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FACULTEIT INGENIEURSWETENSCHAPPEN

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

Sofie Verbrugge

Koen Casier

Jan Van Ooteghem

Bart Lannoo

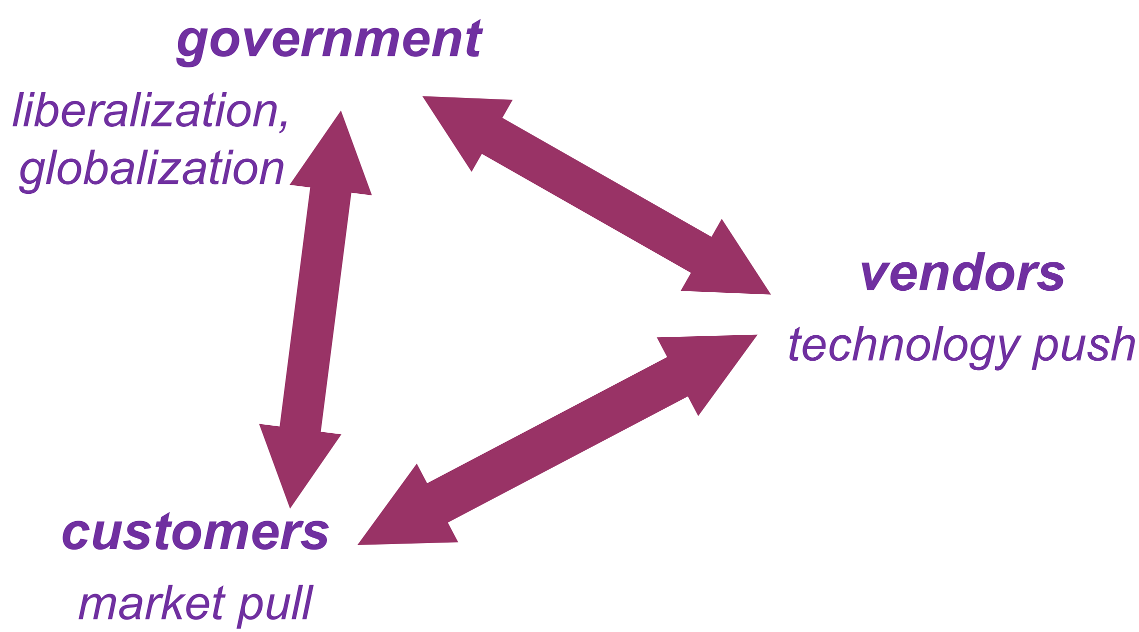
INTEC

IBCN intec broadband communication networks

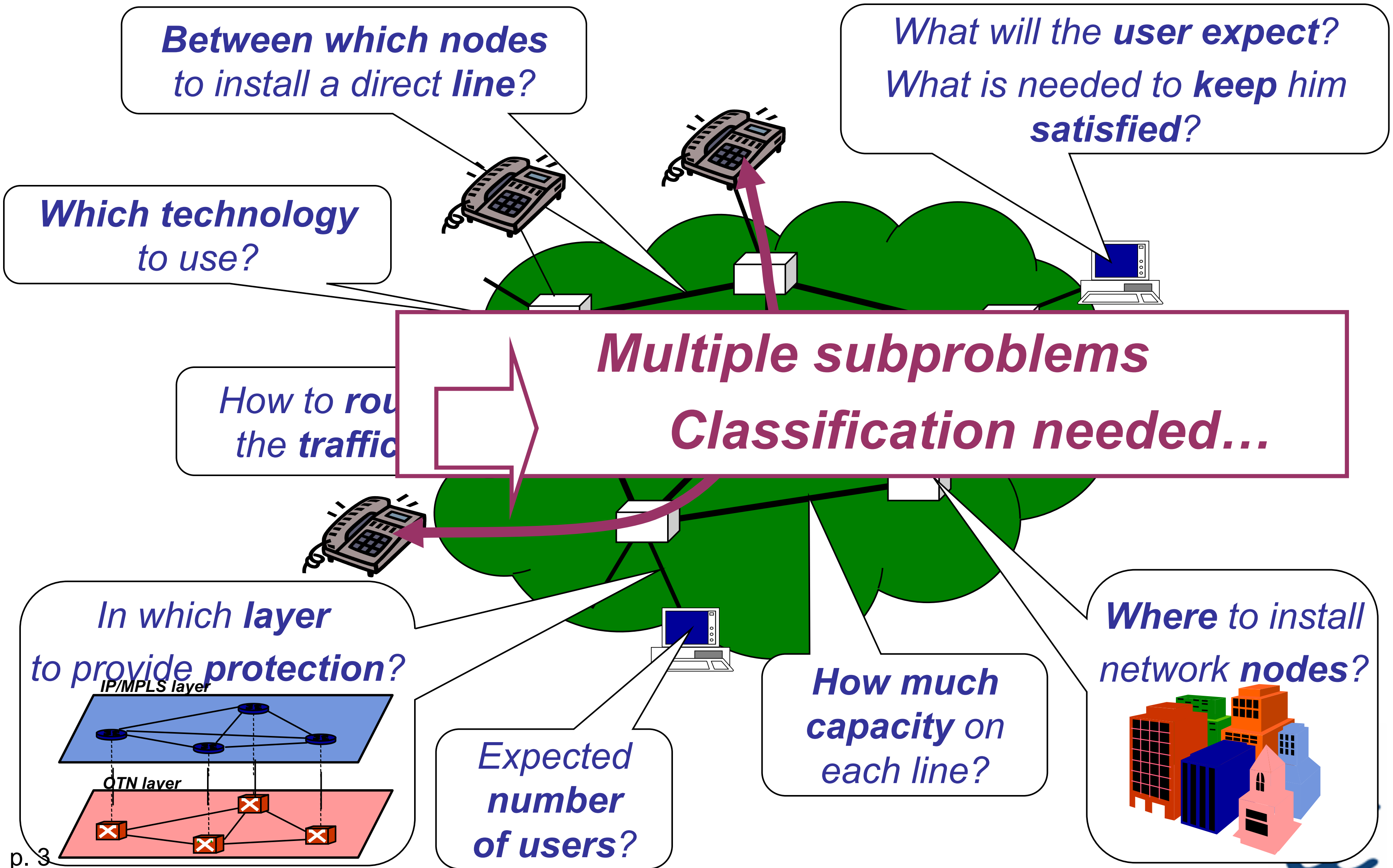
IBBT

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



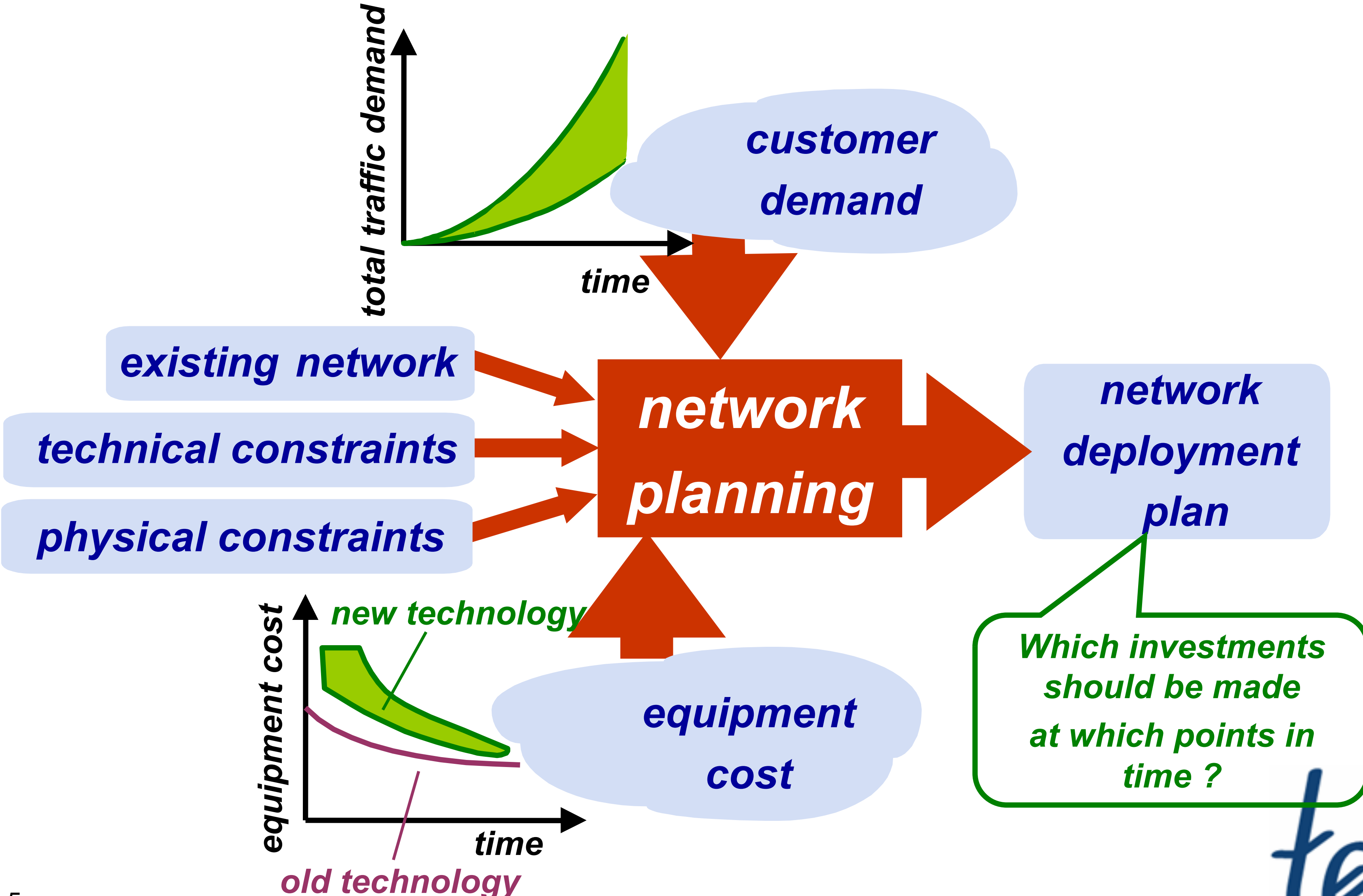
Network planning problem contains many subproblems



Time scale dictates classification

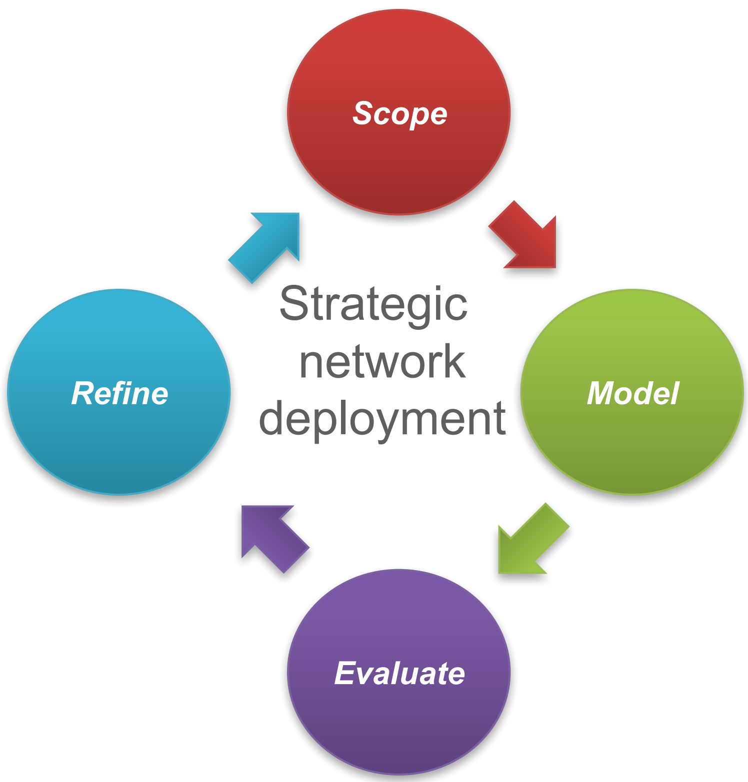
	STP	MTP	LTP
	operational	*tactical*	*strategic*
Planning horizon	*weeks*	*months … 1 year*	*up to 5 years*
Uncertainty of planning environment	*low*	*intermediate*	*high*
Geographical scope of planning decisions	*local*	*subnetwork*	*network-wide*
Relative influence of individual decisions on cash flows	*minor*	*medium*	*major*
	e.g. configuration, monitoring	*e.g.* dimensioning, routing	*e.g.* network topology, technology choice

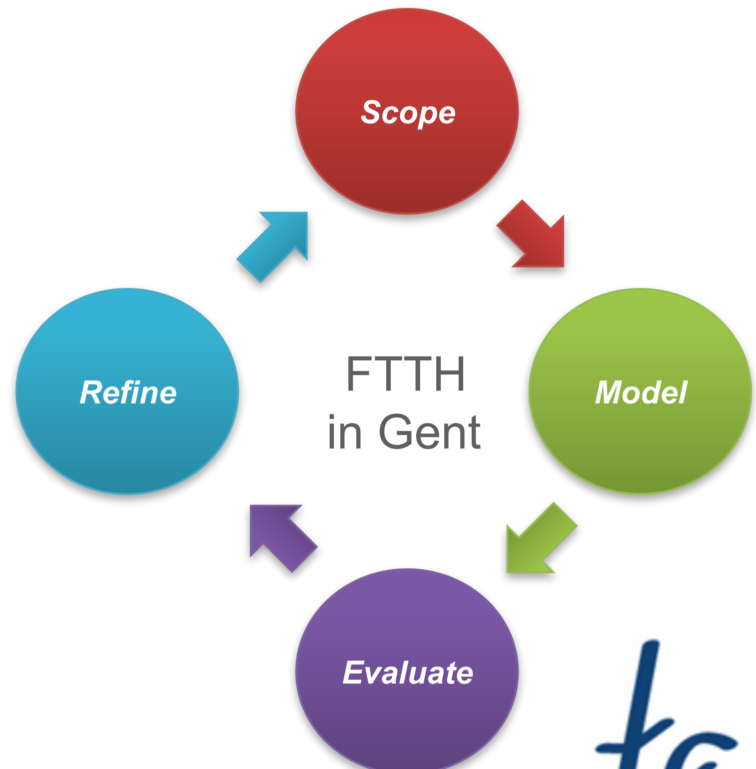
Strategic network planning process



Goal of this tutorial

- Before the break
  - Overview different steps
  - Models to be used
- After the break
  - Reference case
  - Tools Demo

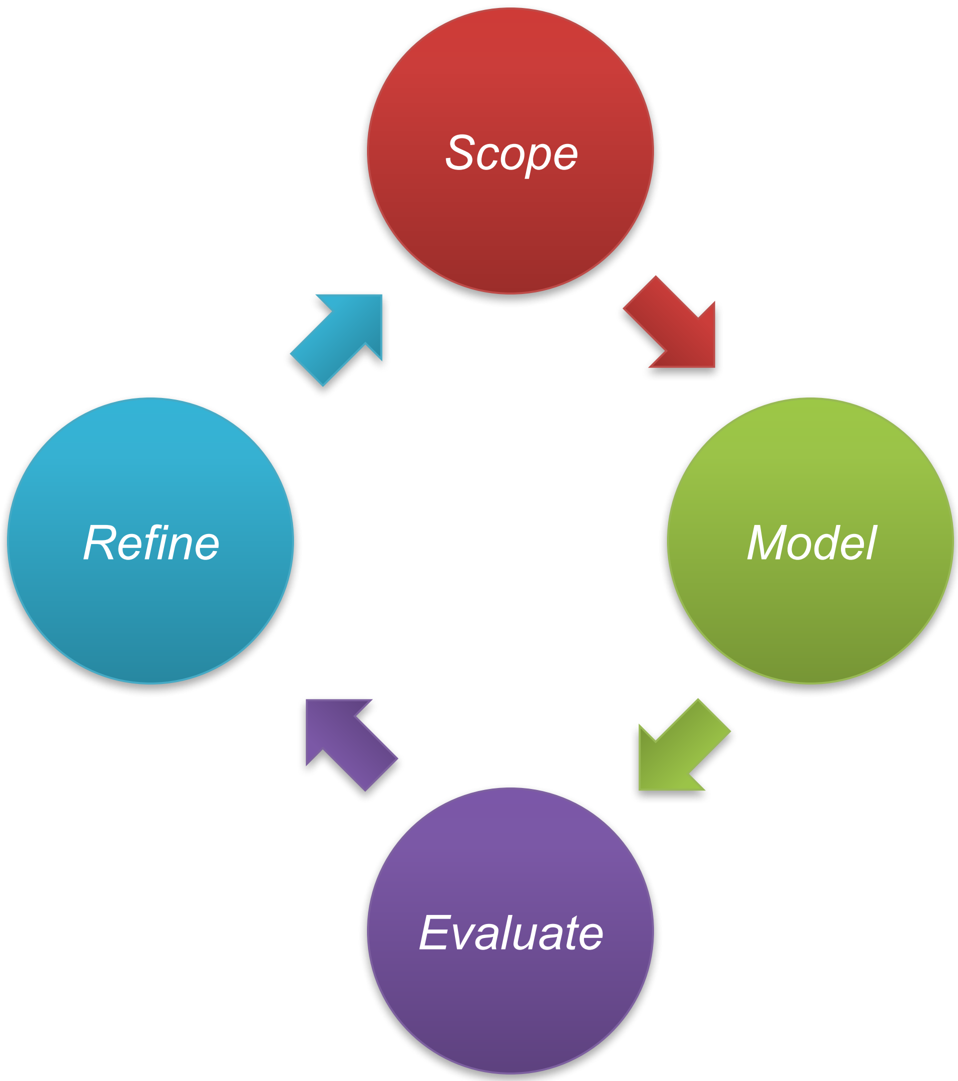


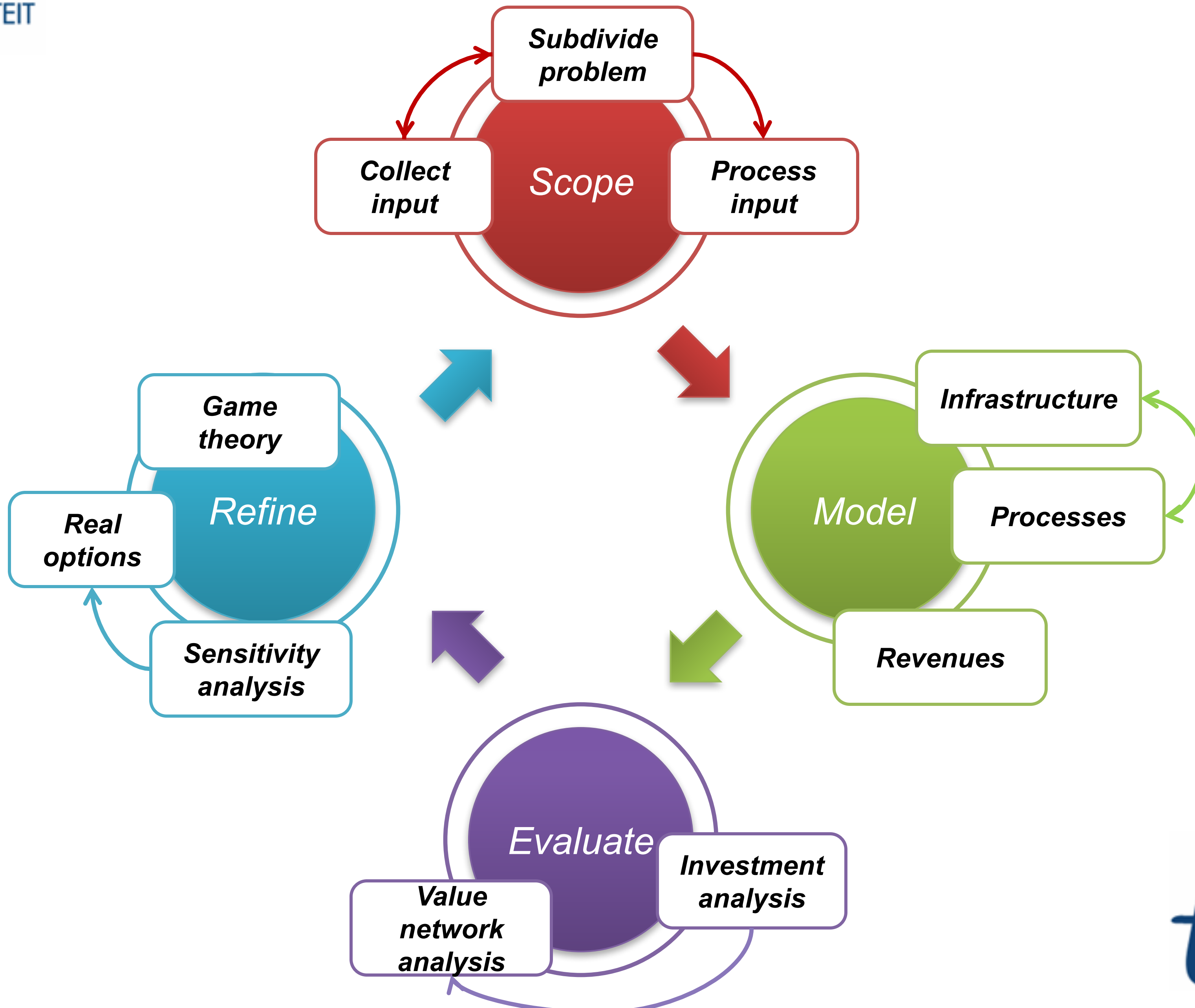


Practical steps in techno-economic evaluation of network deployment planning

GENERAL METHODOLOGY OVERVIEW

Methodology

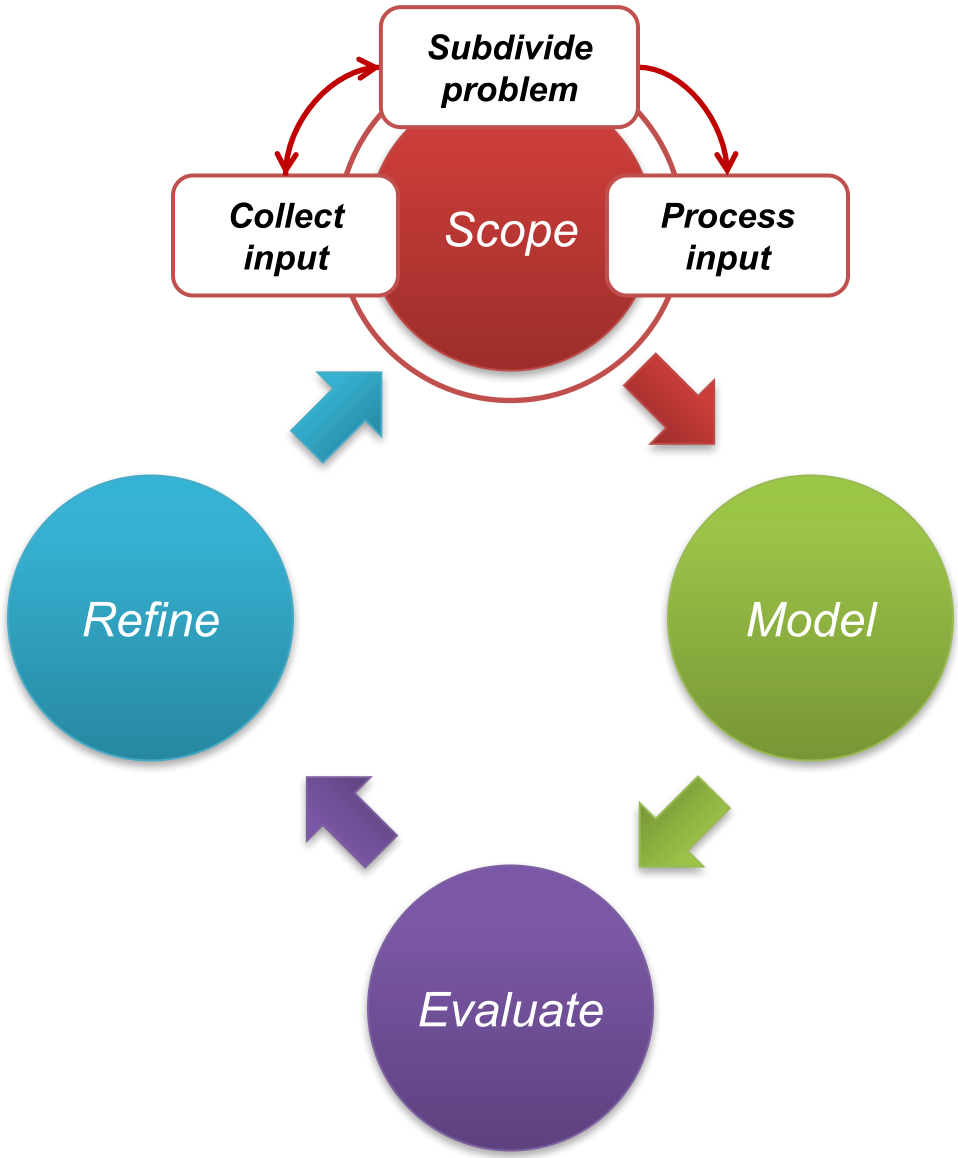



Subdivide problem
Collect input
Scope
Process input
Infrastructure
Model
Processes
Revenues
Evaluate
Investment analysis
Value network analysis
Game theory
Refine
Real options
Sensitivity analysis

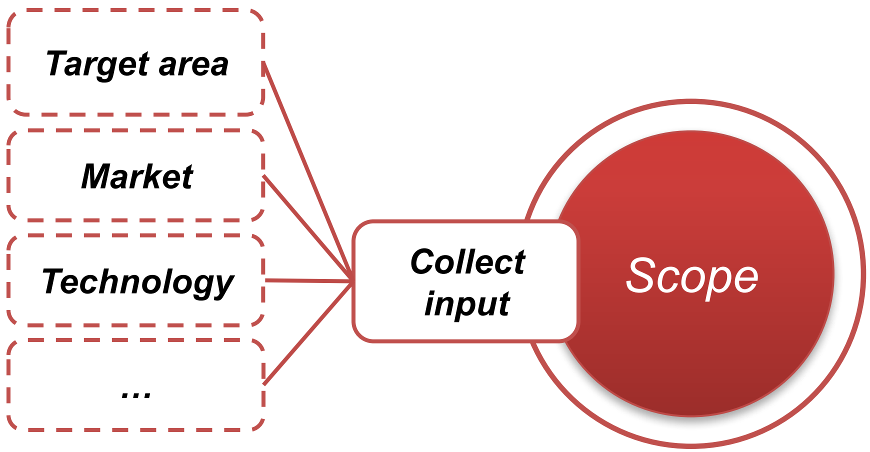
Practical steps in techno-economic evaluation of network deployment planning

SCOPE

Step 1: Scope the problem



Collect input
all available data relevant for the project



Target area input

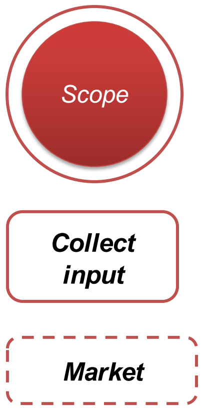
Scope

Collect input

Target area

- 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

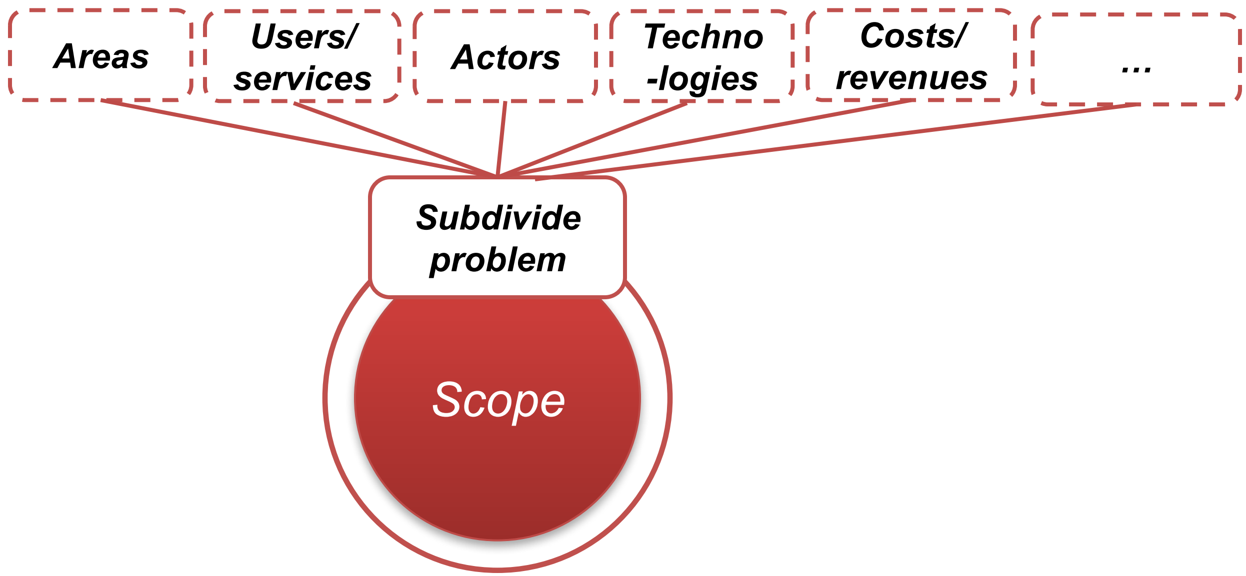
Scope

Collect input

Technology

- State-of-the-art
  - **Available technology standards with their pros and contras**
  - **Commercial products ready for deployment**
  - **Technical specifications**
- Costs
  - **Cost figures for the different technologies**
  - **E.g. equipment costs, installation costs, operational costs, etc.**

Subdivide the problem
in order to define the scope more clearly



Subdivide the problem to reduce complexity

Scope

Subdivide problem

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.)

Scope

Subdivide problem

Areas

Subdivide areas

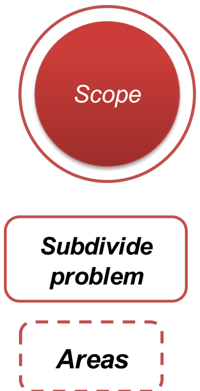
- Impossible to rollout the target area at once
  - **Due to practical limitations**
    - Time constraints
    - Resources (mostly manpower)
  - **Legal permissions**

- Careful selection of rollout sequence
  - **Type of network**
  - **Potential rollout speed**

- Cherry picking!

Cherry picking

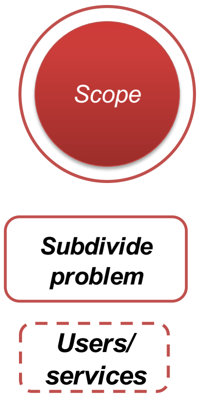
Finding those areas with the highest return on investment



- 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



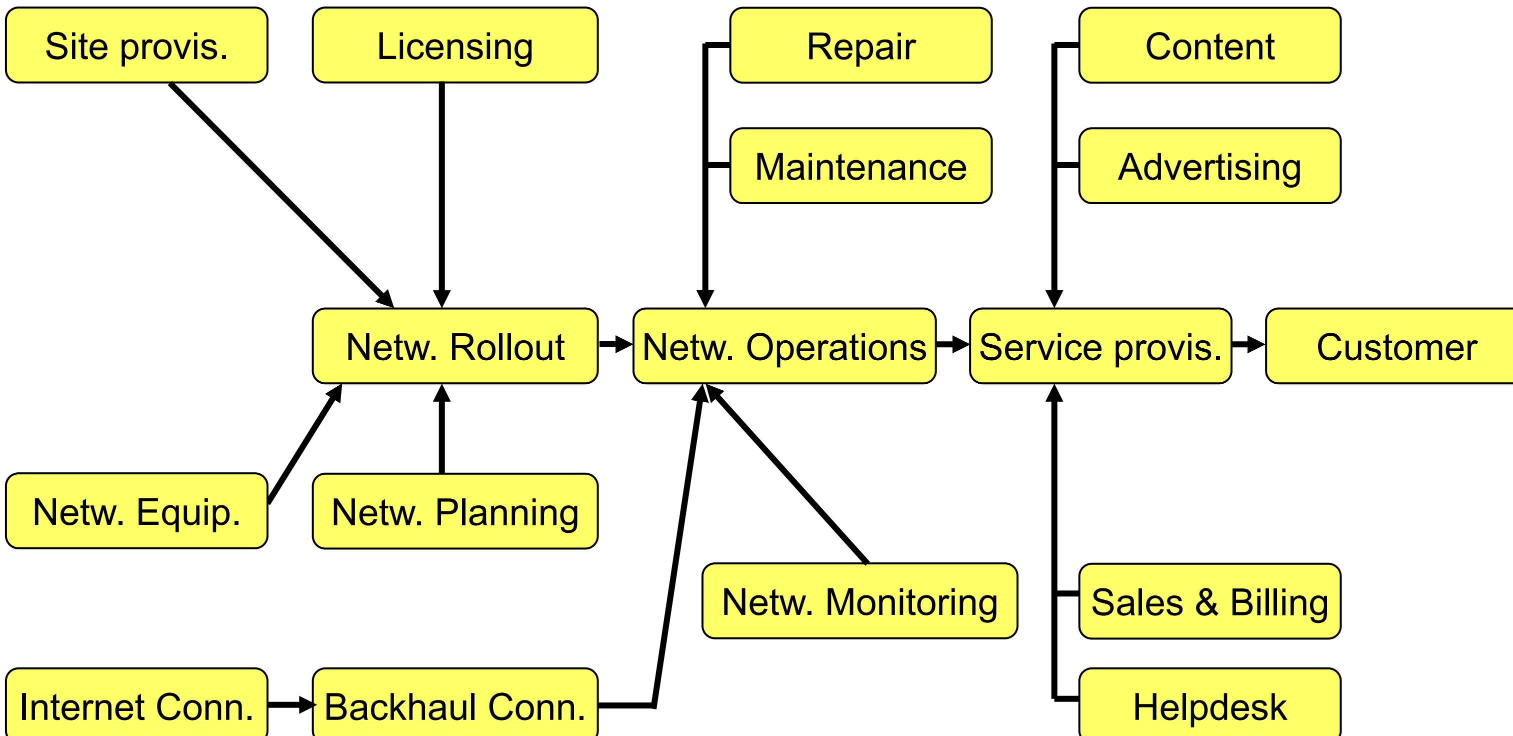
- Define some typical user and service types
  - **Users**
    - Residential vs. industrial
    - Frequent vs. occasional
  - **Services**
    - Data vs. triple play
    - Fixed vs. nomadic vs. mobile

Roles and actors
for a wireless network

Scope

Subdivide problem

Actors

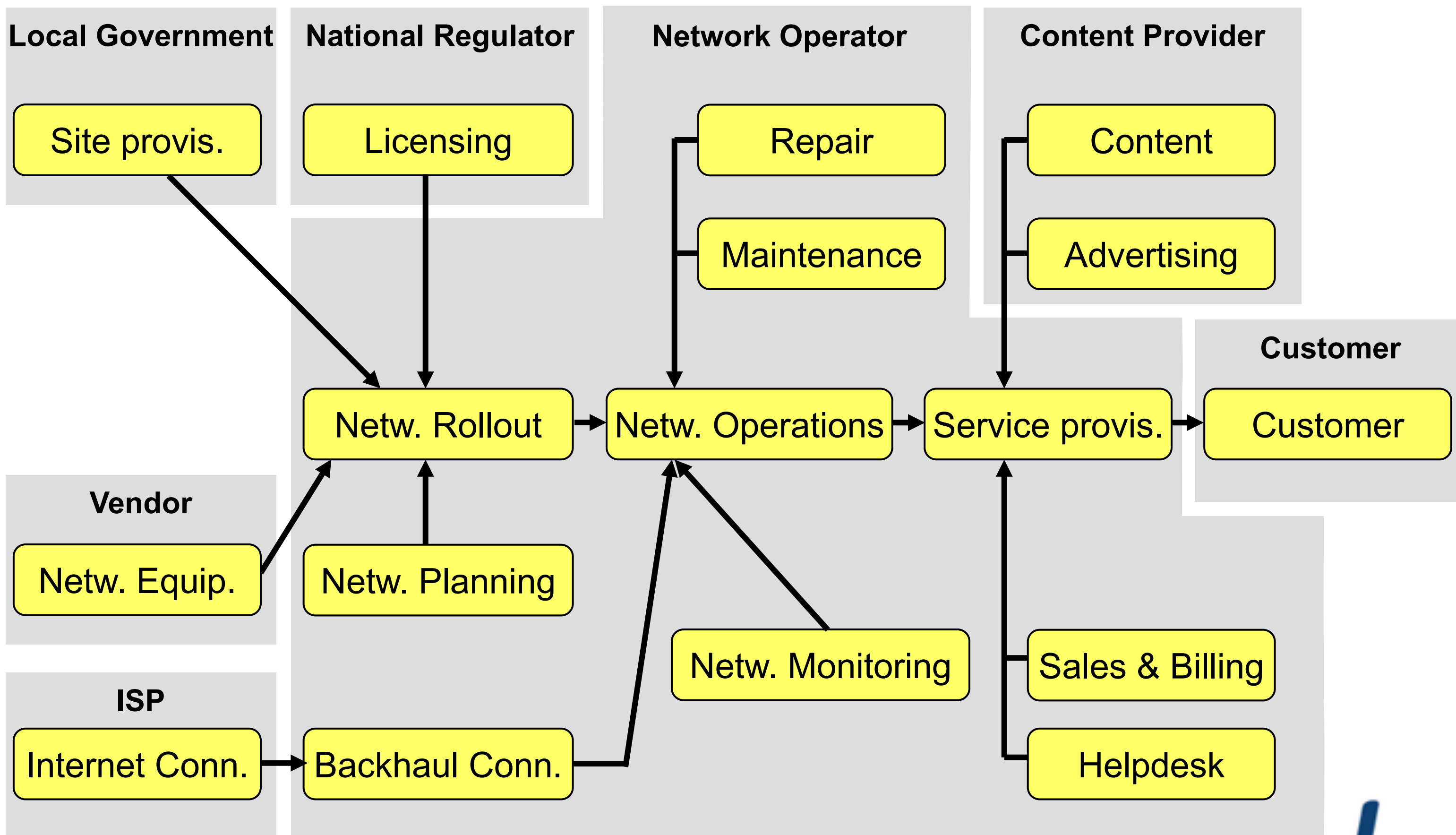


Roles and actors
for a wireless network

Scope

Subdivide problem

Actors

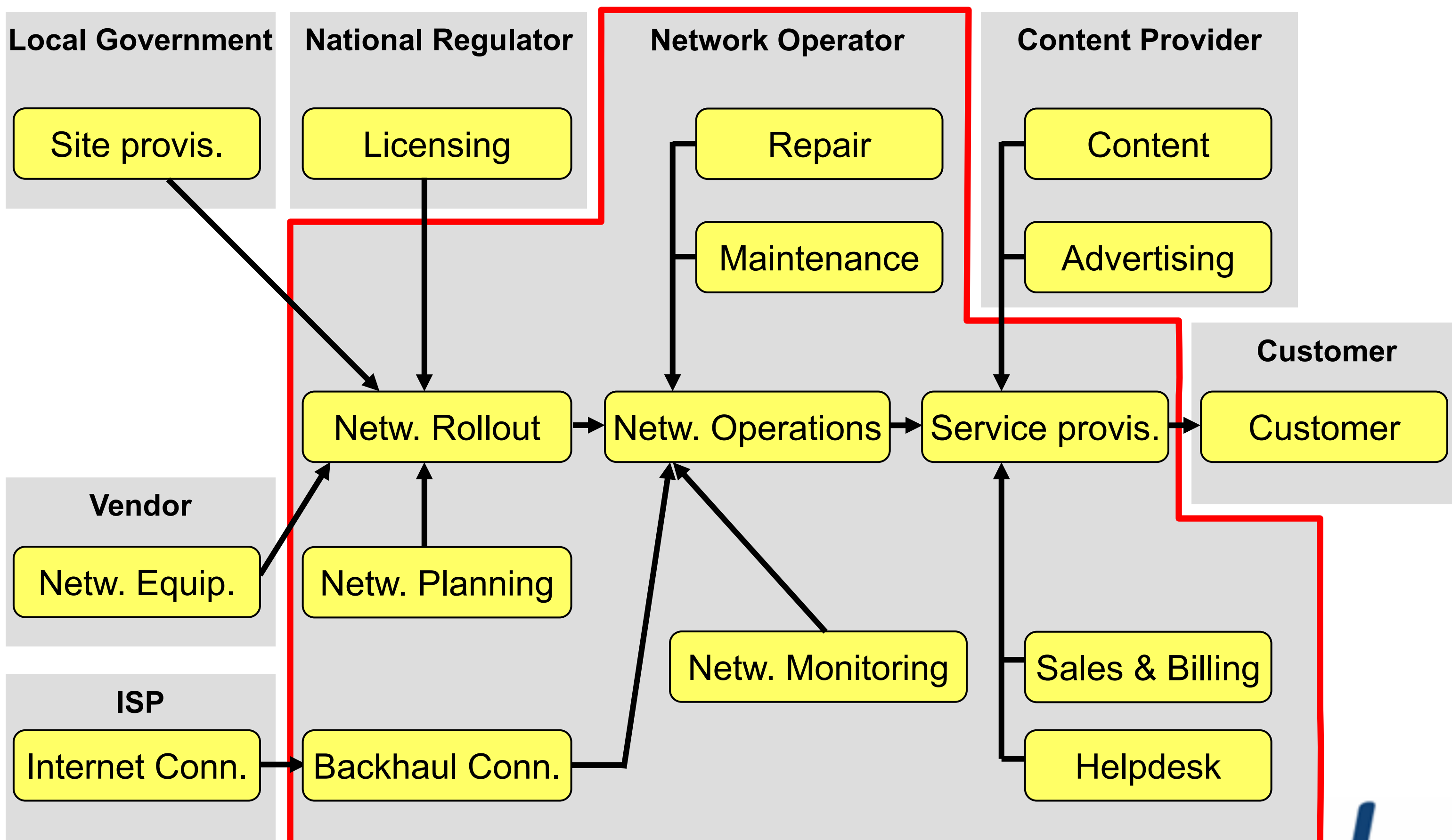


Roles and actors
for a wireless network

Scope

Subdivide problem

Actors



Subdividing technologies

Scope

Subdivide problem

Techno -logies

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

Subdividing technologies

Wireless (coverage)
- Local hotspots
- **Full outdoor coverage**
- Full indoor coverage

Wireless (installation)
- **Pylons**
- Buildings
- Street lampposts

Subdivide costs / revenues

Scope

Subdivide problem

Costs/ revenues

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

Costs

- CapEx (depreciated)
  - Land, buildings
  - Passive infrastructure
  - Equipment
  - Network deployment
  - …
- OpEx
  - Power consumption
  - Floor space
  - Maintenance
  - Repair
  - …

equipment driven

activity driven

Standard: eTOM

Scope

Subdivide problem

Costs/ revenues

Direct versus indirect costs

Scope

Subdivide problem

Costs/ revenues

- Direct costs
  - **Equipment**
  - **Powering**
  - **Activities**
  - **…**
- Indirect costs
  - **Environmental impact**
    - CO_2 emissions
  - **Impact on employment**
  - **…**

Longer term impact

Direct versus indirect revenues

Scope

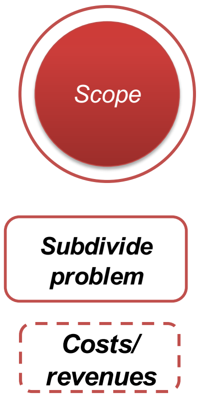
Subdivide problem

Costs/ 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



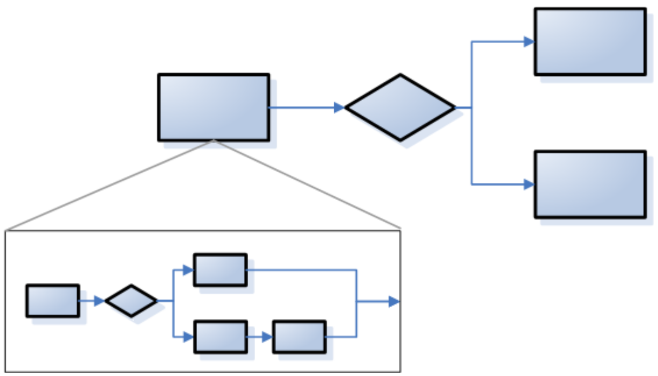
- Standardized by TMF: ITU-T M.3050
- AB process decomposition model
  - **Process model, not state model!**
  - **Grouping**
    - Vertical: purpose of the processes
    - Horizontal: where those processes are taking place
  - **Decomposition: notional level 0 to maximum of 3 levels**
    - NOT the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

Hierarchical process architecture

Scope

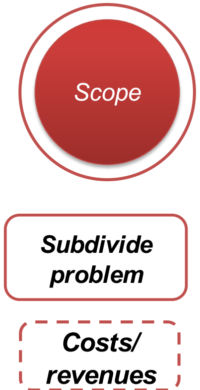
Subdivide problem

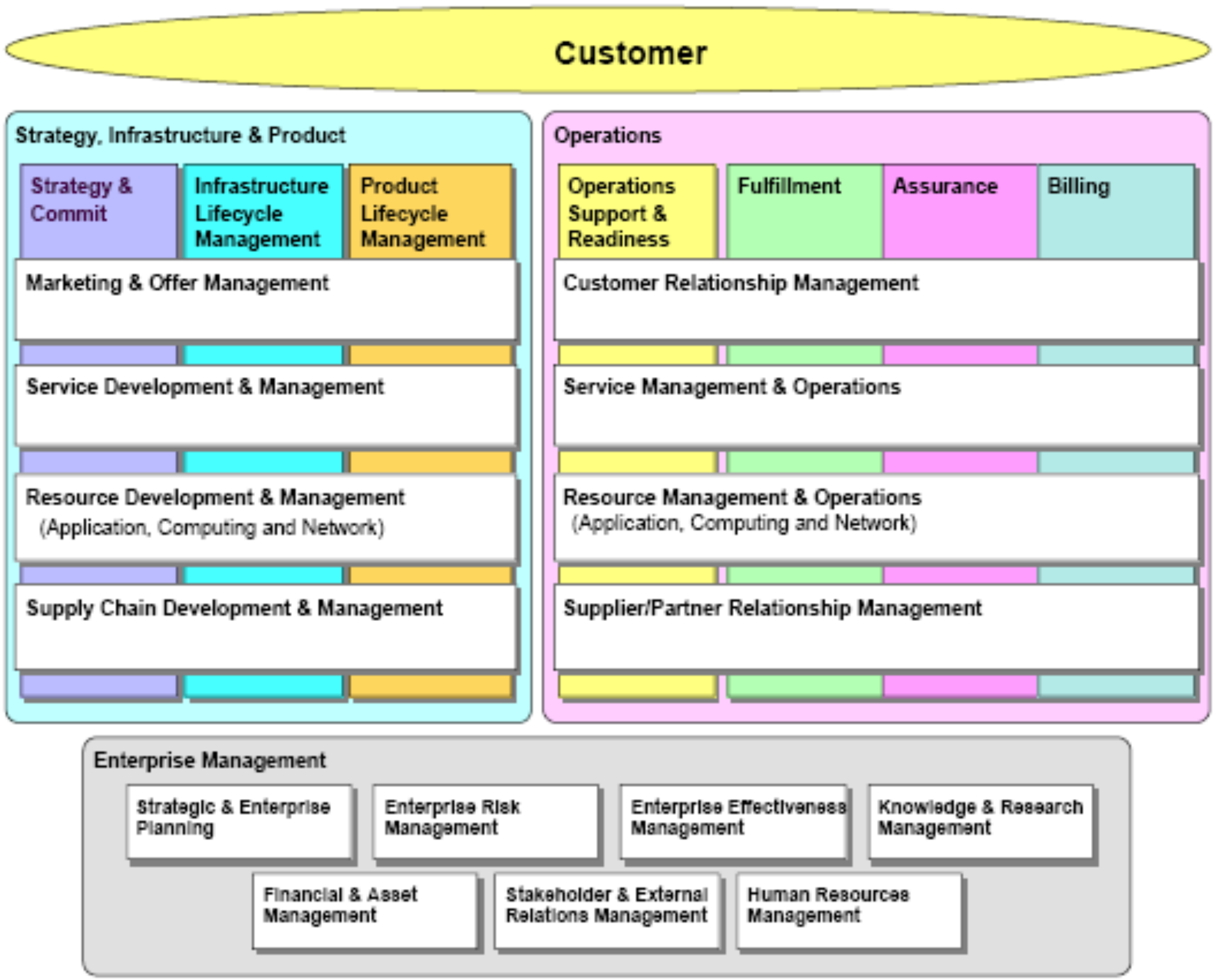
Costs/ revenues



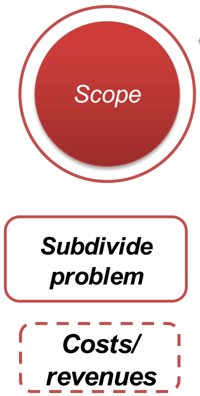
- Different level of processes
  - **Level 0: business activities**
  - **Level 1: process groupings**
  - **Level 2: core processes**
  - **Level 3: business process flows**
  - **Level 4: operational process flows**
  - **Level 5: detailed process flows**

