator

Content Provider

Site provis.

Licensing

Repair

Content

Netw. Rollout

Netw. Operations

Service provis.

Netw. Monitoring

Sales & Billing

Vendor

Netw. Equip.

Netw. Planning

ISP

Internet Conn.

Backhaul Conn.

Outsourced

Customer relations

ISP

Helpdesk

Consortium

Outsourcing

External cash flow

Internal cash flow

Value network analysis

Money flows

Money flows

p. 101

p. 102
When different services, firms or ... share part of their costs..

Services, Firms, ...

Cost

A B C

Direct

Shared

Common

Evaluate Value Services, Firms, ...

Cost allocation

Value network analysis

p. 103

..it is often necessary or useful to know which part of the cost is linked to which service

Services, Firms, ...

Cost

A B C

Direct

Shared

Common

Evaluate Value Services, Firms, ...

Cost allocation

Value network analysis

p. 104
Stand Alone Cost allocates as a stand-alone installation

Services, Firms, ...

<table>
<thead>
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<th>A</th>
<th>B</th>
<th>C</th>
<th>SAC</th>
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<tbody>
<tr>
<td>Direct</td>
<td></td>
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</tr>
<tr>
<td>Shared</td>
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<td></td>
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</tr>
<tr>
<td>Common</td>
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p. 105

Stand Alone Cost allocates as a stand-alone installation

Services, Firms, ...

<table>
<thead>
<tr>
<th>Cost</th>
<th>A</th>
<th>B</th>
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<td>Direct</td>
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<td>Shared</td>
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<tr>
<td>Fixed</td>
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<tr>
<td>Common</td>
<td>Variable</td>
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<tr>
<td>Fixed</td>
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<td></td>
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</tr>
</tbody>
</table>

p. 106
**Fully Allocated Cost**
allocates the costs more “fairly”

<table>
<thead>
<tr>
<th>Cost</th>
<th>A</th>
<th>B</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Direct</td>
<td></td>
<td></td>
<td>FAC</td>
</tr>
<tr>
<td>Shared</td>
<td>Variable</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Fixed</td>
<td></td>
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</tr>
<tr>
<td>Common</td>
<td>Variable</td>
<td></td>
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</tr>
<tr>
<td></td>
<td>Fixed</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

p. 107

---

**Long Run Incremental Cost**
allocates only the incremental costs

<table>
<thead>
<tr>
<th>Cost</th>
<th>A</th>
<th>B</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Direct</td>
<td></td>
<td></td>
<td>LRIC</td>
</tr>
<tr>
<td>Shared</td>
<td>Variable</td>
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<tr>
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<td>Fixed</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Common</td>
<td>Variable</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Fixed</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

p. 108
Long Run Incremental Cost allocates only the incremental costs

<table>
<thead>
<tr>
<th>Cost</th>
<th>A</th>
<th>B</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Direct</td>
<td></td>
<td></td>
<td>blue</td>
</tr>
<tr>
<td>Shared</td>
<td>VARIABLE</td>
<td></td>
<td>blue</td>
</tr>
<tr>
<td></td>
<td>FIXED</td>
<td></td>
<td></td>
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<tr>
<td>Common</td>
<td>VARIABLE</td>
<td></td>
<td>blue</td>
</tr>
<tr>
<td></td>
<td>FIXED</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Economies of scale and scope

Sunk Costs

An overview from highest to lowest allocated cost

<table>
<thead>
<tr>
<th>cost</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>A</th>
<th>B</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Direct Variable</td>
<td></td>
<td></td>
<td>blue</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Direct Fixed</td>
<td></td>
<td></td>
<td>blue</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shared Variable</td>
<td></td>
<td></td>
<td>blue</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shared Fixed</td>
<td></td>
<td></td>
<td>blue</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
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<td>Common Variable</td>
<td></td>
<td></td>
<td>blue</td>
<td></td>
<td></td>
<td></td>
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<td></td>
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</tr>
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<td></td>
<td></td>
<td>blue</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

ECONOMIES OF SCALE AND SCOPE

SUNK COSTS
Cost allocation example for a data center

- **Direct Variable**: Maintenance, replacement, extensions, etc.
- **Direct Fixed**: Specific software and hardware, installation, etc.
- **Shared Variable**: Servers installed, software-licenses, etc.
- **Shared Fixed**: Telecom cabling and equipment, Backbone connection, etc.
- **Common Variable**: Powering, cooling, etc.
- **Common Fixed**: Housing, management, licenses, etc.