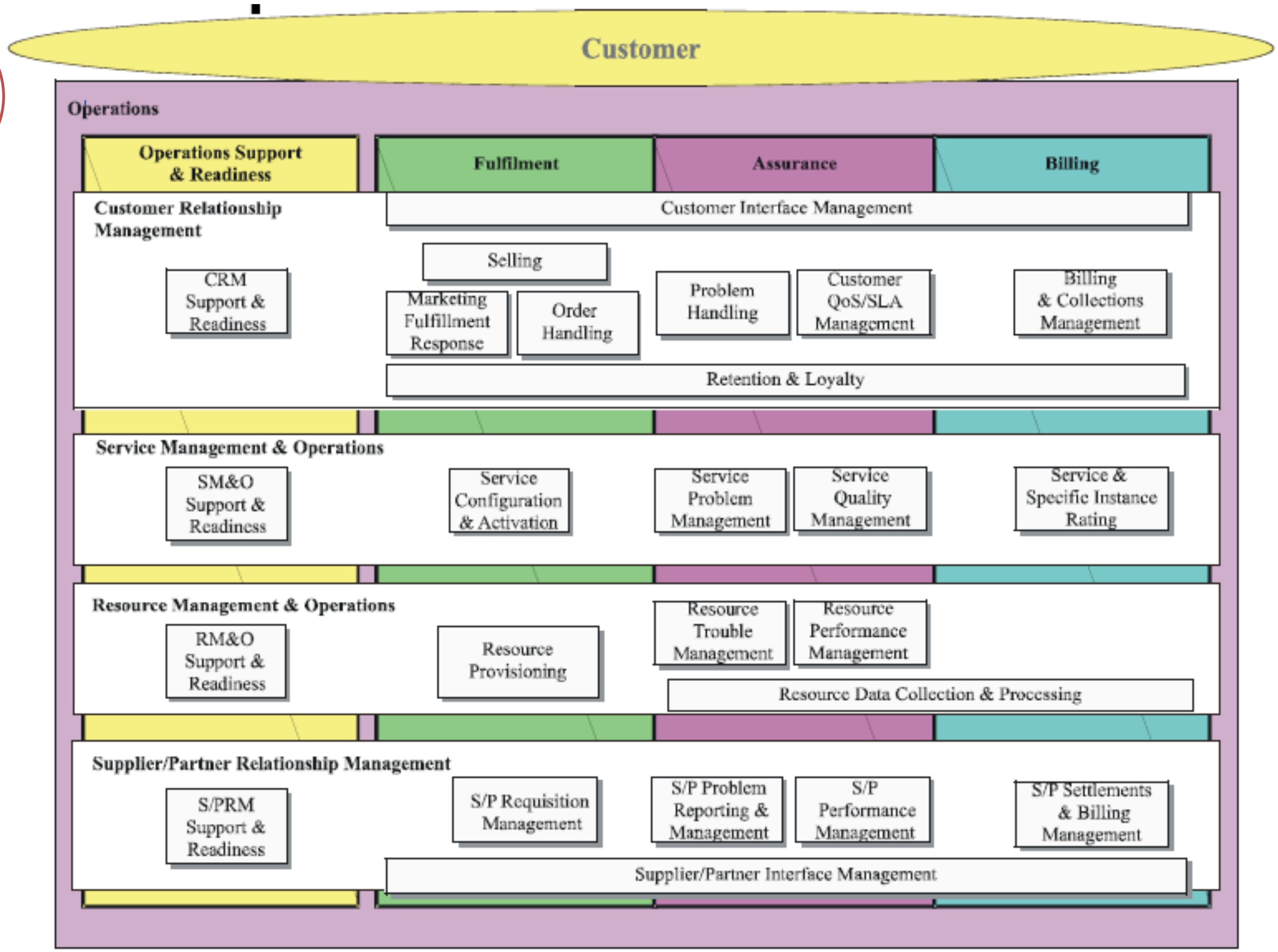
enhanced Telecom Operations Map





eTOM OPS: level 0, 1, 2 processes



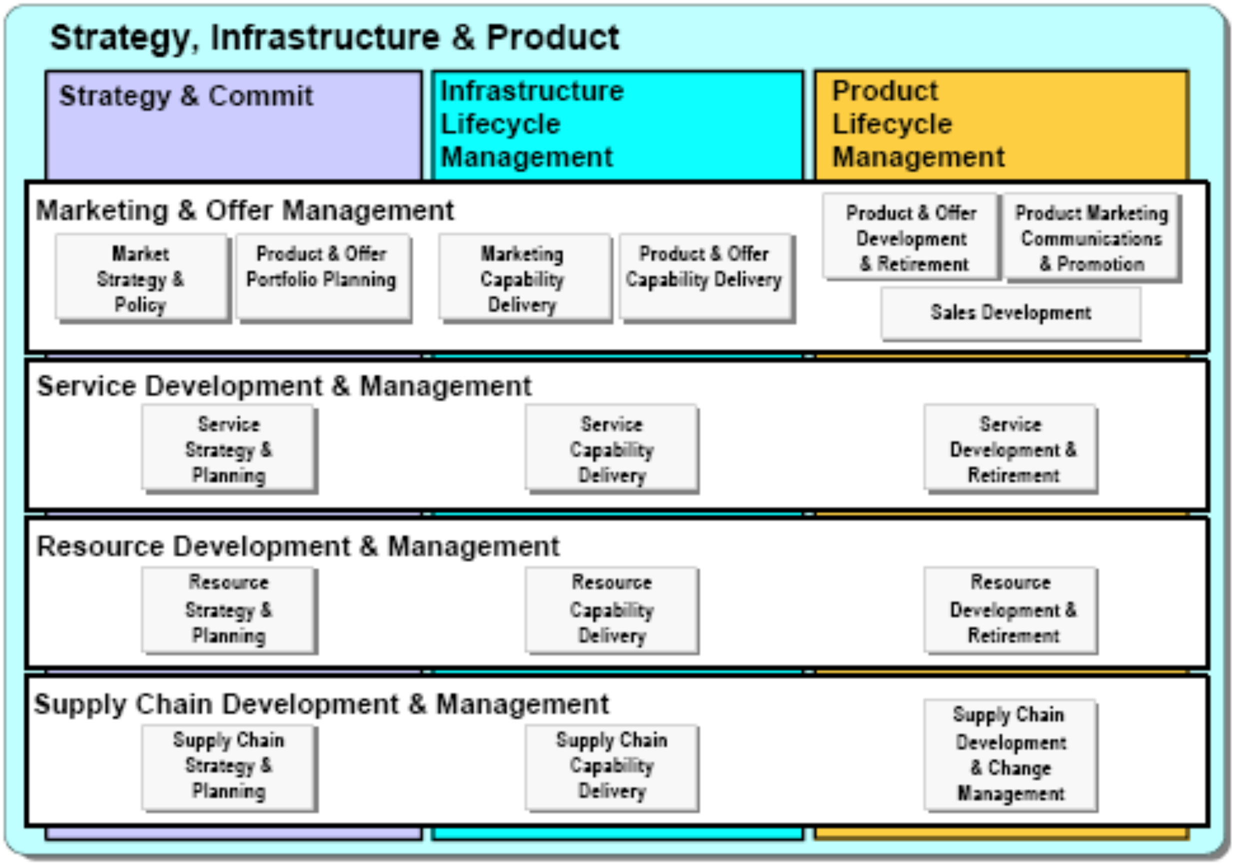


eTOM SIP: level 0, 1, 2 processes

Scope

Subdivide problem

Costs/ revenues

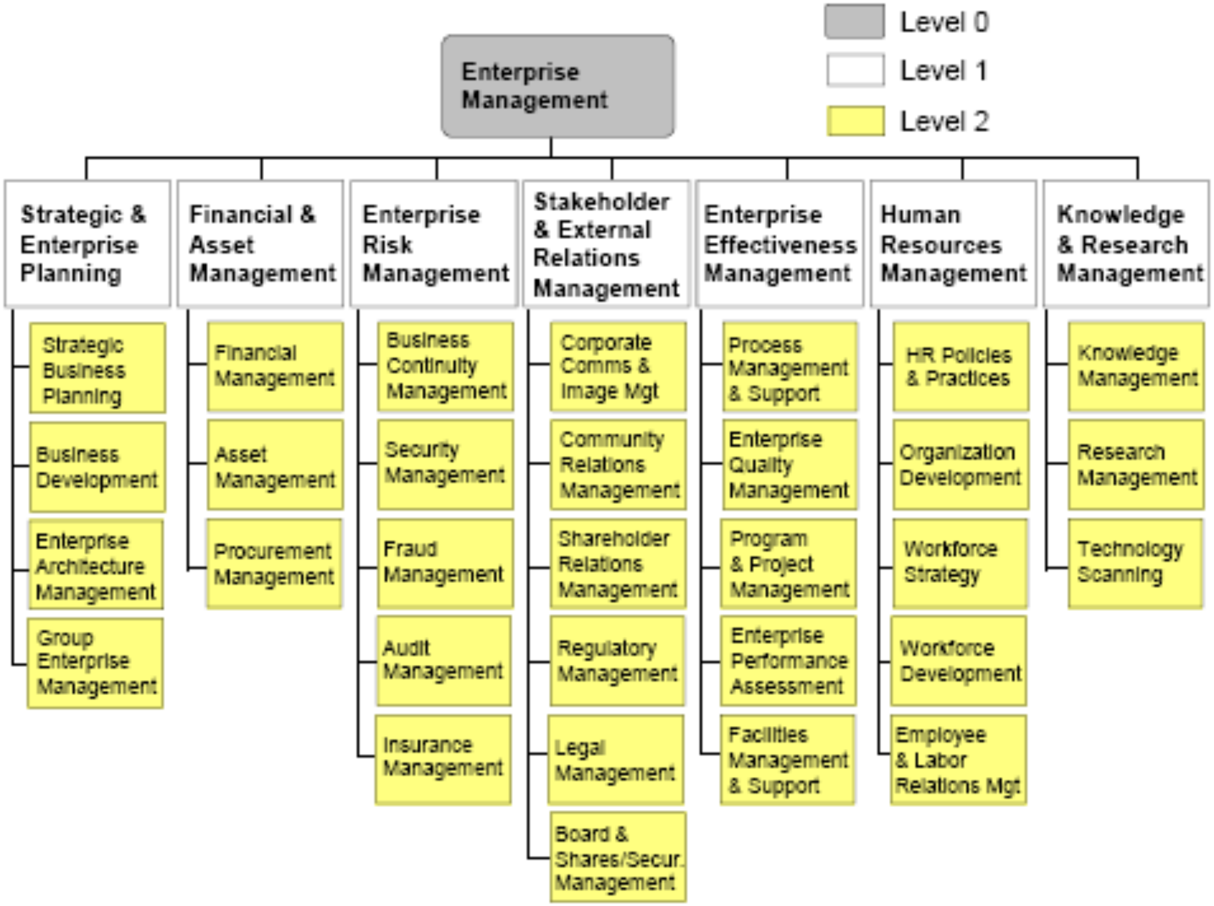


eTOM EM: level 0, 1, 2 processes

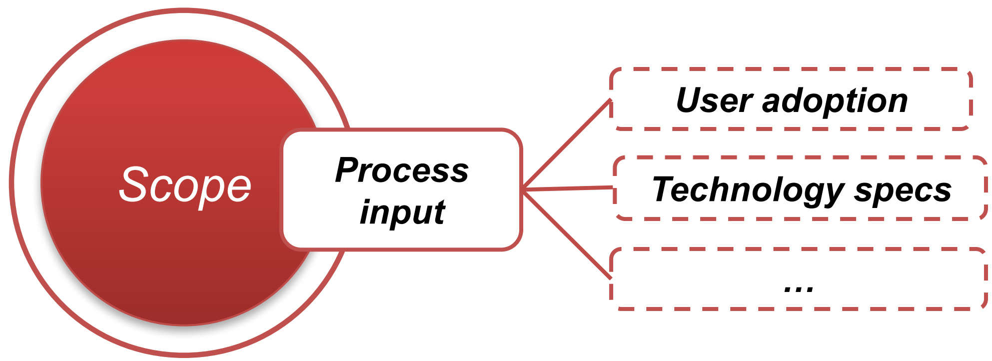
Scope

Subdivide problem

Costs/ revenues



Process input
required before actual modeling starts

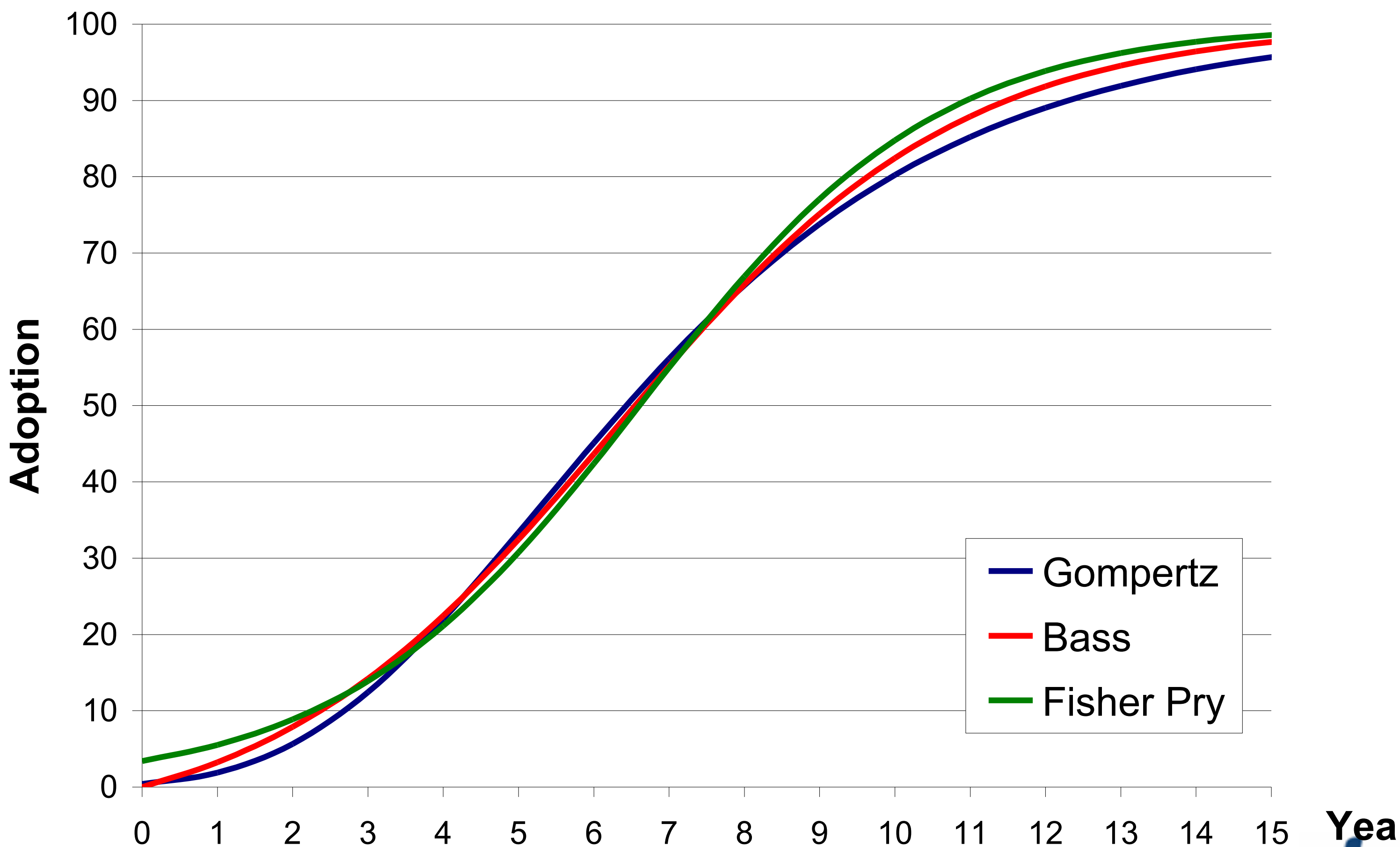


Different user adoption models exist
Cumulative market share: S-shaped curve

Scope

Process input

User adoption



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Bass
Adoption forecasting formula

Scope

Process input

User adoption

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

m = market potential

p = innovation coefficient

q = imitation coefficient

Gompertz
Adoption forecasting formula

Scope

Process input

User adoption

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

m = market potential

a = inflection point (at 37% adoption)

b = slope impacting factor

Fisher-Pry

Adoption forecasting formula

Scope

Process input

User adoption

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

m = market potential

a = inflection point (at 50% adoption)

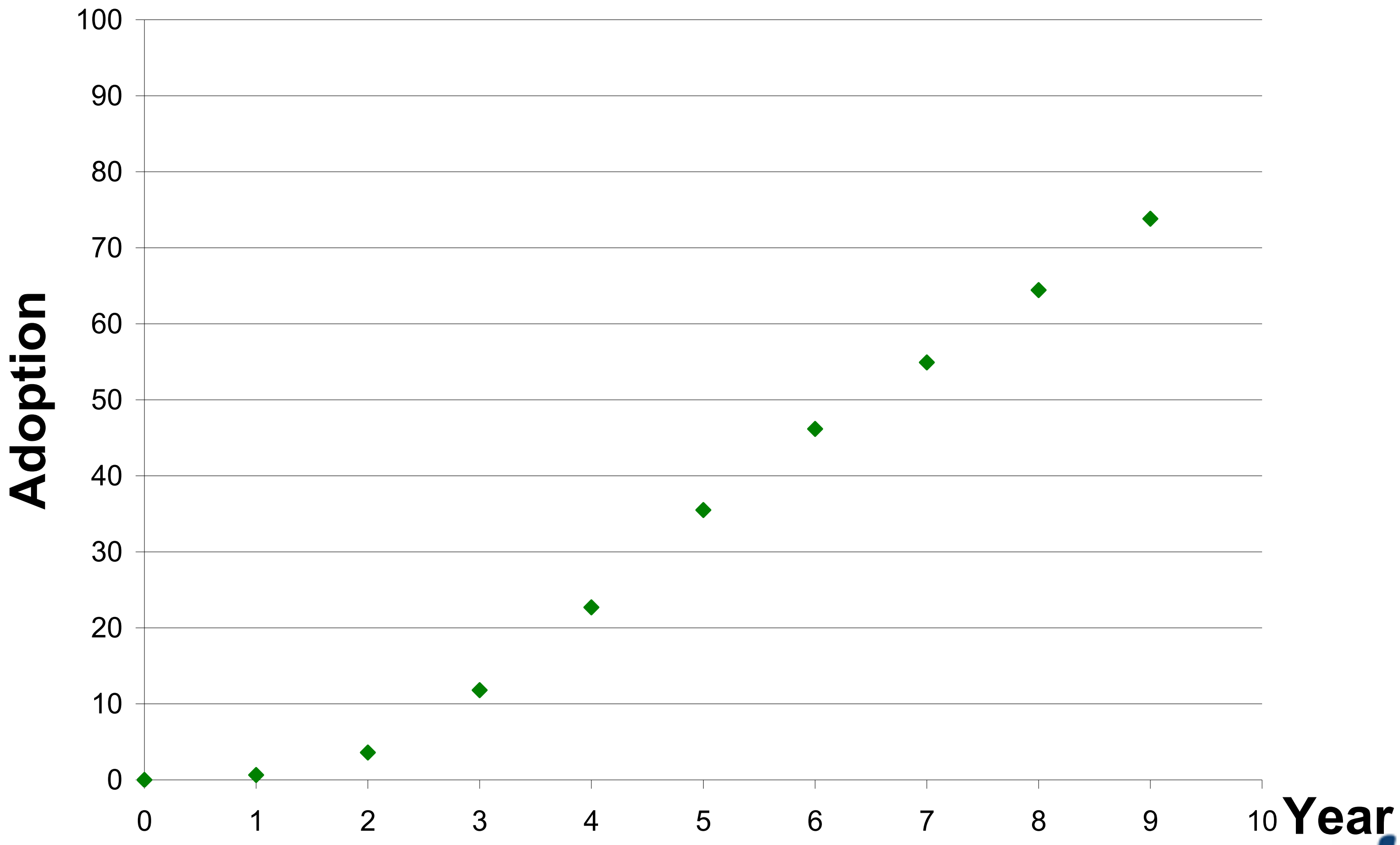
b = slope impacting factor

Fitting to the data points and choosing the best model

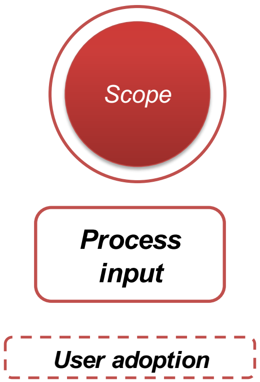
Scope

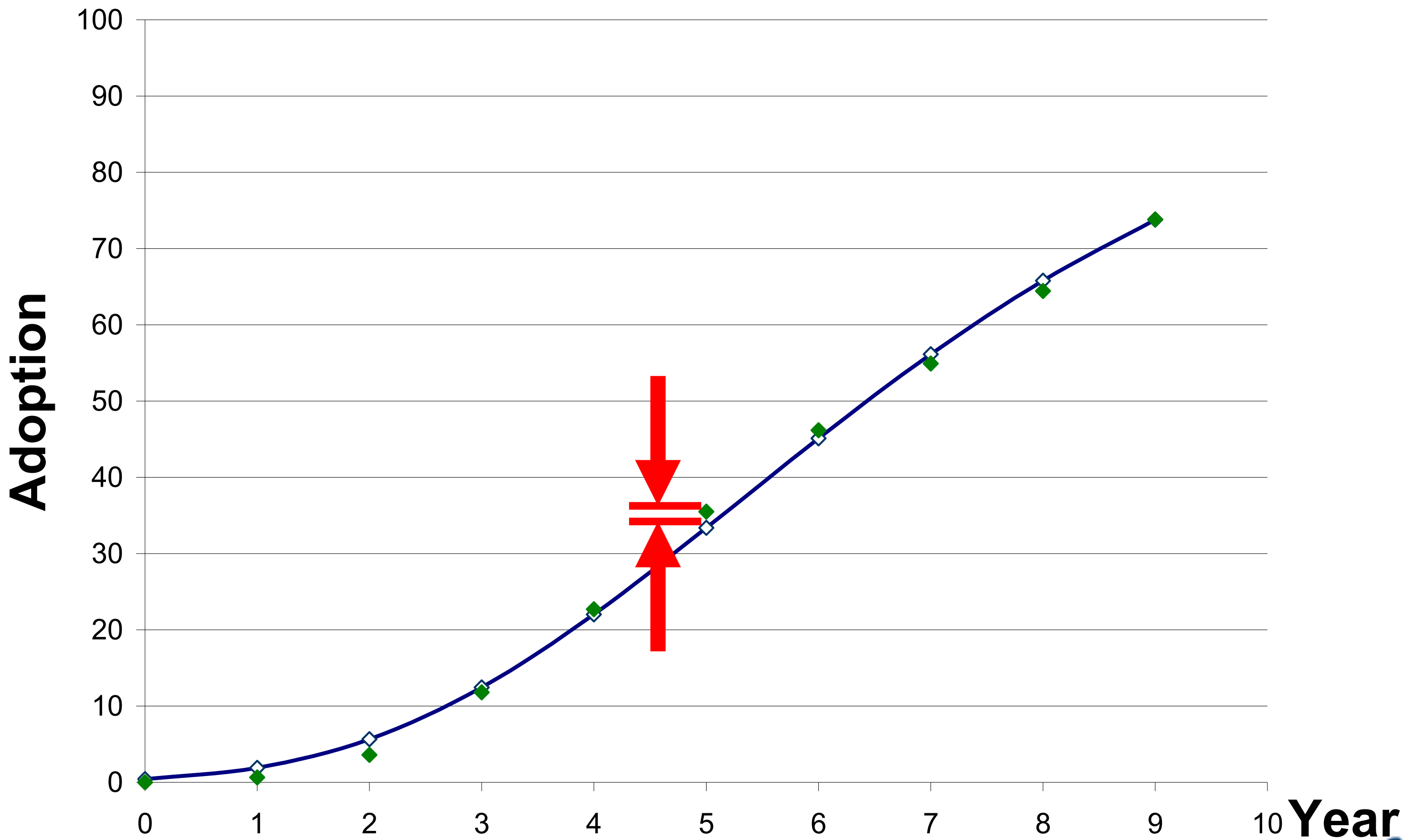
Process input

User adoption



According to the reliability of the model



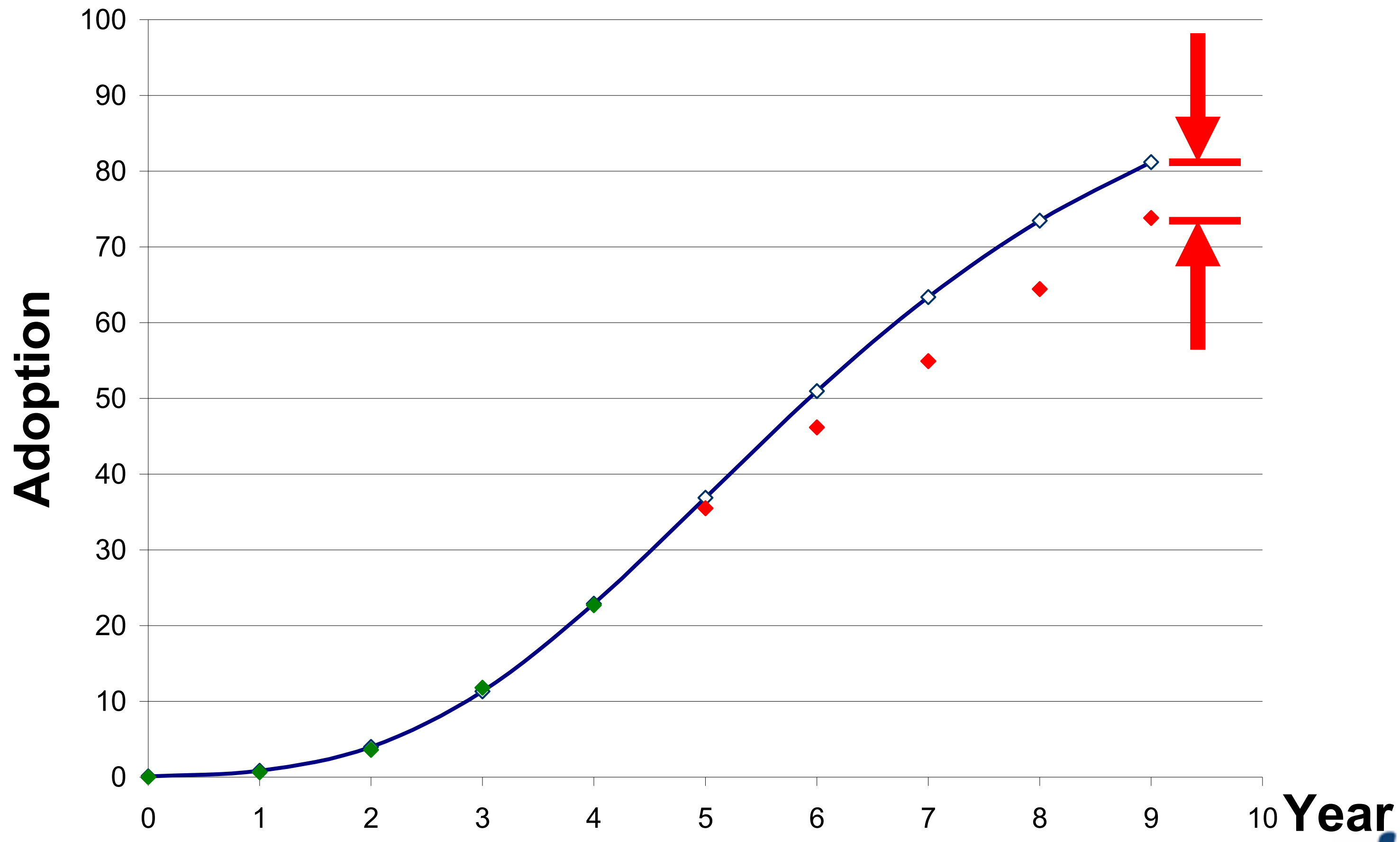


And to the reliability of the forecasts

Scope

Process input

User adoption

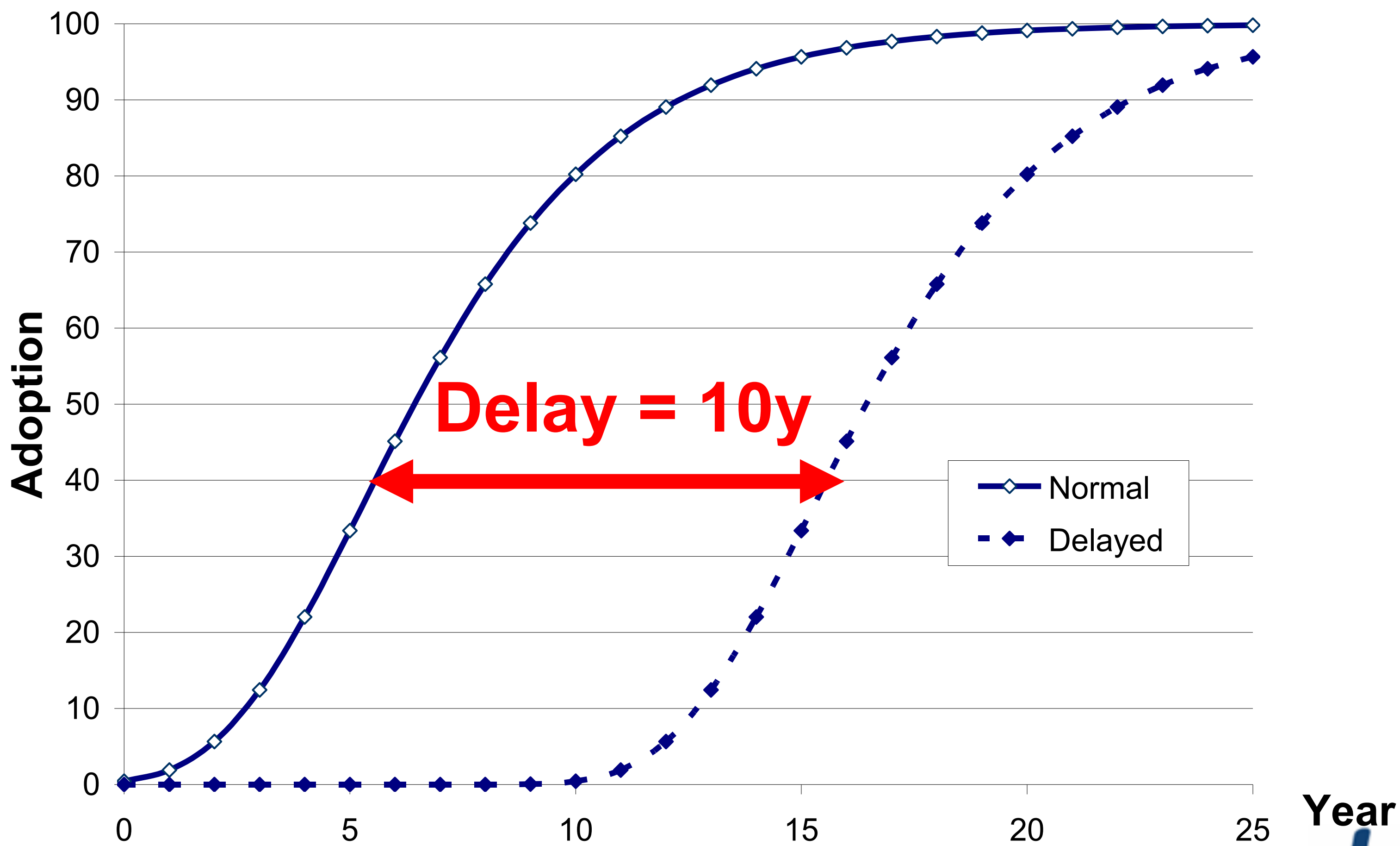


What happens when delaying the rollout

Scope

Process input

User adoption

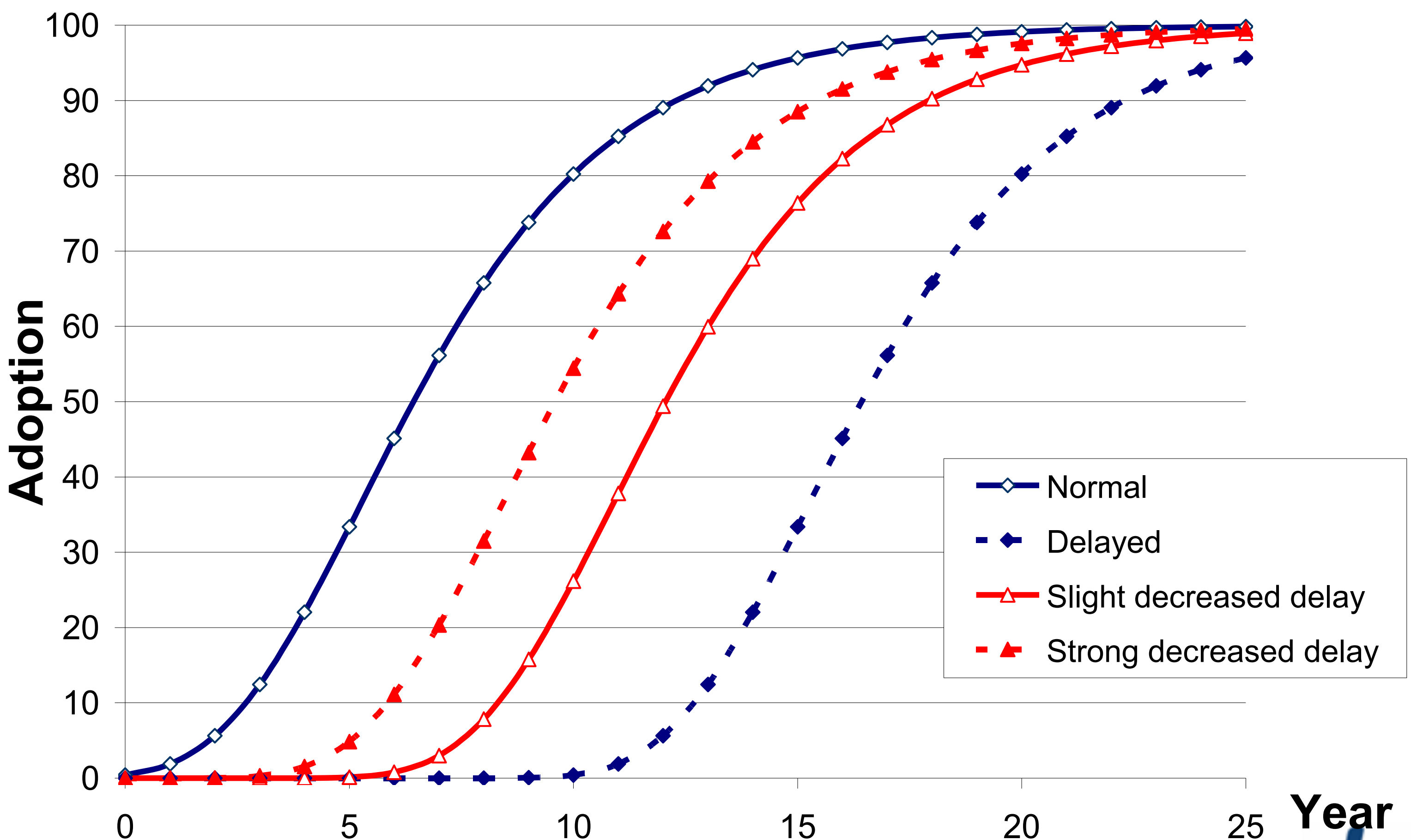


We expect a less than linear increase in delay (e.g. word of mouth, technical evolution, etc.)

Scope

Process input

User adoption

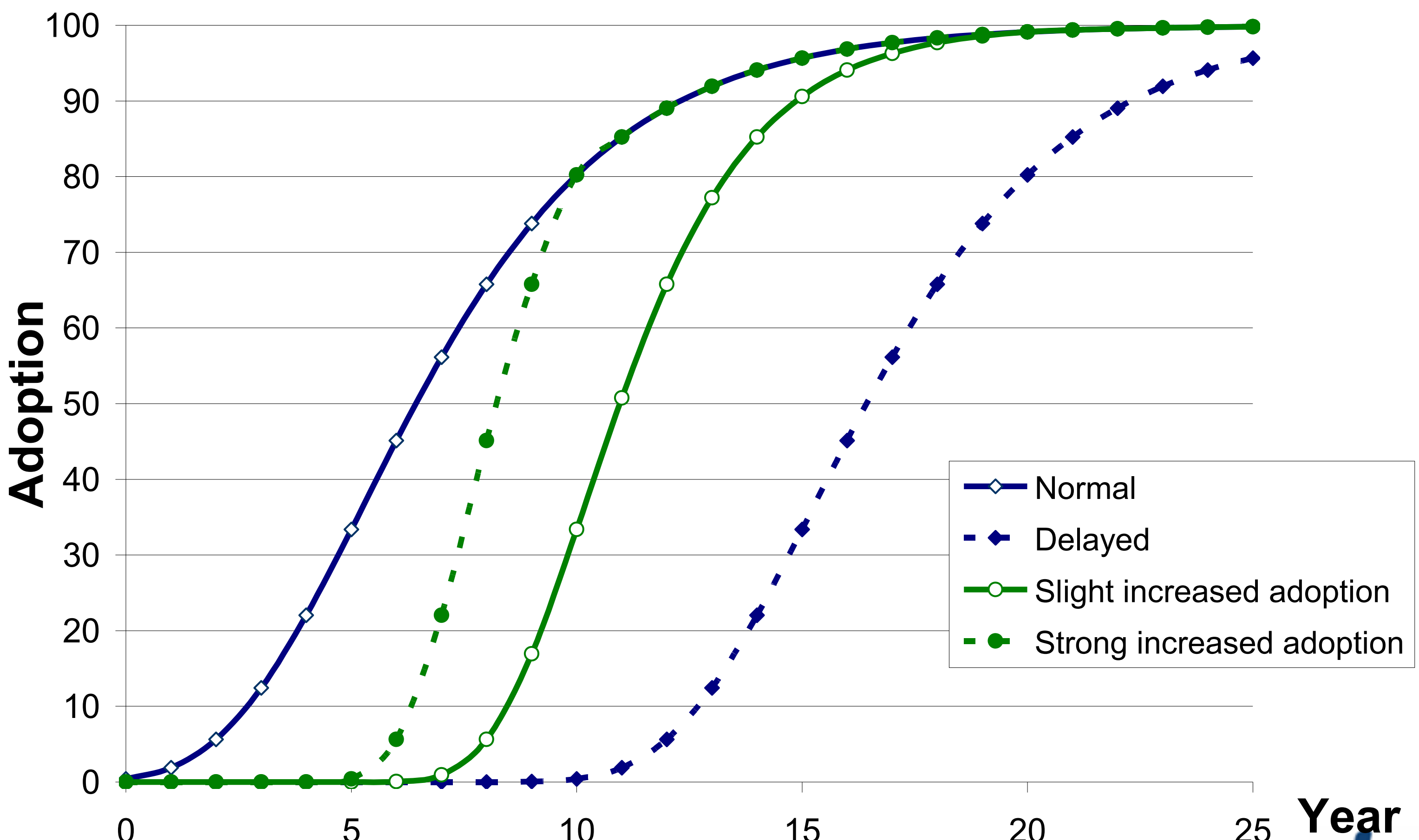


We expect a stronger take-up

Scope

Process input

User adoption

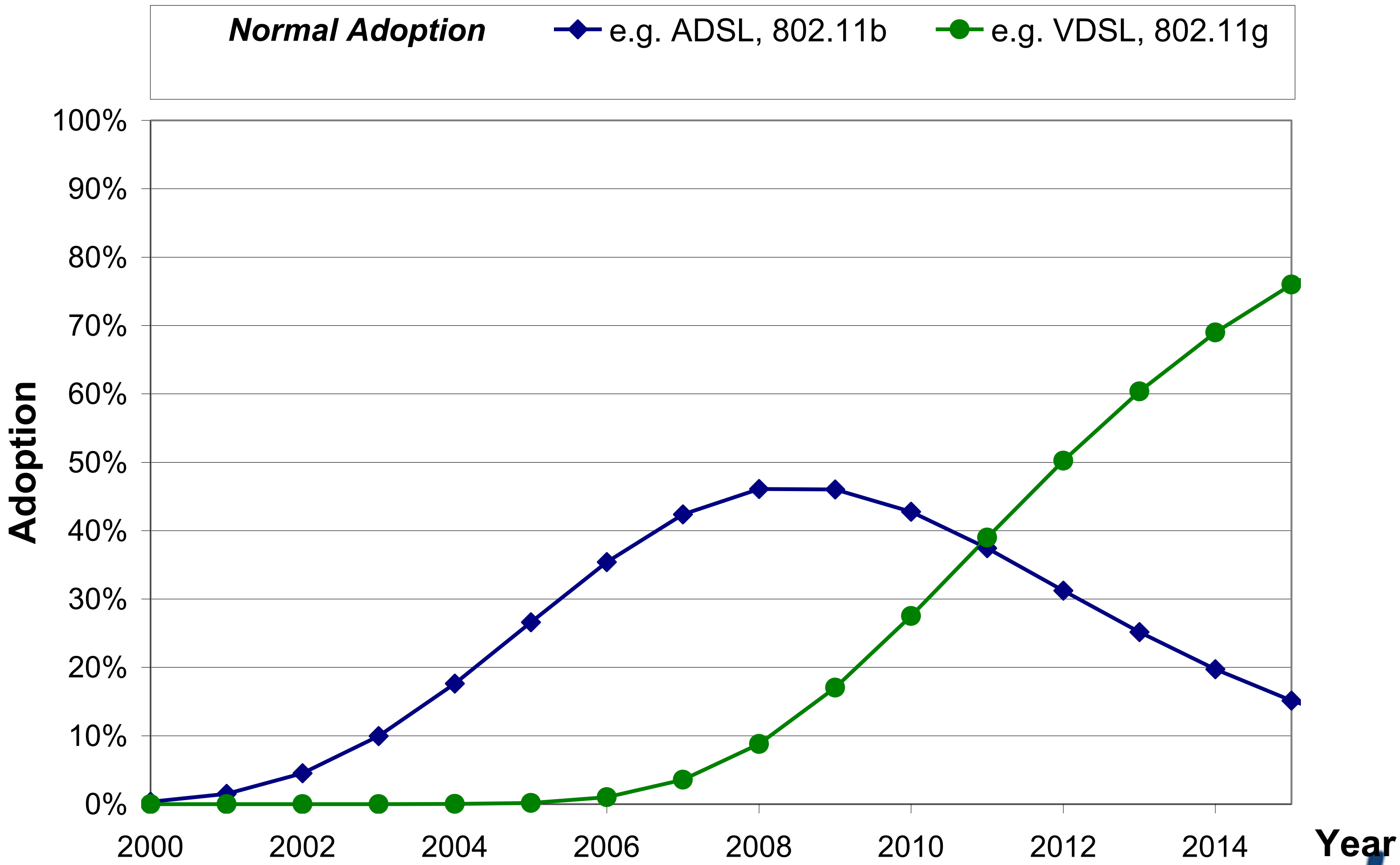


Influence of momentary influences
(e.g. analog switch-off)

Scope

Process input

User adoption

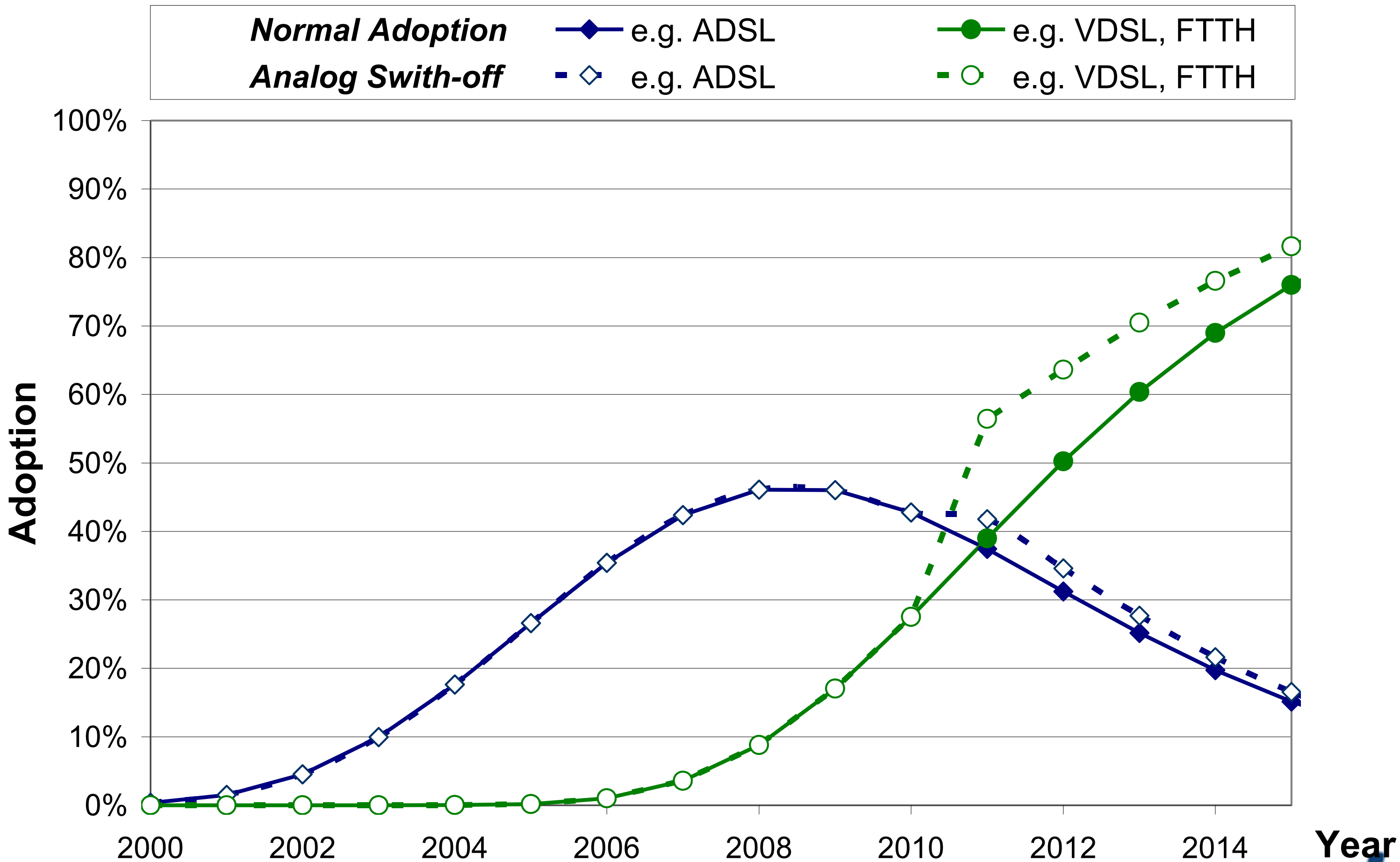


Analog switch-off might push adoption in one year to the full market-potential

Scope

Process input

User adoption

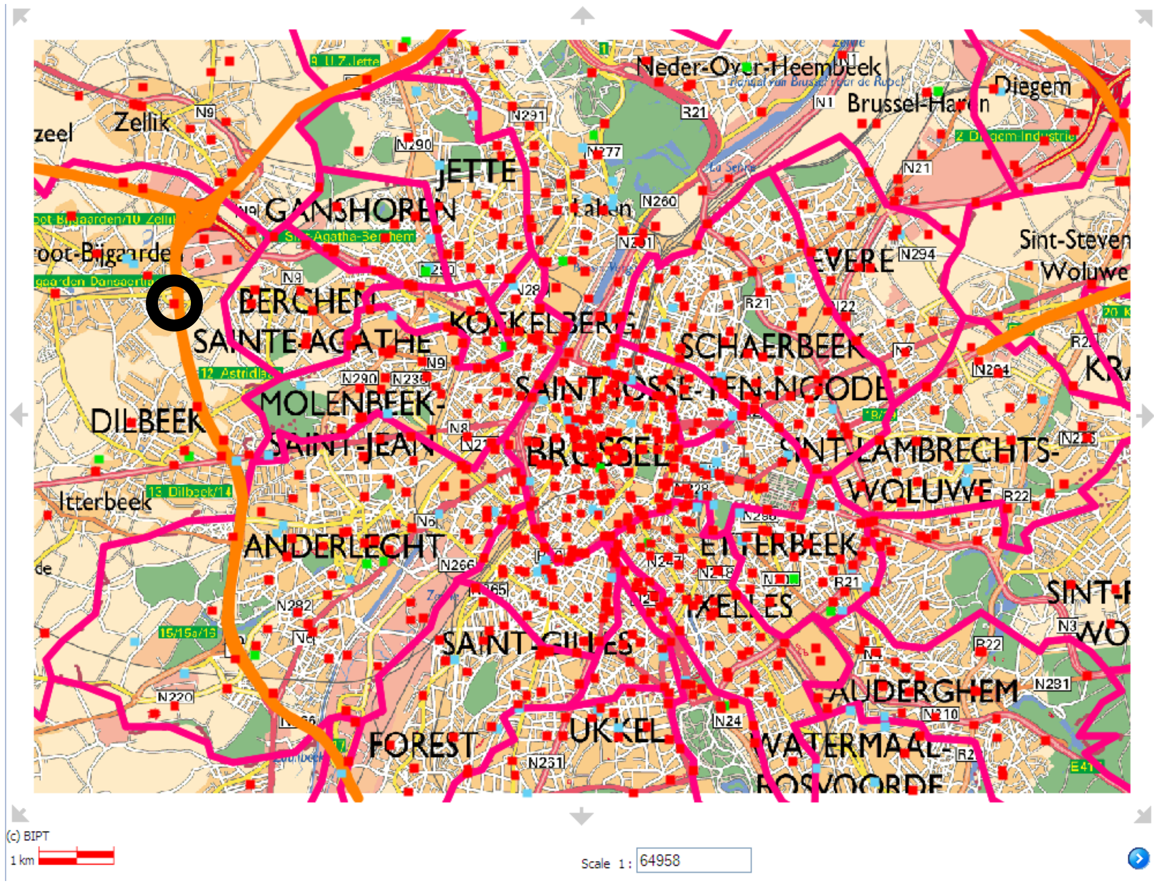


Existing site locations
for mobile/wireless networks

Scope

Process input

Technology specs



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

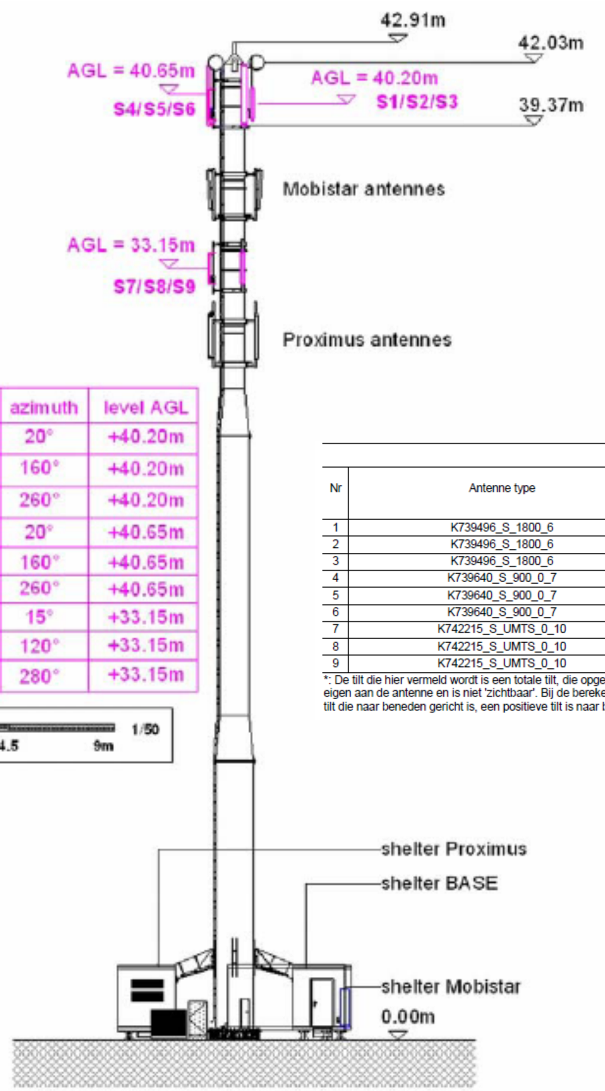
- Operational sites
- Sites under construction
- Construction permit requested

Detailed infrastructure information
for mobile/wireless networks

Scope

Process input

Technology specs



sector	azimuth	level AGL
sector 1	20°	+40.20m
sector 2	160°	+40.20m
sector 3	260°	+40.20m
sector 4	20°	+40.65m
sector 5	160°	+40.65m
sector 6	260°	+40.65m
sector 7	15°	+33.15m
sector 8	120°	+33.15m
sector 9	280°	+33.15m

Antennes

Nr	Antenne type	Azimut (°)	Hoogte (m)	Breedte (m)	Frequentie (MHz)	Hoogte midden (m)	Vermogen (W)	Tilt* (°)	Elektrische Tilt (°)	Mechan. Tilt (°)	Hor. openings-hoek (°)	Vert. openings-hoek (°)	Winst (dBi)
1	K739496_S_1800_6	20	1.3	0.15	1800	40.2	50.1	-7.0	-6.0	-1.0	65.0	7.0	18.0
2	K739496_S_1800_6	160	1.3	0.15	1800	40.2	50.1	-7.0	-6.0	-1.0	65.0	7.0	18.0
3	K739496_S_1800_6	260	1.3	0.15	1800	40.2	50.1	-4.0	-6.0	2.0	65.0	7.0	18.0
4	K739640_S_900_0_7	20	2.5	0.26	900	40.7	25.1	0.0	0.0	0.0	65.0	7.0	17.5
5	K739640_S_900_0_7	160	2.5	0.26	900	40.7	31.6	0.0	0.0	0.0	65.0	7.0	17.5
6	K739640_S_900_0_7	260	2.5	0.26	900	40.7	25.1	0.0	0.0	0.0	65.0	7.0	17.5
7	K742215_S_UMTS_0_10	15	1.3	0.15	2100	33.2	10.0	0.0	0.0	0.0	63.0	6.5	18.0
8	K742215_S_UMTS_0_10	120	1.3	0.15	2100	33.2	10.0	0.0	0.0	0.0	63.0	6.5	18.0
9	K742215_S_UMTS_0_10	280	1.3	0.15	2100	33.2	10.0	0.0	0.0	0.0	63.0	6.5	18.0

*: De tilt die hier vermeld wordt is een totale tilt, die opgebouwd kan zijn uit een mechanische tilt en een elektrische tilt. De mechanische tilt is 'zichtbaar' doordat de antenne fysisch overhelt. De elektrische tilt is eigen aan de antenne en is niet 'zichtbaar'. Bij de berekeningen wordt rekening gehouden met deze verschillende gegevens om een correcte totale tilt te bekomen. Een negatieve waarde komt overeen met een tilt die naar beneden gericht is, een positieve tilt is naar boven toe gericht.