Practical steps in techno-economic evaluation of network deployment planning

**REFINE**
Step 4: Refine the results

Sensitivity analysis indicates impact of uncertainty
Sensitivity analysis

- Problem: a lot of uncertain input parameters
  - Adoption parameters (end adopt., adopt. speed)
  - Cost parameters (CapEx, OpEx)
  - Revenue parameters (optimal tariff)
- Goal: determining the impact of these parameters
  - Discarding the parameters with a marginal impact
  - Giving extra attention to the important parameters

Basic sensitivity analysis

- Varying one parameter at a time
- Holding the other parameters fixed
  ⇒ First indication of the impact of each of the input parameters
- Much-used measure for this impact
  - Normalized contribution $p_j$ of each parameter $j$ to the variance $\sigma_j^2$ of the outcome

\[
p_j = \frac{\sigma_j^2}{\sum_{j=1}^{m} \sigma_j^2} = \frac{\frac{1}{n} \sum_{i=1}^{n} (x_{ij} - \mu)^2}{\sum_{j=1}^{m} \left( \frac{1}{n} \sum_{i=1}^{n} (x_{ij} - \mu)^2 \right)} = \frac{\sum_{i=1}^{n} (x_{ij} - \mu)^2}{\sum_{j=1}^{m} \sum_{i=1}^{n} (x_{ij} - \mu)^2}
\]
Basic sensitivity analysis
Example: FTTH network

Sensitivity by Monte Carlo simulations
based on probability for uncertainties

<table>
<thead>
<tr>
<th>Triangular</th>
<th>Gaussian</th>
<th>Uniform</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum: 0.90</td>
<td>Mean: 1.00</td>
<td>Minimum: 0.90</td>
</tr>
<tr>
<td>Likeliest: 1.00</td>
<td>Std. Dev.: 0.10</td>
<td>Maximum: 1.10</td>
</tr>
<tr>
<td>Maximum: 1.10</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Sensitivity by Monte Carlo simulations

Points of attention

- Questions:
  - Which is the most-suited distribution?
  - Over which range are the parameters varied?

- Possible sources of information
  - Information from historical data
    - Stock information on vendors
    - Cost-erosion figures
  - Information from fitting reliability
    - e.g. deviation from optimal fitting to a fitting over first 50% of the data-points
  - Commonly used example (“benchmark”)
    - Gaussian, standard deviation = 10% (compared to mean value)
    - Can be refined by adapting some distributions in a next step

Possible sources of information:

- Information from historical data
  - Stock information on vendors
  - Cost-erosion figures
- Information from fitting reliability
  - e.g. deviation from optimal fitting to a fitting over first 50% of the data-points
- Commonly used example (“benchmark”)
  - Gaussian, standard deviation = 10% (compared to mean value)
  - Can be refined by adapting some distributions in a next step

Most interesting results

- Impact of uncertain parameters on the outcome (e.g. normalized contribution of each parameter to the variance of the outcome)
- Forecast of the outcome distribution
- Multi-year trend analysis of the outcome

E.g.: NPV forecast for an FTTH rollout considering different business models
Real options allow to value flexibility to react to uncertainty

Real options as an extension of NPV

- Weak aspect of NPV evaluation
  - Assumes strict planning, with no flexibility

- Real projects
  - Anticipate on changing market circumstances

- Solution: “real options thinking” principle
Origin: financial options

An option gives the buyer
the right to buy or sell
an asset
for a predetermined exercise price
over a limited time period.

Value of call option on exercise date

\[ S = \text{value share on exercise date} \]
**Value of call option on exercise date**

- Call option = right to buy (a stock)
  - Predetermined exercise price: X
  - Market value of the stock on exercise date: S

- On exercise date
  - MAX (0, S-X)
  - Always positive value

- Value of option = end value + time value
  - End value = value if today was exercise date
  - Time value
    - Grows with a growing time to maturity
    - Grows with volatility of share value
    - Small when difference between S and X is big