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

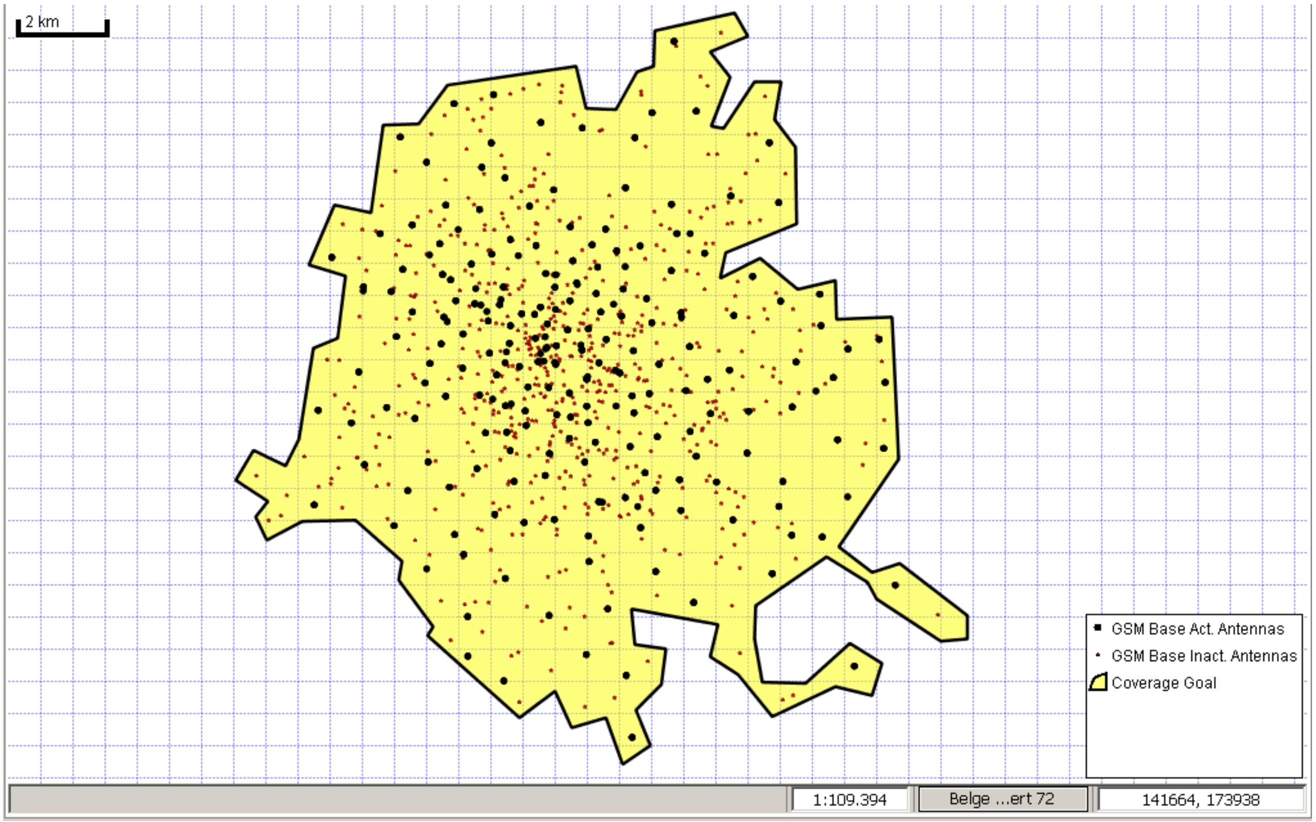
Processed information map
for mobile/wireless networks

Scope

Process input

Technology specs

Antenna locations for Brussels



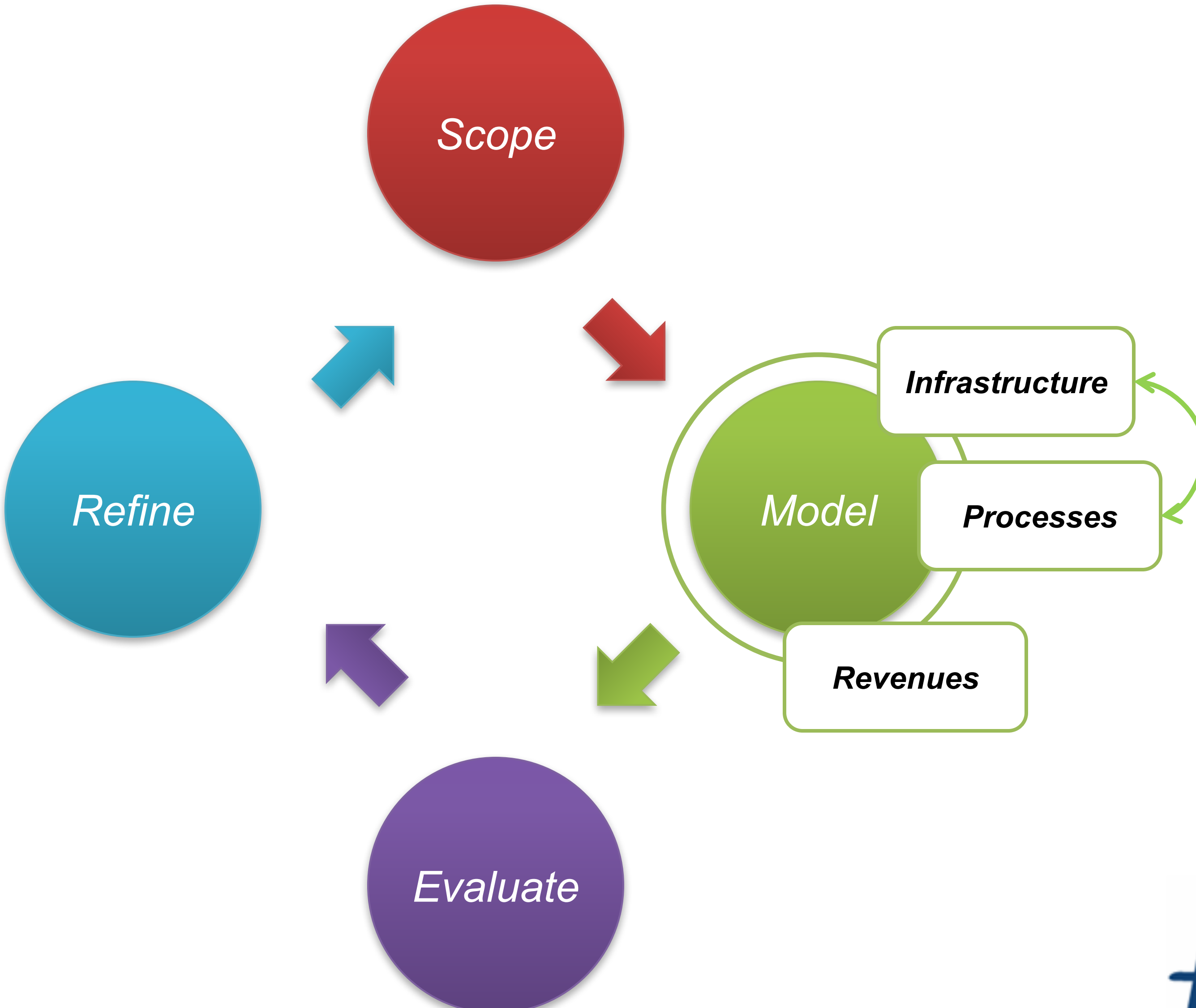
Extra info per antenna:

Location, operators, types, height, power, tilt, etc.

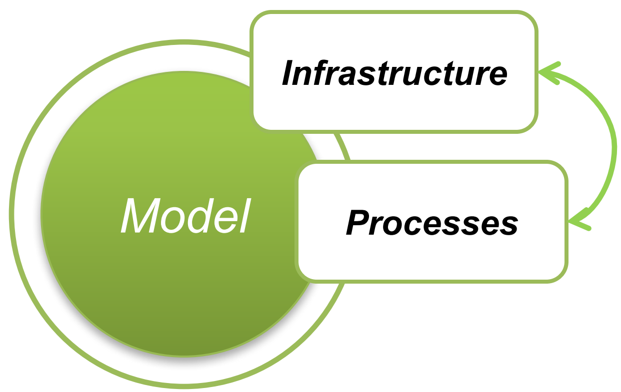
Practical steps in techno-economic evaluation of network deployment planning

MODEL

Step 2: Model costs and revenues



Model infrastructure and processes
using appropriate level of detail

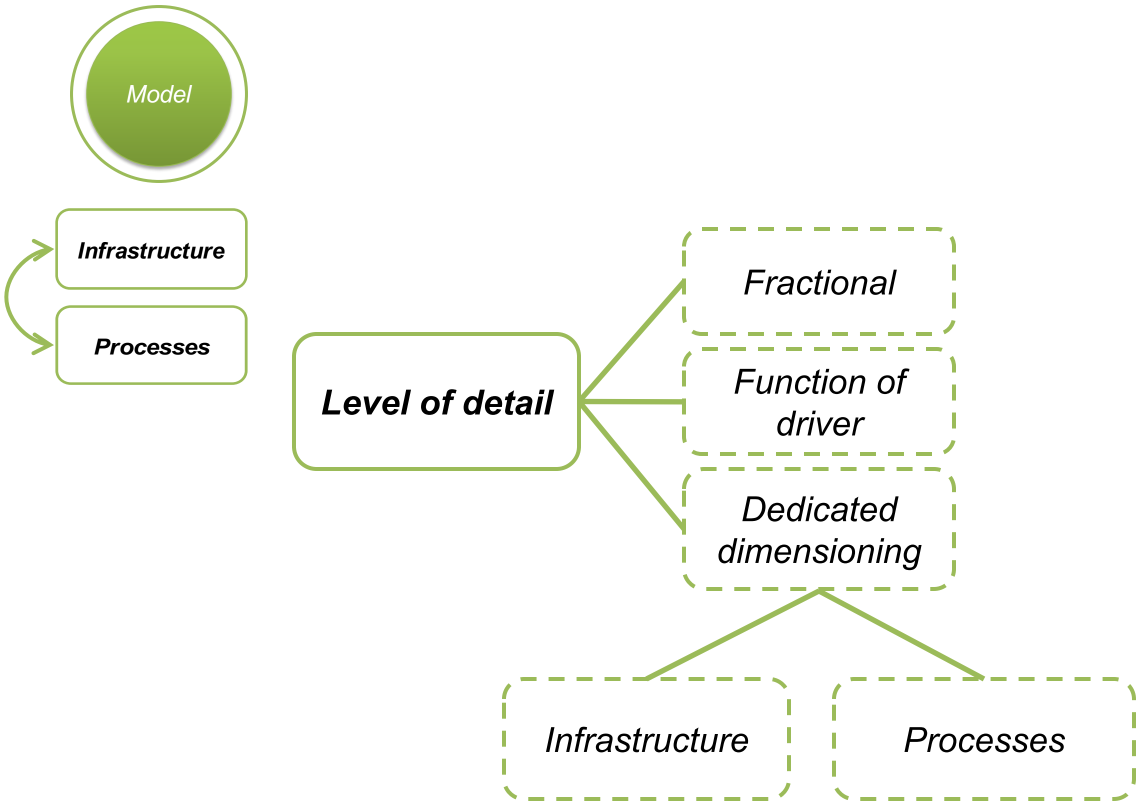


Increasing level of detail

Model

- 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

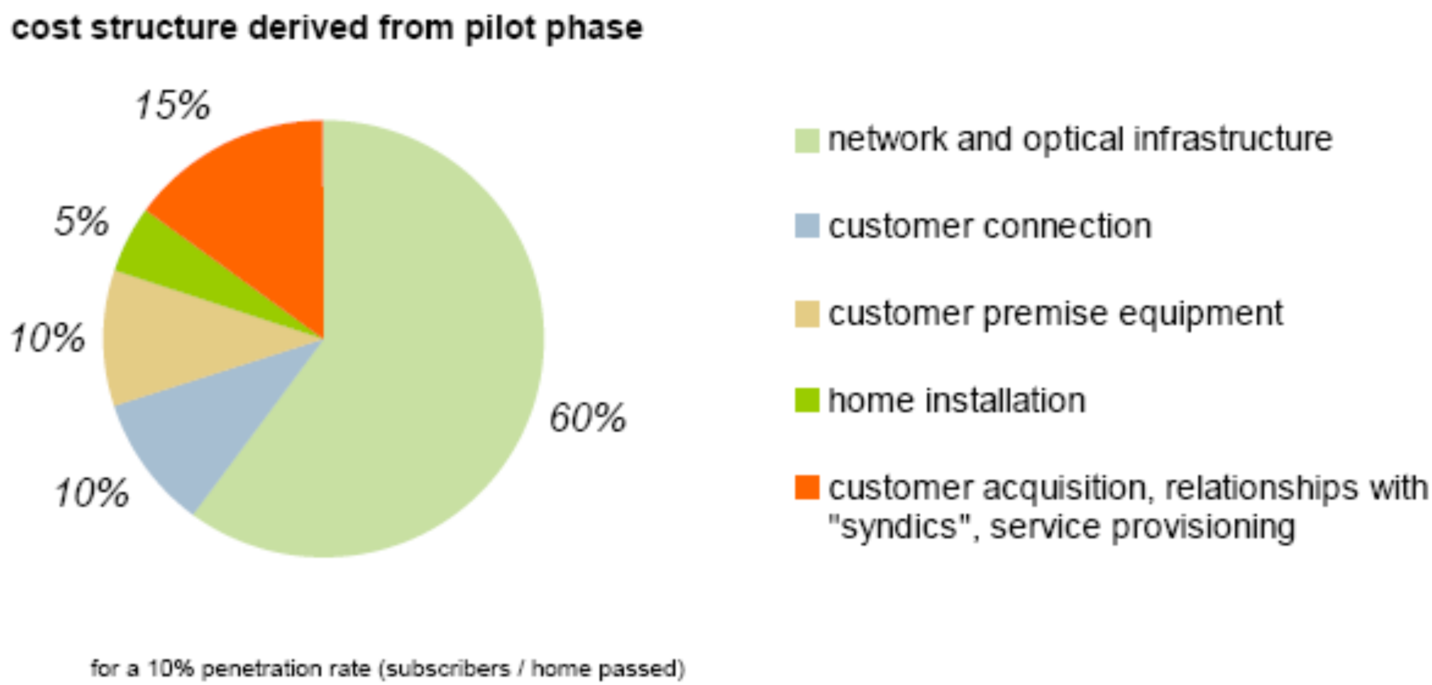


Fractional cost modeling

Model

Infrastructure

Processes



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

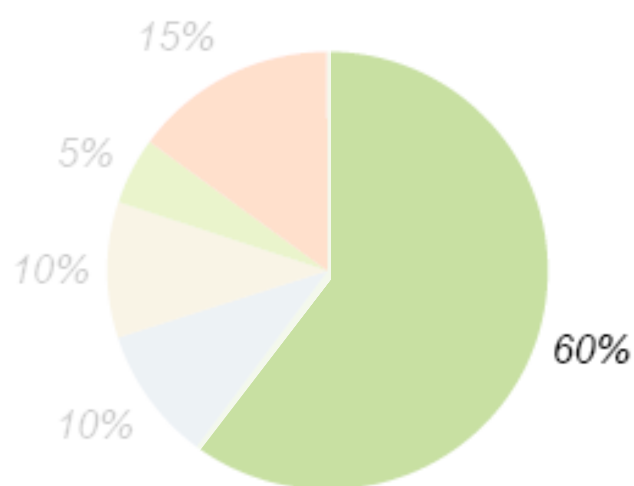
Function of driver cost modeling

Model

Infrastructure

Processes

cost structure derived from pilot phase



network and optical infrastructure

for a 10% penetration rate (subscribers / home passed)

Examples of drivers:

- *installation length (50€/m)*
- *customer base (1k €/cust)*
- …

→ combinations possible

Wireless network dimensioning
Cell size calculation

Model

Infrastructure

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

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

PHYSICAL RANGE

User density & service req.
(required bandwidth)

+

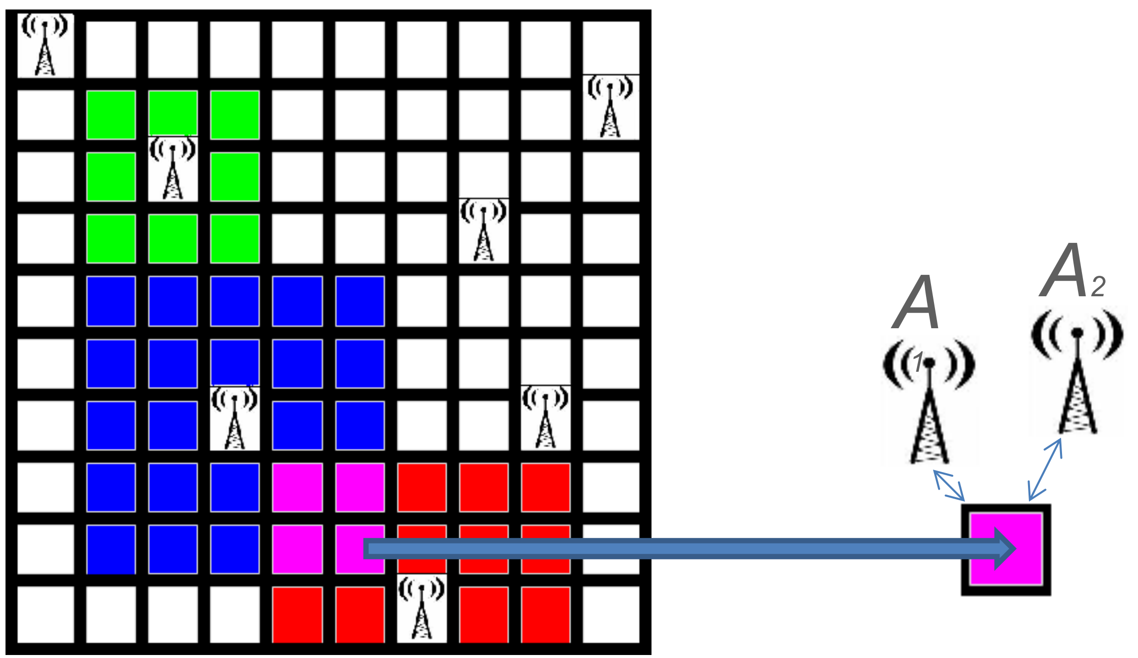
Technology performance
(attainable bandwidth)

SERVICE RANGE

Cell sizes

Wireless network dimensioning
Methodology

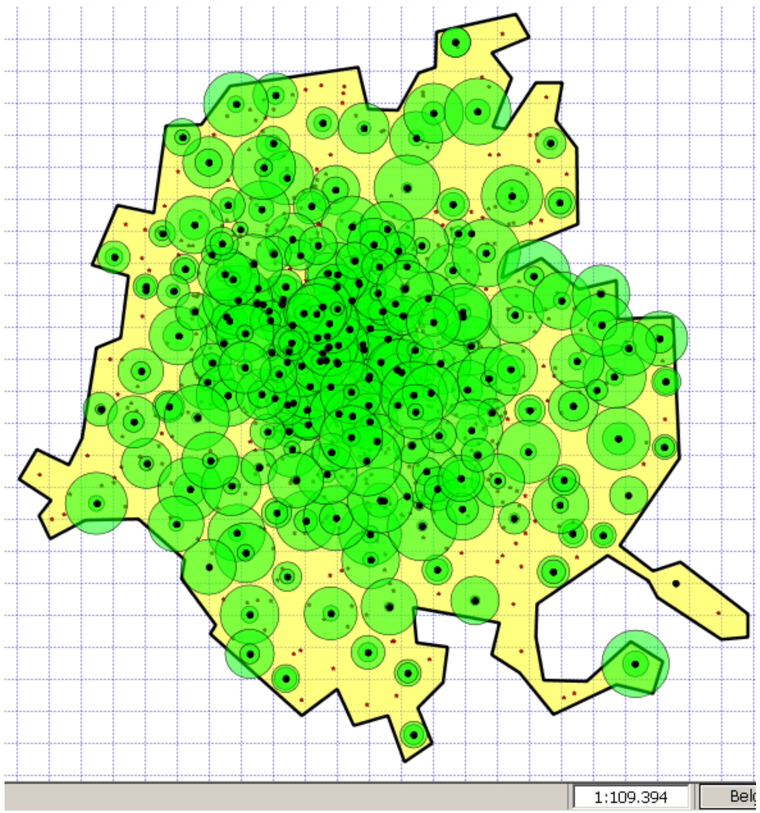
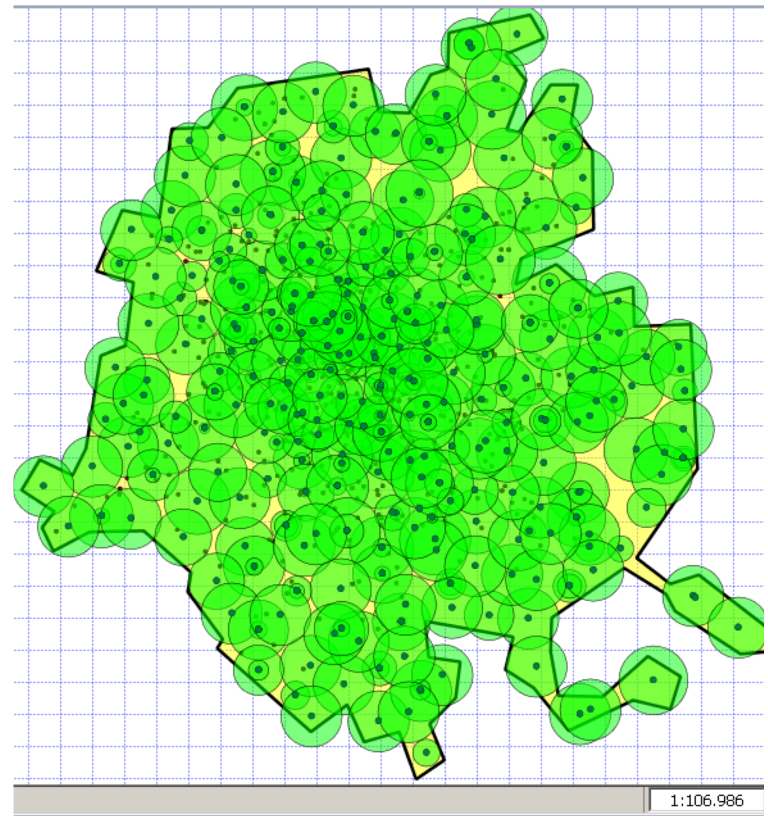
1. Map (& reduce) all site-information (e.g. on grid)
2. Calculate range for each site installation
3. Select optimal sites for required coverage
4. Analyze the regions of overlap



Wireless network dimensioning
Existing GSM operator in Brussels

Model

Infrastructure

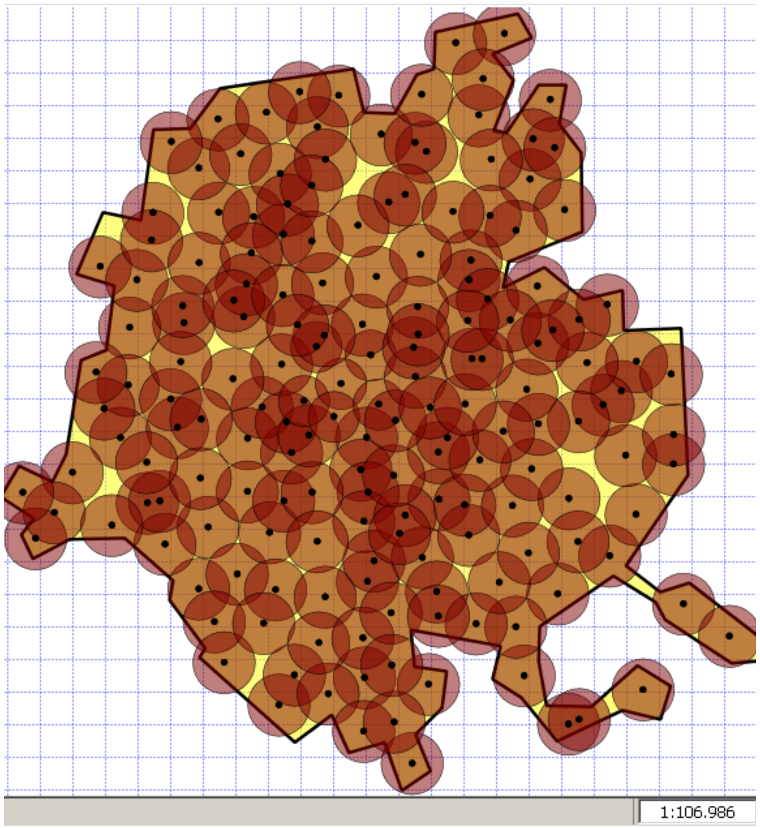
	Original coverage	Optimized solution
		
GSM:	71.4% cov., 409 ant.	96.6% cov., 367 ant.
3G:	36.9% cov., 193 ant.	87.7% cov., 584 ant.

Wireless network dimensioning
Greenfield dimensioning in Brussels

Model

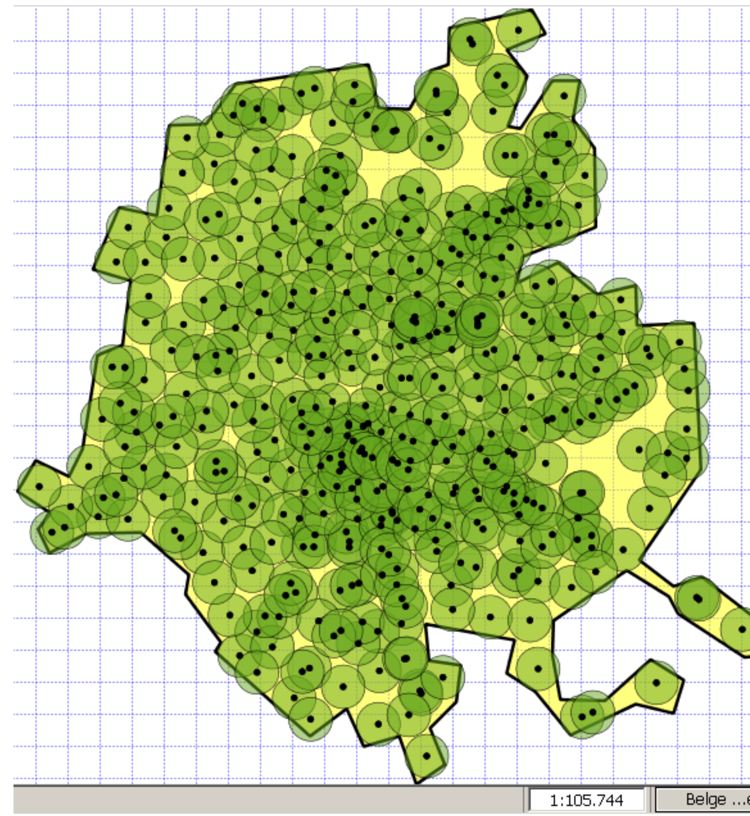
Infrastructure

New GSM operator



96.8% coverage
177 antennas

New 3G operator

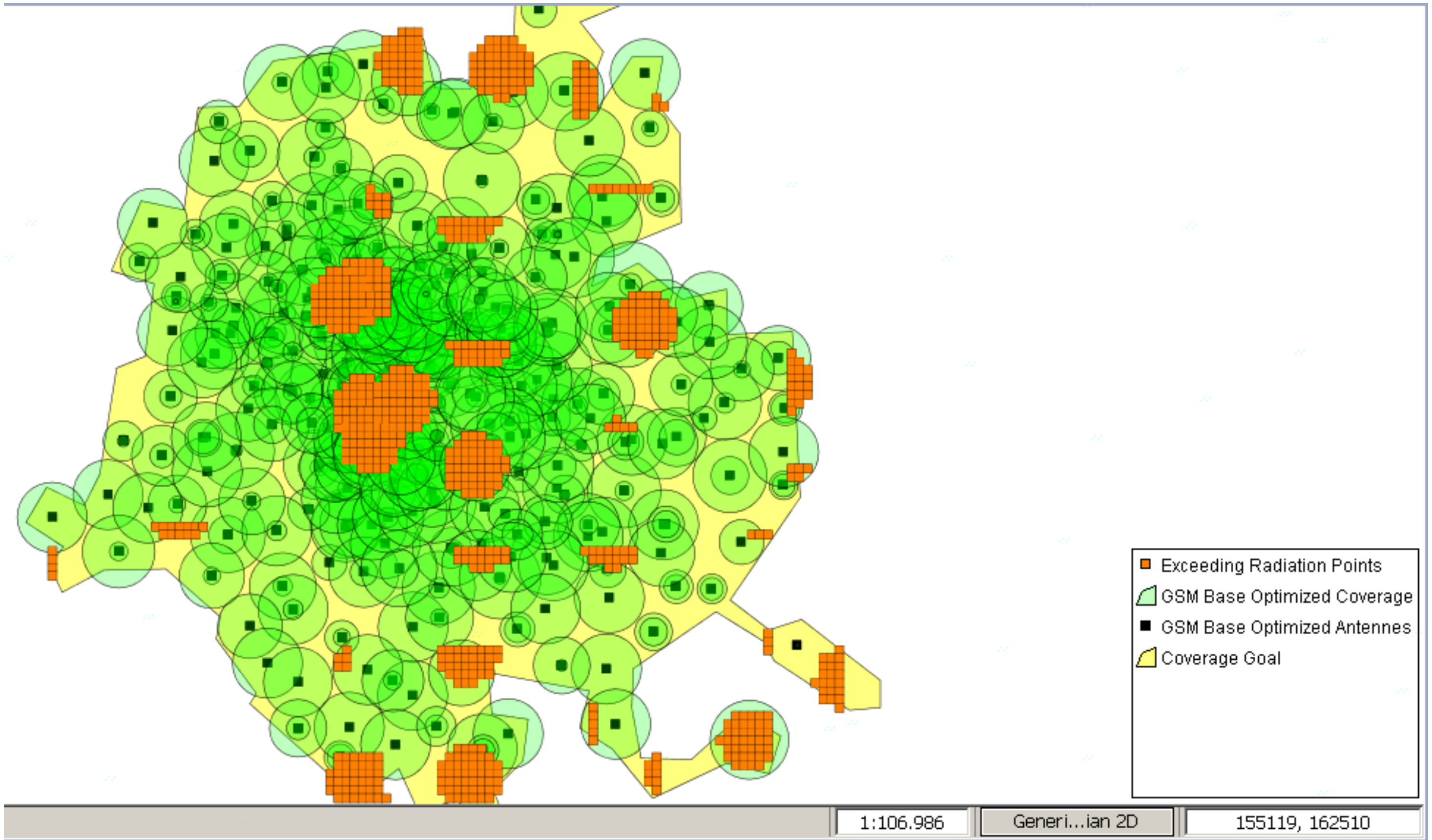


91.61% coverage
419 antennas

Wireless network exposure
taking regulation into account

Model

Infrastructure



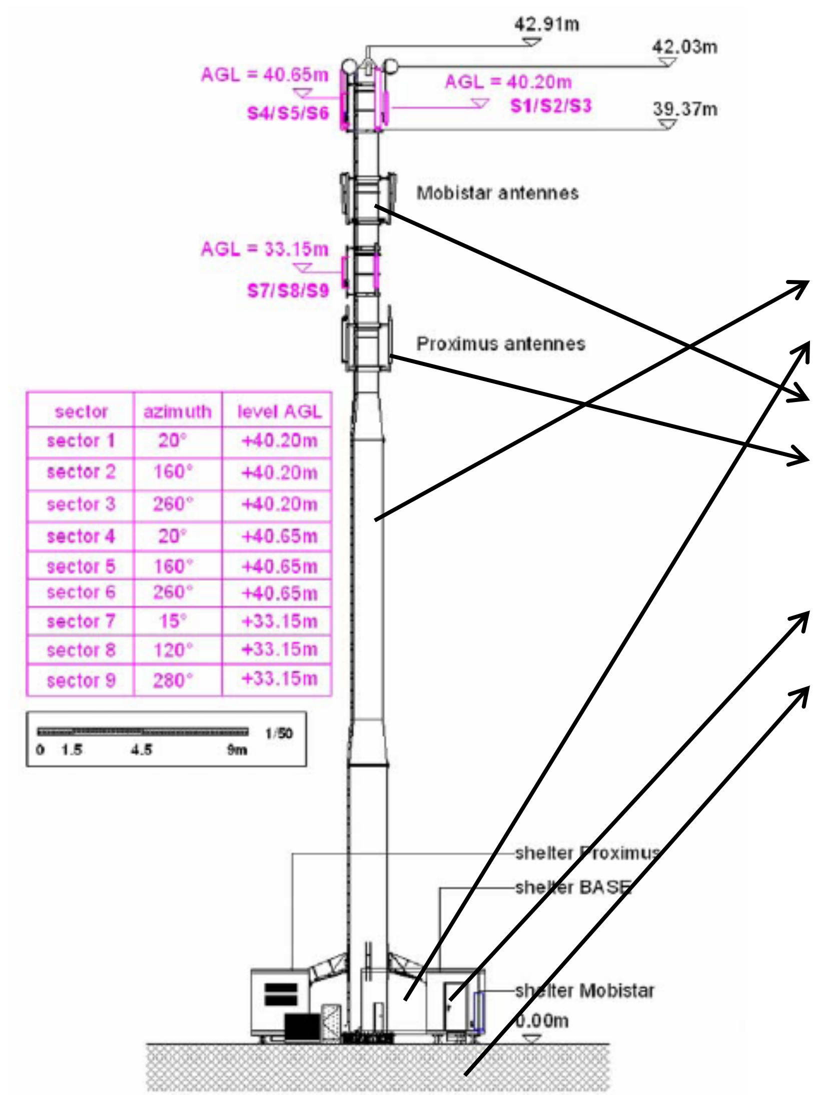
Antenna power is set above its maximum for some locations

→ Exceeding exposure limits

Wireless network dimensioning
Bill of material

Model

Infrastructure

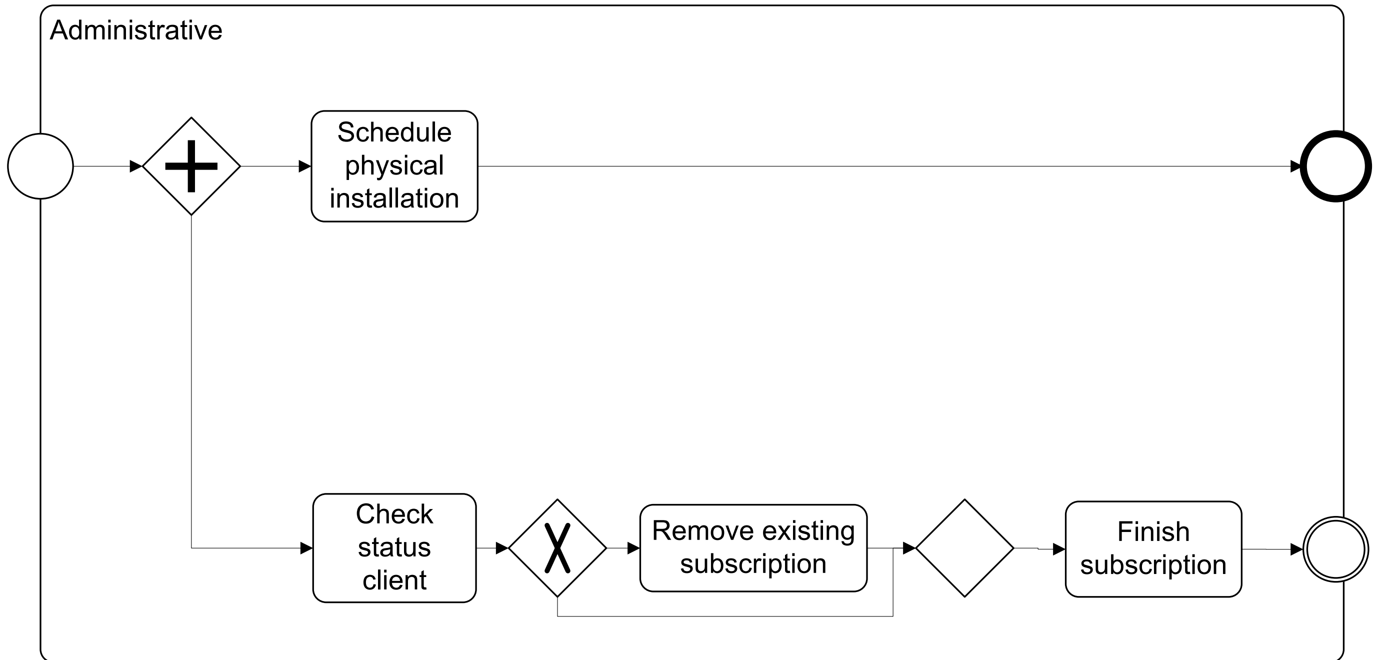


sector	azimuth	level AGL
sector 1	20°	+40.20m
sector 2	160°	+40.20m
sector 3	260°	+40.20m
sector 4	20°	+40.65m
sector 5	160°	+40.65m
sector 6	260°	+40.65m
sector 7	15°	+33.15m
sector 8	120°	+33.15m
sector 9	280°	+33.15m

- *# sites*
- *# base stations*
- *# antennas*
- *# sectors*

- *Shelter*
- *Backhaul connection equipment*

Process based cost modeling



Standards: BPMN, XPDL

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

BPMN: graphical format

Model

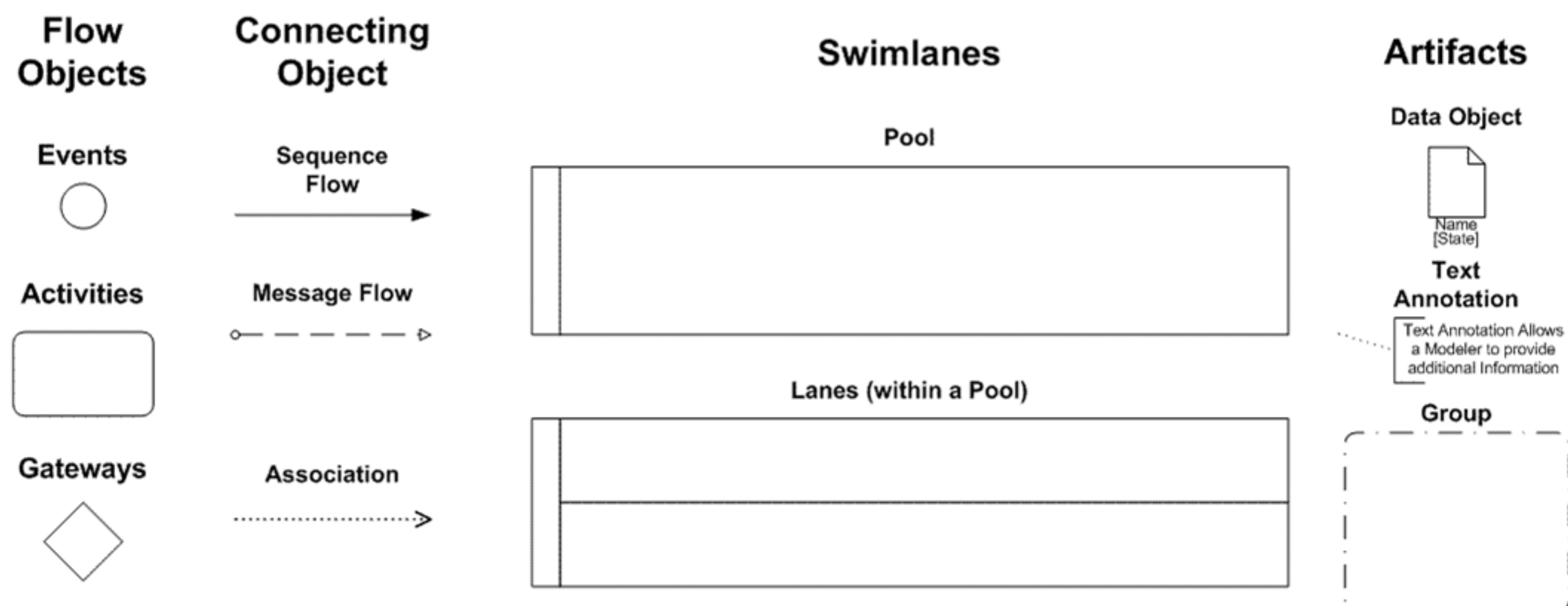
Processes

- 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

Model

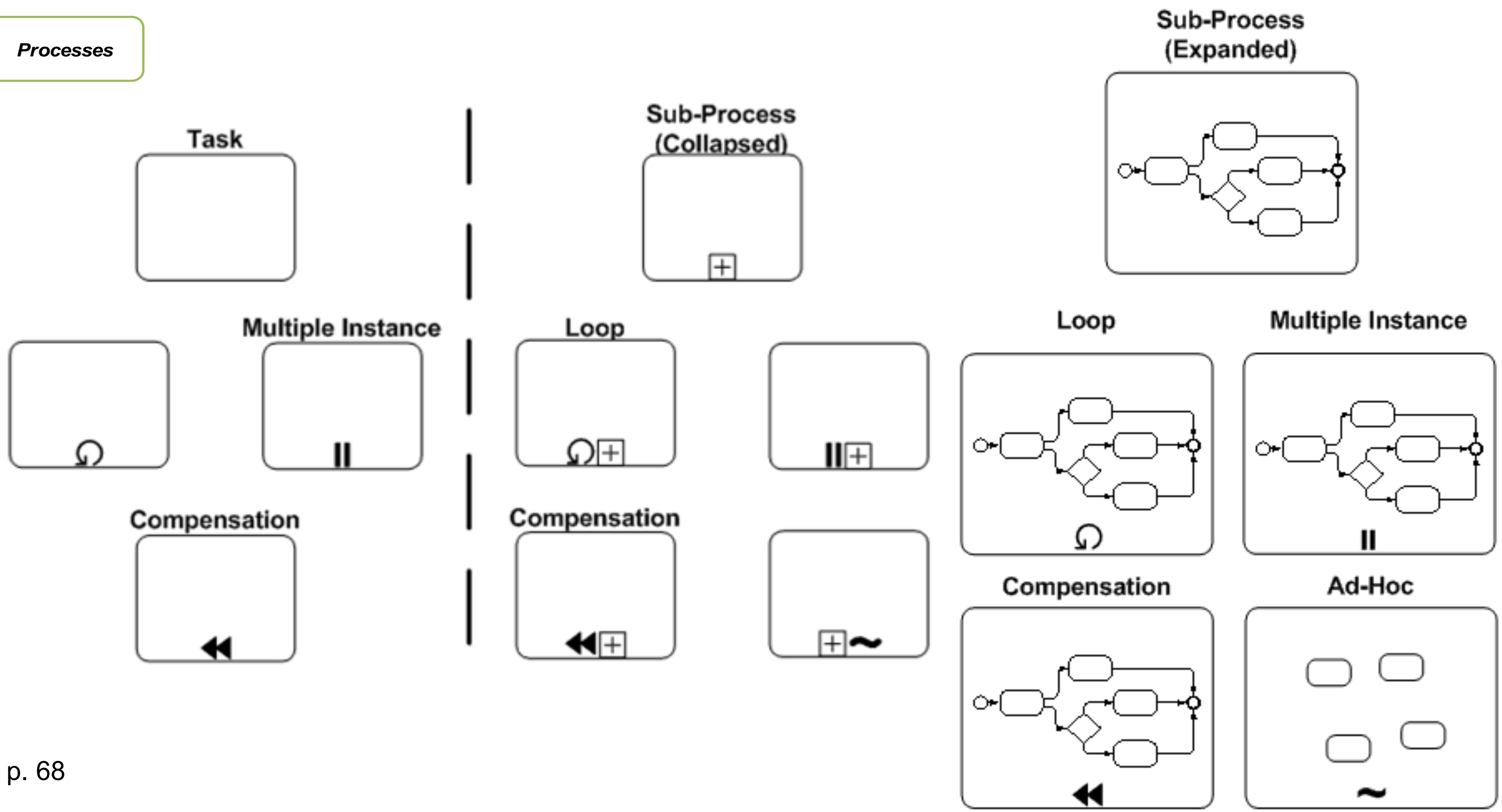
Processes



Activities
from Complete BPMN Elements

Model

Processes



Events
from Complete BPMN Elements

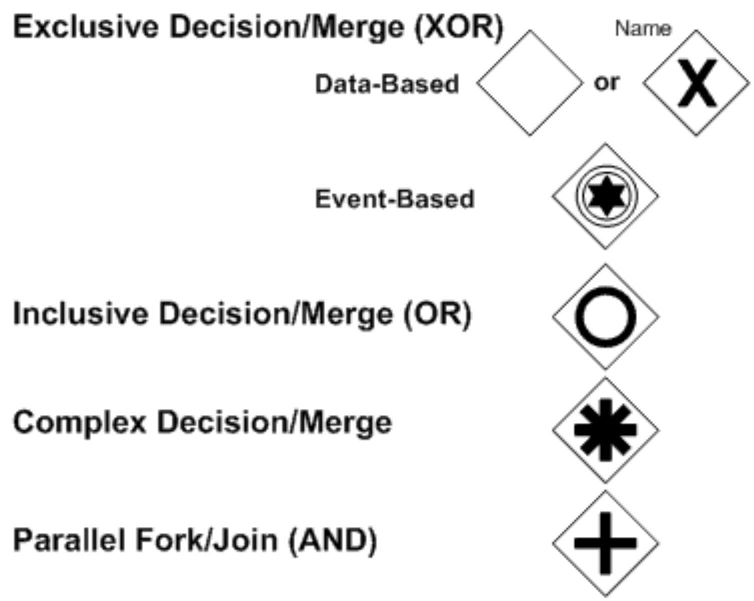
Model

Processes

Gateways
from Complete BPMN Elements

Model

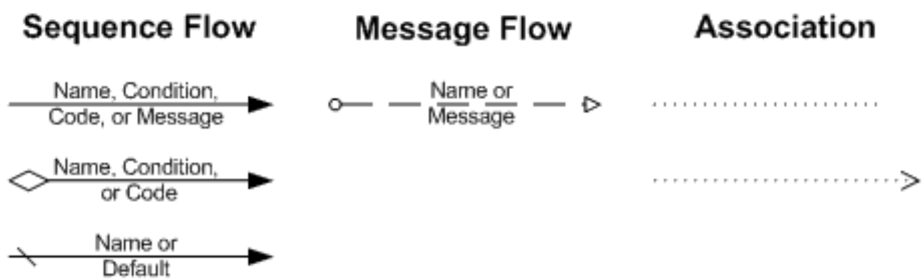
Processes



Connections
from Complete BPMN Elements

Model

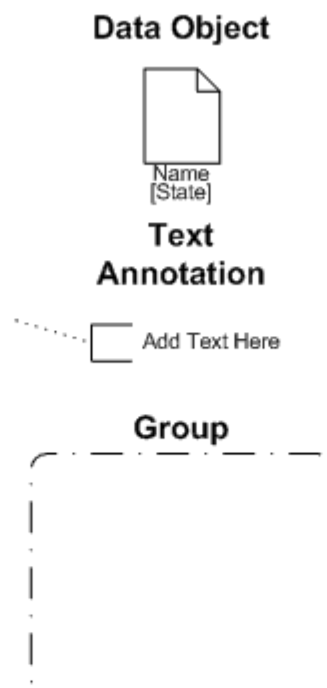
Processes



Artifacts
from Complete BPMN Elements

Model

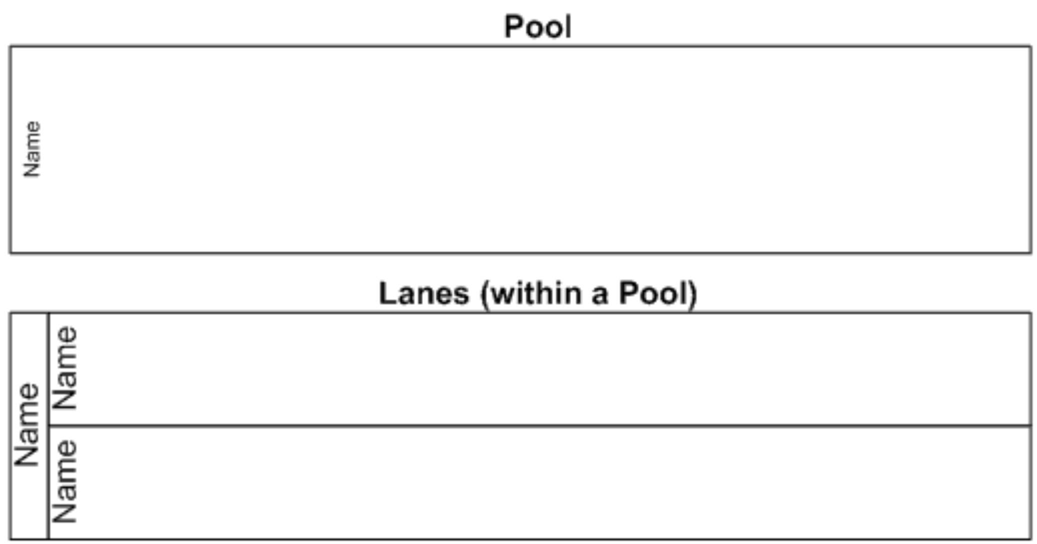
Processes



Pools
from Complete BPMN Elements

Model

Processes



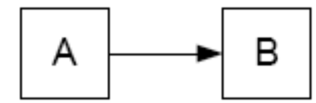
XPDL: textual format

Model

Processes

- 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 !

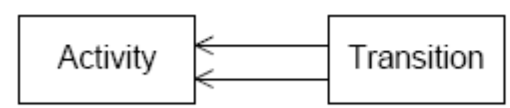
Example Arc



XPDL Transition

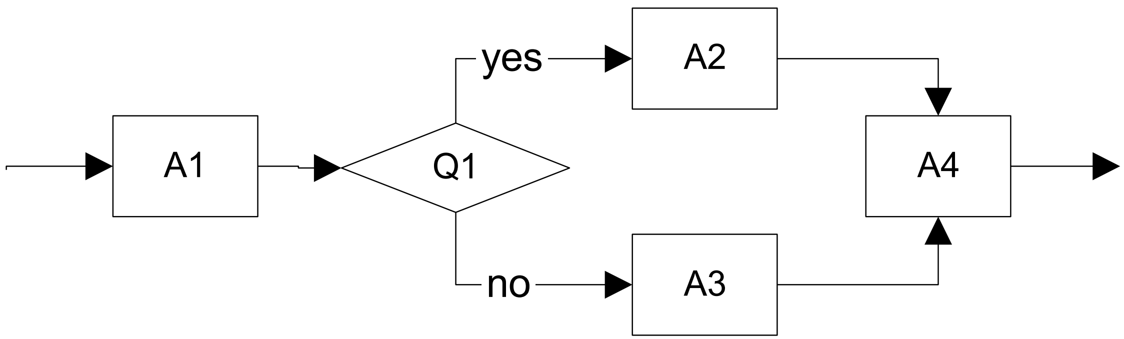
```
<Activity Id="A"/>
<Activity Id="B"/>
<Transition
 From="A" To="B"/>
```

UML Representation



Activity-based costing

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



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

5. total OpEx cost for network scenario

Define cost of an action

Model

Processes

- Straightforward approach:
  cost of action = time needed to perform action * 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
  = wages + *training + tools and transport*
  = wages (1 + *weight factor*)

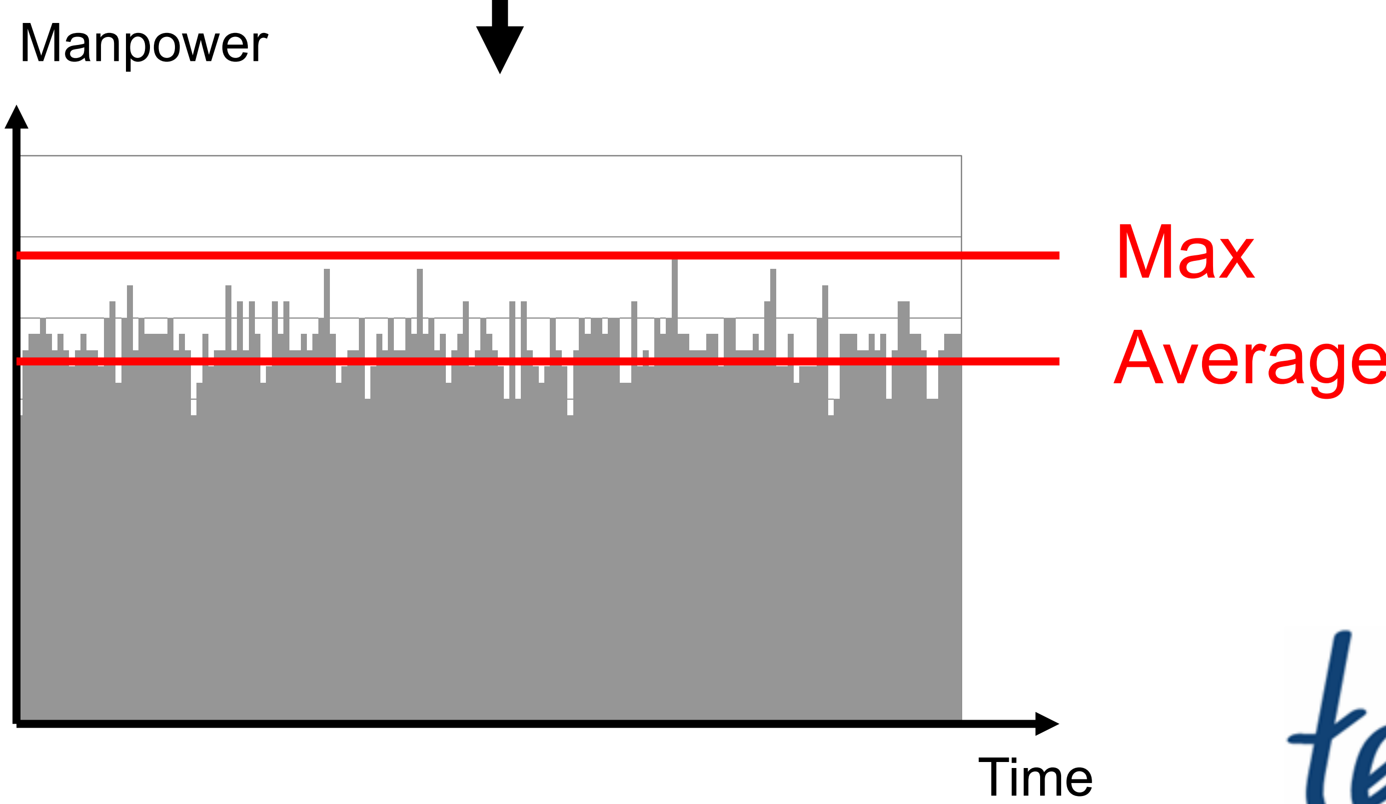
  weight factor per category:
  e.g. technicians need more tools than administrative personnel

Simulation based costing
Example: repair process simulation

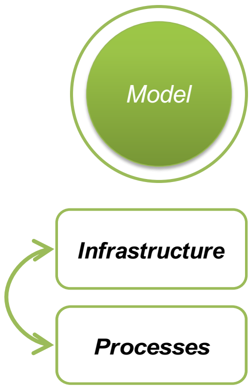
Model

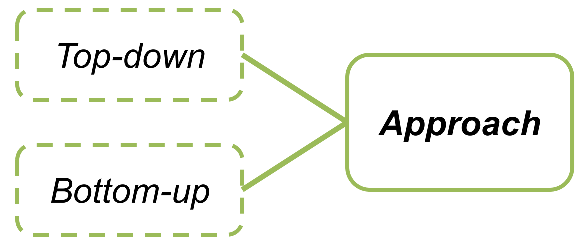
Processes

Model + simulation



Where will the input come from?





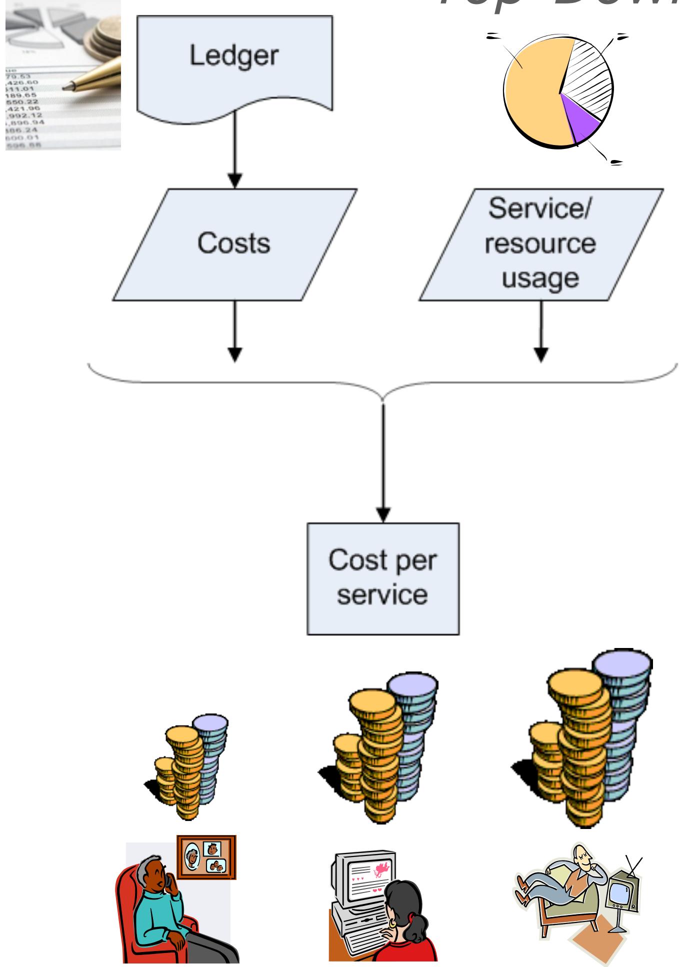
Modeling approach

Model

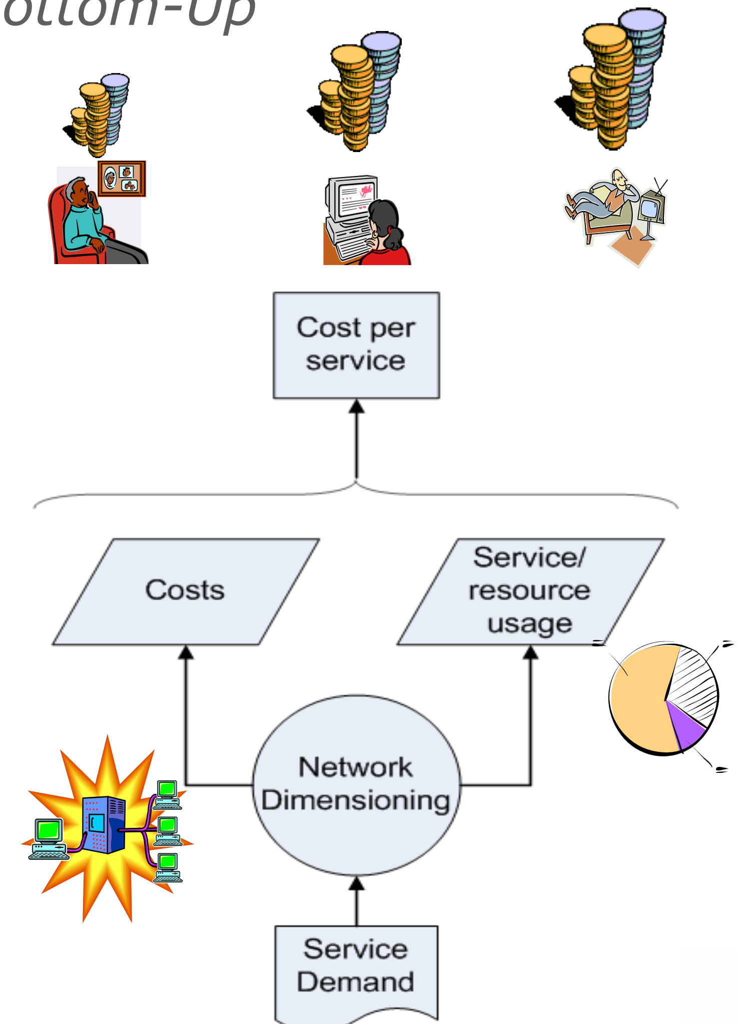
Infrastructure

Processes

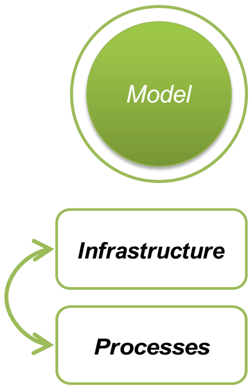
Top-Down

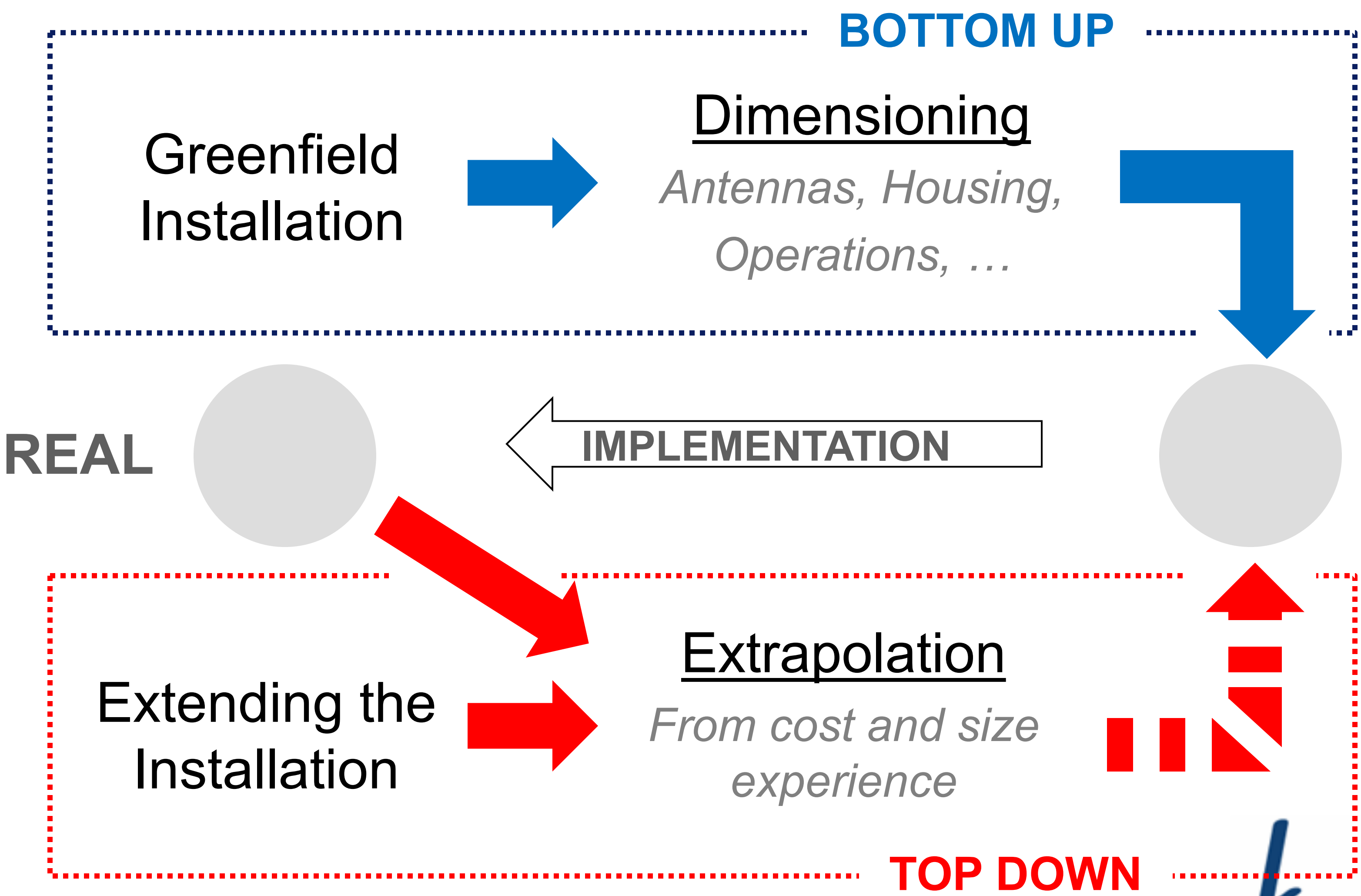


Bottom-Up

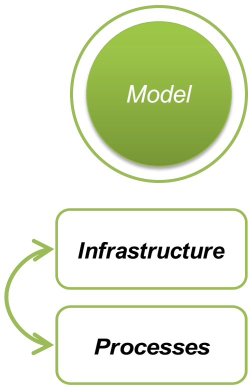


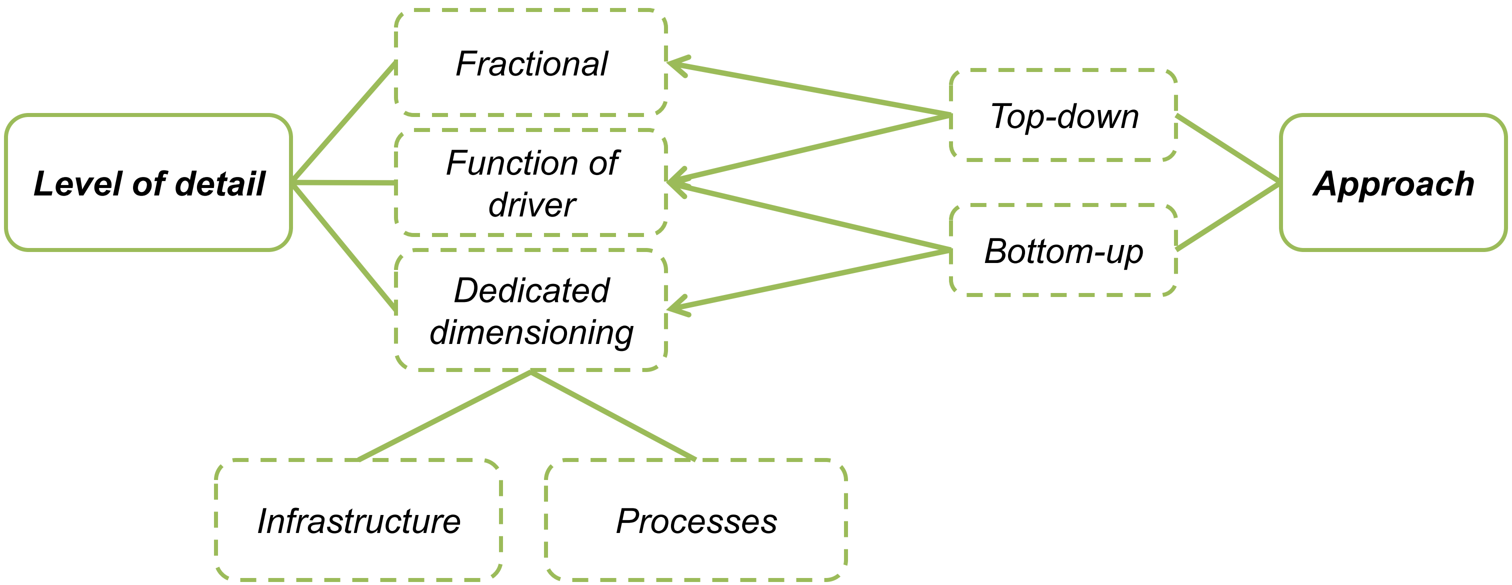
Both approaches
example for a wireless network rollout



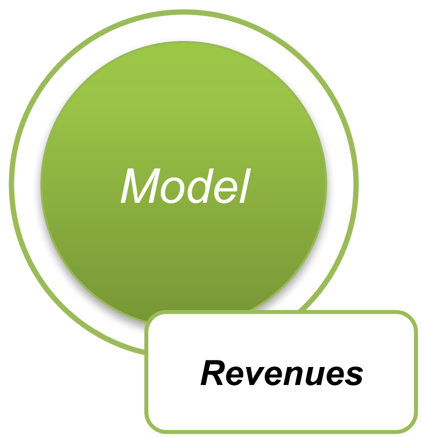


Approach versus level of detail





Model revenues
in a similar way as costs



Direct revenues

Model

Revenues

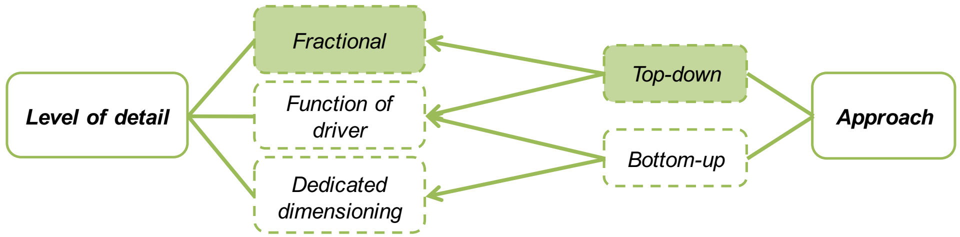
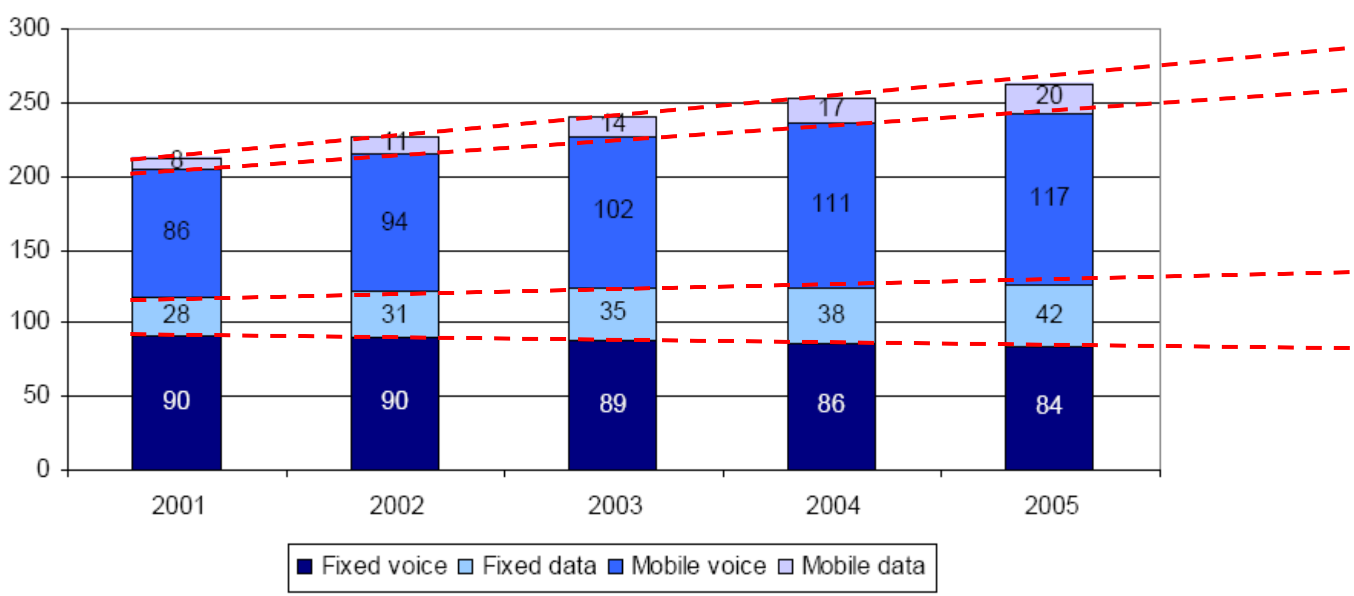
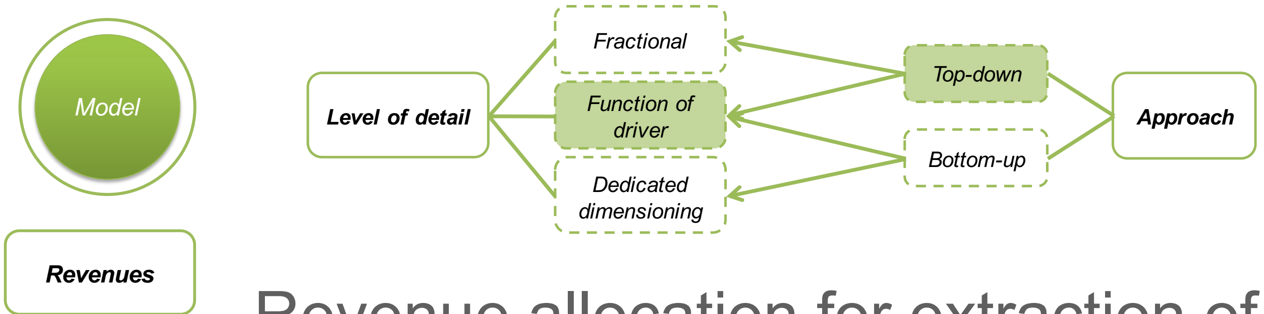


Figure 14: Telecom services revenues in EU-25, 2001-2005
EUR billions



Source: IDATE from national regulation authorities

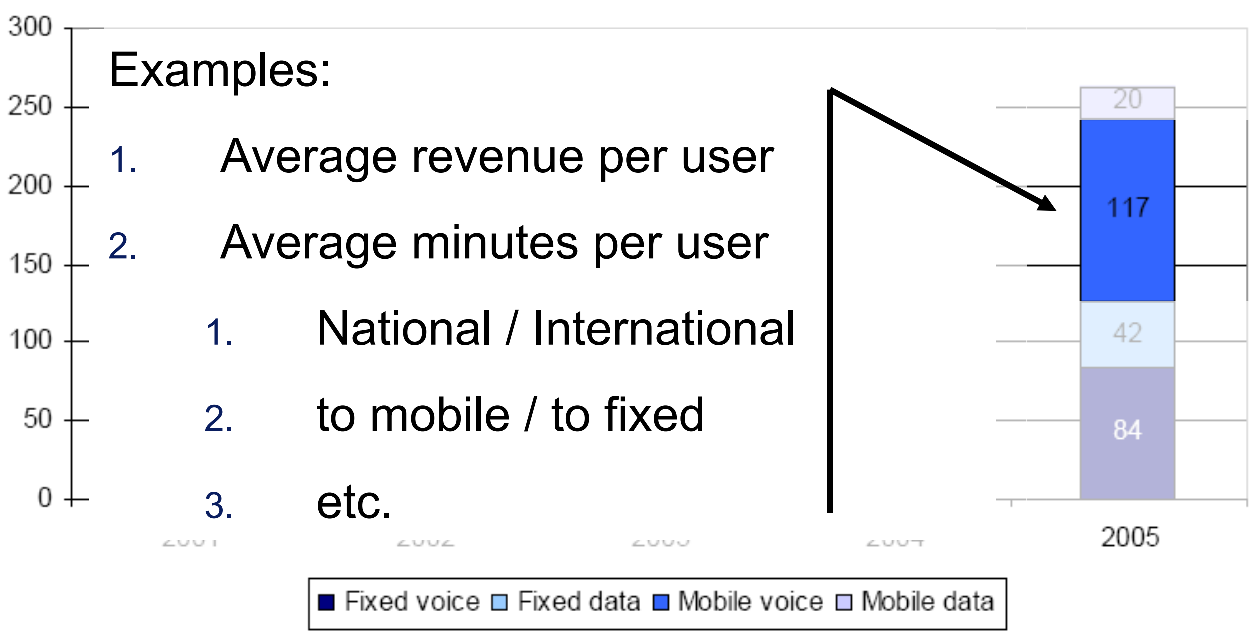
Direct revenues



Revenue allocation for extraction of input revenues

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

EUR billions

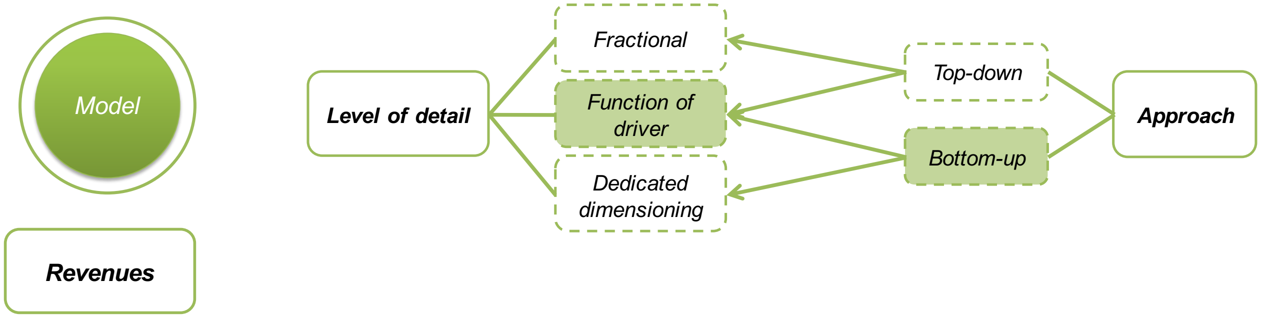


Examples:

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.)

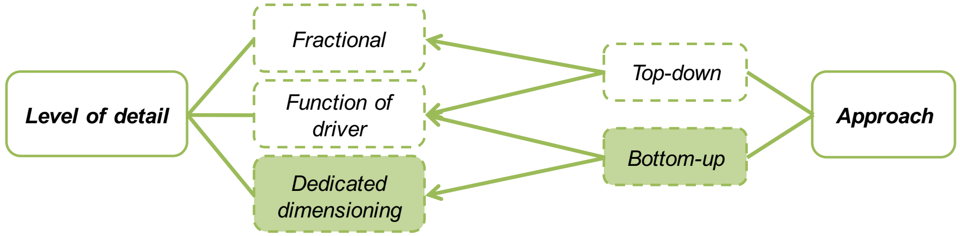
Advertisement revenues +

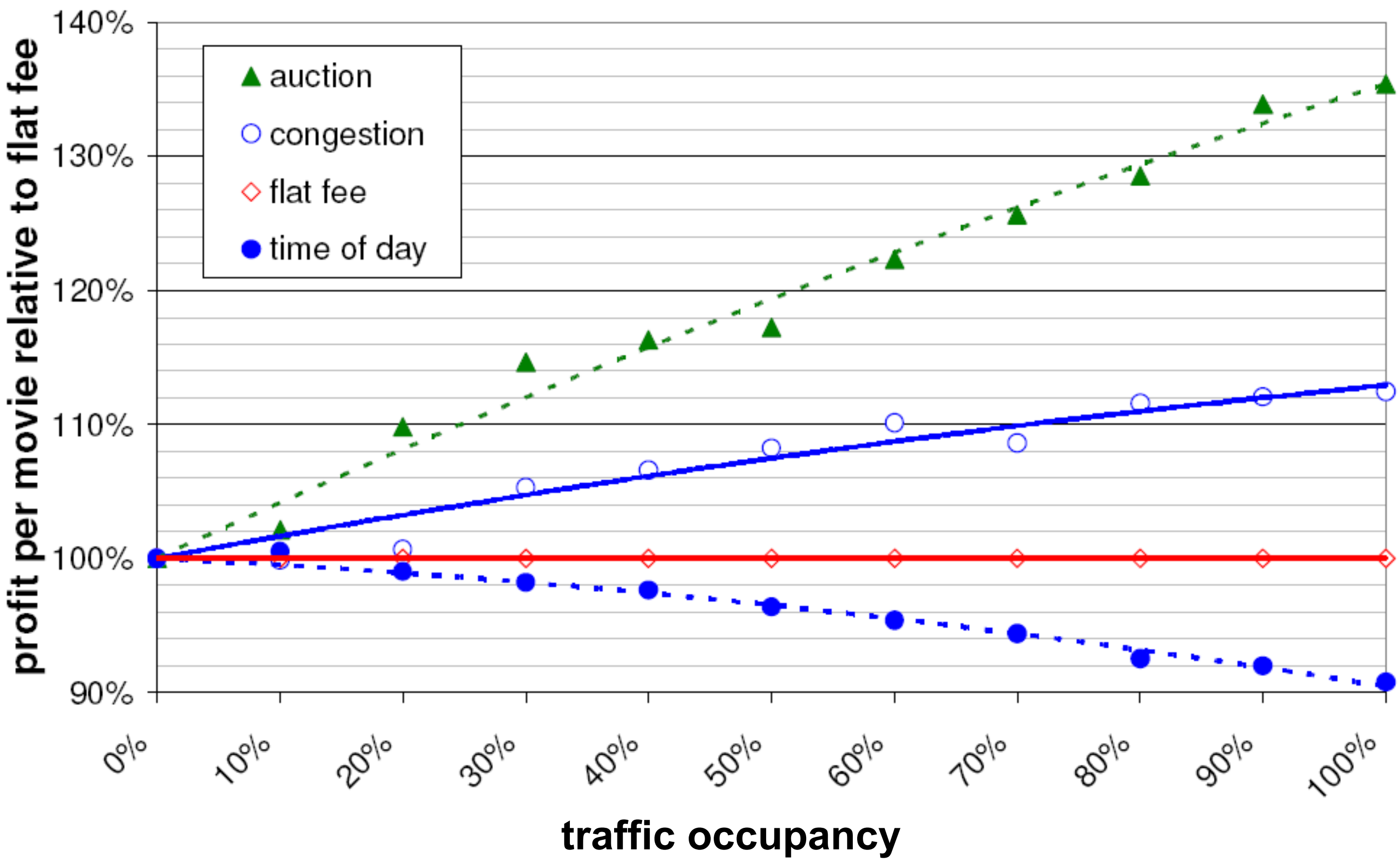
Revenues for IPTV service

Pricing

Model

Revenues

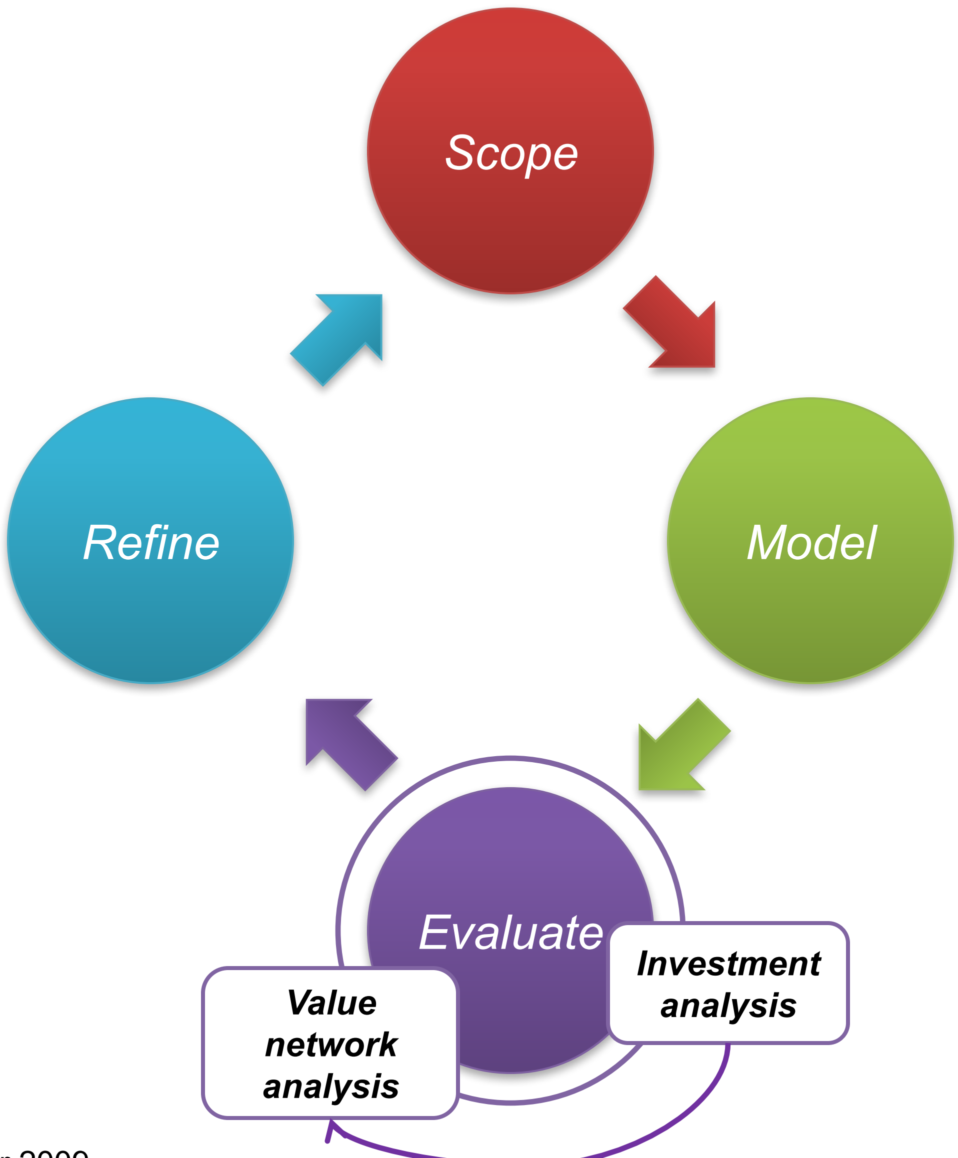




Practical steps in techno-economic evaluation of network deployment planning

EVALUATE

Step 3: Evaluate the project



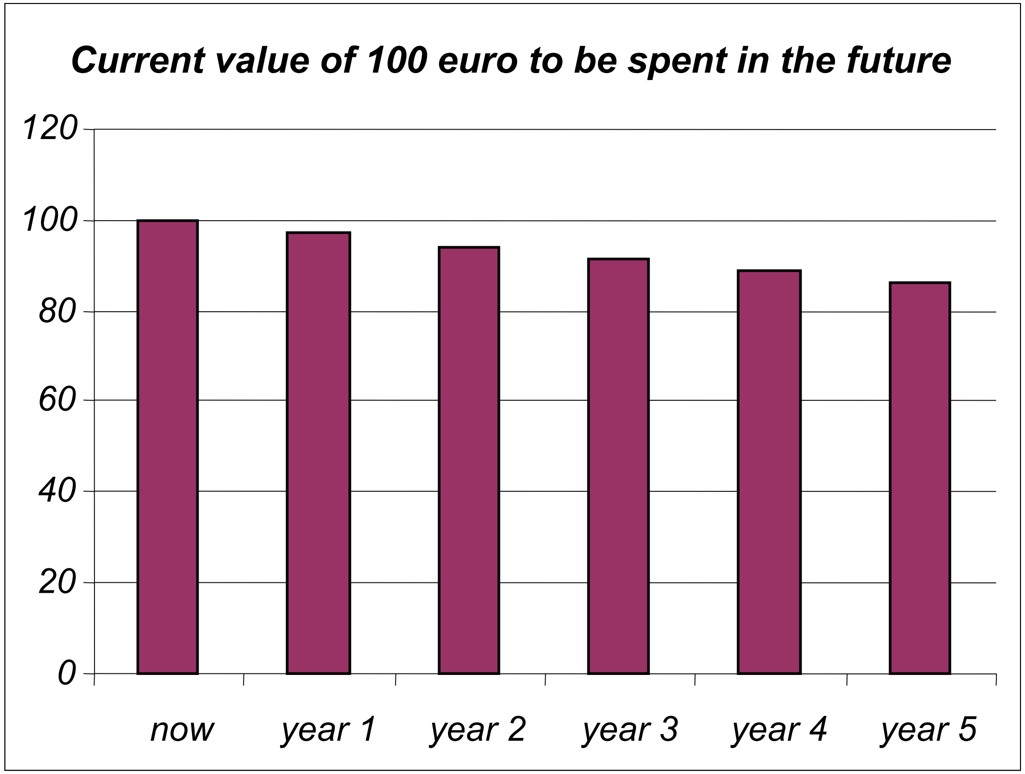
Present value of future cash flows

Evaluate

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

where

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



Defining Rate of Return
Capital Asset Pricing Model (CAPM)

Evaluate

$$E(R_i) = R_f + \beta_{im}\left(E(R_m) - R_f\right)$$

where

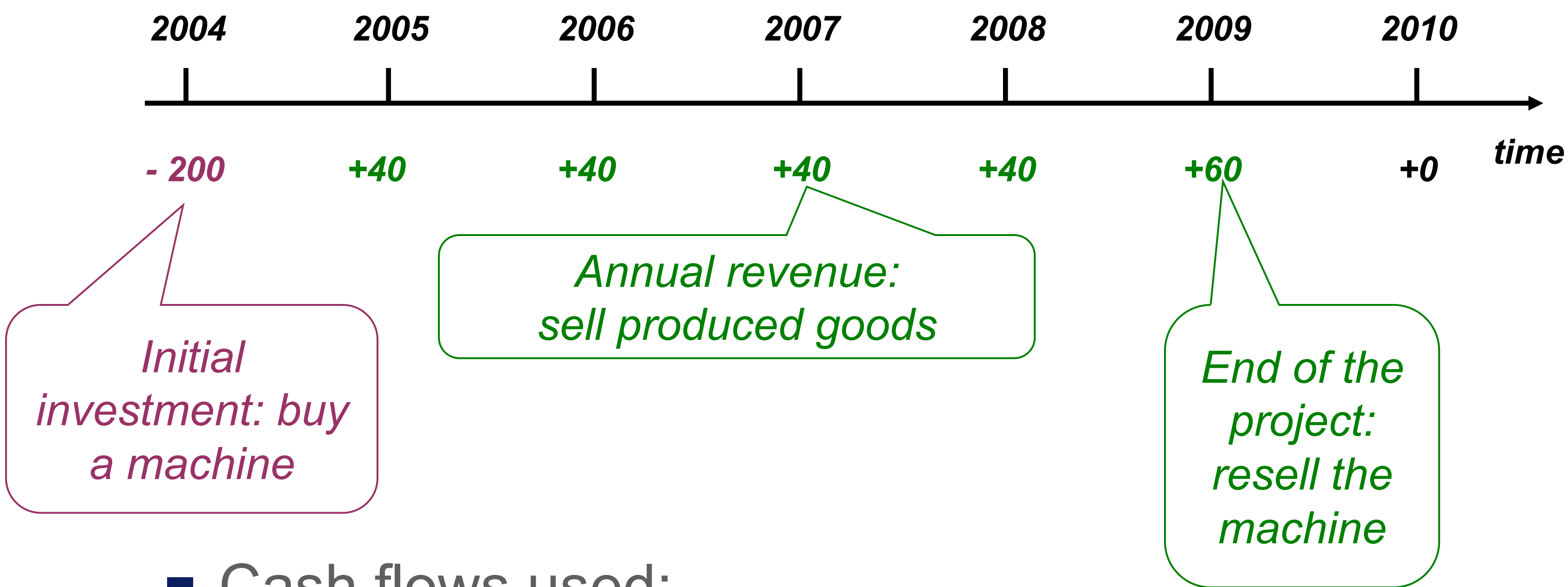
$E(R_i)$	**expected return on the capital asset**
R_f	**risk-free rate of interest**
β_{im}	**sensitivity of the asset returns to market returns**
R_m	**expected return of the market**
$E(R_m) - R_f$	**the *market premium* or *risk premium***

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

UNIVERSITEIT GENT

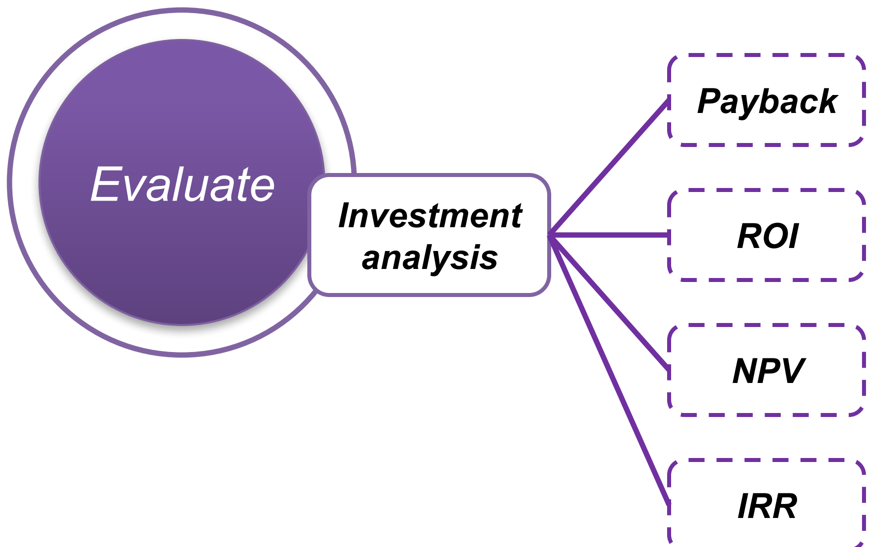
Investment decisions

Evaluate



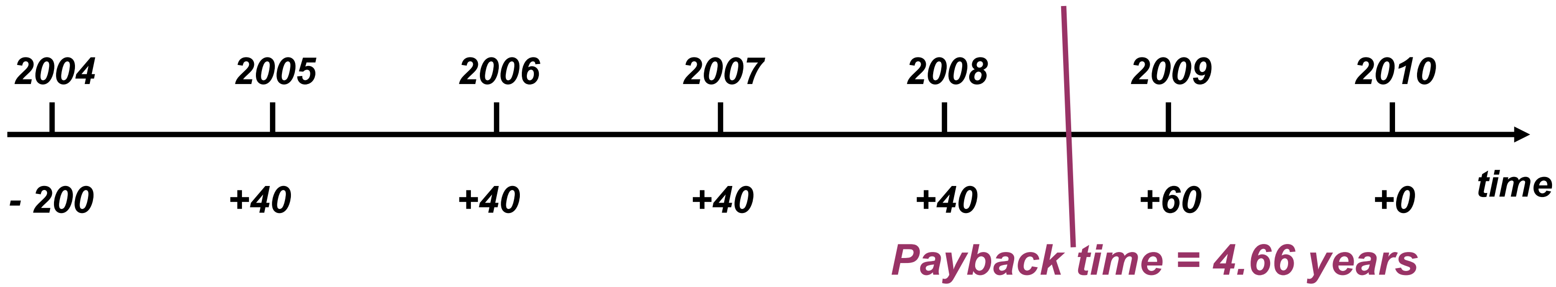
- Cash flows used:
  - **Incremental, operational, after taxes, economical lifetime**

Investment analysis
for static case uses traditional techniques



(Discounted) payback time

- **Payback time = time needed to pay back initial investment**



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)

Evaluate

Investment analysis

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)

Evaluate

Investment analysis

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 >= 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)

Evaluate

Investment analysis

IRR

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

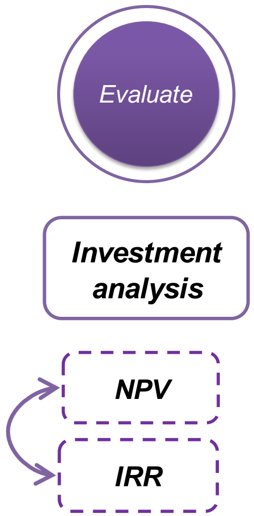
$$\sum_{t=0}^{n} \frac{CF_t}{(1+IRR)^t} = 0$$

Obj.
- IRR >= 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

NPV compared to IRR



- Two mutually exclusive projects

	CF0	CF1	NPV (r=0)	IRR
Small budget	-1 euro	1.5 euro	0.5 euro	50%
Large budget	-10 euro	11 euro	1 euro	10%

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

	CF0	CF1	NPV (r=0)	IRR
Large budget instead of small budget	-10 – (-1) = -9 euro	11-1.5 = 9.5 euro	0.5 euro	0.5/9 = 5.55..%

➔ follow NPV

Comparing two projects
using multiple methods

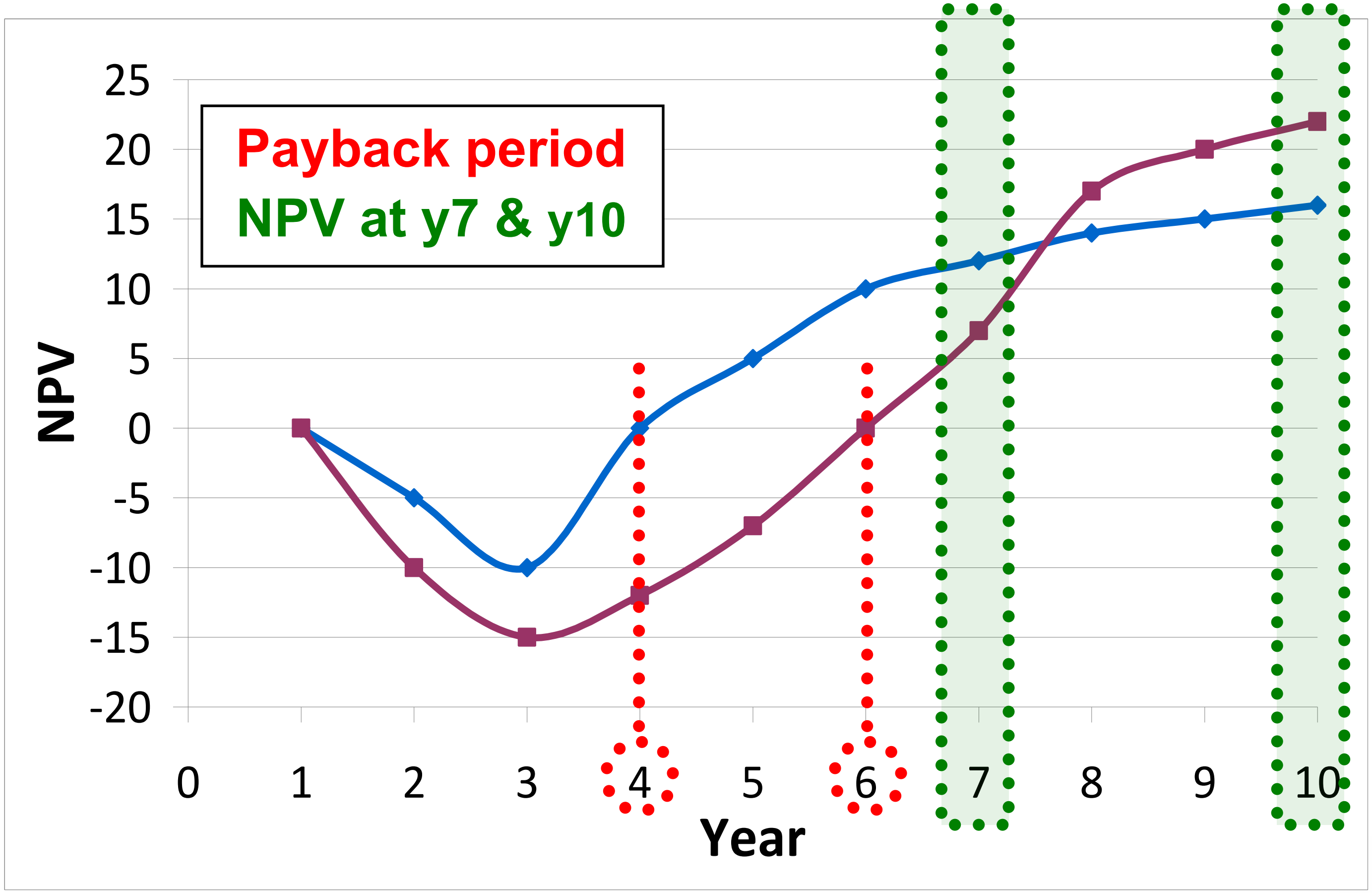
Evaluate

Investment analysis

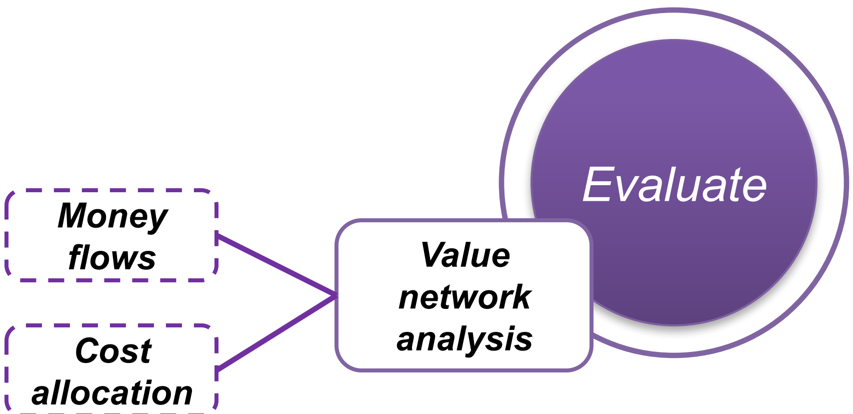
Payback

NPV

Lifetime important



Value network analysis
adds quantitative results to business model



Value network analysis
allows to compare different models

Evaluate

Value network analysis

Money flows

- Third party 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

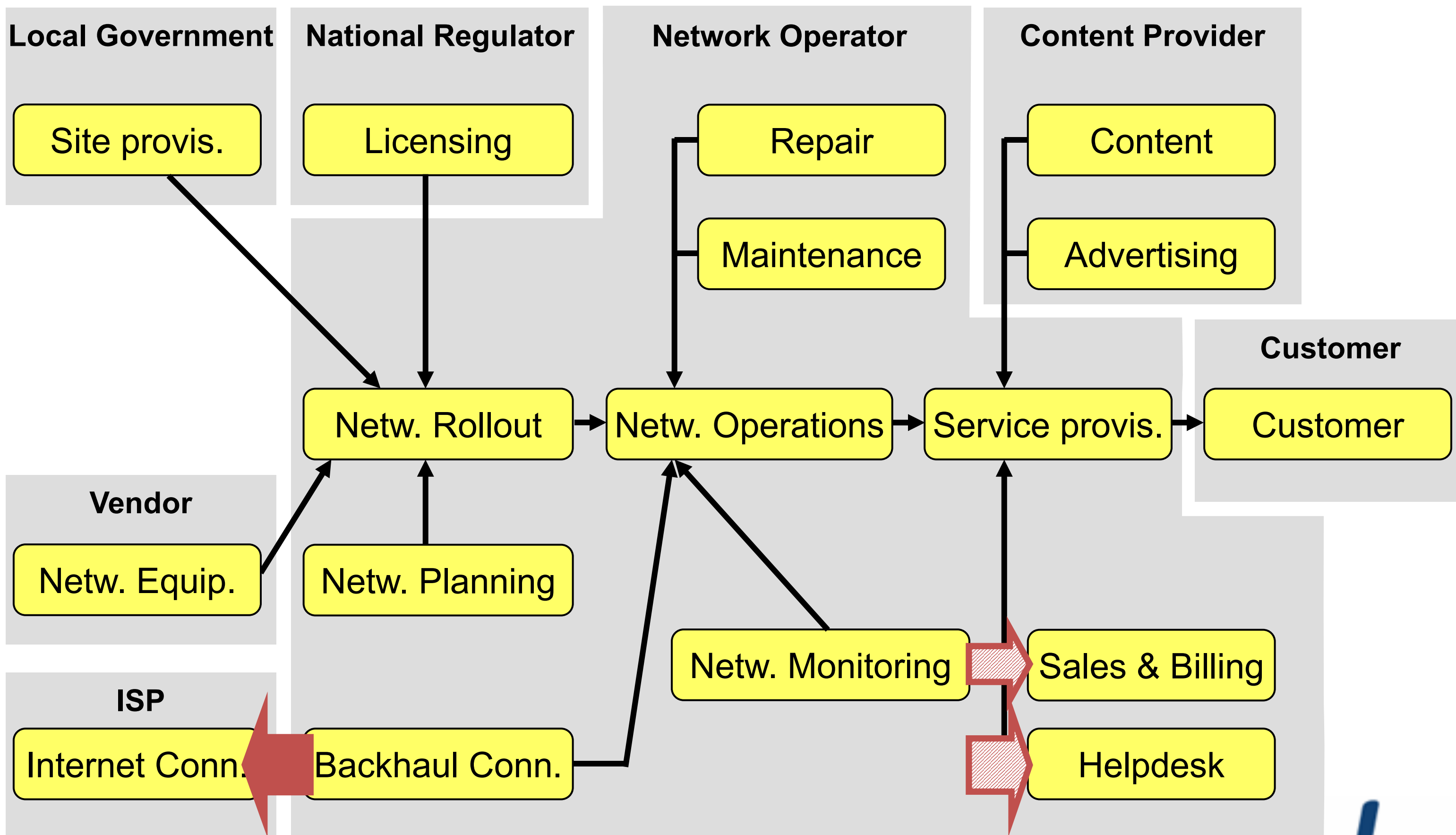
Value network analysis
for a wireless network

Evaluate

Value network analysis

Money flows

Cost savings + revenue sharing ⇒ BC changes!



External cash flow **Internal cash flow**

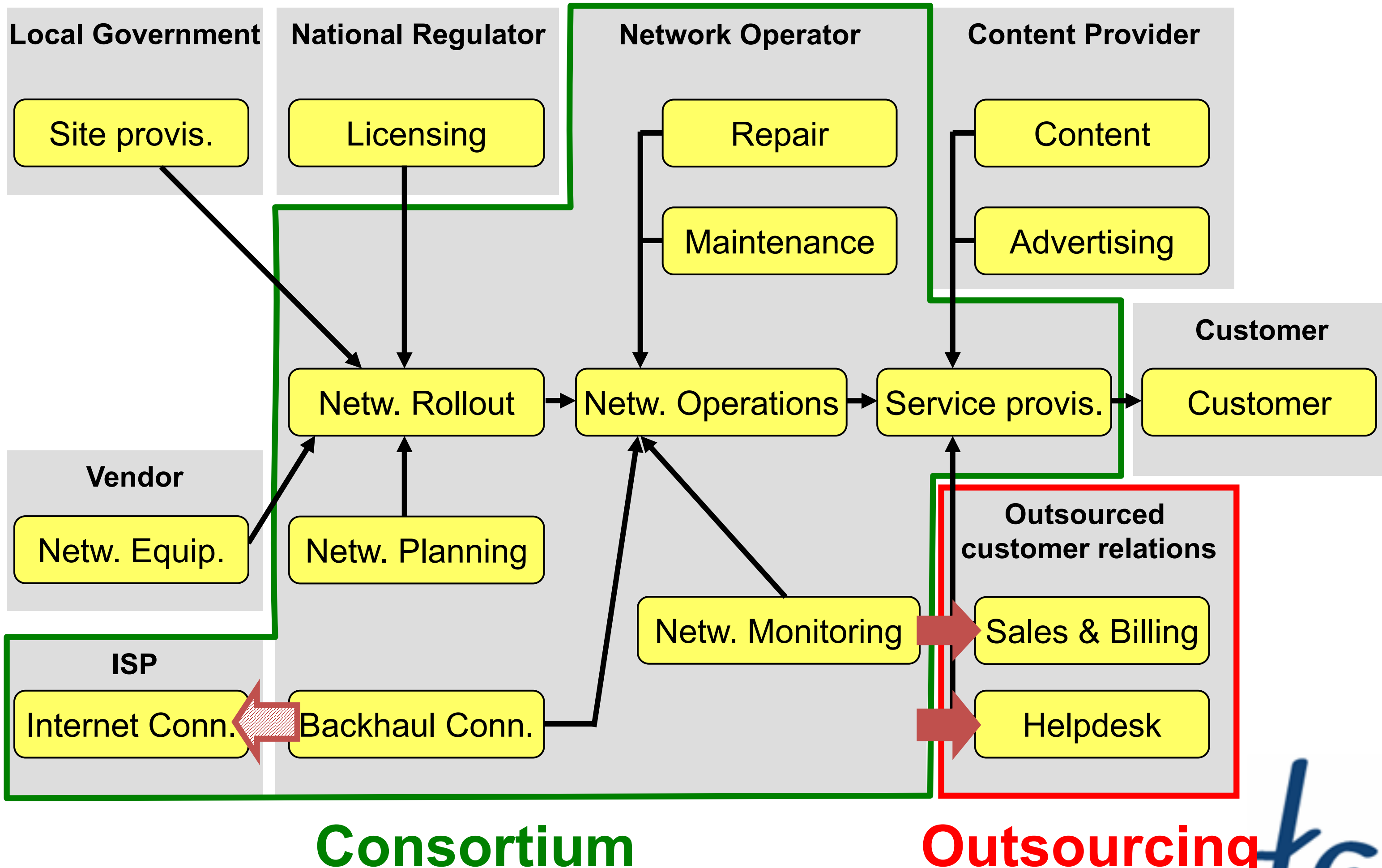
Value network analysis
for a wireless network

Evaluate

Value network analysis

Money flows

Cost savings + revenue sharing ⇒ BC changes!