---

**Financial versus real options**

<table>
<thead>
<tr>
<th>Stock option</th>
<th>Real option</th>
</tr>
</thead>
<tbody>
<tr>
<td>( X ) exercise price of the option</td>
<td>investments required to carry out the project</td>
</tr>
<tr>
<td>( S ) value of the underlying stock</td>
<td>NPV of the cash flows generated by the investment project</td>
</tr>
<tr>
<td>( \sigma ) volatility of the stock</td>
<td>risk grade of the project</td>
</tr>
<tr>
<td>( r ) the risk-free interest rate</td>
<td>risk-free interest rate</td>
</tr>
<tr>
<td>( t ) life time of the option</td>
<td>time period where company has the opportunity to invest in the project</td>
</tr>
</tbody>
</table>
### Types of options: 7S framework

<table>
<thead>
<tr>
<th>Real Option Category</th>
<th>Real Option Type</th>
<th>Description</th>
<th>Telco examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Invest/ grow</td>
<td>Scale up</td>
<td>Cost-effective sequential investments as market grows</td>
<td>Expand area of wireless coverage from cities to semi-urban areas</td>
</tr>
<tr>
<td></td>
<td>Switch up</td>
<td>Switch products given a shift in underlying price/demand</td>
<td>Start offering dedicated wavelengths using DWDM in case of equipment price drops</td>
</tr>
<tr>
<td></td>
<td>Scope up</td>
<td>Enter another industry cost-effectively</td>
<td>Start offering IPTV next to Internet connectivity</td>
</tr>
<tr>
<td>Defer/ learn</td>
<td>Study/start</td>
<td>Delay investment until more info/skill is acquired</td>
<td>Wait till competitor strategy is more clear</td>
</tr>
<tr>
<td>Disinvest/ shrink</td>
<td>Scale down</td>
<td>Shrink or shut down project as new info changes expected payoffs</td>
<td>Abandon one region if competitor drops prices there</td>
</tr>
<tr>
<td></td>
<td>Switch down</td>
<td>Switch to more cost-effective and flexible assets as new info is obtained</td>
<td>Lease wavelengths instead of dark fiber in some regions of lower demand</td>
</tr>
<tr>
<td></td>
<td>Scope down</td>
<td>Abandon operations in related industry if there is no further potential</td>
<td>Stop offering hot spot services if market does not take off</td>
</tr>
</tbody>
</table>

"For European call option
Assumes 2 possible end values

\[ S \rightarrow U \]

\[ S \rightarrow D \]

Can be expanded for more time periods: software needed
Option valuation: Black and Scholes

- **Formula for European call option**

\[
C = N(d_1)S - Xe^{-rt}N(d_2)
\]

- **Assumptions**
  - Arbitrage-free pricing: financial transactions that make immediate profit without any risk do not exist.
  - Stock prices $S$ follow Brownian motion (random walk).

\[
d_1 = \frac{\ln(S/X) + rt - \sigma^2 t / 2}{\sigma \sqrt{t}}
\]

\[
d_2 = \frac{\ln(S/X) + rt - \sigma^2 t / 2}{\sigma \sqrt{t}}
\]

$N(d) =$ cumulative normal distribution
$X =$ exercise price of the option
$S =$ current value of the share
$\sigma^2 =$ variance of the return of the share per time period
$r =$ risk free interest rate

Option valuation: simulation

- Introduces a flexible planning in the calculations.
- Applicable on any type of option.
- Start from description of static case (pre-defined planning):
  - Indicate uncertainty.
  - Indicate flexibility.
- Choose a “decision variable” to adapt the planning:
  - Evaluation parameters (e.g. NPV, IRR, payback time).
  - Uncertain input parameters (e.g. take rate, investment costs).

\[dS = \mu S dt + \sigma S dw\]
Option valuation: Example

- Deploying parking sensor network in a city
  - Two zones
  - Uncertainty factors:
    - Future chance of getting caught
    - Sensor failure
    - ...
- Starting small or large?
  - Low vs. high investment?
  - Low vs. high payoff?
- Base case:
  - NPV calculation

Base case: starting small or large?

**NPV**

- Total rollout
  - High increase in chance of getting caught (30%)
    - $50,000 + $150,000 = €200,000
  - Low increase in chance of getting caught (60%)
    - $30,000 + $150,000 = €180,000
  - No increase in chance of getting caught (20%)
    - $10,000 + $150,000 = €160,000

- No rollout
  - High increase in chance of getting caught (30%)
    - $50,000
  - Low increase in chance of getting caught (60%)
    - $30,000
  - No increase in chance of getting caught (20%)
    - $10,000
Base case: starting small or large?

- Base case:
  - Choose the total rollout

- Option to expand:
  - Start of small, evaluate expansion next year
  - Expansion means extra investment
  - Delayed expansion = missed payoffs
  - New NPV calculation

p. 133
Base case: starting small or large?

- Now choose small rollout with expansion option
- Value expansion option:
  - Value small rollout with option – total rollout without option
  - €550,000 - €500,000
  - €50,000

Option valuation: simulation
Example: flexible rollout scheme, method

- Rollout of a Parking Sensor Network
  - Project of 6 years
  - Year 0: rollout in zone 1
  - Flexibility: year of zone 2 rollout
  - Fast, normal and slow rollout speed
Option valuation: simulation
Example: flexible rollout scheme, method

**Simulation**

- **Implement uncertainty**
  - Distribution standard NPV
  - Mean = 7.52 million

- **Implement flexibility**
  - Choose best case
    - NPV = MAX(slow, normal, fast)
  - Mean = 7.72 million

**NPV evolution**

- Normal rollout
- Fast rollout
- Slow rollout

**Distribution NPV Standard**

<table>
<thead>
<tr>
<th>Millions</th>
<th>4.00M</th>
<th>4.50M</th>
<th>5.00M</th>
<th>5.50M</th>
</tr>
</thead>
<tbody>
<tr>
<td>Count</td>
<td>40</td>
<td>60</td>
<td>80</td>
<td>100</td>
</tr>
</tbody>
</table>

**Distribution NPV Options**

<table>
<thead>
<tr>
<th>Millions</th>
<th>4.00M</th>
<th>4.50M</th>
<th>5.00M</th>
<th>5.50M</th>
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</thead>
<tbody>
<tr>
<td>Count</td>
<td>40</td>
<td>60</td>
<td>80</td>
<td>100</td>
</tr>
</tbody>
</table>

p. 137
Game theory models competition between different players

Game theory

Type of games

Solving a game

Game theory

Refine

Game theory is a discipline aimed at modeling situations in which decision makers have to make specific actions that have mutual, possibly conflicting, consequences.
**Game theory**

1. **Modeling**
   Not real – but realistic model of interaction

2. **Decision makers**
   Any number of so-called “players” (though often 2)
   e.g. Operators, Vendors, Regulators, Customers, etc.

3. **Specific actions**
   Each player has dedicated actions (not the same)
   e.g.: Start or cease rollout, buyout competitor, ...

4. **Mutual**
   Combined calculation model with interaction of players
   e.g.: competition for adoption, effects of EOS, etc.

5. **Possibly conflicting**
   Competitive and cooperative actions
   Final goal = optimize own utility within the game

6. **Consequences**
   Utility or payoff: valuation of the profit of each player
   e.g.: NPV, customer perceived value, cooperative profits, etc.

---

**Game theory comes in many different flavors**

- Cooperative ↔ Non Cooperative
- Symmetric ↔ Asymmetric
- Zero sum ↔ Non Zero Sum
- Simultaneous ↔ Sequential
- Perfect information ↔ Non Perfect
  Information
- Infinite ↔ Finite
- Discrete ↔ Continuous
- Static ↔ Multi-stage
- Meta Games

---

p. 141

---

p. 142
Visualization of a game theoretic model

Normal Form

Extensive

<table>
<thead>
<tr>
<th>A1</th>
<th>A2</th>
<th>A3</th>
</tr>
</thead>
<tbody>
<tr>
<td>B1</td>
<td>1,0</td>
<td>1,2</td>
</tr>
<tr>
<td>B2</td>
<td>0,3</td>
<td>0,1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>A1</th>
<th>A2</th>
<th>A3</th>
</tr>
</thead>
<tbody>
<tr>
<td>B1</td>
<td>1,0</td>
<td>1,2</td>
</tr>
<tr>
<td>B2</td>
<td>0,3</td>
<td>0,1</td>
</tr>
</tbody>
</table>

Imperfect information
Player B does not know what player 1 has done

p. 143

p. 144
Approaches towards finding an equilibrium

Nash equilibrium
no player can gain by changing unilaterally his strategy

Iterated dominance
Dominance: strategy better than another strategy independent of opponents
Iterated: iteratively removing dominated strategies