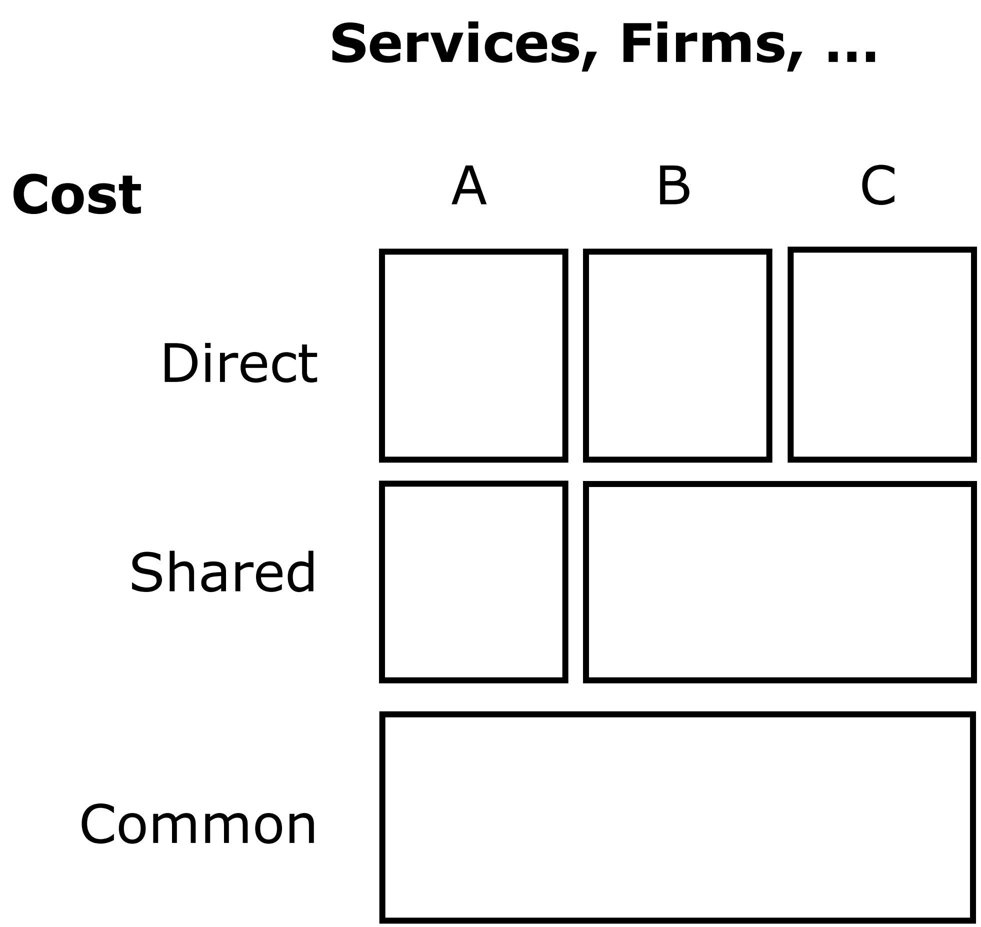


When different services, firms or … share part of their costs..

Evaluate

Value network analysis

Cost allocation

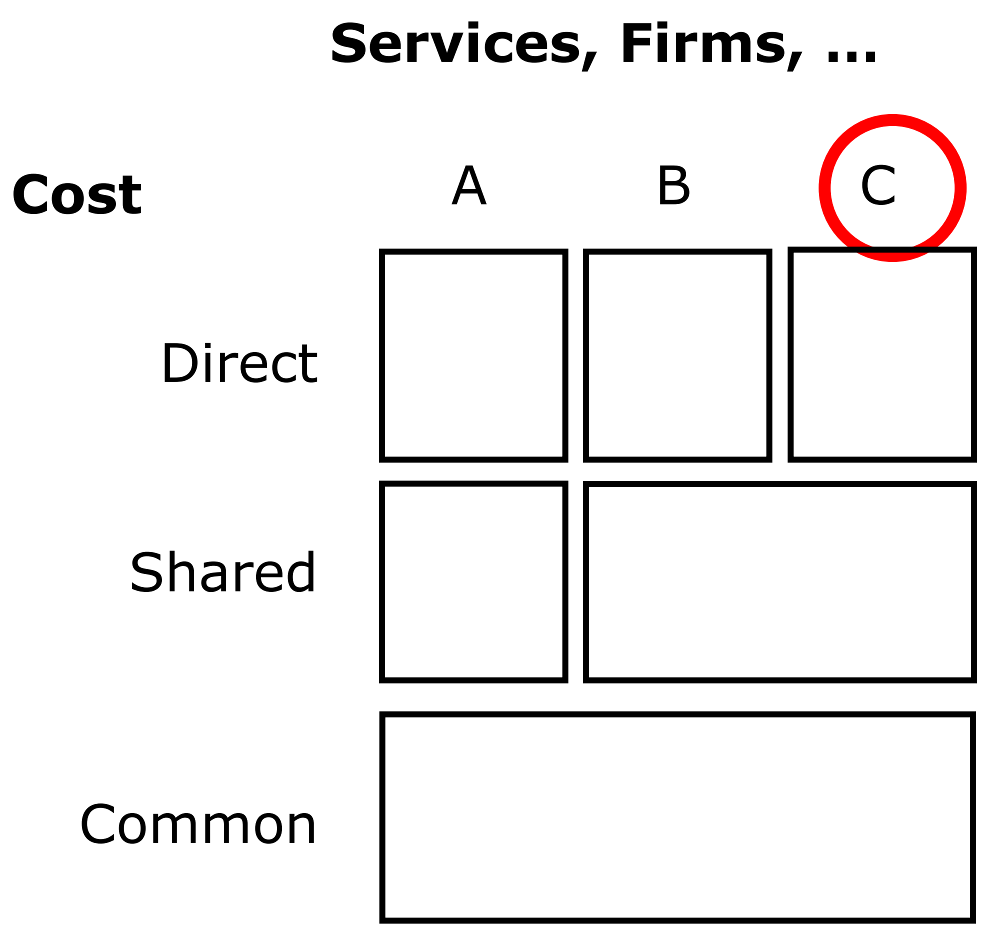


..it is often necessary or useful to know which part of the cost is linked to which service

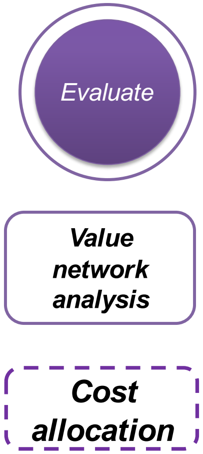
Evaluate

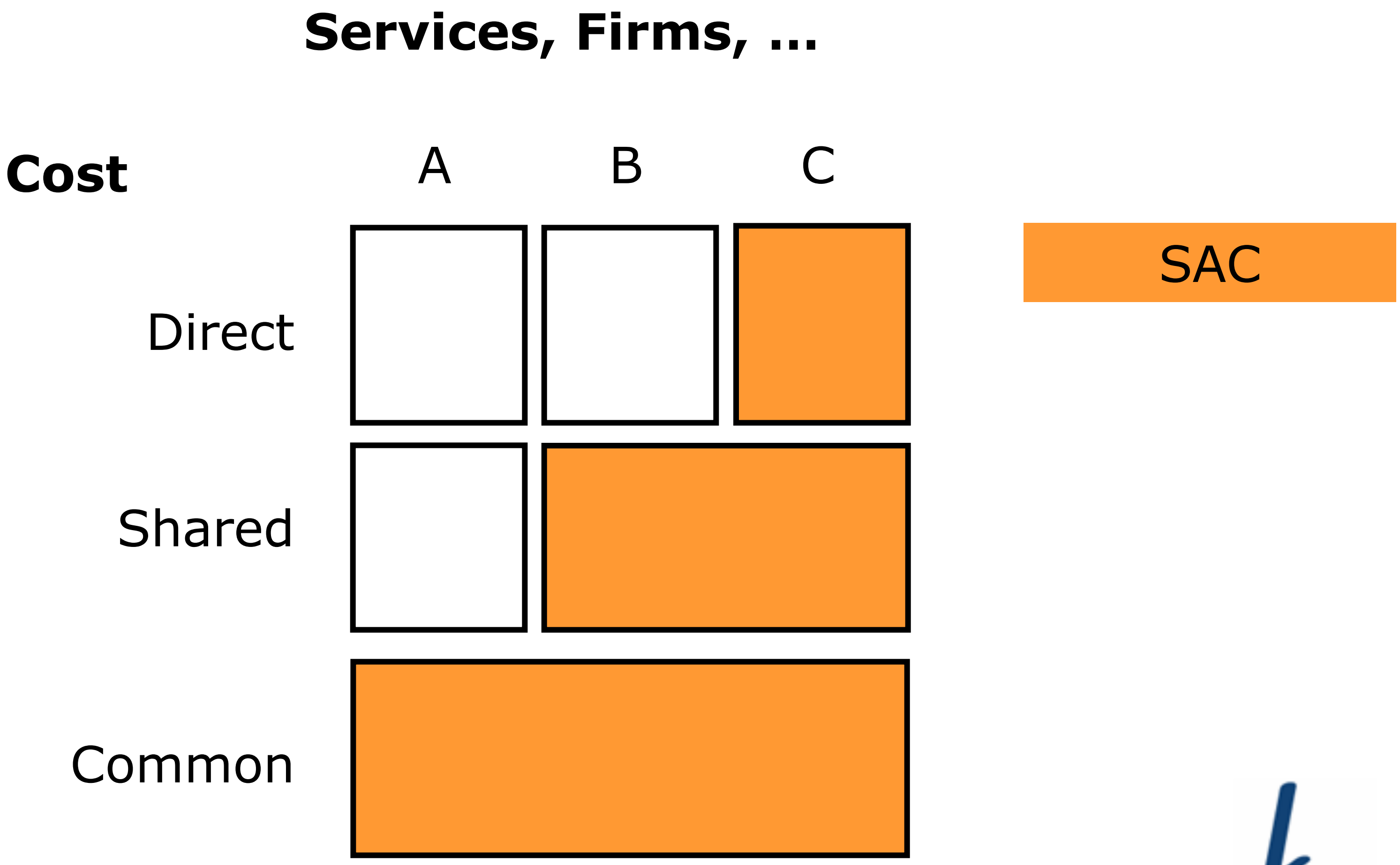
Value network analysis

Cost allocation

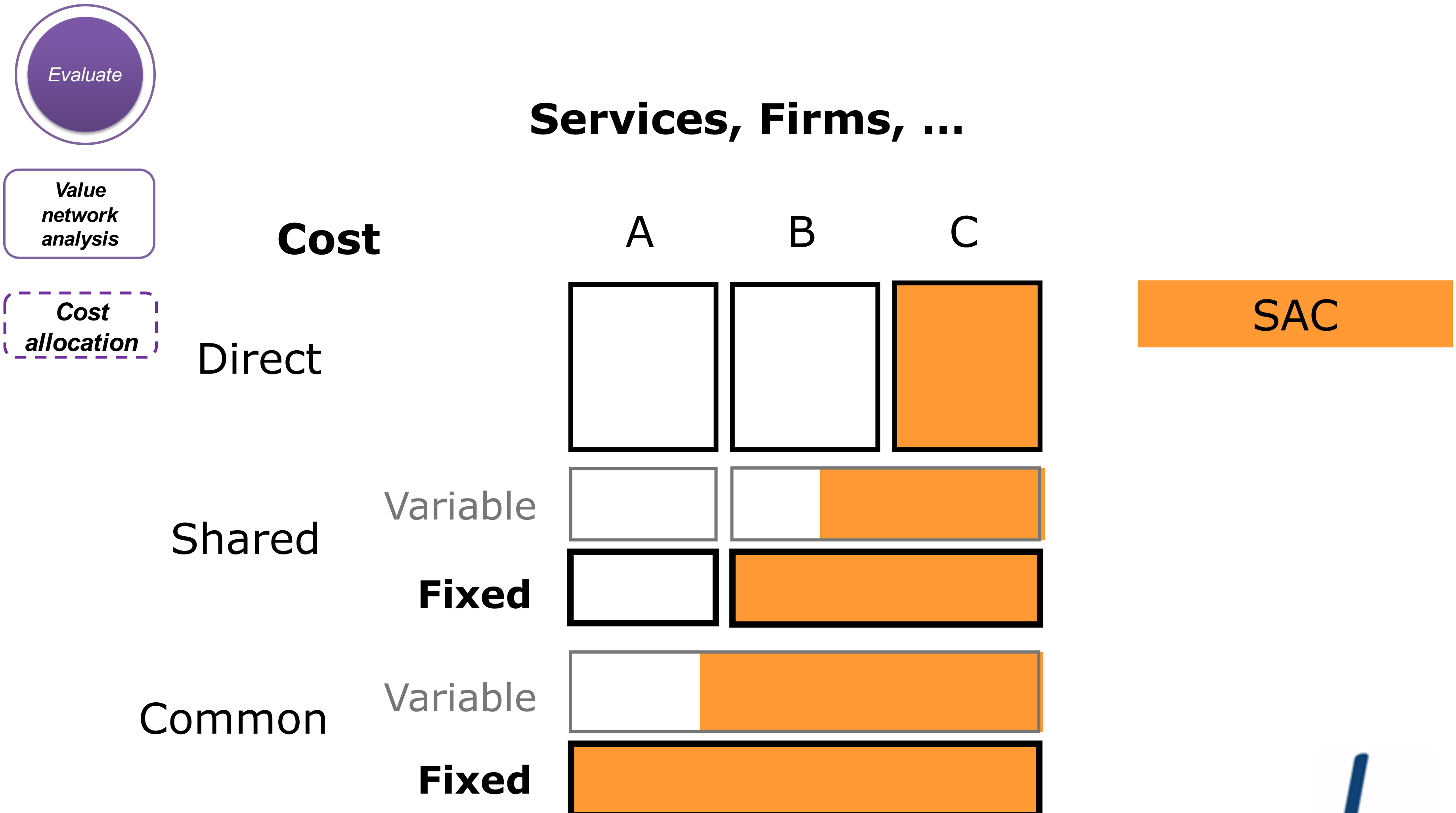


Stand Alone Cost
allocates as a stand-alone installation





Stand Alone Cost
allocates as a stand-alone installation



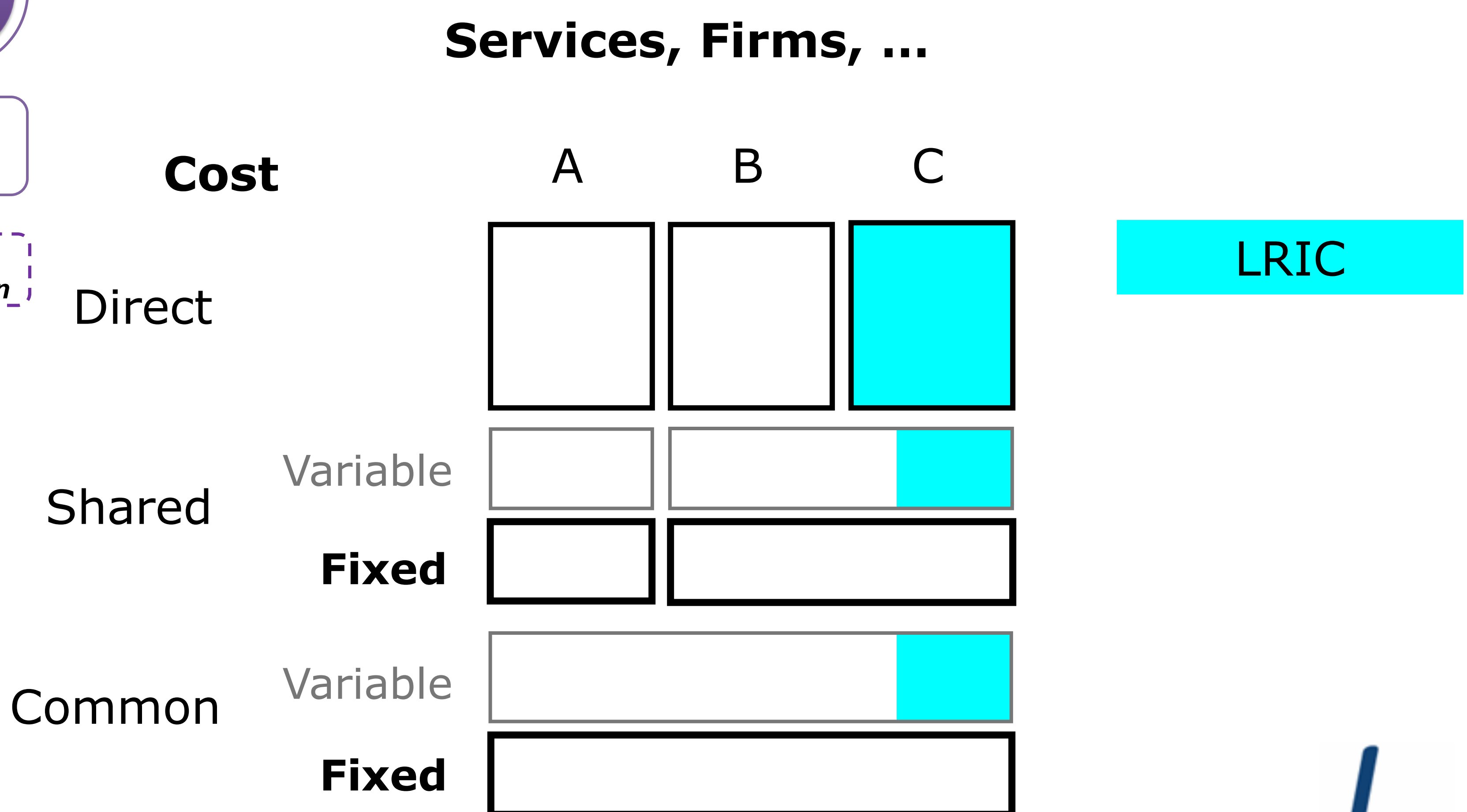
Fully Allocated Cost
allocates the costs more “fairly”

Long Run Incremental Cost
allocates only the incremental costs

Evaluate

Value network analysis

Cost allocation

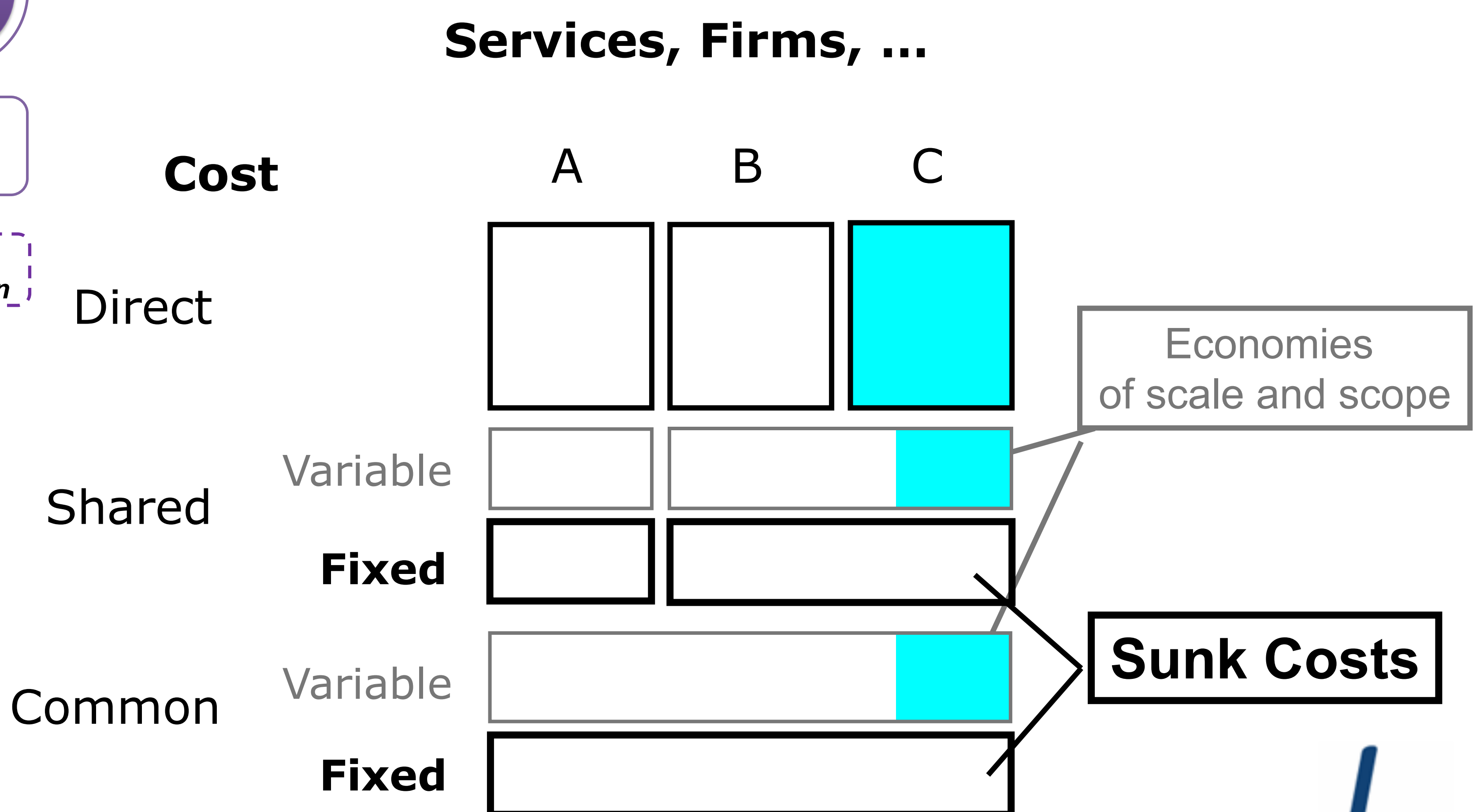


Long Run Incremental Cost
allocates only the incremental costs

Evaluate

Value network analysis

Cost allocation

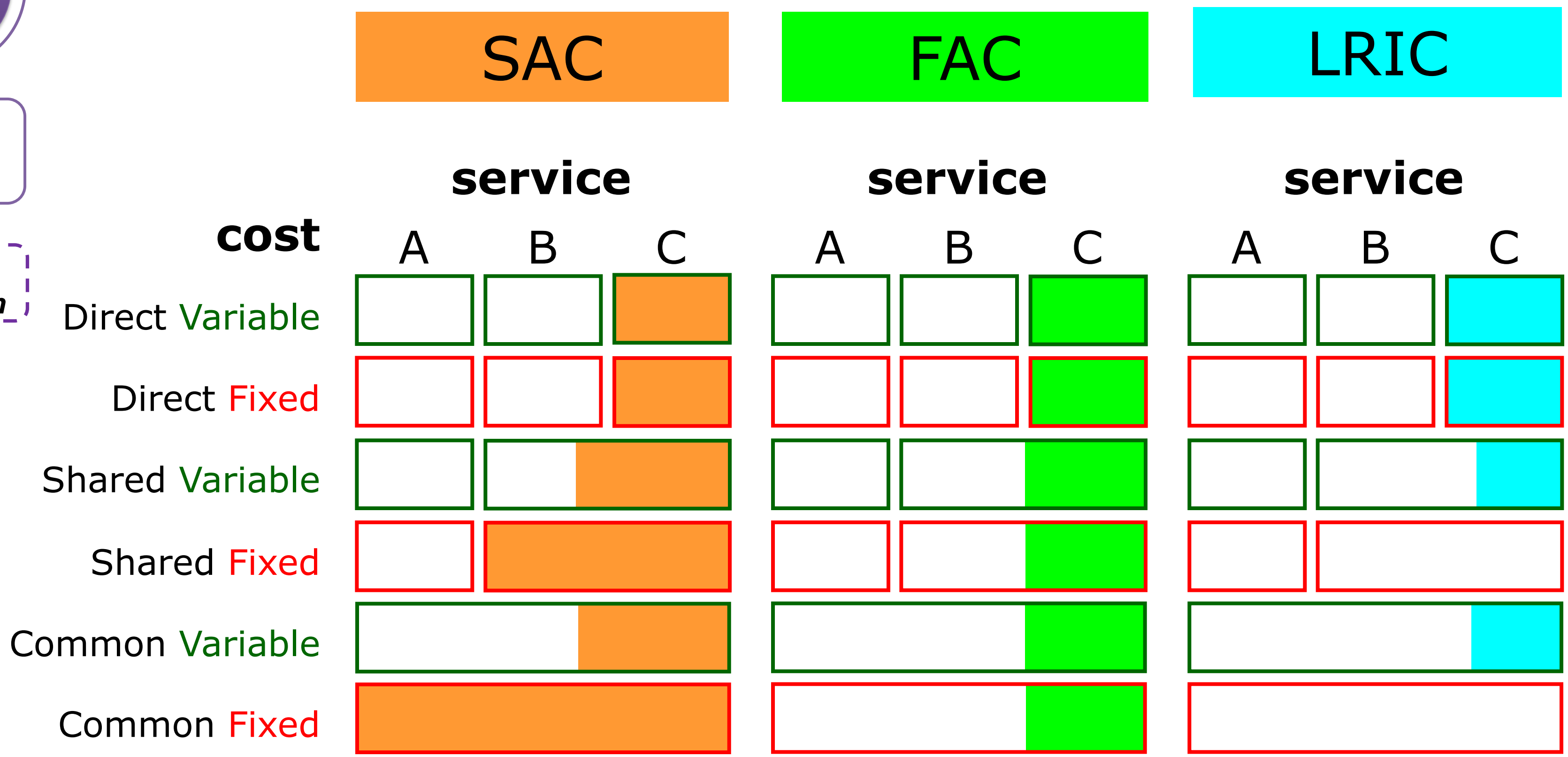


An overview
from highest to lowest allocated cost

Evaluate

Value network analysis

Cost allocation

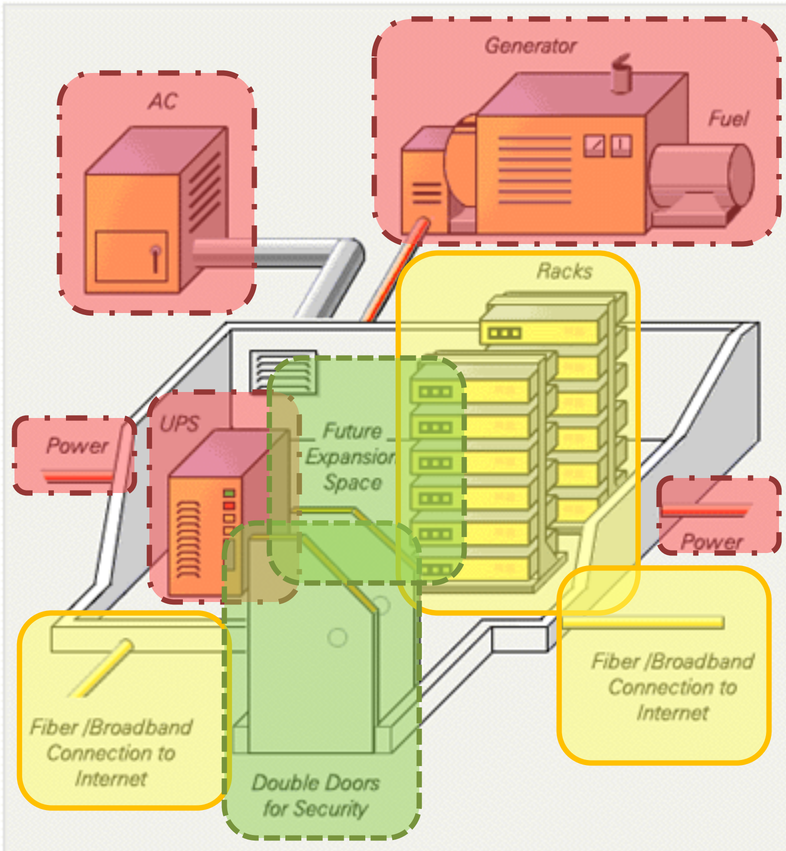


Cost allocation
example for a data center

Evaluate

Value network analysis

Cost allocation

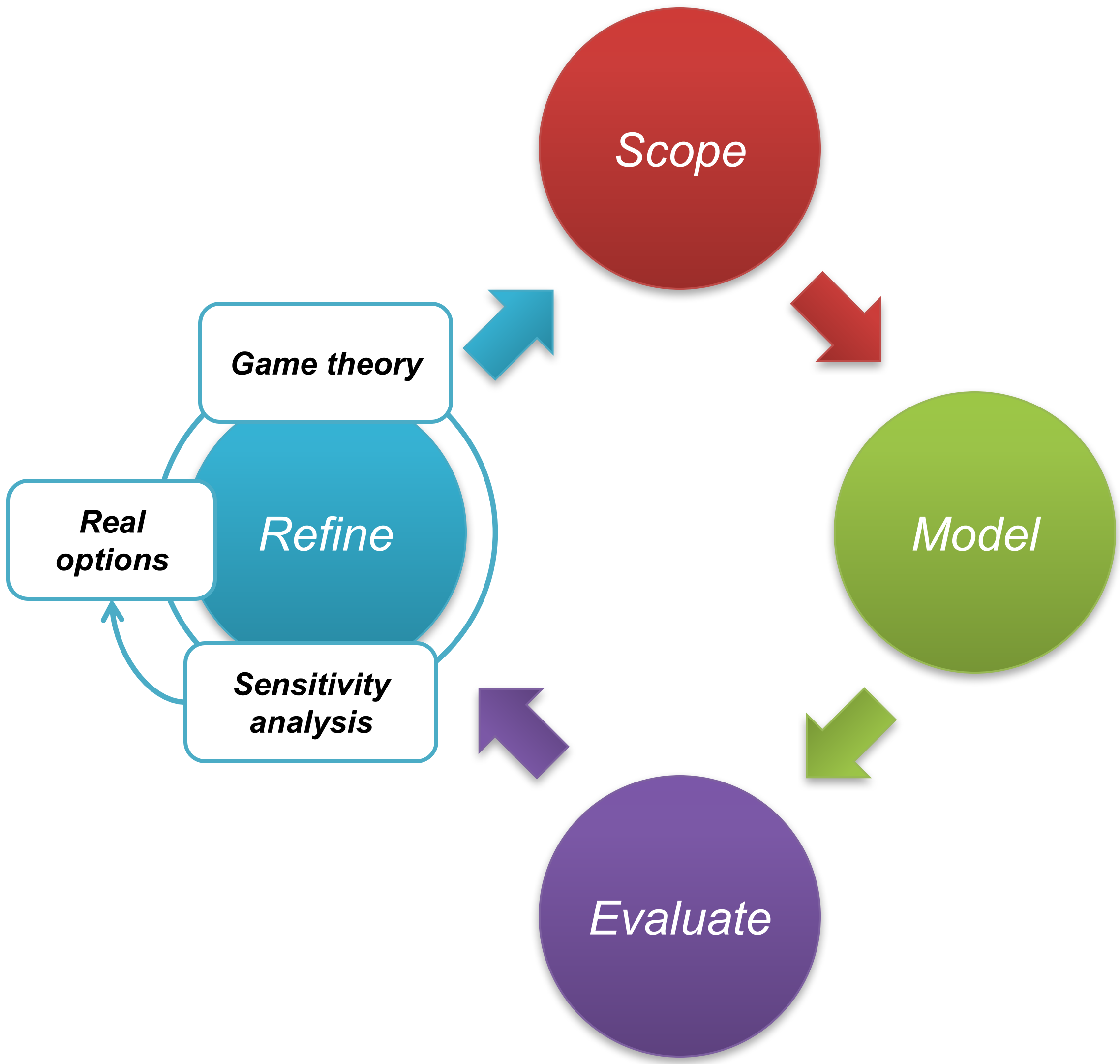


- **Direct Variable**: Maintenance, replacement, extensions, etc.
- **Direct Fixed**: Specific software and hardware, Installation, etc.
- **Shared Variable**: Servers installed, Software-licenses, etc.
- **Shared Fixed**: Telecom cabling and equipment, Backbone connection, etc.
- **Common Variable**: Powering, Cooling, etc.
- **Common Fixed**: Housing, Management, Licenses, etc.

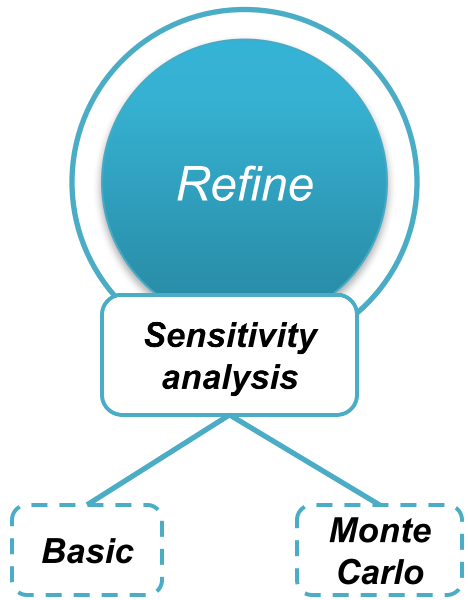
Practical steps in techno-economic evaluation of network deployment planning

REFINE

Refine the results



Sensitivity analysis
indicates impact of uncertainty



Sensitivity analysis

Refine

Sensitivity analysis

Basic

- 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

Refine

Sensitivity analysis

Basic

- 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 σ_j^2 of the outcome**

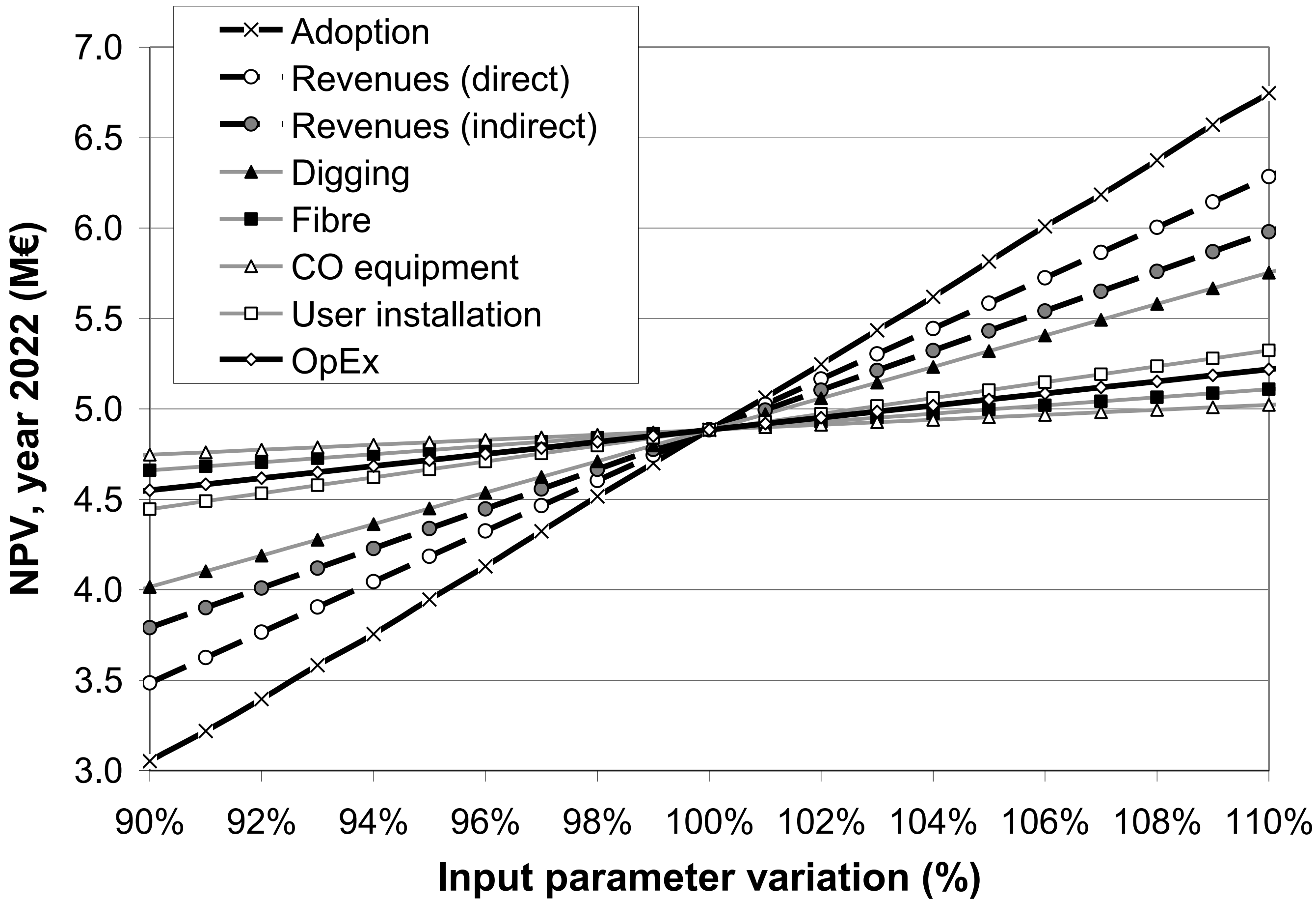
$$p_j = \frac{\sigma_j^2}{\sum_{j=1}^{m} \sigma_j^2} = \frac{\frac{1}{n}\sum_{i=1}^{n}(x_{ij}-\mu)^2}{\sum_{j=1}^{m}\left(\frac{1}{n}\sum_{i=1}^{n}(x_{ij}-\mu)^2\right)} = \frac{\sum_{i=1}^{n}(x_{ij}-\mu)^2}{\sum_{j=1}^{m}\sum_{i=1}^{n}(x_{ij}-\mu)^2}$$

Basic sensitivity analysis
Example: FTTH network

Refine

Sensitivity analysis

Basic

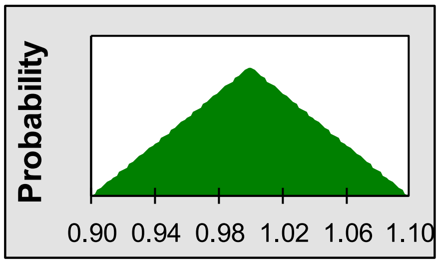
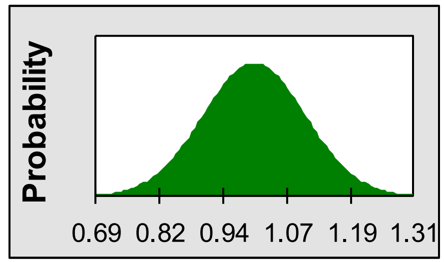
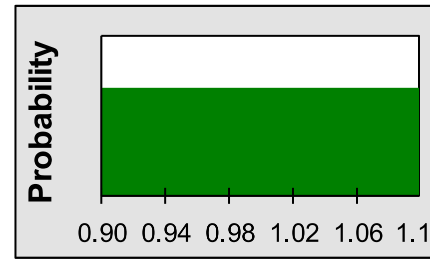


Sensitivity by Monte Carlo simulations
based on probability for uncertainties

Refine

Sensitivity analysis

Monte Carlo

Triangular	Gaussian	Uniform
		
Minimum: 0.90 Likeliest: 1.00 Maximum: 1.10	Mean: 1.00 Std. Dev.: 0.10	Minimum: 0.90 Maximum: 1.10

Sensitivity by Monte Carlo simulations
Points of attention

Refine

Sensitivity analysis

Monte Carlo

- 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

Sensitivity by Monte Carlo simulations
Most interesting results

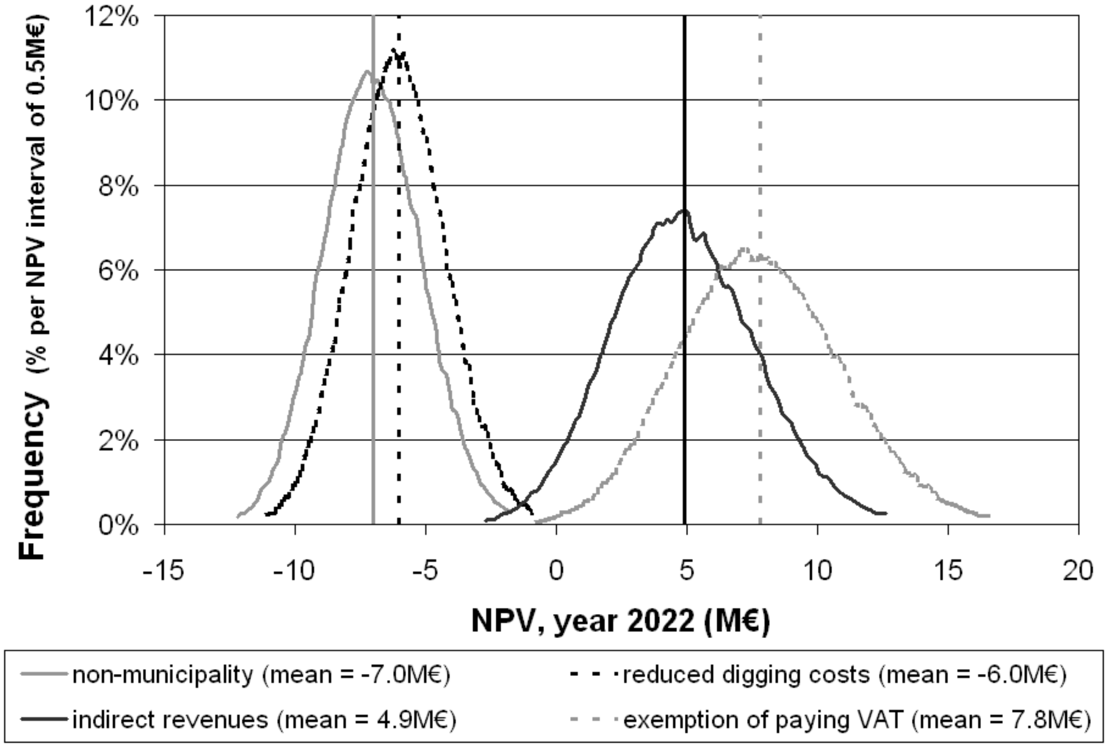
Refine

Sensitivity analysis

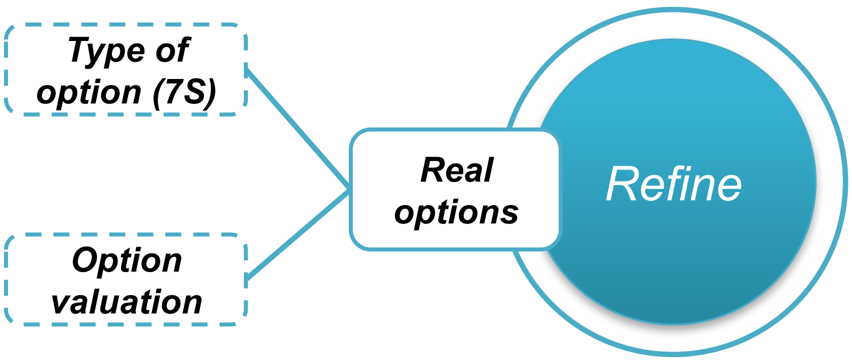
Monte Carlo

- 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

Refine

Real options

- 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

Refine

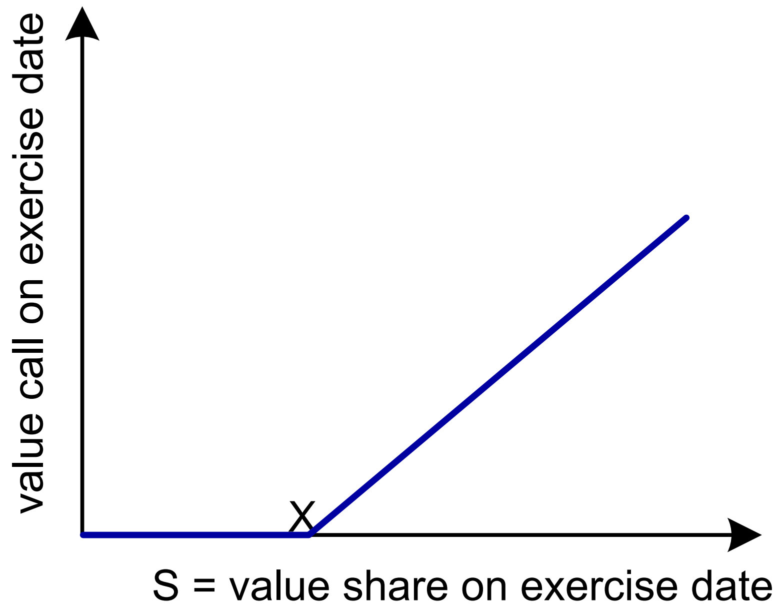
Real options

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

Refine

Real options



Value of call option on exercise date

Refine

Real options

- 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

Refine

Real options

Type of option (7S)

	Stock option	Real option
X	exercise price of the option	investments required to carry out the project
S	value of the underlying stock	NPV of the cash flows generated by the investment project
σ	volatility of the stock	risk grade of the project
r	the risk-free interest rate	risk-free interest rate
t	life time of the option	time period where company has the opportunity to invest in the project

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Types of options: 7S framework

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Refine

Real options

Type of option (7S)

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

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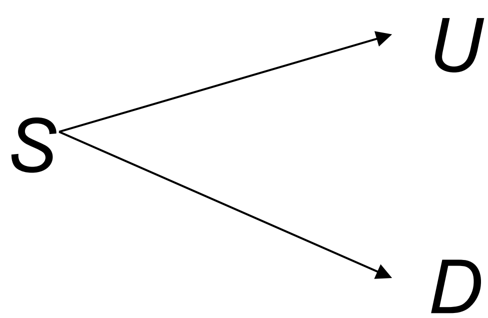
Option valuation: binomial method

Refine

Real options

Option valuation

- For European call option
- Assumes 2 possible end values



- Can be expanded for more time periods: software needed

Option valuation: Black and Scholes

Refine

Real options

Option valuation

- Formula for European call option

$$C = SN(d1) - Xe^{-rt}N(d2)$$

$$d1 = \frac{\ln(S/X) + rt + \sigma^2 t/2}{\sigma\sqrt{t}}$$

$$d2 = \frac{\ln(S/X) + rt - \sigma^2 t/2}{\sigma\sqrt{t}}$$

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

- Assumptions
  - **arbitrage-free pricing: financial transactions that make immediate profit without any risk do not exist**
  - **stock prices *S* follow Brownian motion (random walk)**
    $dS = \mu S dt + \sigma S dw$

Option valuation: simulation

Refine

Real options

Option valuation

- 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)**

Option valuation: Example

Refine

Real options

Option valuation

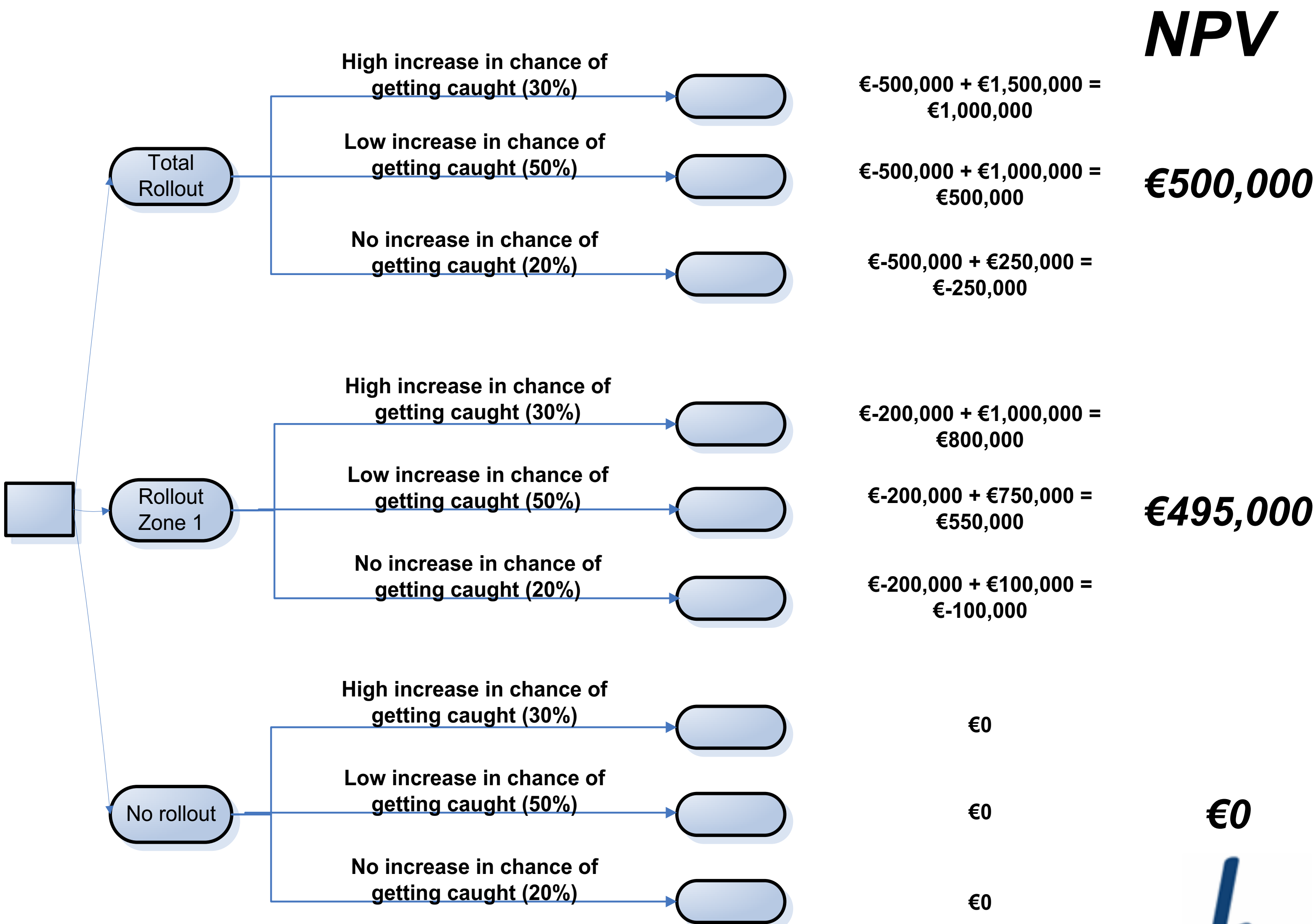
- Deploying parking sensor network in a city
  - **Two zones**
  - **Uncertainty factors:**
    - Future chance of getting caught
    - Sensor failure
    - …
- Starting small or large?
  - **Low vs. high investment?**
  - **Low vs. high payoff?**
- Base case:
  - **NPV calculation**

Base case: starting small or large?

Refine

Real options

Option valuation



Base case: starting small or large?