Backward induction
Cut unrealistic branches from a multi-stage game tree moving in a recursive manner from the latest action to the first action

Example of iterated dominance

Normal Form

\[
\begin{array}{ccc}
A1 & A2 & A3 \\
B1 & 1,0 & 1,2 & 0,1 \\
B2 & 0,3 & 0,1 & 2,0 \\
\end{array}
\]

Extensive Form

\[
\begin{array}{c}
A1 \\
B1 \\
B2 \\
\end{array}
\begin{array}{c}
A2 \\
B1 \\
B2 \\
\end{array}
\begin{array}{c}
A3 \\
B1 \\
B2 \\
\end{array}
\]

\[
\begin{array}{c}
1,0 \\
0,3 \\
0,1 \\
1,2 \\
0,1 \\
2,0 \\
\end{array}
\]

p. 146
Iterated dominance (normal form)
Backward induction (extensive form)

Normal Form

Extensive Form

Market for wireless network deployment

p. 147

p. 148
Result (NPV) = Revenues - Costs

Player 1 increases his price

For more details, refer to pages 149 and 150.
Results (NPV) for the different scenarios
(original [i,a] & higher price p1 [ii,b])

Full matrix for both players strategies

<table>
<thead>
<tr>
<th>Player 1</th>
<th>Low</th>
<th>High</th>
<th>...</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>i</td>
<td>a</td>
<td></td>
</tr>
<tr>
<td>Low</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>ii</td>
<td>b</td>
<td></td>
</tr>
<tr>
<td>High</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

p. 151

p. 152
### Playing the realistic game (iterated dominance), for two competing wireless access networks

NPVs (M€) for different service prices: 1st iteration

<table>
<thead>
<tr>
<th>Price (€)</th>
<th>Player 1: WiFi</th>
<th>Player 2: 3G femtocells</th>
</tr>
</thead>
<tbody>
<tr>
<td>22</td>
<td>2.467 1.369 2.505 1.387 2.600 1.455 2.701 1.368 2.891 1.294</td>
<td><strong>No play</strong></td>
</tr>
<tr>
<td>23</td>
<td>2.482 1.404 2.600 1.488 2.722 1.468 2.834 1.437 2.935 1.377</td>
<td><strong>No play</strong></td>
</tr>
<tr>
<td>24</td>
<td>2.512 1.554 2.646 1.585 2.749 1.577 2.865 1.532 2.979 1.539</td>
<td><strong>No play</strong></td>
</tr>
<tr>
<td>25</td>
<td>2.507 1.557 2.636 1.679 2.773 1.683 2.906 1.650 3.021 1.507</td>
<td><strong>No play</strong></td>
</tr>
<tr>
<td>26</td>
<td>2.479 1.709 2.627 1.771 2.771 1.785 2.899 1.764 3.035 1.704</td>
<td><strong>No play</strong></td>
</tr>
</tbody>
</table>

#### 3G femto: NPV 2_22 < NPV 2_23 & NPV 2_26 < NPV 2_25

#### WiFi: NPV 1_22,23 < NPV 1_24

---

### Playing the realistic game (iterated dominance), for two competing wireless access networks

After 2nd iteration ➔ example with 2 Nash Equilibria

<table>
<thead>
<tr>
<th>Price (€)</th>
<th>Player 1: WiFi</th>
<th>Player 2: 3G femtocells</th>
</tr>
</thead>
<tbody>
<tr>
<td>22</td>
<td></td>
<td><strong>No play</strong></td>
</tr>
<tr>
<td>23</td>
<td></td>
<td><strong>No play</strong></td>
</tr>
<tr>
<td>24</td>
<td>2.646 1.585 2.749 1.577 2.865 1.532</td>
<td><strong>No play</strong></td>
</tr>
<tr>
<td>25</td>
<td>2.636 1.679 2.773 1.683 2.906 1.650</td>
<td><strong>No play</strong></td>
</tr>
<tr>
<td>26</td>
<td>2.527 1.771 2.771 1.785 2.899 1.764</td>
<td><strong>No play</strong></td>
</tr>
</tbody>
</table>