Refine

Real options

Option valuation

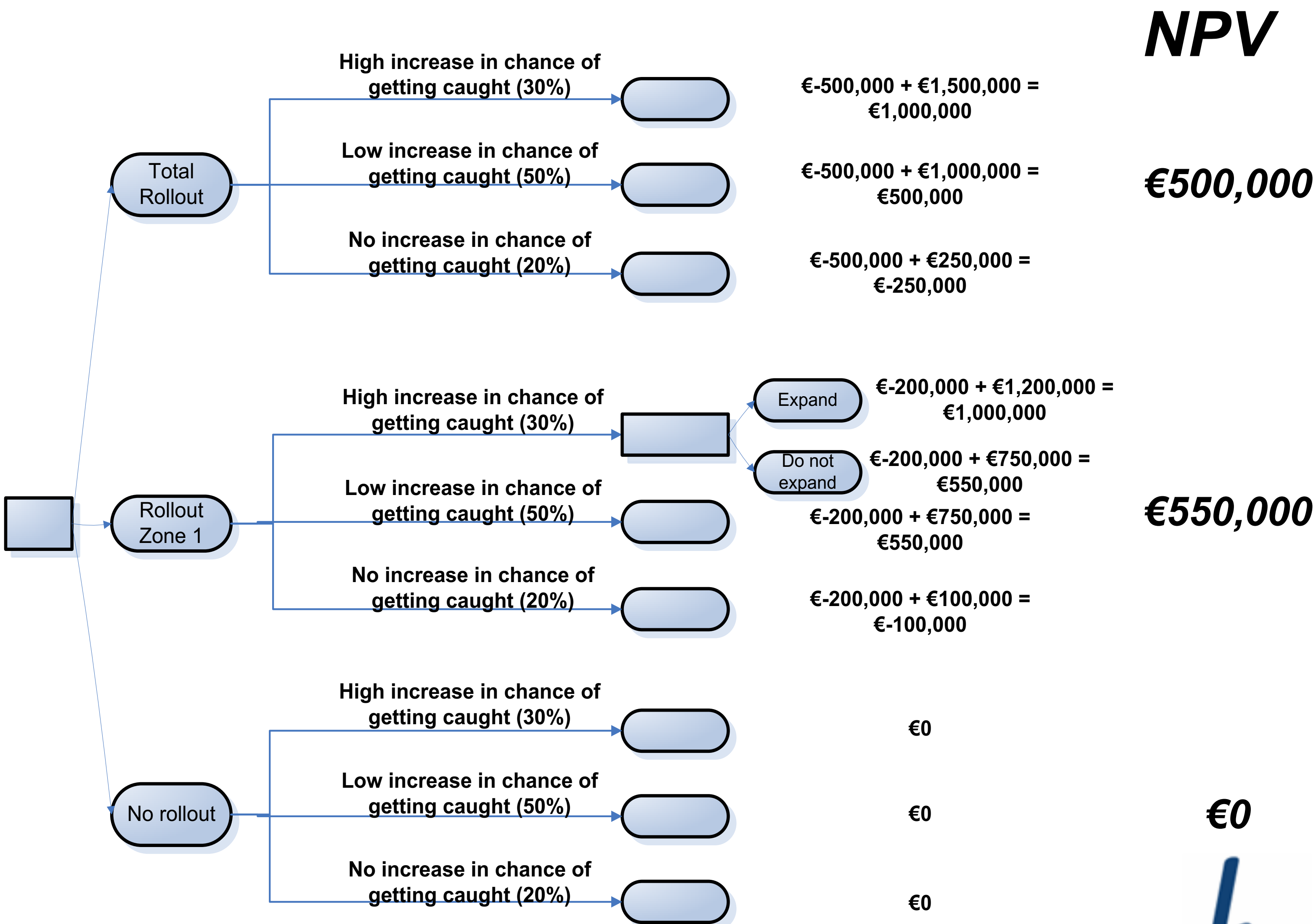
- Base case:
  - **Choose the total rollout**
- Option to expand:
  - **Start off small, evaluate expansion next year**
  - **Expansion means extra investment**
  - **Delayed expansion = missed payoffs**
  - **New NPV calculation**

Base case: starting small or large?

Refine

Real options

Option valuation



Base case: starting small or large?

Refine

Real options

Option valuation

- 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

Refine

Real options

Option valuation

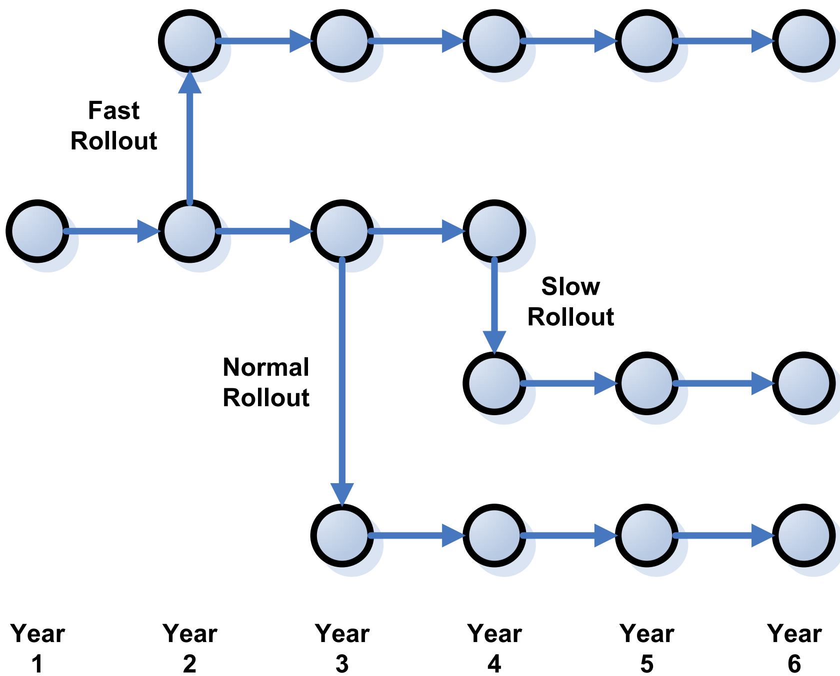
- Rollout of a Parking Sensor Network
  - **Project of 6 years**
  - **Year 0: rollout in zone 1**
  - **Flexibility: year of zone 2 rollout**
  - **Fast, normal and slow rollout speed**

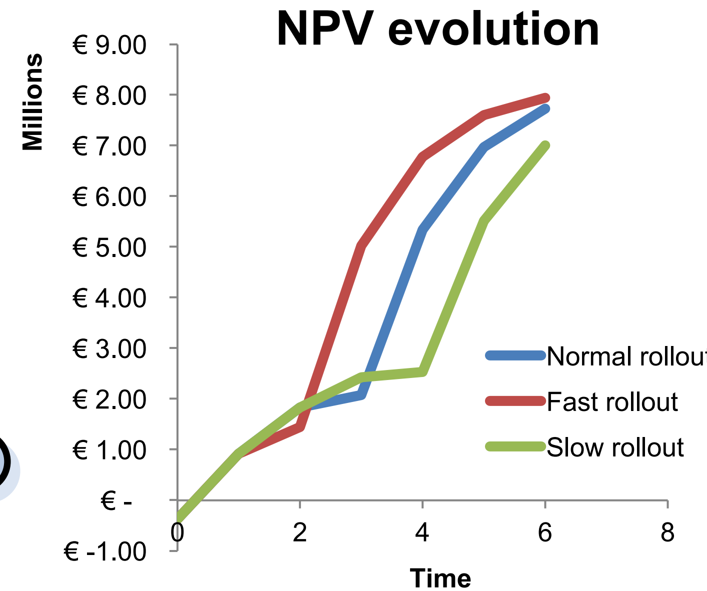
Option valuation: simulation
Example: flexible rollout scheme, method

Refine

Real options

Option valuation





Option valuation: simulation
Example: flexible rollout scheme, method

Refine

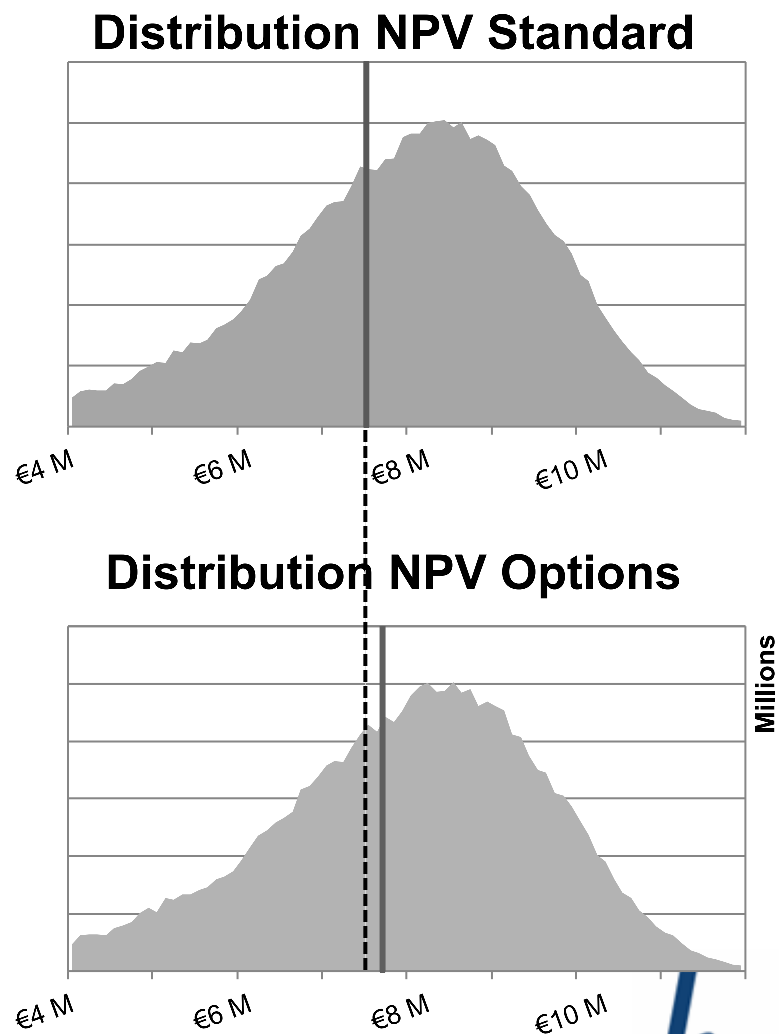
Real options

Option valuation

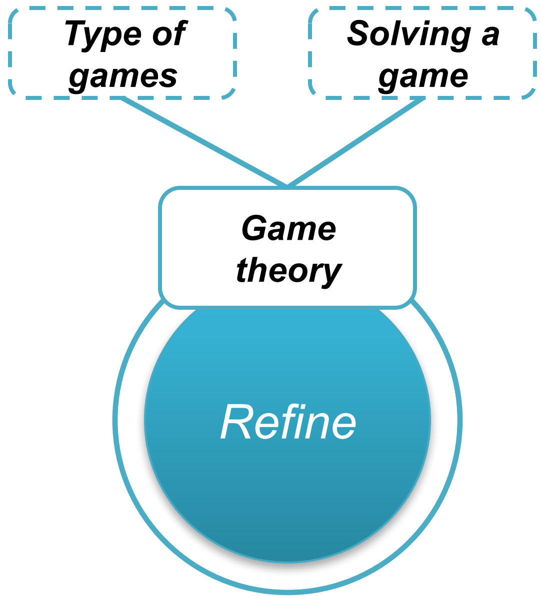
Simulation

- Implement **uncertainty**
  - **Distribution standard NPV**
  - **Mean = 7.52 million**
- Implement **flexibility**
  - **Choose best case**

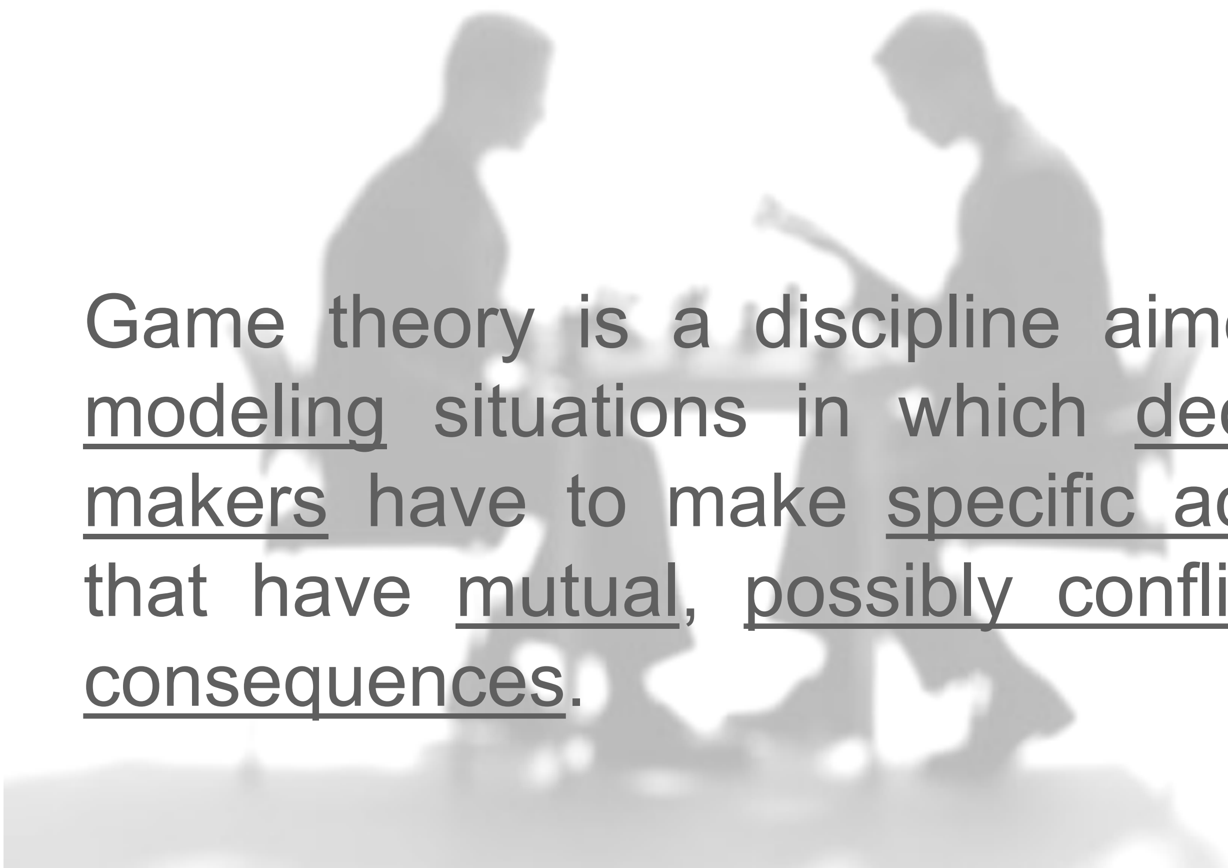
    NPV = MAX(slow, normal, fast)
  - **Mean = 7.72 million**



Game theory
models competition between different players



Game theory



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

Refine

Game theory

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

Refine

Game theory

Type of games

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		

Visualization of a game theoretic model

Refine

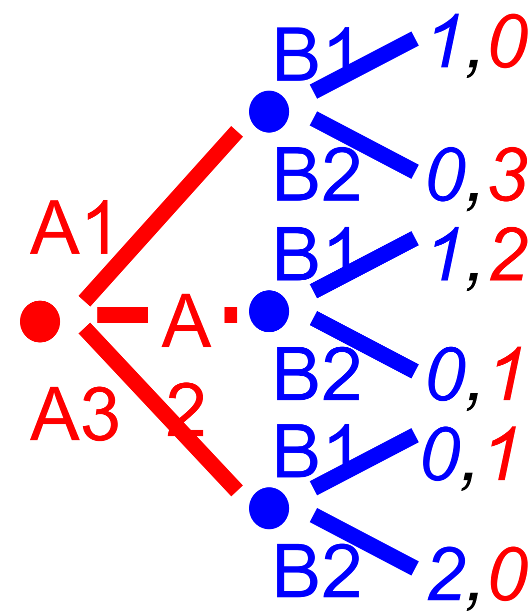
Game theory

Type of games

Normal Form

	A1	A2	A3
B1	*1,0*	*1,2*	*0,1*
B2	*0,3*	*0,1*	*2,0*

Extensive Form



Visualization of a game theoretic model

Refine

Game theory

Type of games

Normal Form

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B1	*1,0*	*1,2*	*0,1*
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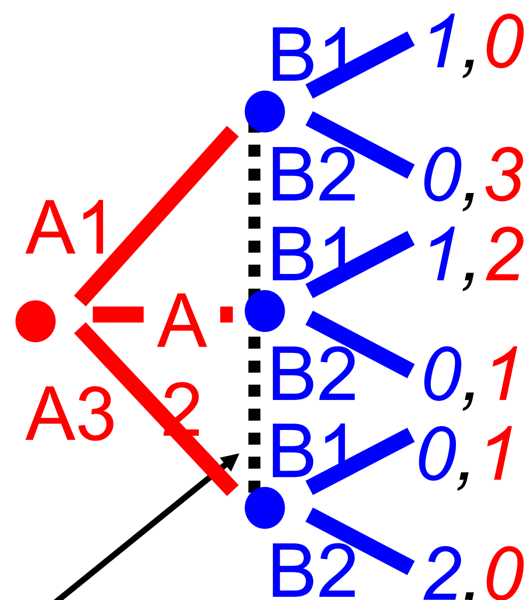
Extensive Form



Imperfect information

Player B does not know what player 1 has done

Approaches towards finding an equilibrium

Refine

Game theory

Solving a game

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

Refine

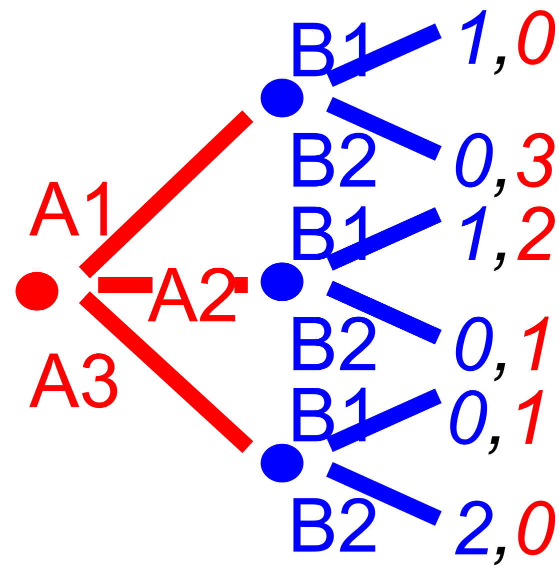
Game theory

Solving a game

Normal Form

	A1	A2	A3
B1	1,0	1,2	0,1
B2	0,3	0,1	2,0

Extensive Form



Iterated dominance (normal form)
Backward induction (extensive form)

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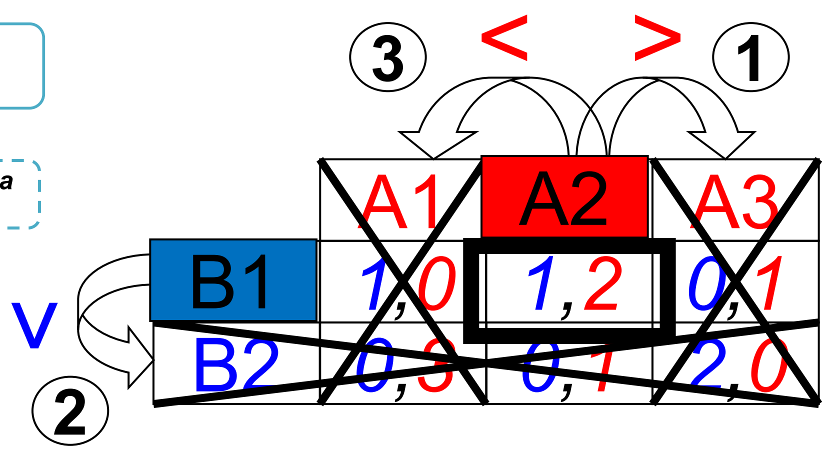
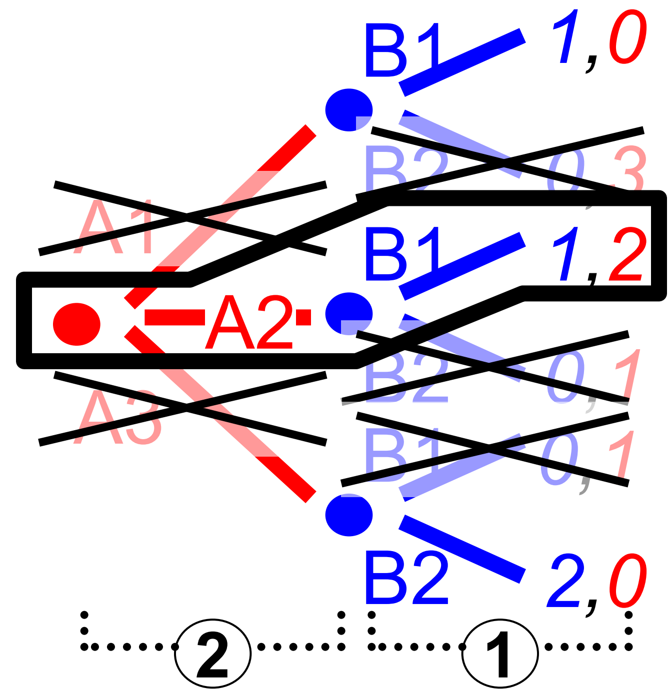
Game theory

Solving a game

Normal Form



Extensive Form

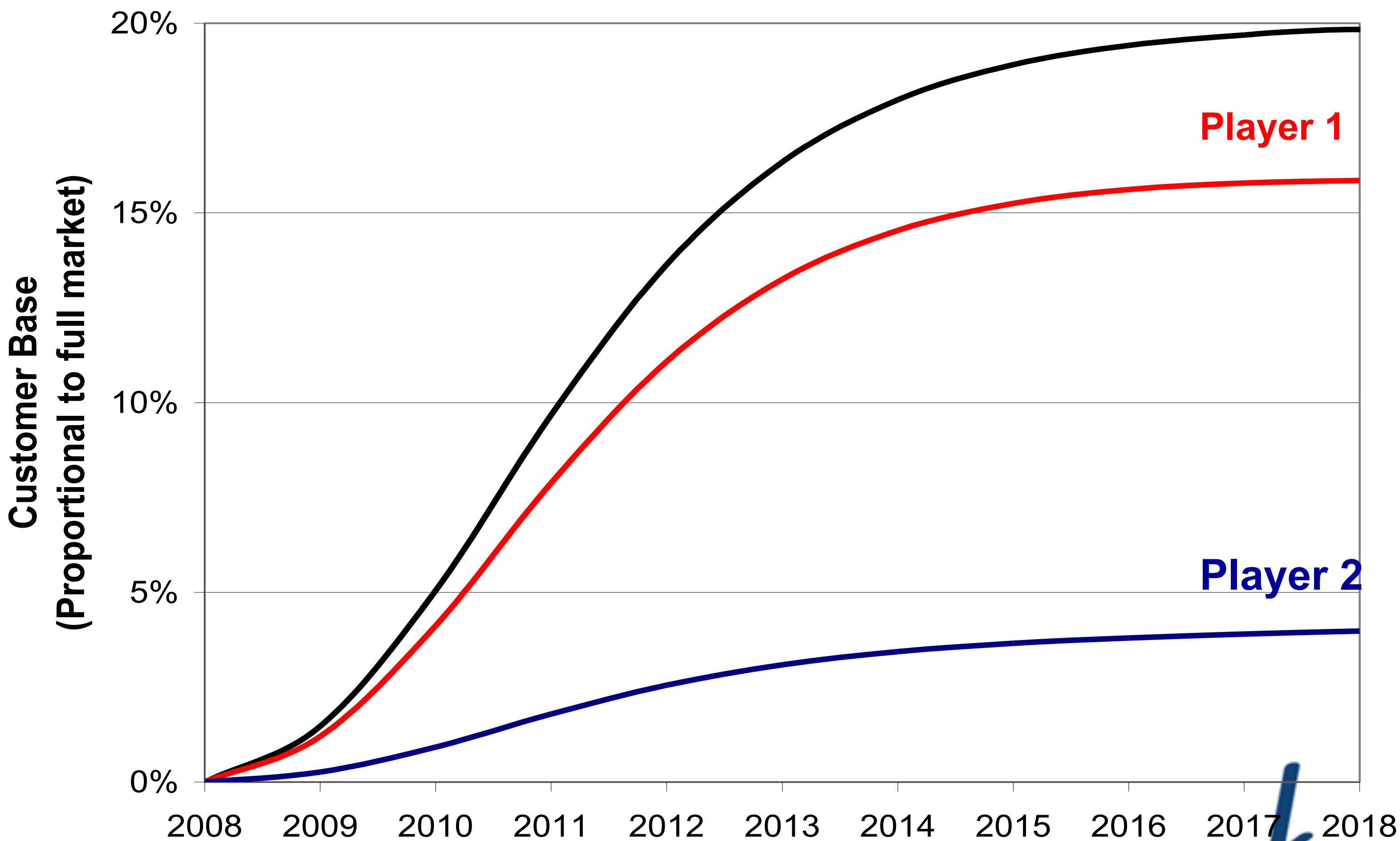


Market for wireless network deployment

Refine

Game theory

Solving a game

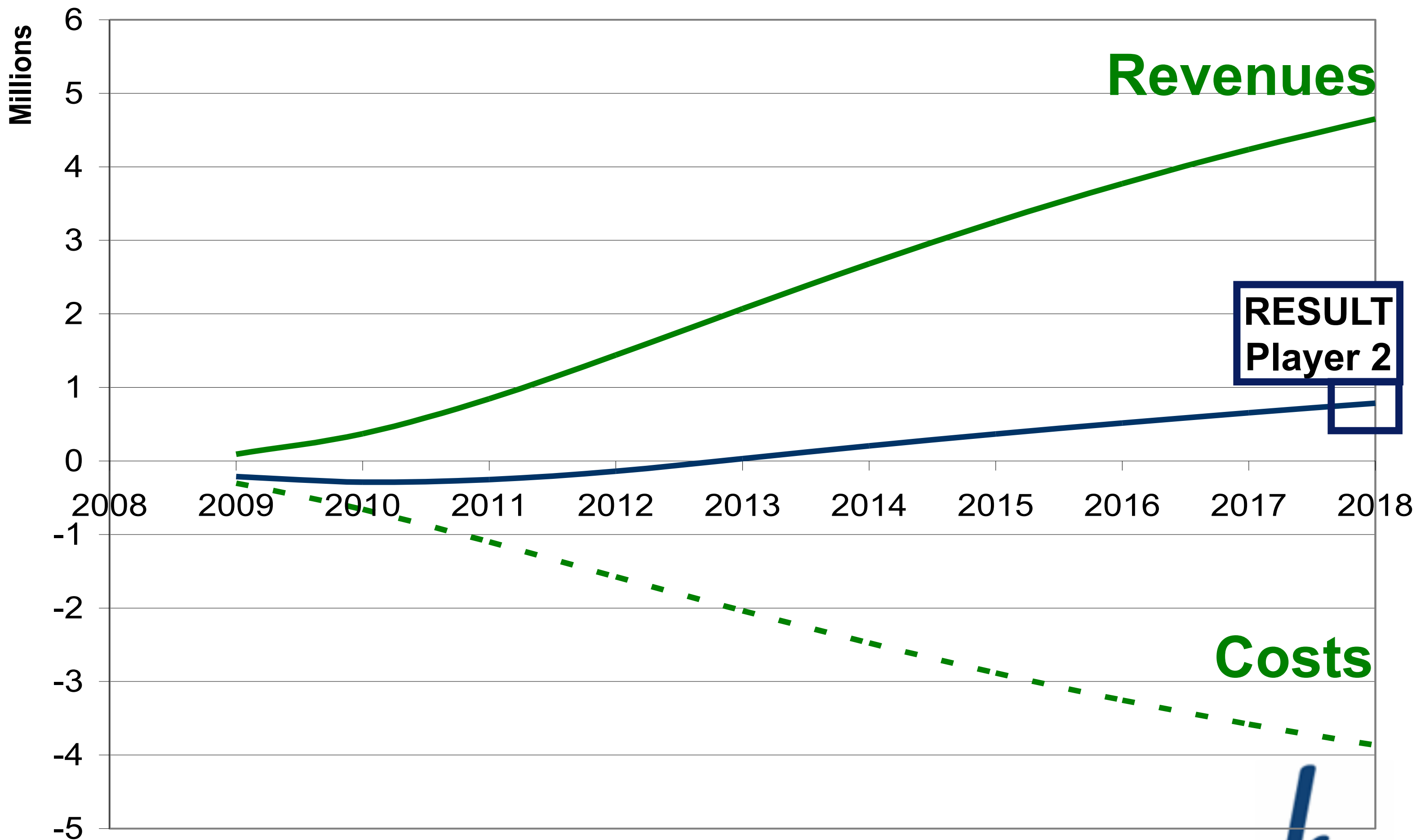


Result (NPV) = Revenues - Costs

Refine

Game theory

Solving a game

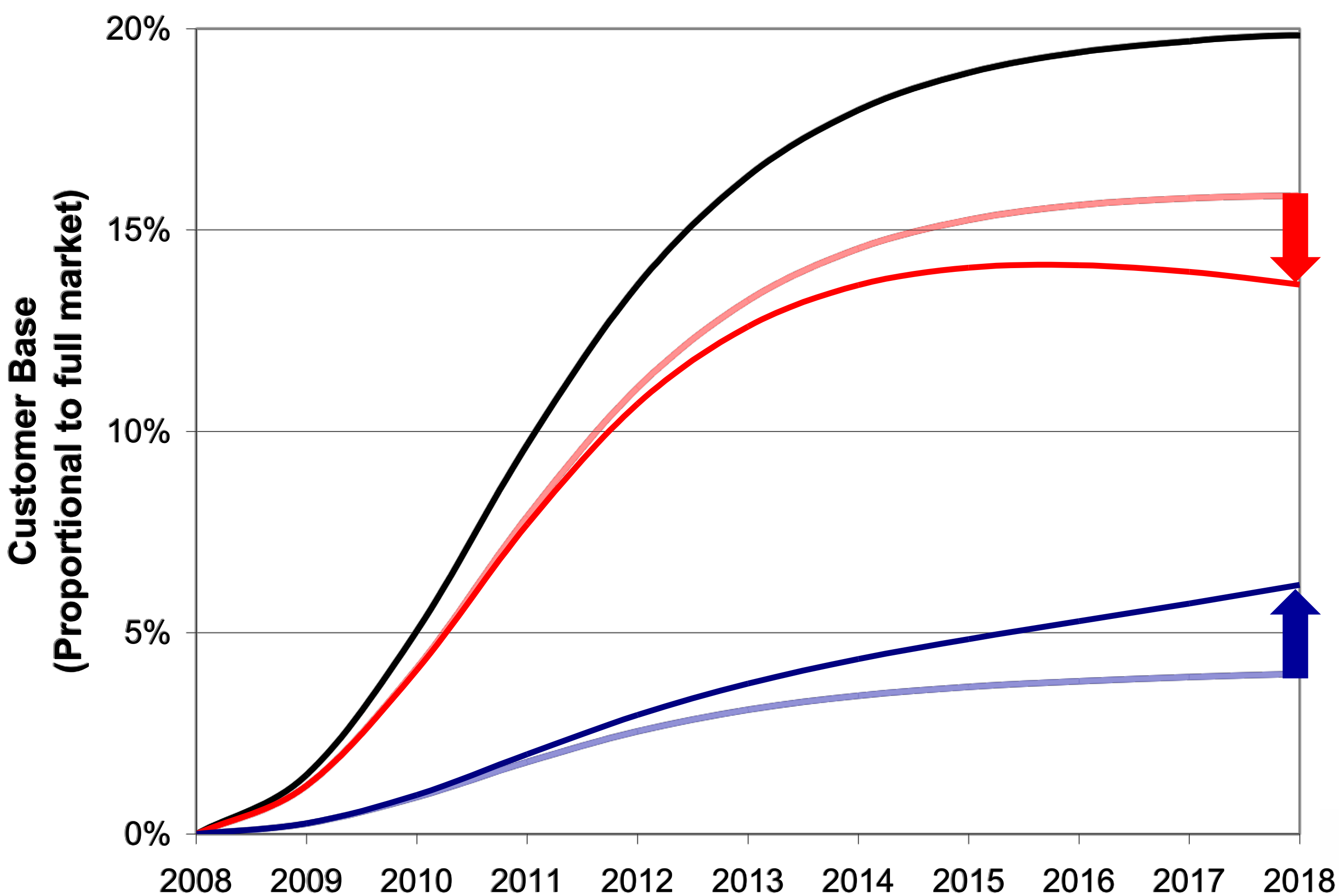


Player 1 increases his price

Refine

Game theory

Solving a game

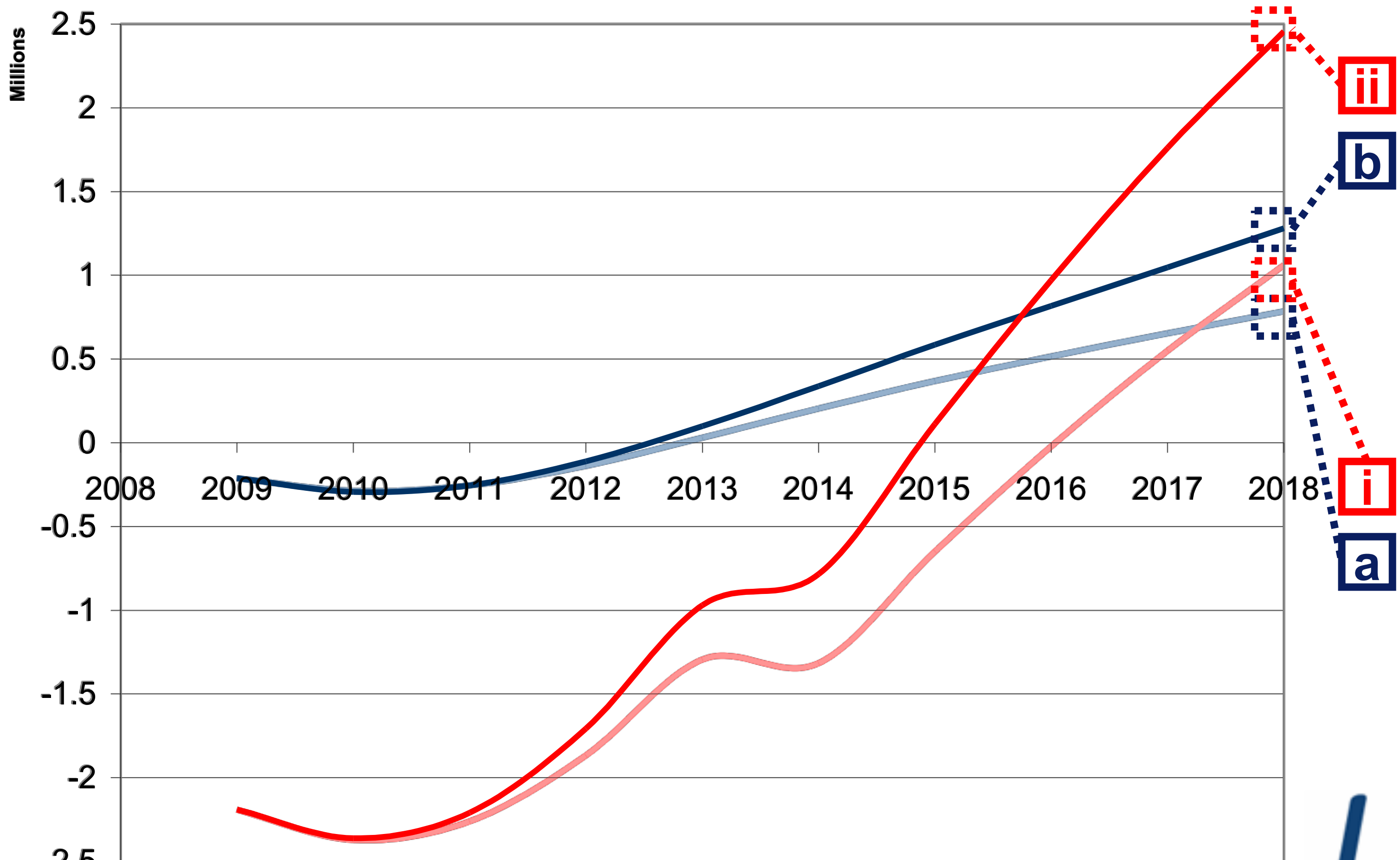


Results (NPV) for the different scenarios
(original [i,a] & higher price p1 [ii,b])

Refine

Game theory

Solving a game



Full matrix for both players strategies

Player 2

Player 1

Player 1 \ Player 2	Low	High	...
...			
Low	i | a		
High	ii | b		
...			

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

Refine

Game theory

Solving a game

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

Price (€)		Player 2: 3G femtocells									
		22		23		24		25		26	
Player 1: WiFi	22	2.467	[illegible]	2.565	1.367	2.680	1.356	2.791	[illegible]	2.901	[illegible]
	23	[illegible]	[illegible]	2.600	1.488	2.722	1.468	[illegible]	1.437	[illegible]	1.417
	24	2.512	1.554	2.646	1.585	2.749	1.577	2.865	1.532	2.979	1.509
	25	2.507	1.637	2.636	1.679	2.773	1.683	2.906	1.650	3.021	1.607
	26	2.479	1.700	2.627	1.771	2.771	1.785	2.899	1.764	3.035	1.707

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

Refine

Game theory

Solving a game

After 2nd iteration → example with 2 Nash Equilibria

Price (€)		Player 2: 3G femtocells									
		22		23		24		25		26	
Player 1: WiFi	22										
	23										
	24			2.646	1.585	2.749	1.577				
	25			2.636	1.679	2.773	1.683				
	26			2.627	1.771	2.771	1.785				

WiFi: *NPV 1_26 < NPV 1_25*

Practical steps in techno-economic evaluation of network deployment planning

TOOL OVERVIEW

Tools for infrastructure & cost modeling

Toolkit	application	license
OPNET SP Guru / IT Guru	Network planning and (cost-effective) optimization	Academic ed. Commercial
VPI OnePlan	Network design & planning Economic analysis	Commercial
TONIC	Techno-economic tool Spreadsheet based Including a cost database	Negotiation with IST-FP5 TONIC partners

Tools for process modeling

Toolkit	BPMN	XPDL	license
CaseWise	As an extension	As an extension	Commercial, Free for TMForum members
Mega: MegaProcess	yes	yes	Commercial
IDS Scheer: ARIS	yes	yes	Commercial
MS Visio	yes	no	Commercial
Tibco business studio	yes	yes	Free

Tools for process simulation

Toolkit	Graphical modeling	Open Source	License
GPSS	No	No	Free limited ed. Commercial
VenSim (including M-Wave model)	Yes	No	Free limited ed. Commercial
SimJava	No	Yes	Free
Ptolemy II	Yes	Yes	Free

Tools used within refinement

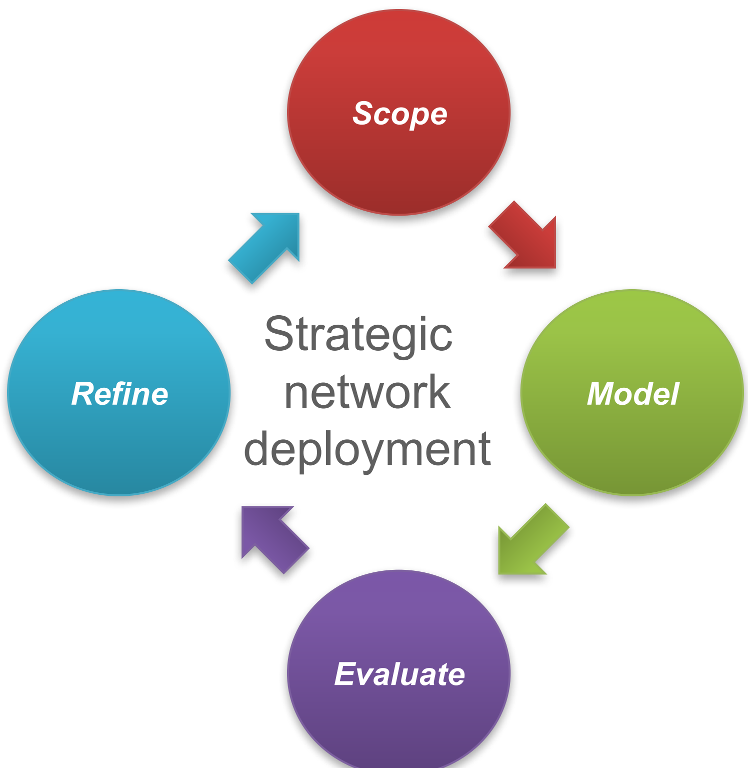
Toolkit	Type	Open Source	License
Gambit	Game theory	Yes	Free
Jannealer	Optimization by means of Simulated annealing	Yes	Free
Linear programming tools (e.g. solver, mathlab, etc.)	Integer Linear Programming	Typically not	Commercial
Crystal Ball	Sensitivity analysis and RO by simulation	No	Commercial

Practical steps in techno-economic evaluation of network deployment planning

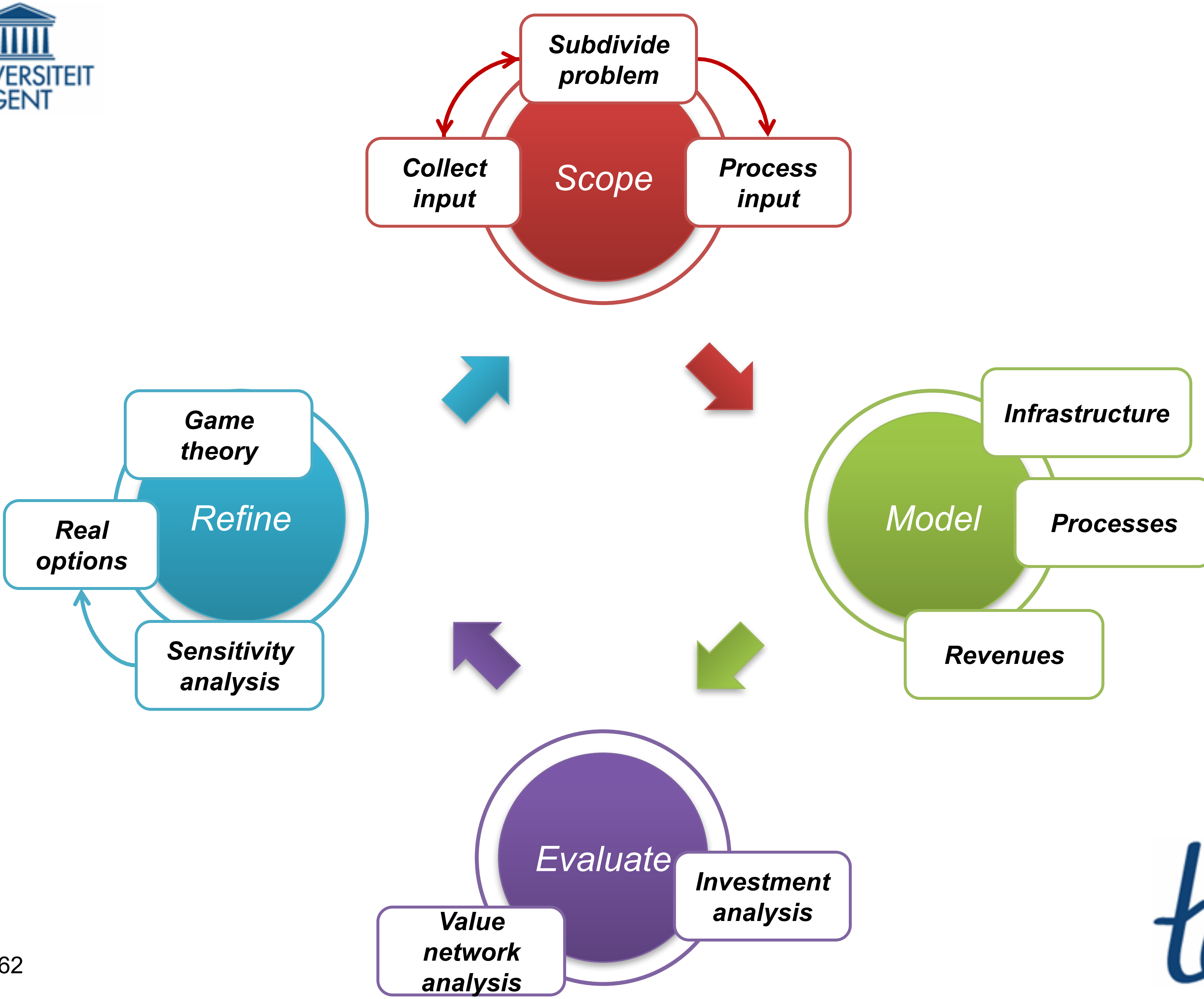
SUMMARY AND CONCLUSIONS

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


Subdivide problem
Collect input
Scope
Process input
Infrastructure
Model
Processes
Revenues
Evaluate
Investment analysis
Value network analysis
Game theory
Refine
Real options
Sensitivity analysis

Practical steps in techno-economic evaluation of network deployment planning

REFERENCES

Major References

Scope

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Evaluate

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Refine

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FACULTEIT INGENIEURSWETENSCHAPPEN

Practical steps in techno-economic evaluation of network deployment planning <u>part 2</u>: case study "FTTH roll-out in Gent"

Sofie Verbrugge

Koen Casier

Jan Van Ooteghem

Bart Lannoo

INTEC

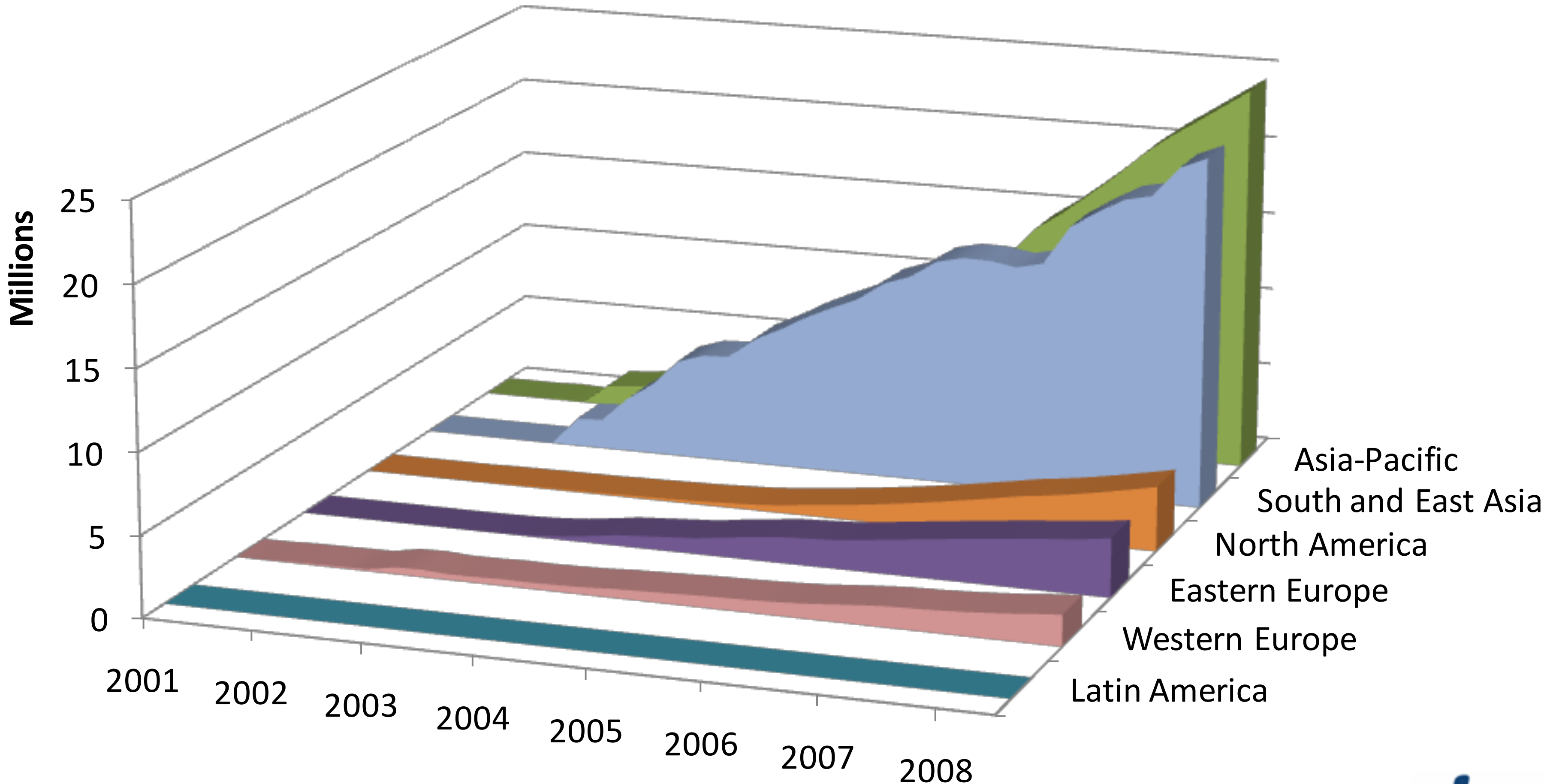
IBCN intec broadband communication networks

IBBT

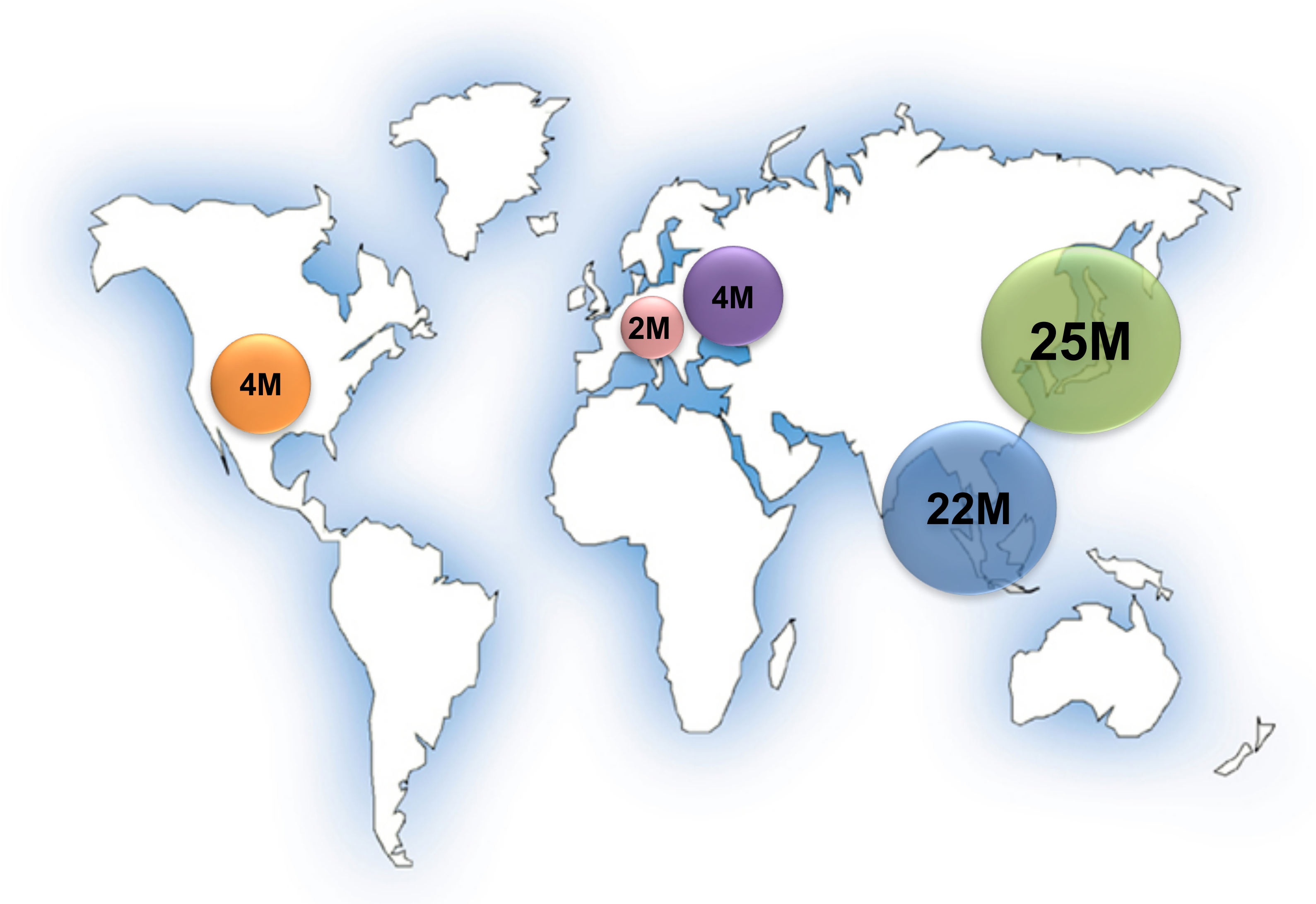
Practical steps in techno-economic evaluation of network deployment planning

REFERENCE CASE

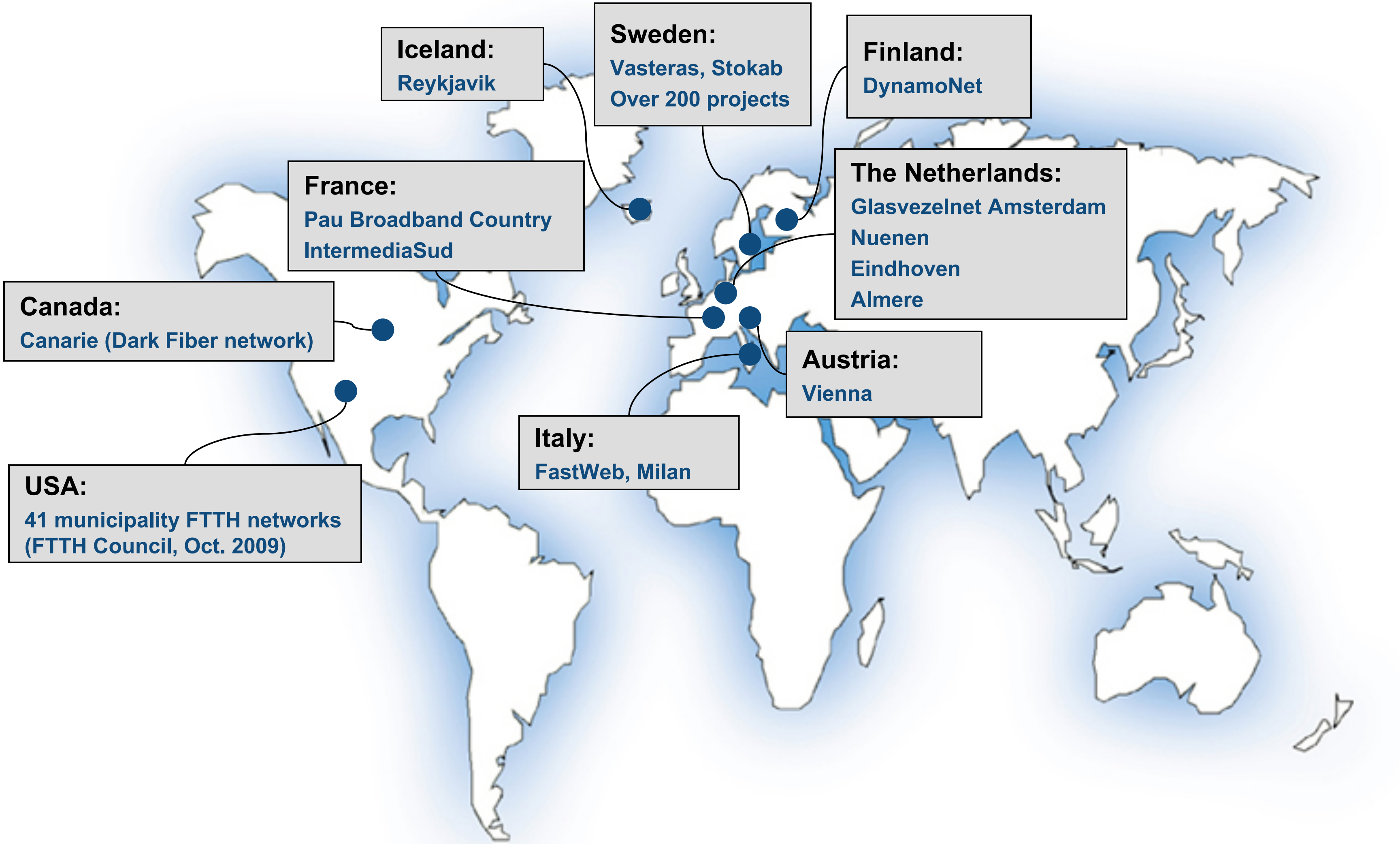
Worldwide FTTH



Worldwide FTTH



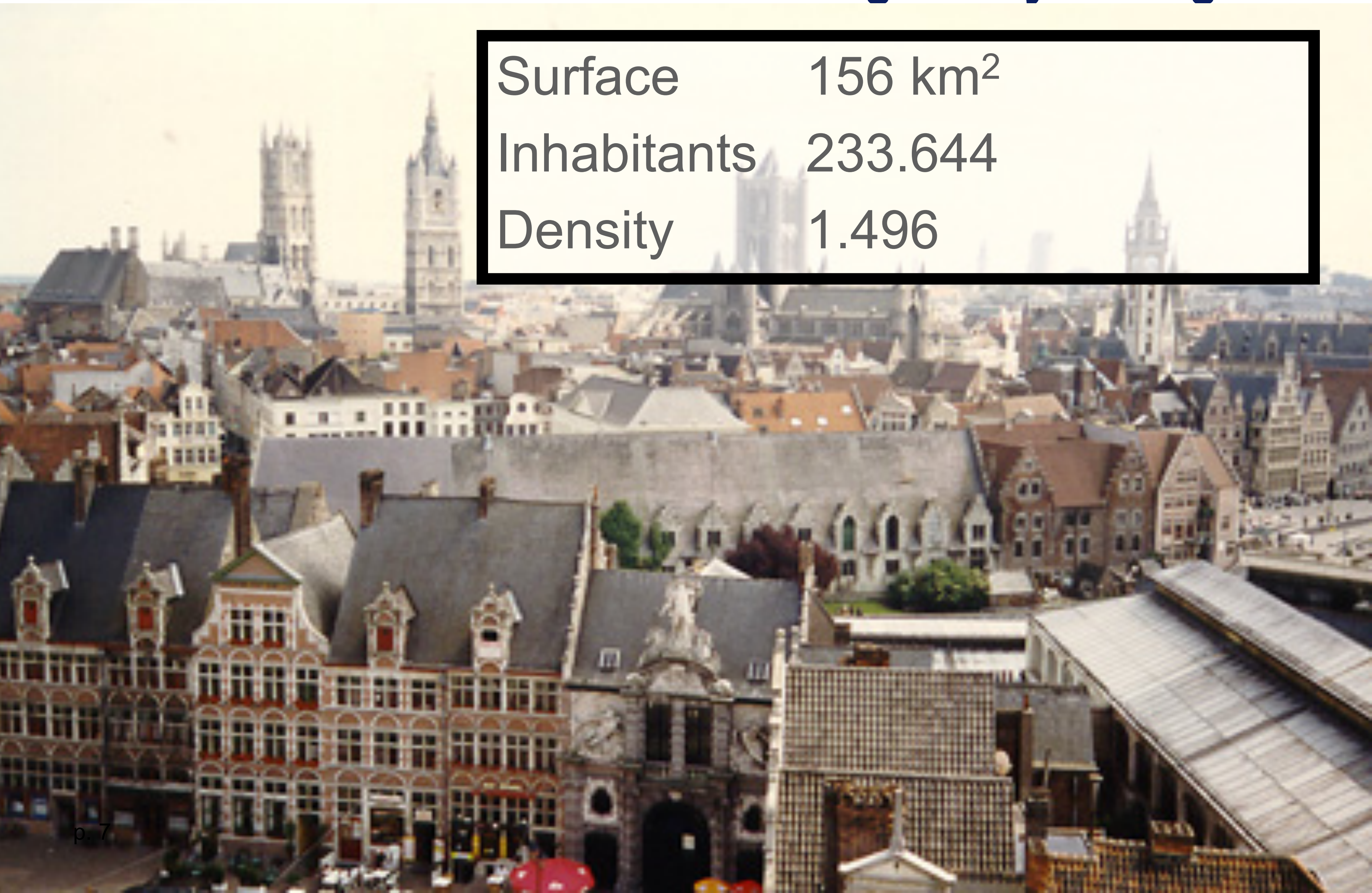
Worldwide examples
of community network projects

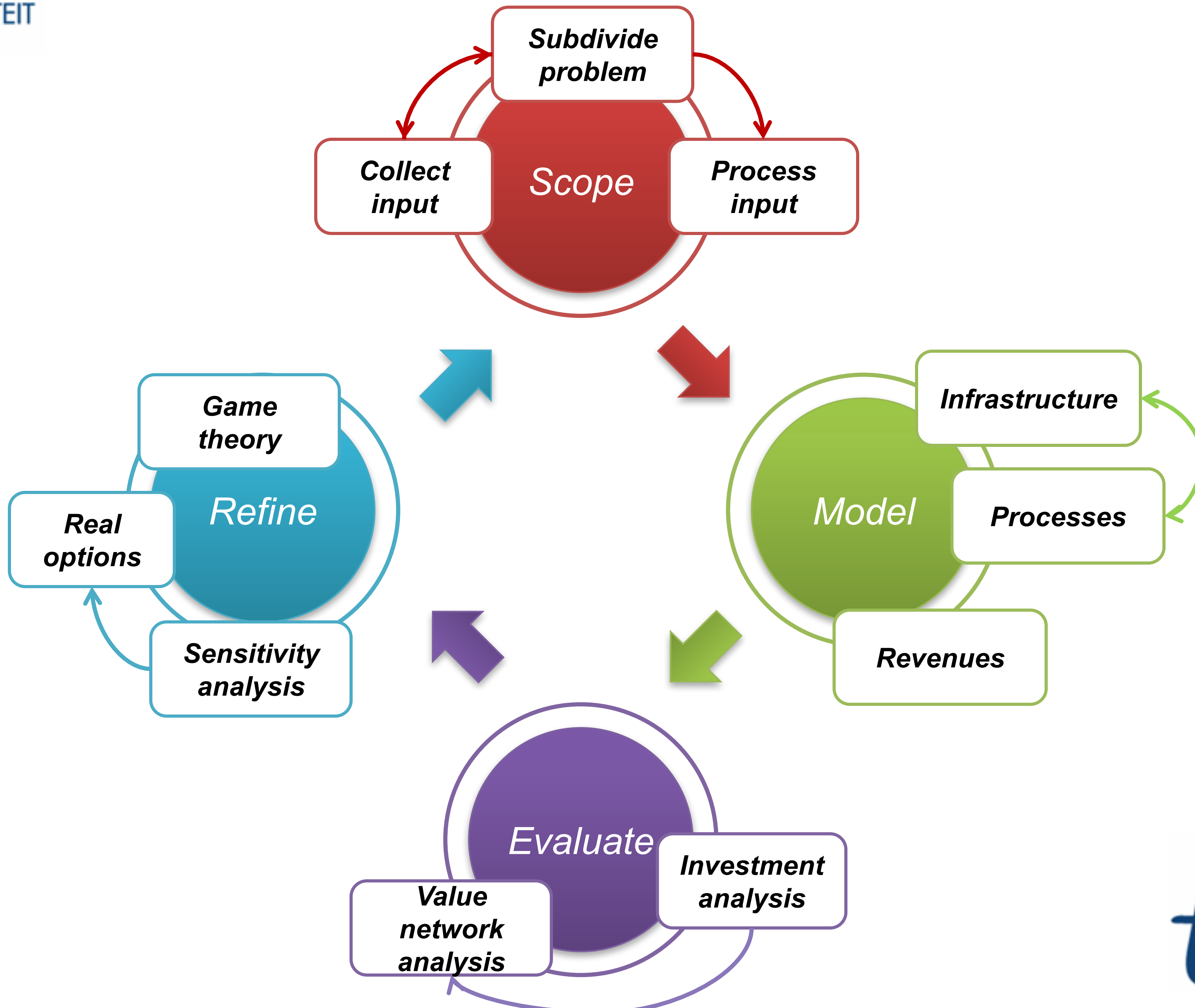


FTTH rollout in Ghent

The city of Ghent
is the third largest city of Belgium

Surface	156 km^2
Inhabitants	233.644
Density	1.496




Subdivide problem
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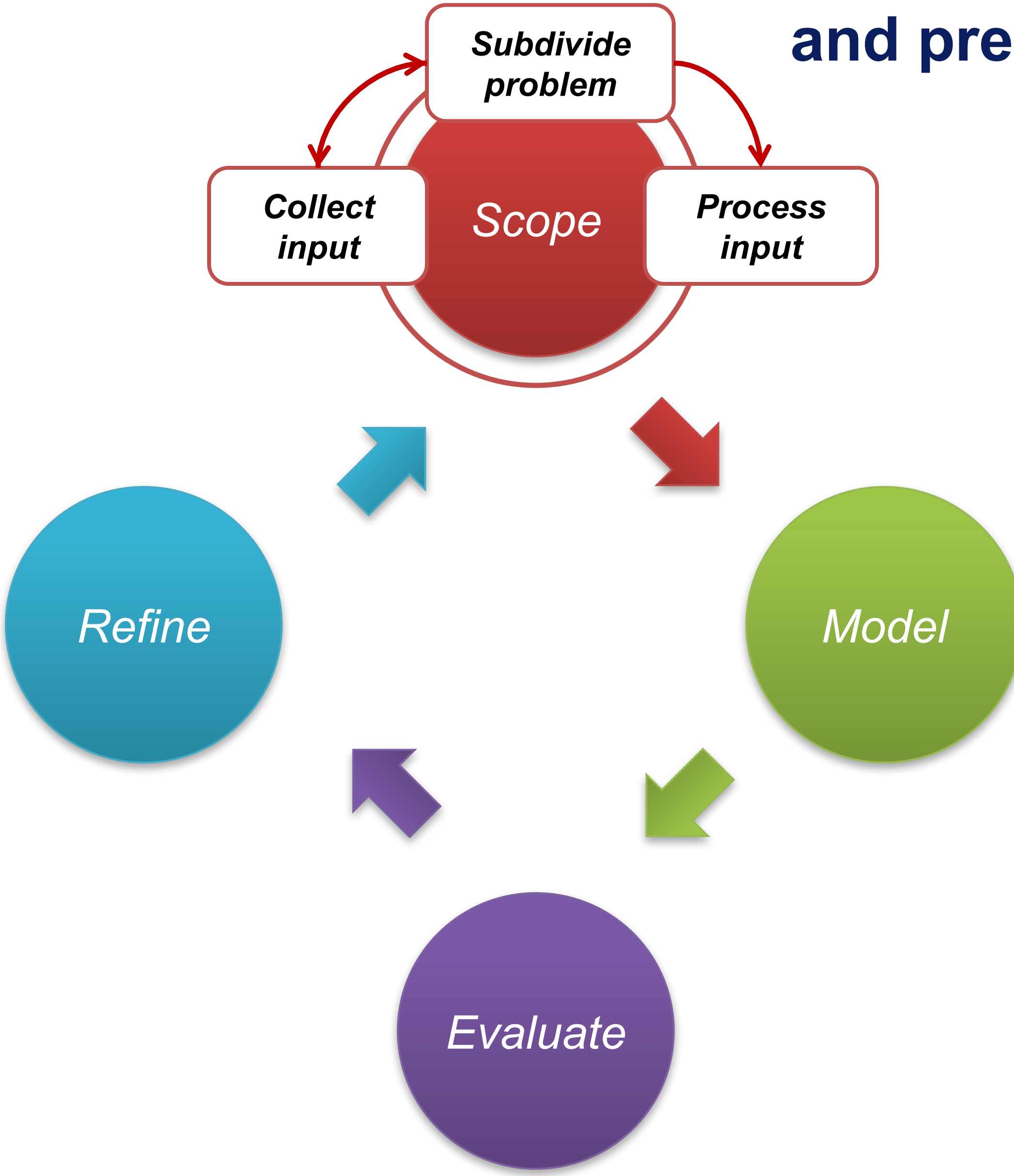
Real options
Sensitivity analysis

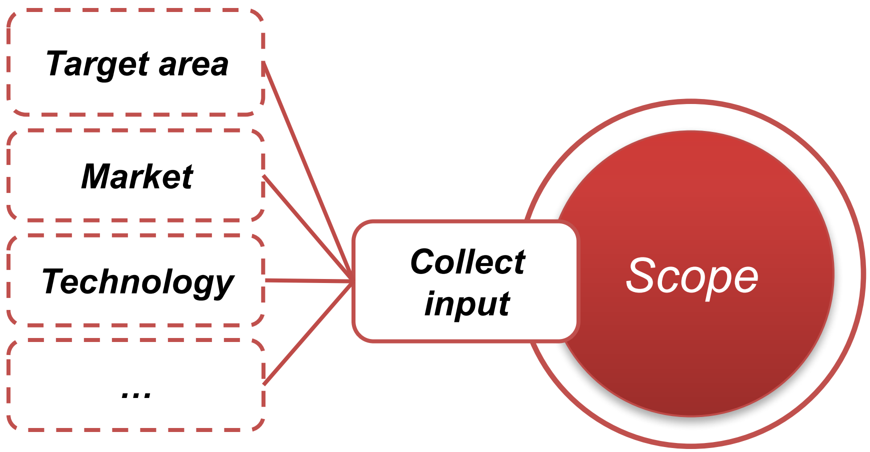
Practical steps in techno-economic evaluation of network deployment planning

SCOPE

Input collection and preprocessing



Collect input
all available data relevant for the project

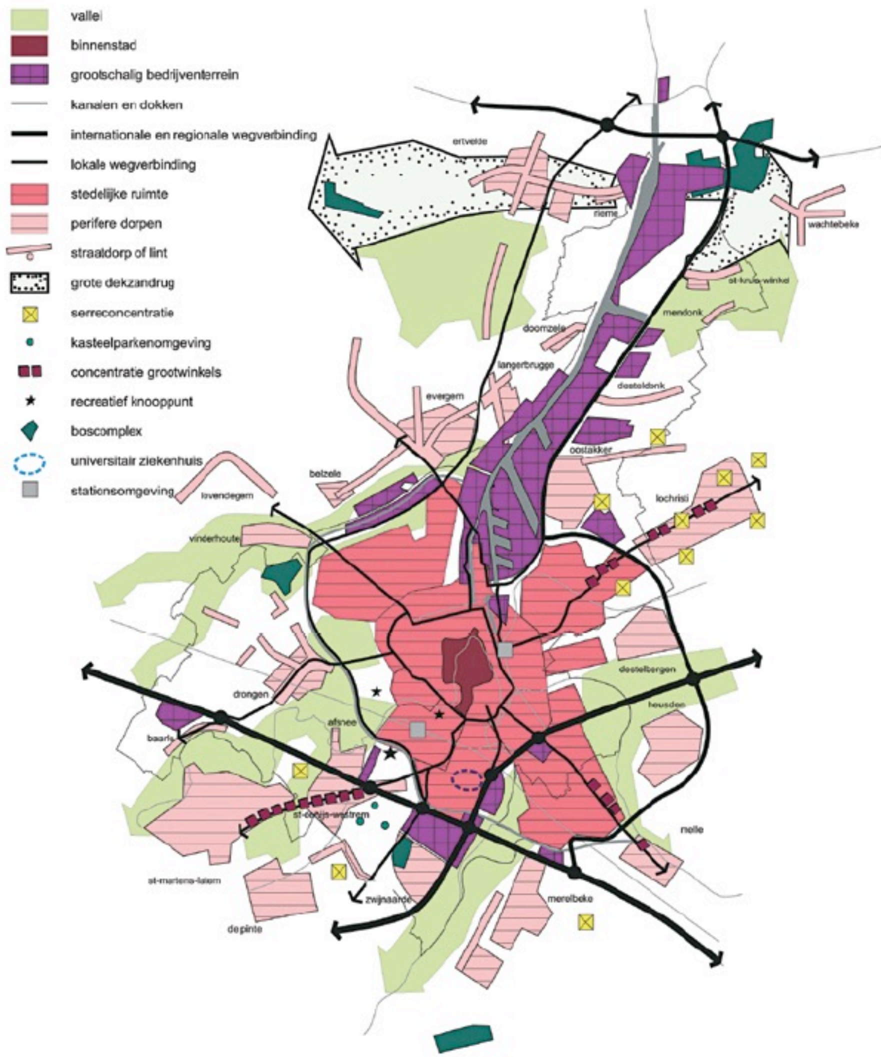


Target area input
Geographic information

Scope

Collect input

Target area



General overview for Ghent

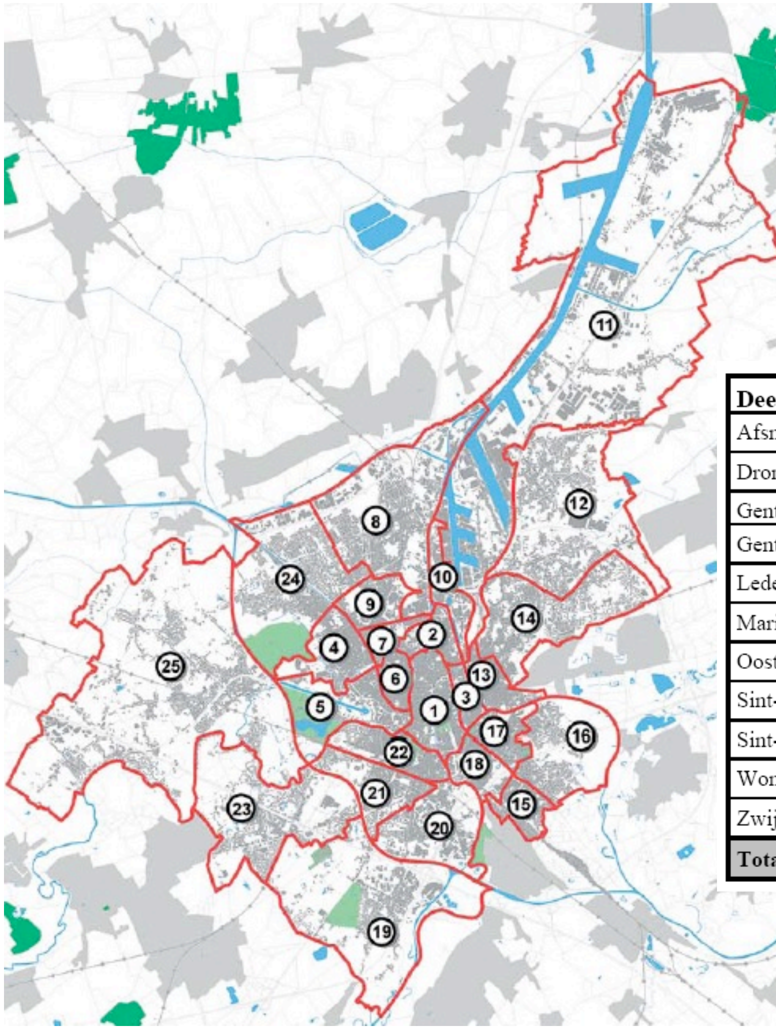
- Transport
- Industrial areas
- Commercial areas
- Residential areas
- Green belt

Target area input
Demographic data

Scope

Collect input

Target area



Population density
& area surface

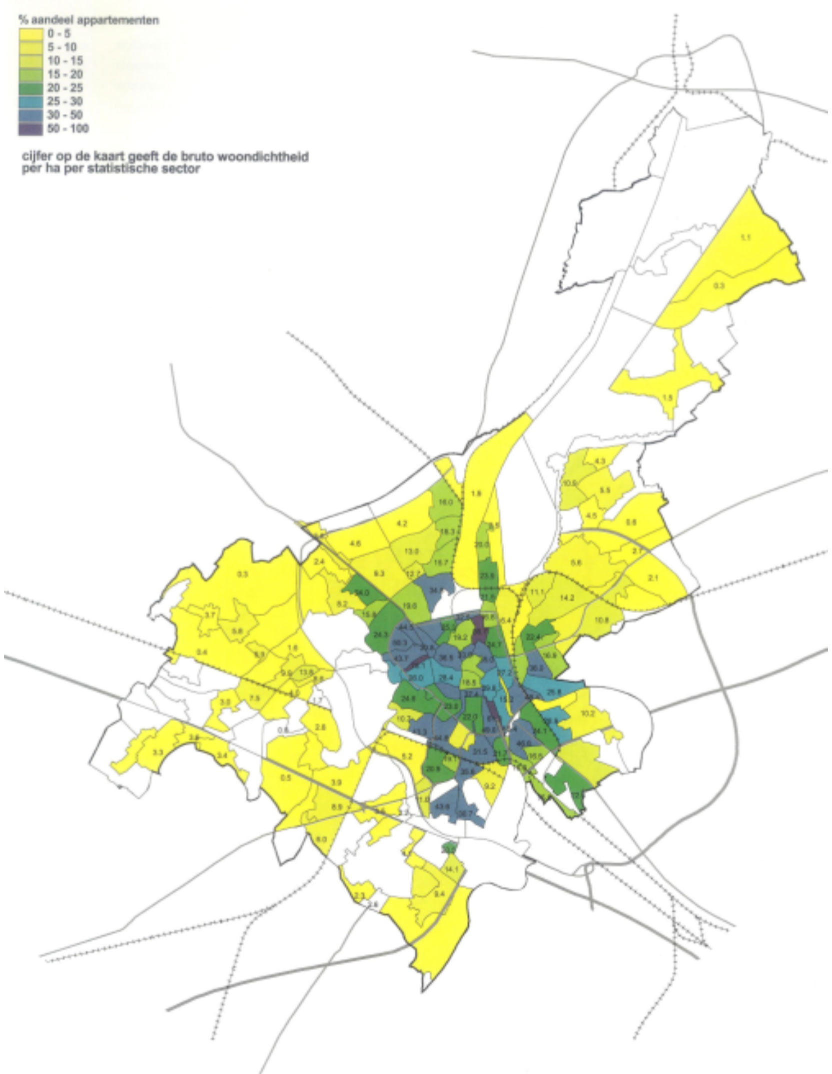
Deelgemeente	oppervlakte	Bevolkingsdichtheid
Afsnee	3,95 km²	359,49
Drongen	27,43 km²	447,54
Gent	70,34 km²	1667,94
Gentbrugge	7,86 km²	2550,25
Ledeberg	1,09 km²	7559,63
Mariakerke	5,20 km²	2246,15
Oostakker	10,47 km²	1195,80
Sint-Amandsberg	5,99 km²	3766,28
Sint-Denijs-Westrem	6,24 km²	832,53
Wondelgem	5,82 km²	2121,65
Zwijnaarde	12,04 km²	569,27
Totaal	**156,43 km²**	**1473,25**

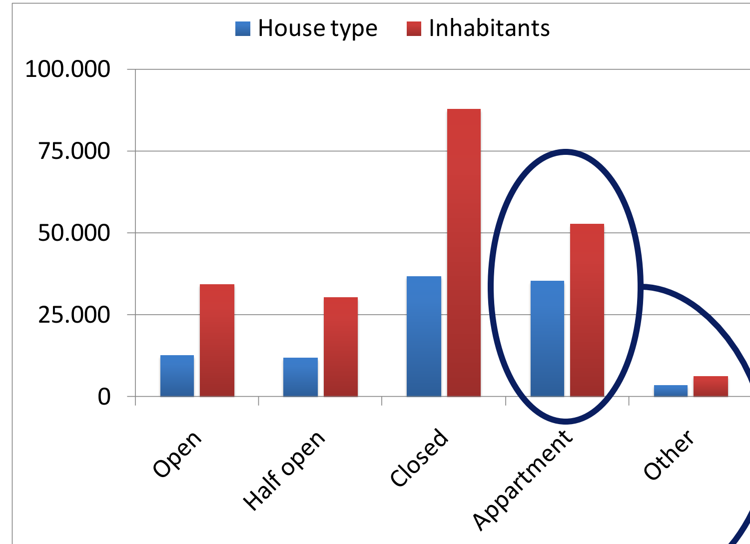
Target area input
Demographic data

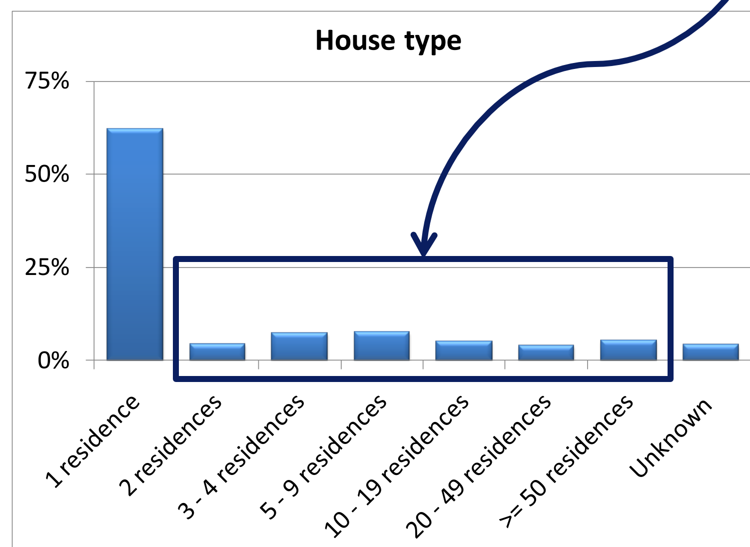
Scope

Collect input

Target area







Market input
Bandwidth drivers

Scope

Collect input

Market

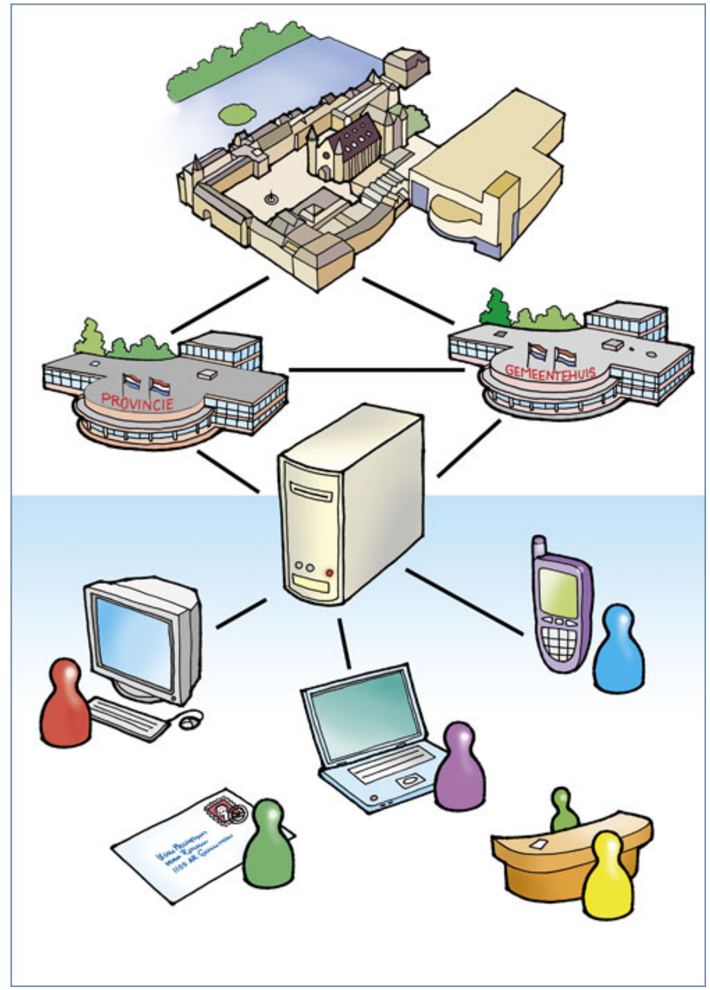
eGovernment

eEducation

eHealth

eBusiness

Leisure



Technology input

Scope

Collect input

Technology

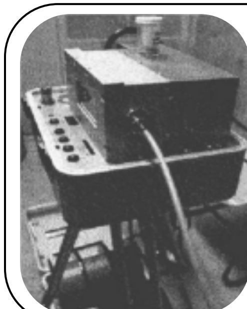
€ /m

Trenching

+ Robust and invisible
- Expensive road works

40 - 60

Blowing Fibre



+ Cheap & install when used
- Ducts available

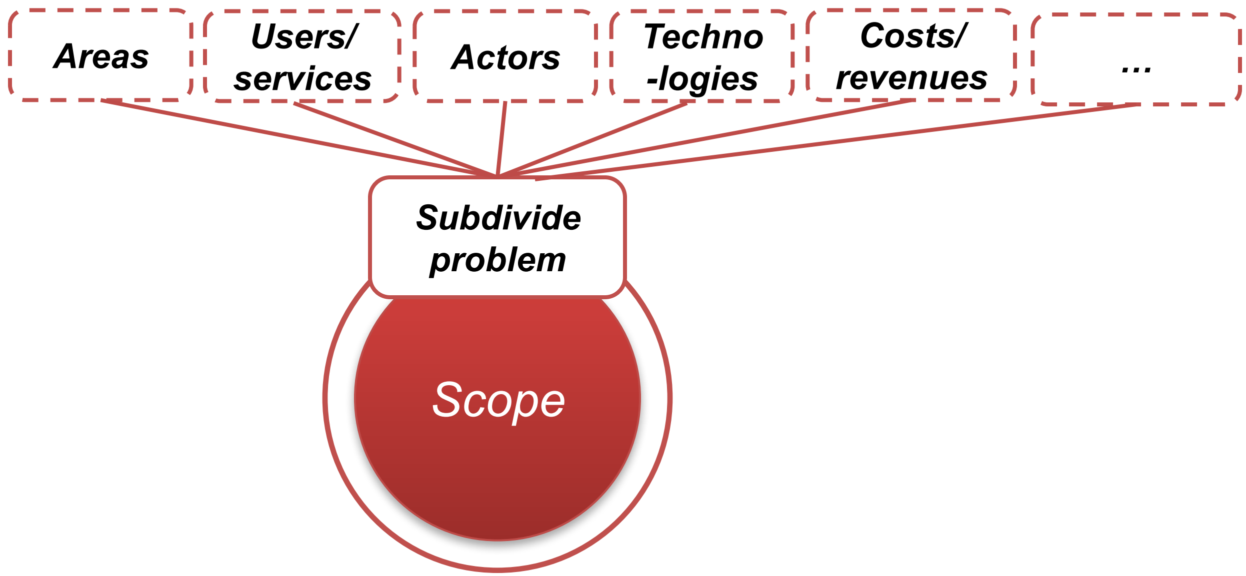
5 - 10

Aerial

+ Fast & cheap
- Vulnerable & regulations

7,5 - 15

Subdivide the problem
in order to define the scope more clearly



The reference case
focuses on a smaller part of Ghent

Scope

Subdivide problem

Areas

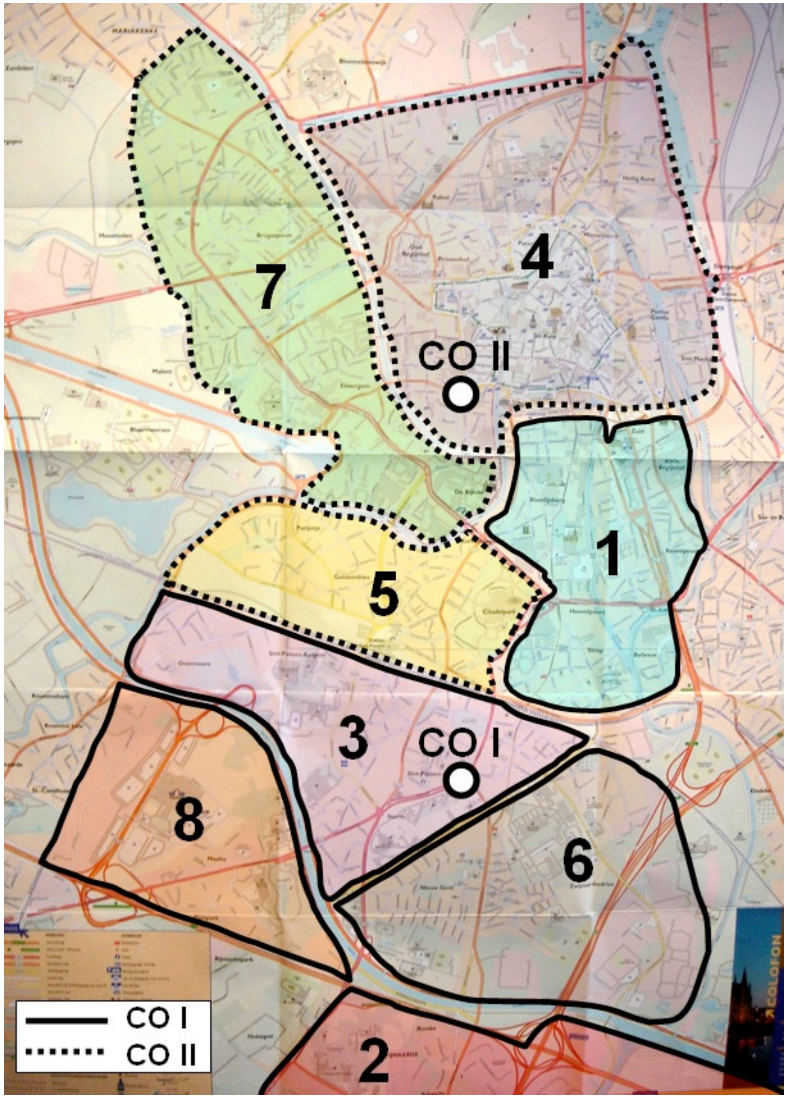
Surface	~~156 km²~~	→ 20 km²
Inhabitants	~~233.644~~	→ 90.000
Density	~~1.496~~	→ 4.500
Companies		→ 222

Definition of rollout areas
for Fiber to the Home network

Scope

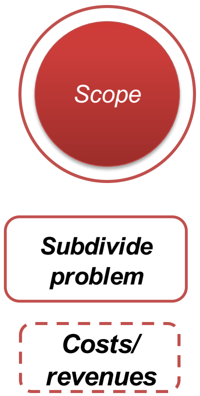
Subdivide problem

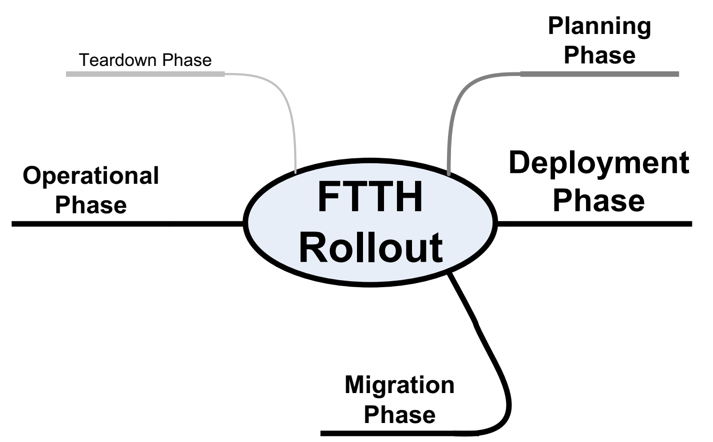
Users/ services



- Cluster example in 8 areas
- Areas based on
  - **Residential**
  - **Industrial**
  - **Public services**
- 2 Central offices ○

Zooming in
using a life-cycle starting point



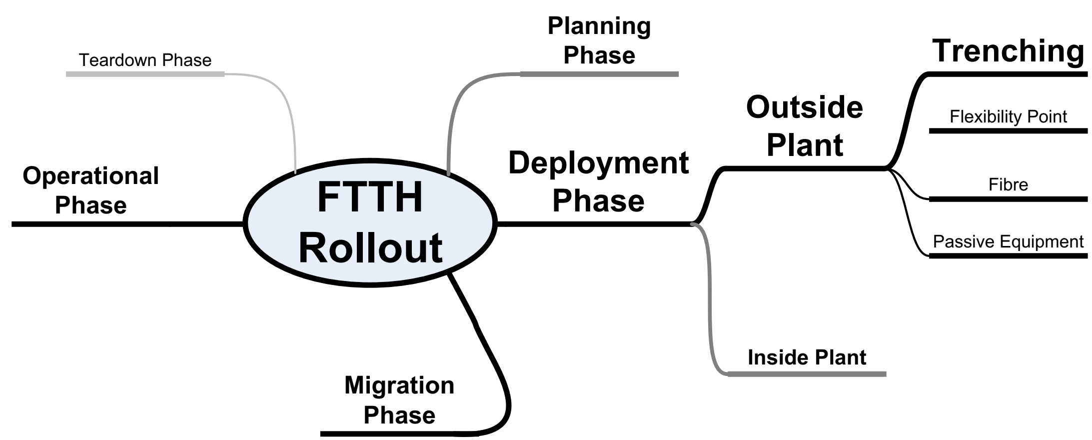


The largest cost part
will be in deployment phase → outside plant → trenching

Scope

Subdivide problem

Costs/ revenues

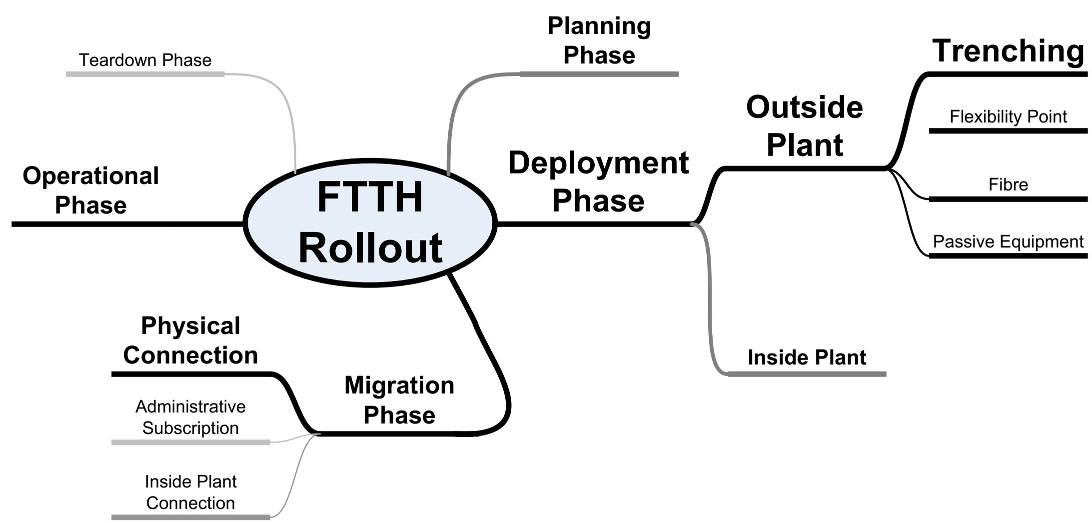


The second largest part
is expected in service migration → connect → physical

Scope

Subdivide problem

Costs/ revenues

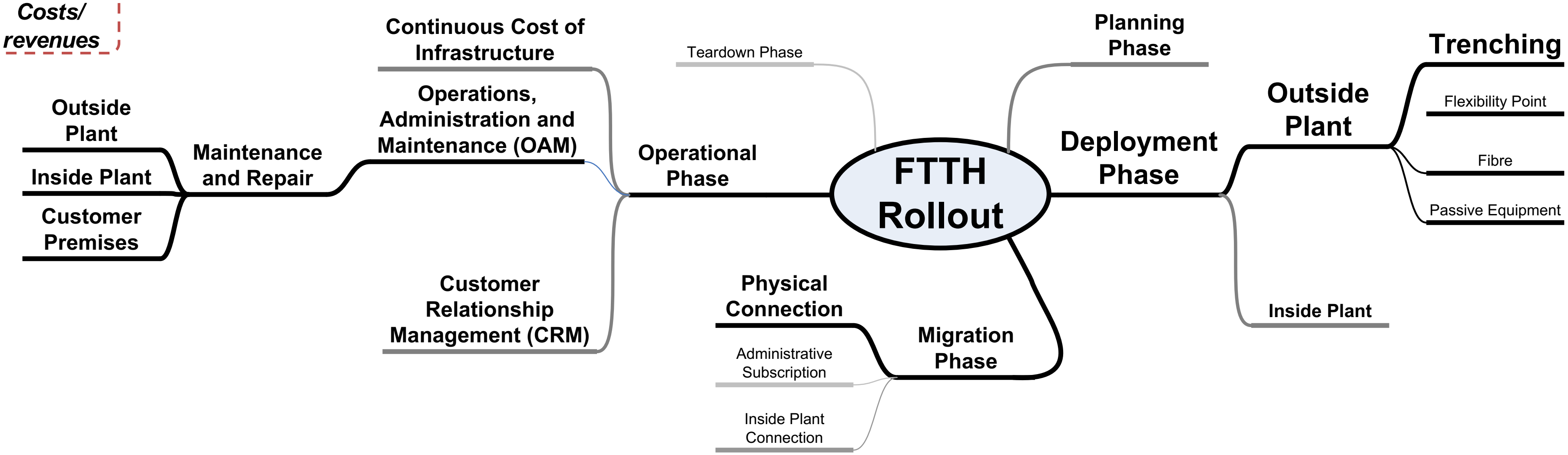


Zooming further
into the largely unpredictable repair cost

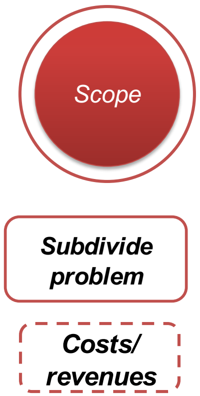
Scope

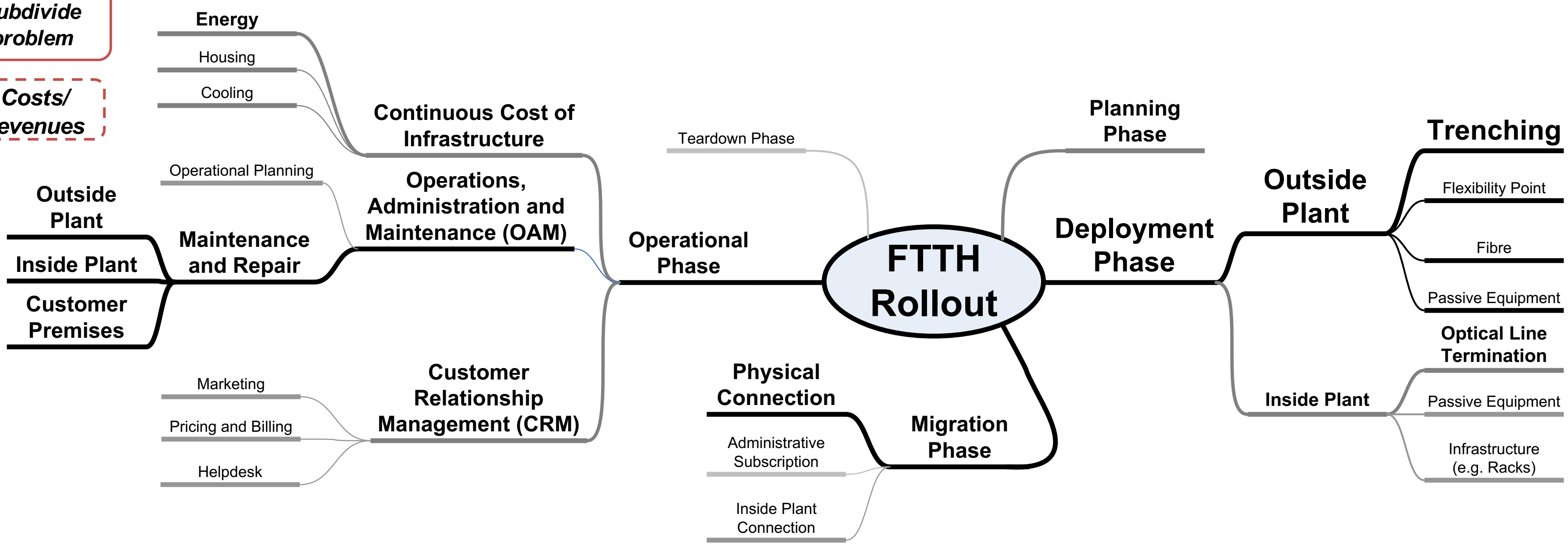
Subdivide problem

Costs/ revenues

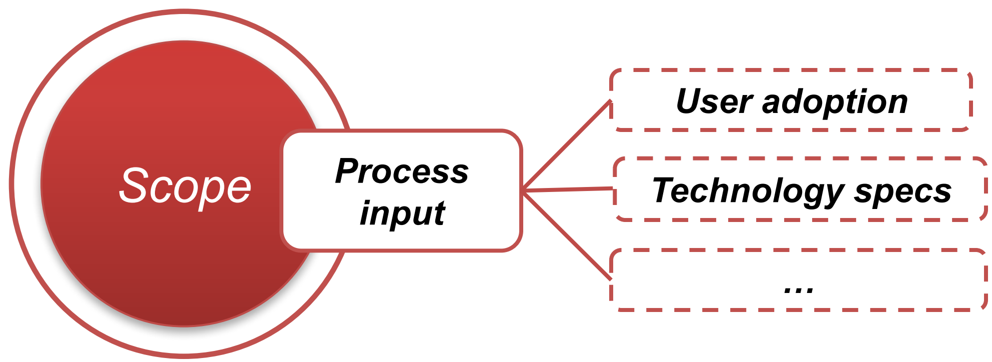


Finally the addition of the missing parts gives a full decomposition of the total costs





Process input
required before actual modeling starts



Customer adoption model

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Scope

Process input

User adoption

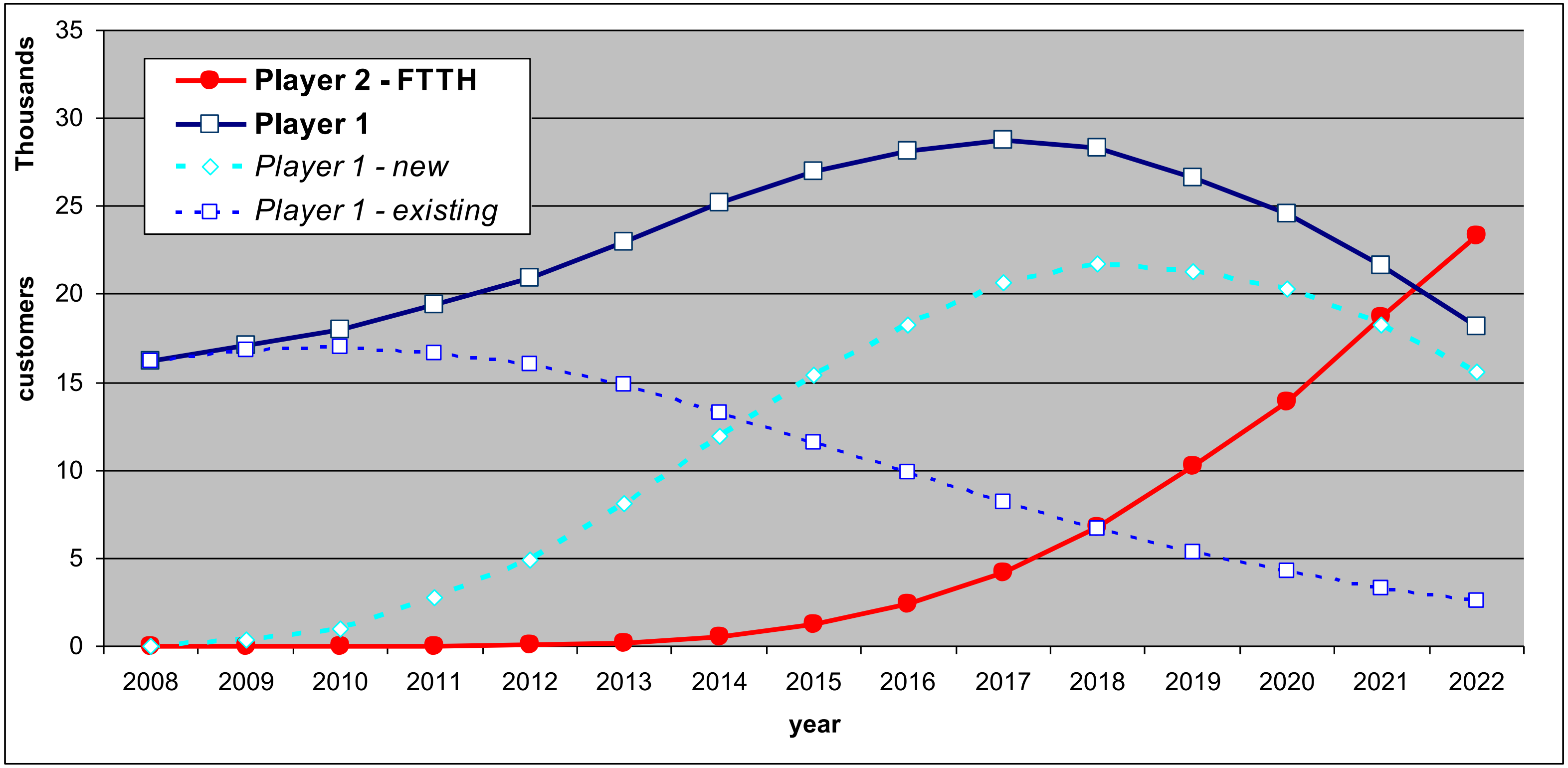
year	CUSTOMER ADOPTION									
	PLAYER 1						PLAYER 2 - FTTH			
	EXISTING	DOCSIS 3.0				TOTAL				
	TOTAL	residential	commercial	industrial	TOTAL	TOTAL	residential	commercial	industrial	TOTAL
2008	**16193**	15460	773	0	**40**	**16233**	0	0	0	**0**
2009	**16820**	16327	816	0	**324**	**17144**	2	0	0	**2**
2010	**17002**	17156	858	0	**1011**	**18014**	11	1	2	**13**
2011	**16664**	18517	926	0	**2779**	**19443**	35	2	7	**44**
2012	**16011**	19892	995	0	**4875**	**20887**	82	4	9	**95**
2013	**14859**	21898	1095	0	**8134**	**22993**	190	10	12	**211**
2014	**13241**	23967	1198	0	**11925**	**25166**	444	23	30	**497**
2015	**11558**	25686	1284	0	**15411**	**26970**	1141	59	57	**1257**
2016	**9904**	26843	1342	0	**18282**	**28186**	2214	113	69	**2395**
2017	**8189**	27436	1372	0	**20619**	**28808**	3916	199	80	**4195**
2018	**6648**	26987	1349	0	**21689**	**28337**	6339	322	101	**6762**
2019	**5376**	25377	1269	0	**21269**	**26645**	9611	488	122	**10220**
2020	**4263**	23428	1171	0	**20336**	**24600**	13080	672	132	**13884**
2021	**3325**	20576	1029	0	**18280**	**21605**	17657	912	141	**18711**
2022	**2557**	17269	863	0	**15575**	**18132**	22009	1130	170	**23308**