#### 3G femto: NPV 2_25 < NPV 2_24

#### WiFi: NPV 1_26 < NPV 1_25
Practical steps in techno-economic evaluation of network deployment planning

TOOL OVERVIEW

Tools for infrastructure & cost modeling

<table>
<thead>
<tr>
<th>Toolkit</th>
<th>application</th>
<th>license</th>
</tr>
</thead>
<tbody>
<tr>
<td>OPNET</td>
<td>Network planning and (cost-effective) optimization</td>
<td>Academic ed. Commercial</td>
</tr>
<tr>
<td>SP Guru / IT Guru</td>
<td></td>
<td></td>
</tr>
<tr>
<td>VPI</td>
<td>Network design &amp; planning Economic analysis</td>
<td>Commercial</td>
</tr>
<tr>
<td>OnePlan</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TONIC</td>
<td>Techno-economic tool Spreadsheet based Including a cost database</td>
<td>Negotiation with IST-FP5 TONIC partners</td>
</tr>
</tbody>
</table>
## Tools for process modeling

<table>
<thead>
<tr>
<th>Toolkit</th>
<th>BPMN</th>
<th>XPDL</th>
<th>license</th>
</tr>
</thead>
<tbody>
<tr>
<td>CaseWise</td>
<td>As an extension</td>
<td>As an extension</td>
<td>Commercial, Free for TMForum members</td>
</tr>
<tr>
<td>Mega: MegaProcess</td>
<td>yes</td>
<td>yes</td>
<td>Commercial</td>
</tr>
<tr>
<td>IDS Scheer: ARIS</td>
<td>yes</td>
<td>yes</td>
<td>Commercial</td>
</tr>
<tr>
<td>MS Visio</td>
<td>yes</td>
<td>no</td>
<td>Commercial</td>
</tr>
<tr>
<td>Tibco business studio</td>
<td>yes</td>
<td>yes</td>
<td>Free</td>
</tr>
</tbody>
</table>

## Tools for process simulation

<table>
<thead>
<tr>
<th>Toolkit</th>
<th>Graphical modeling</th>
<th>Open Source</th>
<th>License</th>
</tr>
</thead>
<tbody>
<tr>
<td>GPSS</td>
<td>No</td>
<td>No</td>
<td>Free limited ed. Commercial</td>
</tr>
<tr>
<td>VenSim (including M-Wave model)</td>
<td>Yes</td>
<td>No</td>
<td>Free limited ed. Commercial</td>
</tr>
<tr>
<td>SimJava</td>
<td>No</td>
<td>Yes</td>
<td>Free</td>
</tr>
<tr>
<td>Ptolemy II</td>
<td>Yes</td>
<td>Yes</td>
<td>Free</td>
</tr>
</tbody>
</table>
### Tools used within refinement

<table>
<thead>
<tr>
<th>Toolkit</th>
<th>Type</th>
<th>Open Source</th>
<th>License</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gambit</td>
<td>Game theory</td>
<td>Yes</td>
<td>Free</td>
</tr>
<tr>
<td>Jannealer</td>
<td>Optimization by means of Simulated annealing</td>
<td>Yes</td>
<td>Free</td>
</tr>
<tr>
<td>Linear programming tools</td>
<td>Integer Linear Programming</td>
<td>Typically not</td>
<td>Commercial</td>
</tr>
<tr>
<td>Crystal Ball</td>
<td>Sensitivity analysis and RO by simulation</td>
<td>No</td>
<td>Commercial</td>
</tr>
</tbody>
</table>

**Summary and Conclusions**

Practical steps in techno-economic evaluation of network deployment planning
Practical steps in network deployment planning

- Overview different steps
- Models to be used

- Overall picture is important
  - Techno-economics: not only technology
  - Know impact of certain part in overall costs/revenues

- Choose required level of detail for the different parts
  - Focus on main cost driving aspects first
  - Don’t get lost in detail

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Scope

Strategic network deployment

Refine

Evaluate

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Scope

Subdivide problem

Collect input

Process input

Refine

Game theory

Real options

Sensitivity analysis

Evaluate

Investment analysis

Value network analysis

Model

Processes

Revenues

Infrastructure

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p. 161

p. 162
Practical steps in techno-economic evaluation of network deployment planning

REFERENCES

Major References

**Scope**

Major References

Model


Evaluate

Major References


Thanks for your attention!
Any questions?

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http://www.ibcn.intec.ugent.be/te/

Check out our white paper as well