Adoption
for new and existing network services

Scope

Process input

User adoption

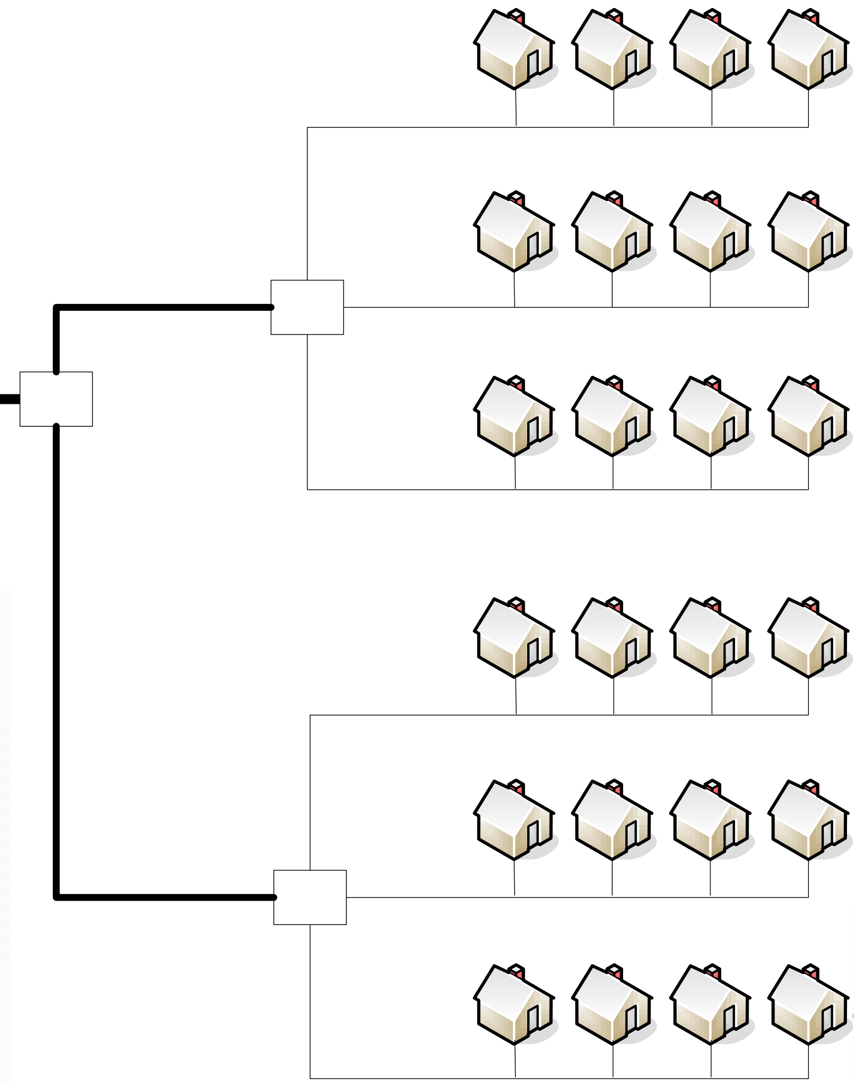


Fibre transports light (data)
from & to the customer

Scope

Process input

Technology specs



Conversion between optical and electronic signals
at the customer premises

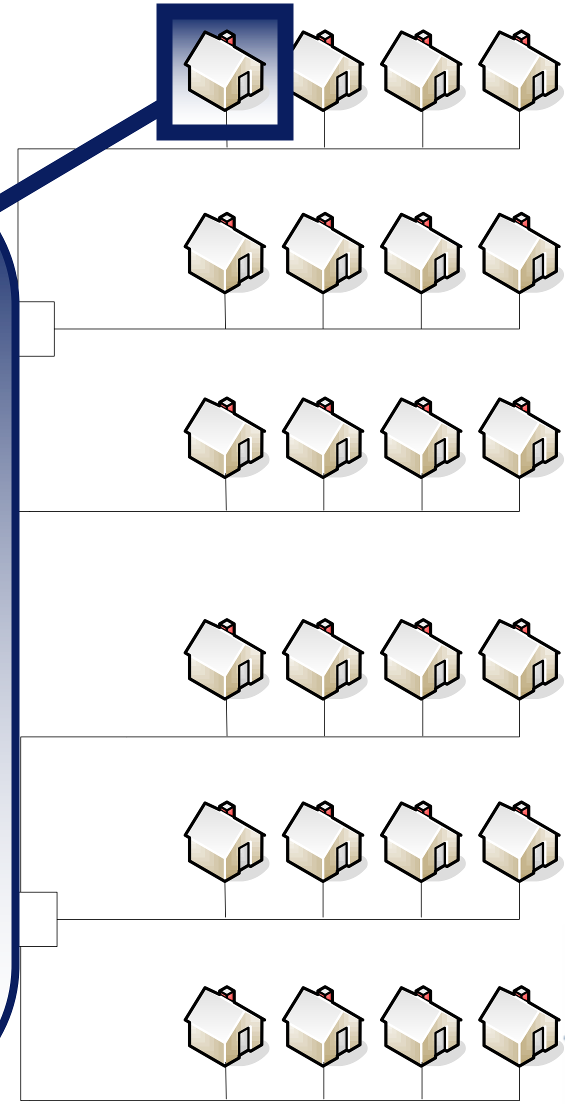
Scope

Process input

Technology specs

Customer premises

Optical Network Termination (ONT)



Passive flexibility and aggregation
in the field

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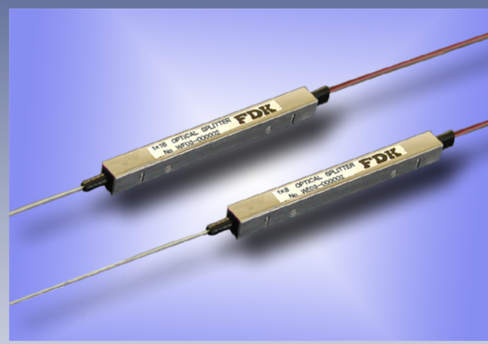
Scope

Process input

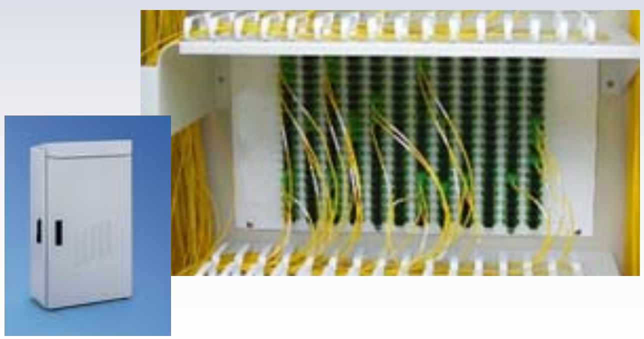
Technology specs

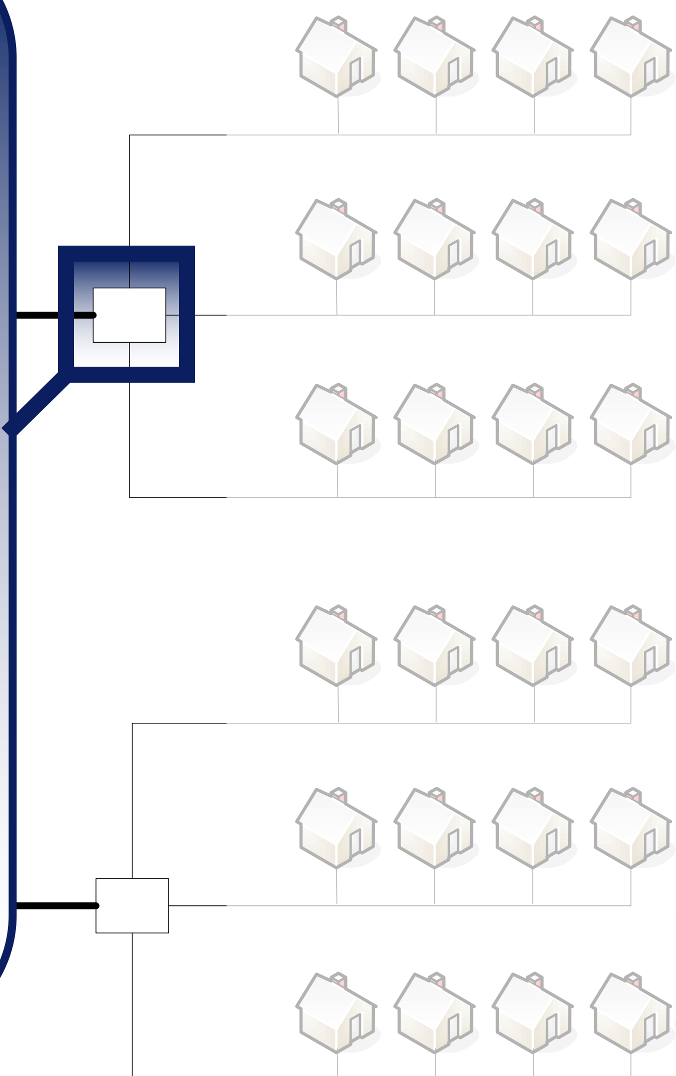
Aggregation

Optical splitters



Flexibility points



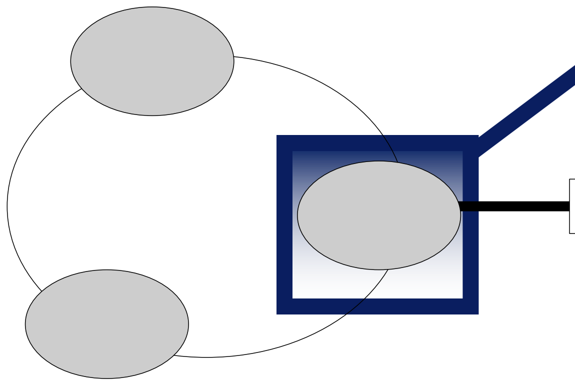


Optical line termination
and aggregation into the metro-core network

Scope

Process input

Technology specs



Central Office (CO)

Optical Line Termination

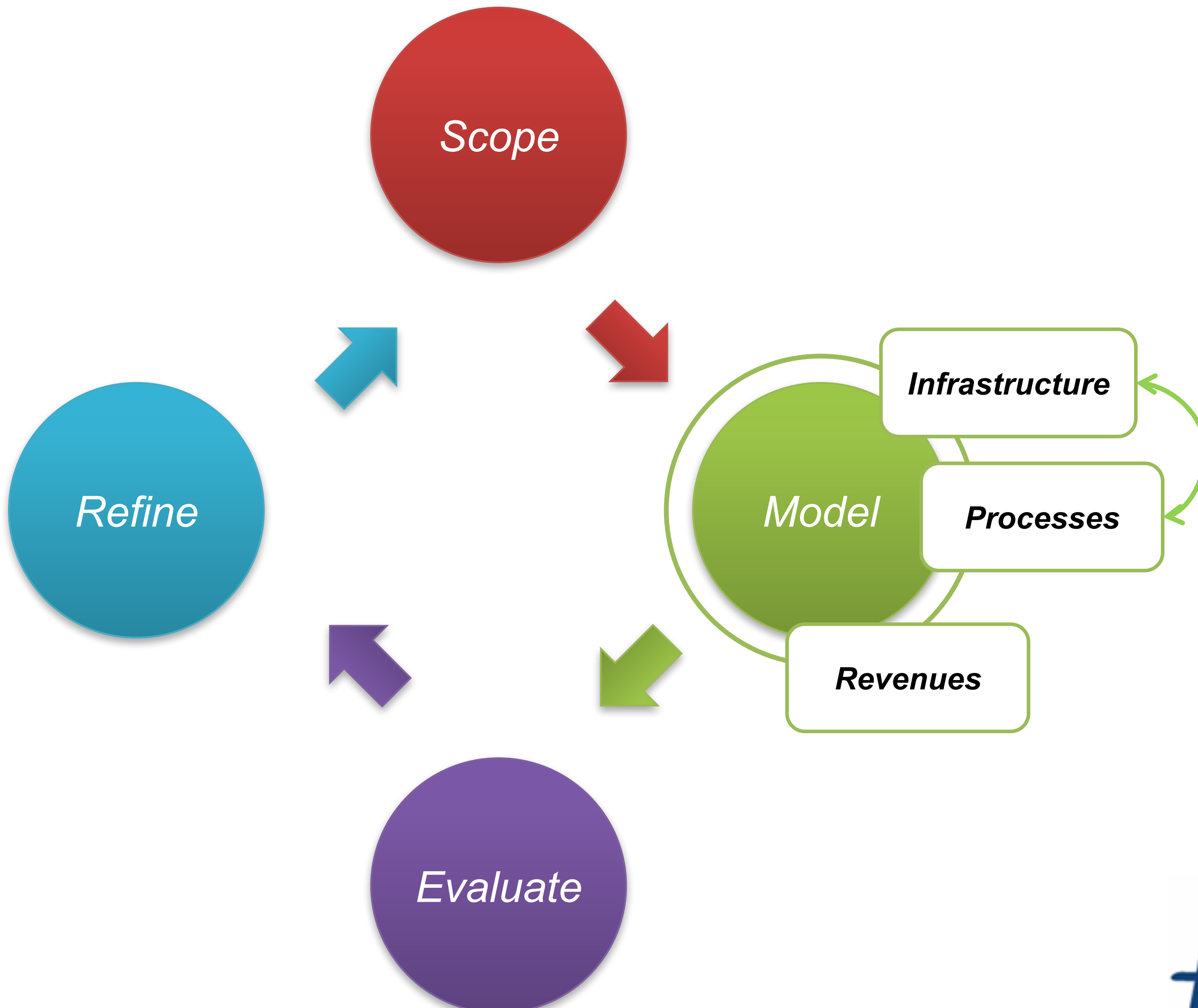
Connects to metro-core

Connects to applications

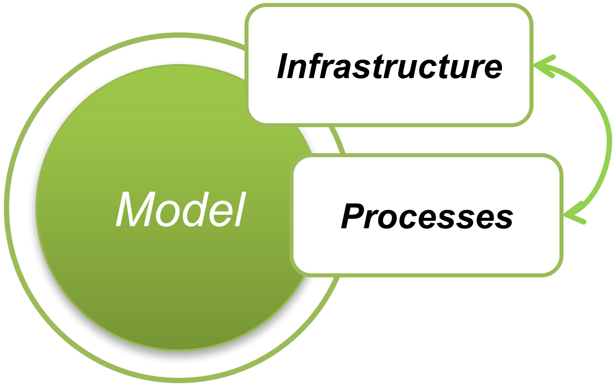
Practical steps in techno-economic evaluation of network deployment planning

MODEL

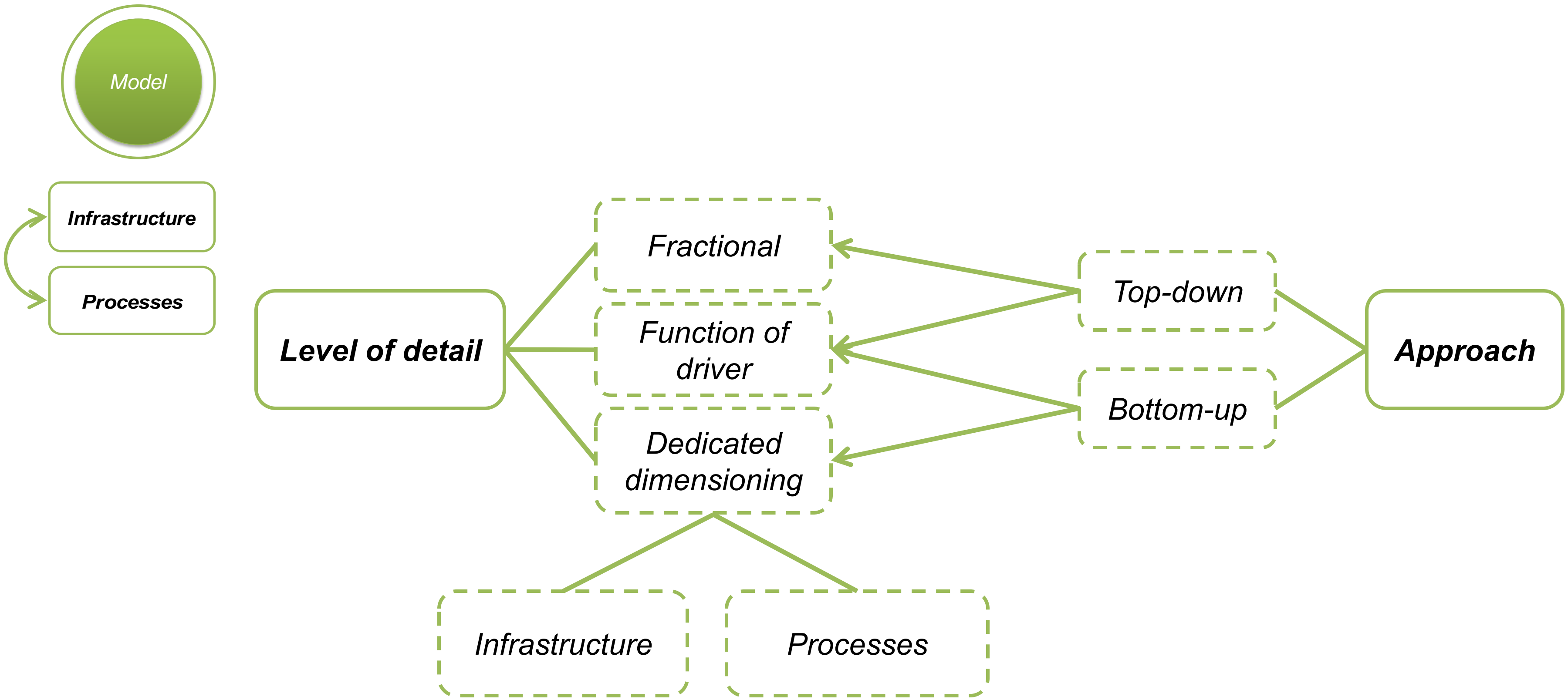
Model
costs and revenues



Model infrastructure and processes
using appropriate level of detail



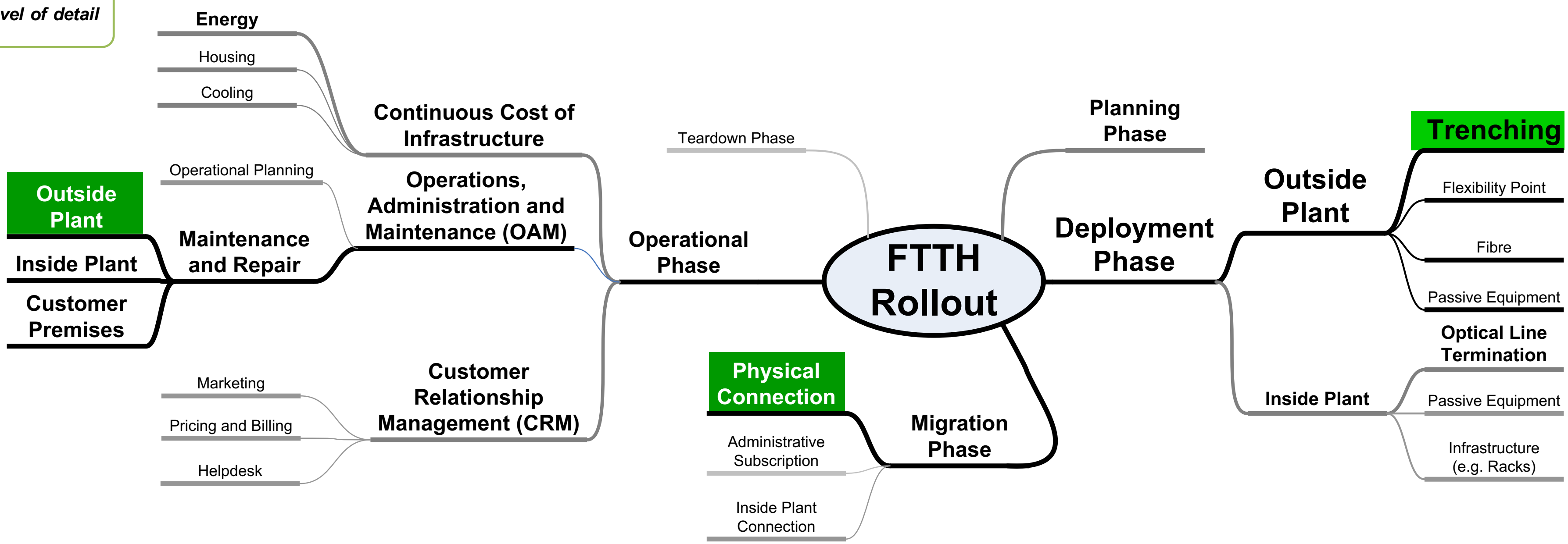
Approach versus level of detail

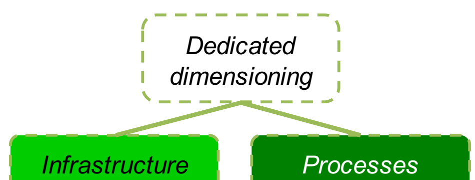


Dedicated dimensioning
in cost models for FTTH rollout

Model

Level of detail

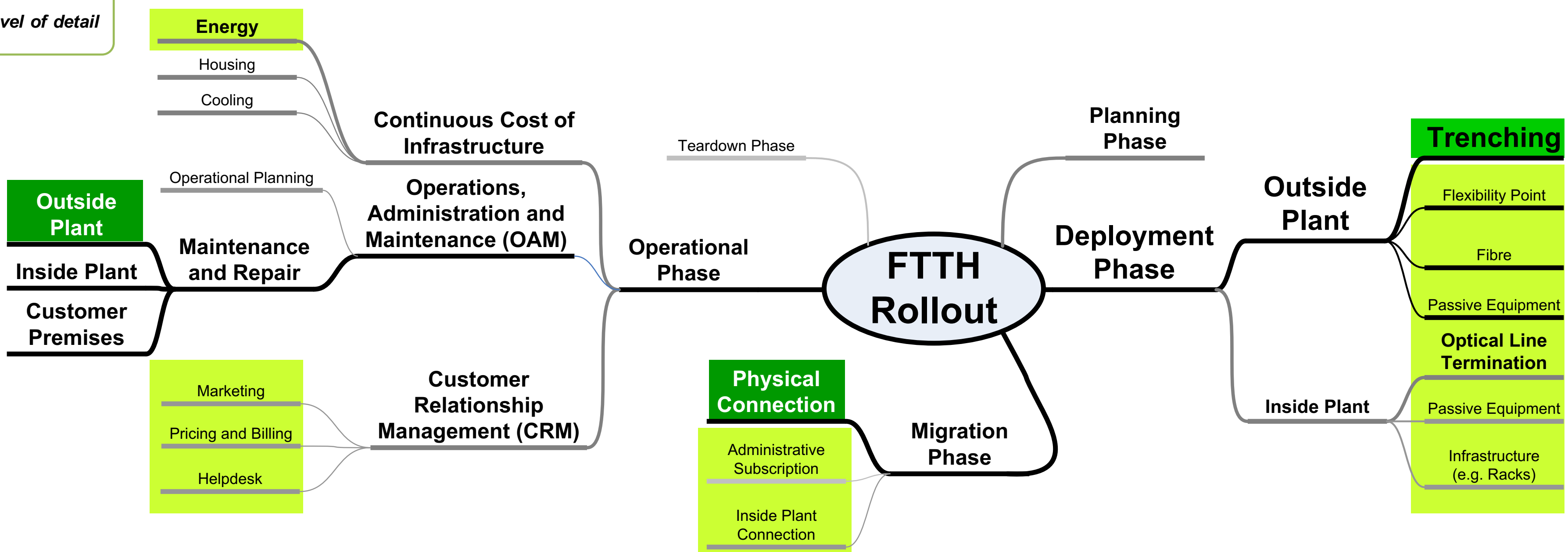


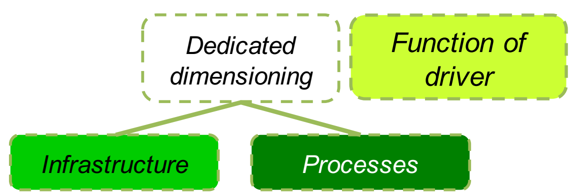


Driver based
cost models for FTTH rollout

Model

Level of detail





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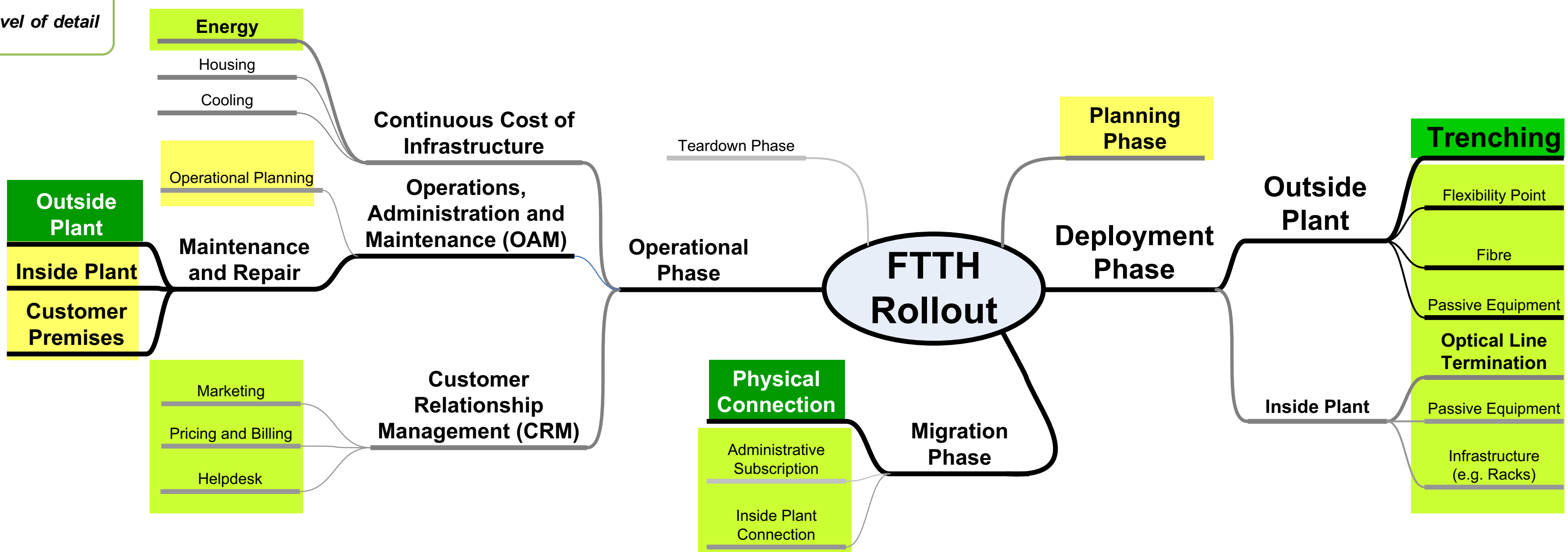
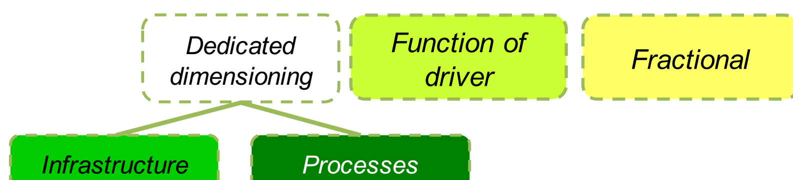
Fractional
cost models for FTTH rollout

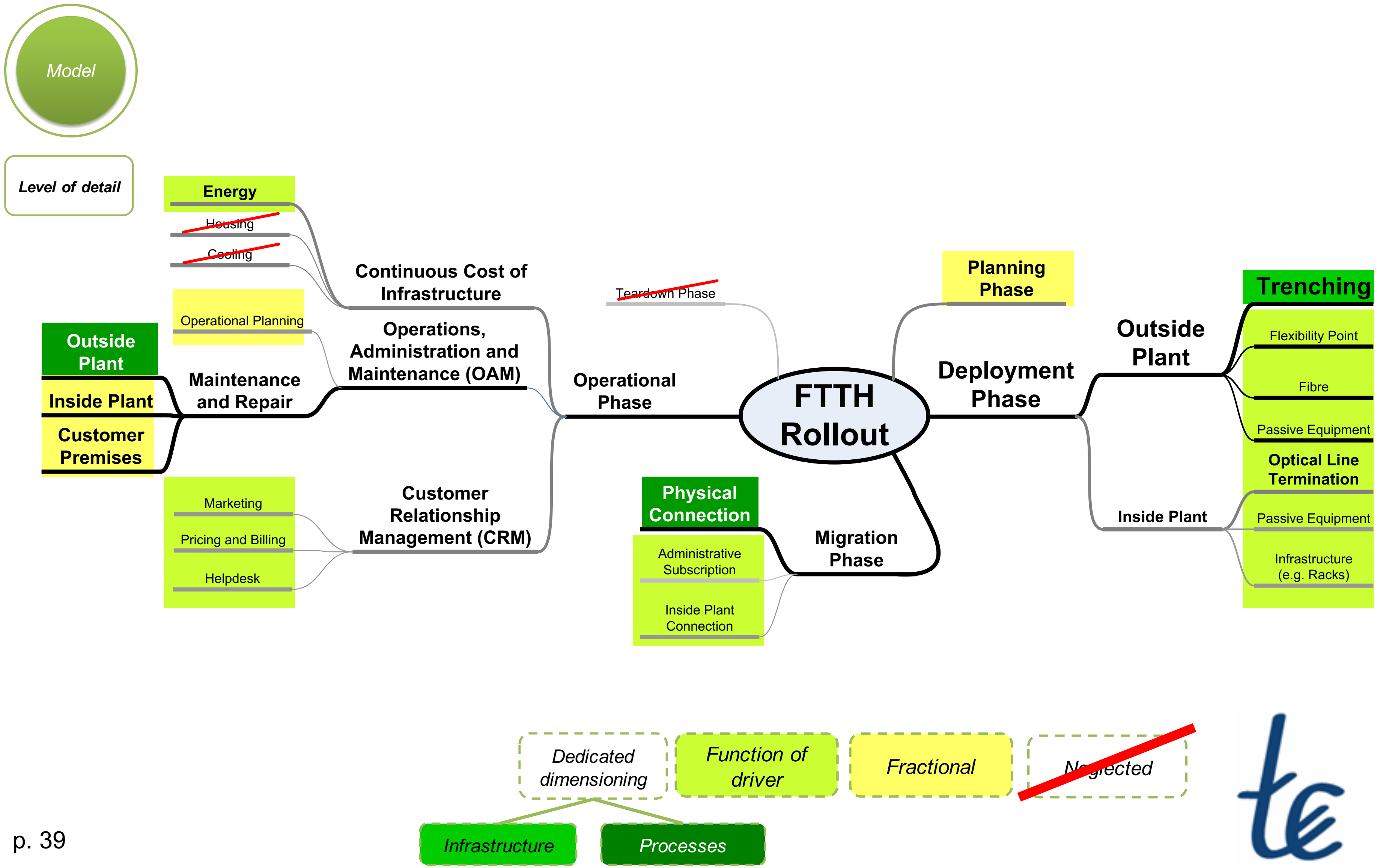
Model

Level of detail





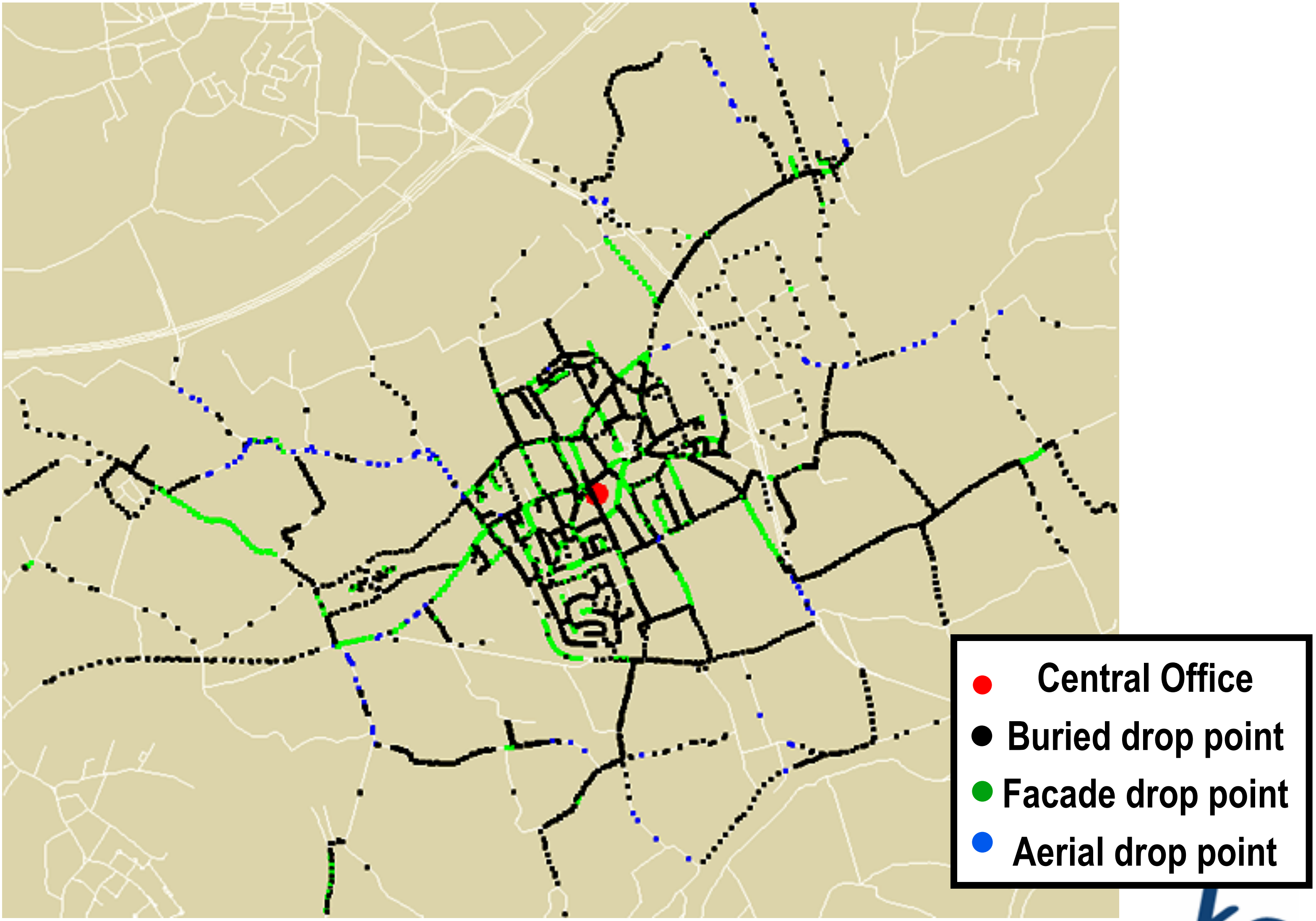
Neglected
cost models for FTTH rollout



Dimensioning of the trenching length..

Model

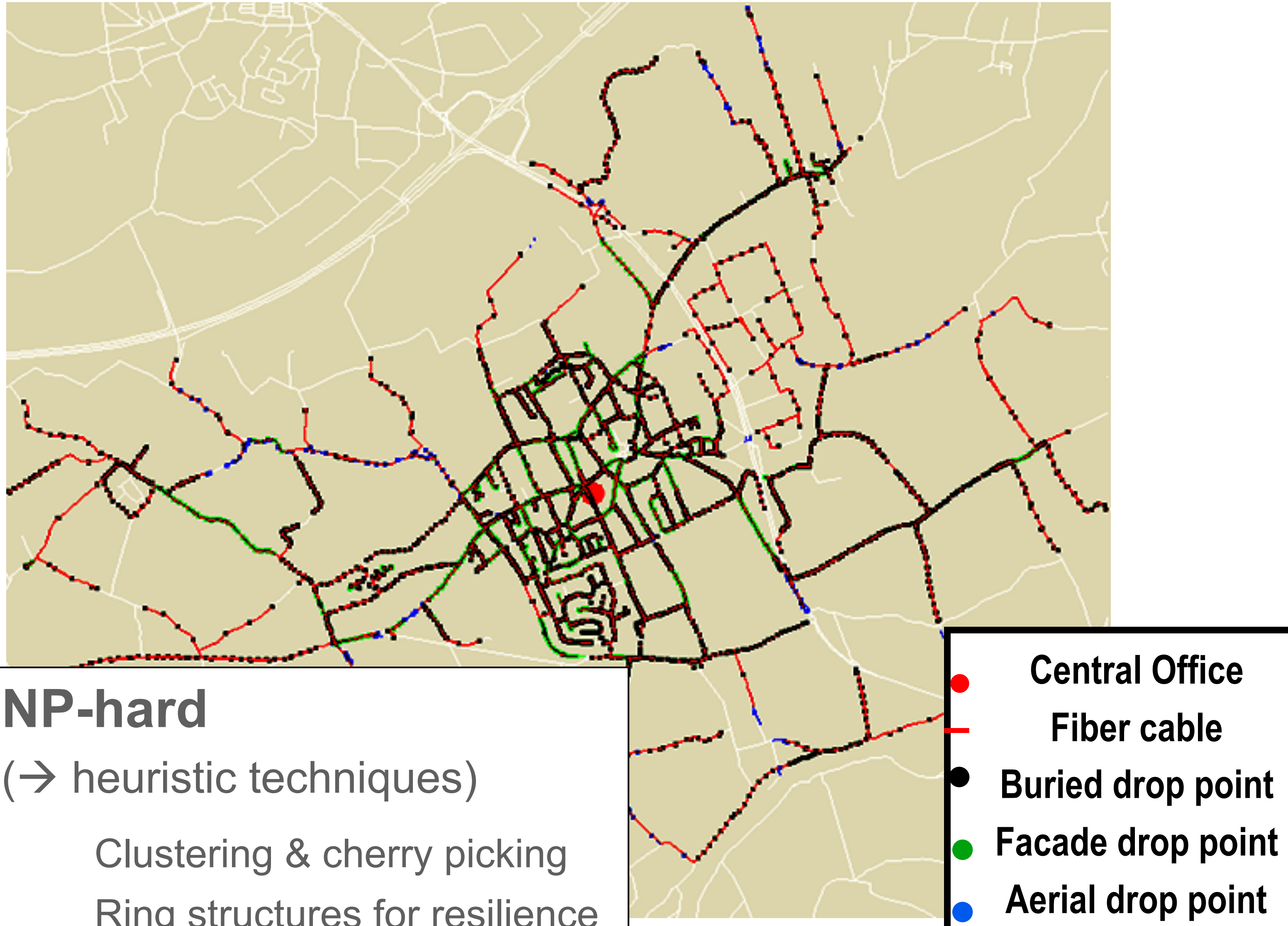
Infrastructure



Model

Infrastructure

..by constructing a Steiner Tree



NP-hard

(→ heuristic techniques)

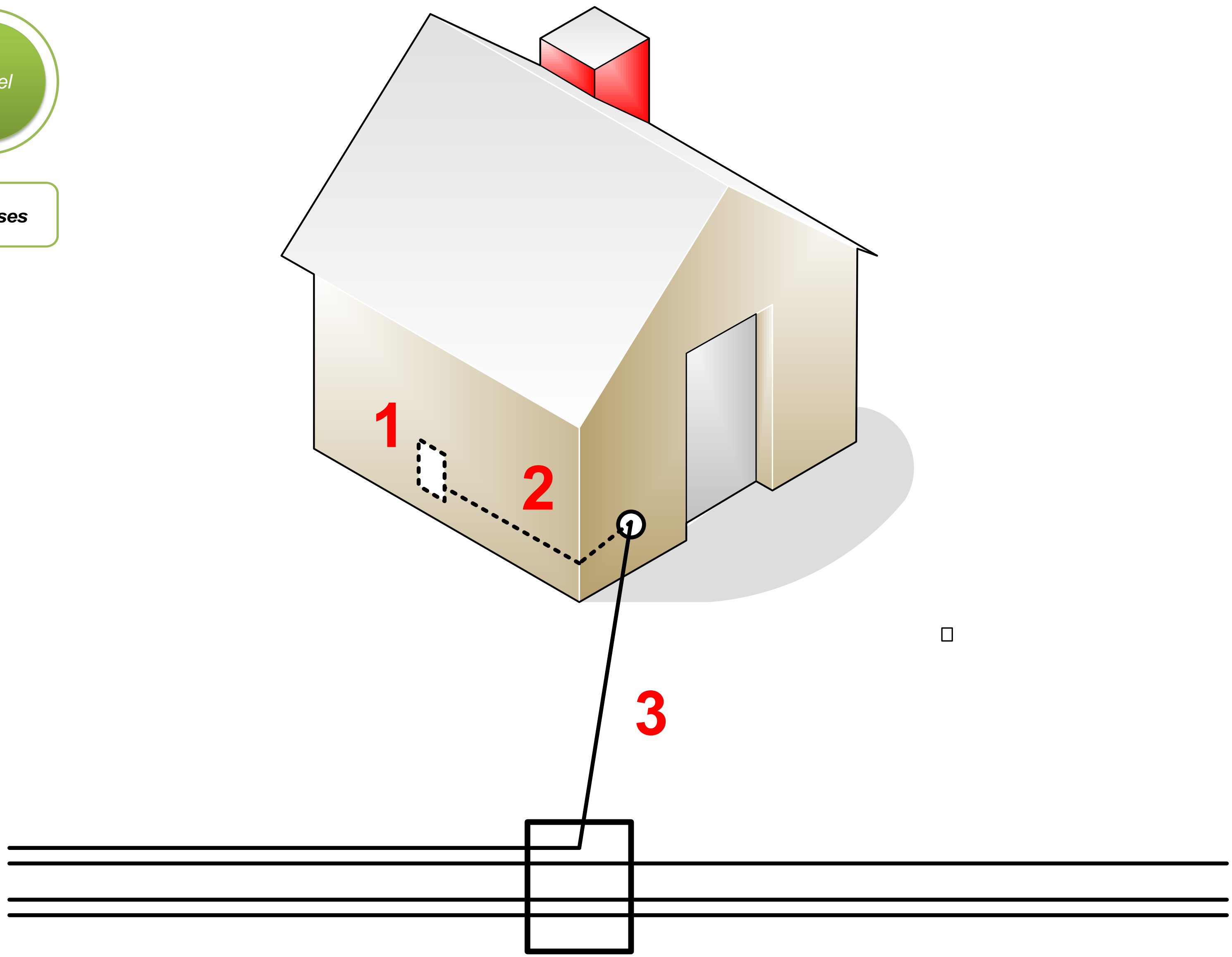
Clustering & cherry picking

Ring structures for resilience

Connecting the customer to the network and services

Model

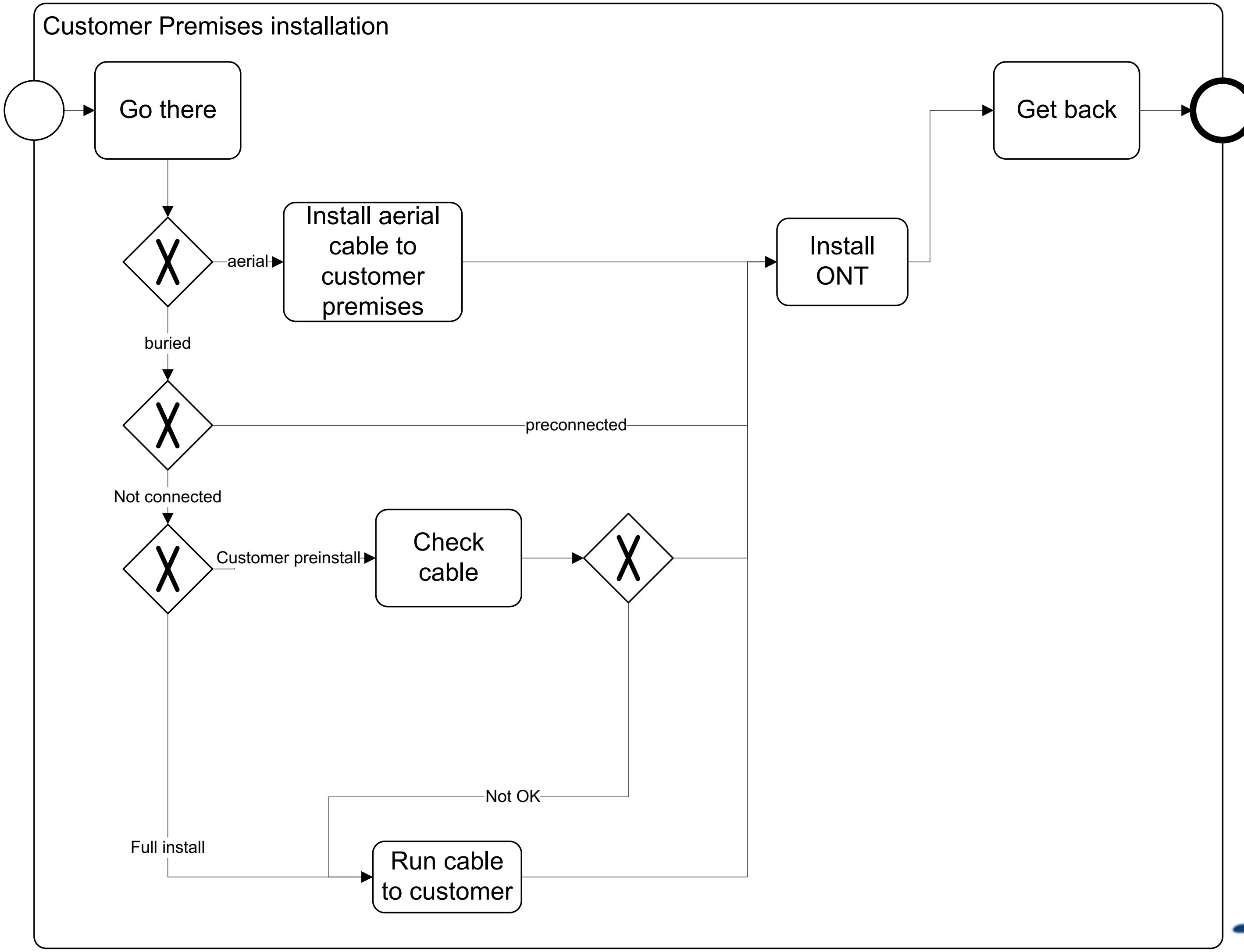
Processes



Operational process
for connecting the customer to the network

Model

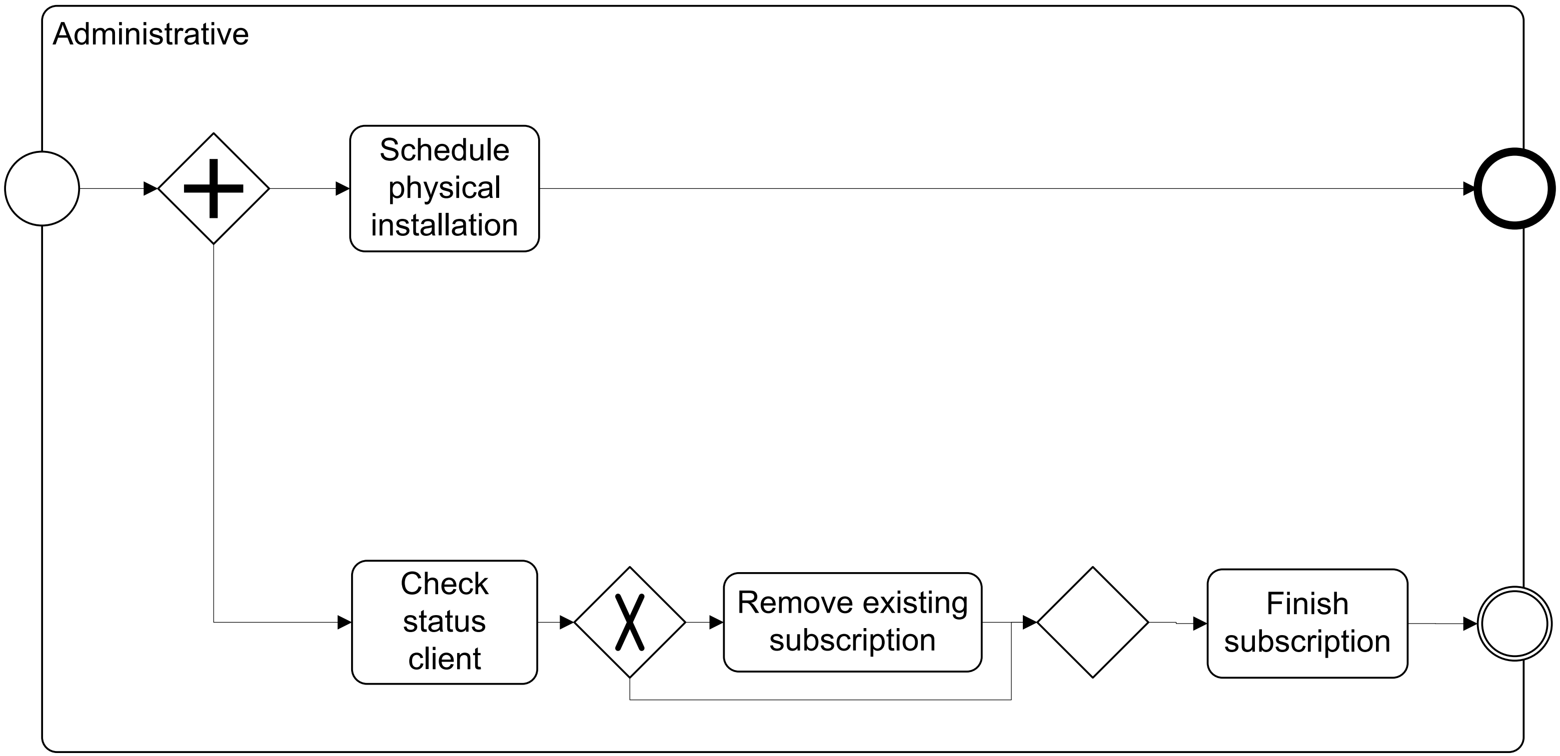
Processes



Operational process
for connecting the customer to the services

Model

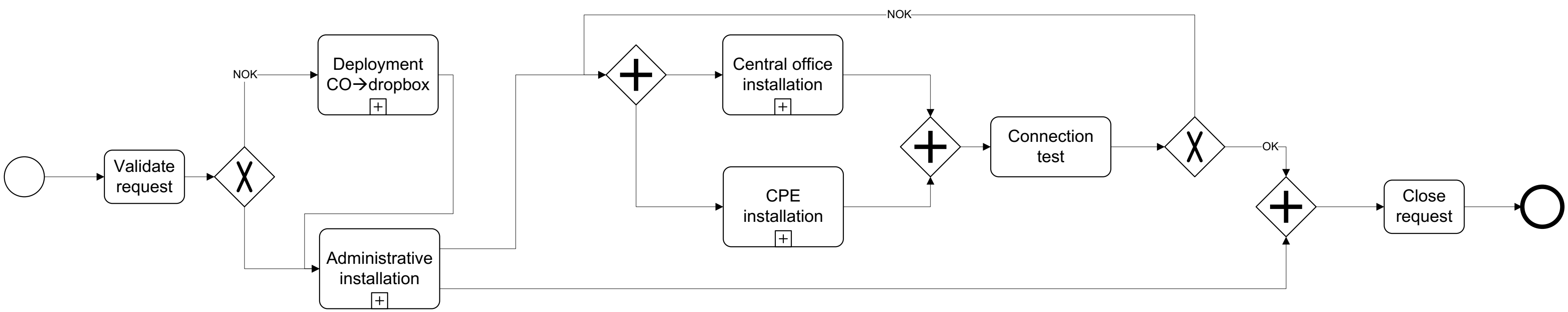
Processes



Deployment
from CO to customer

Model

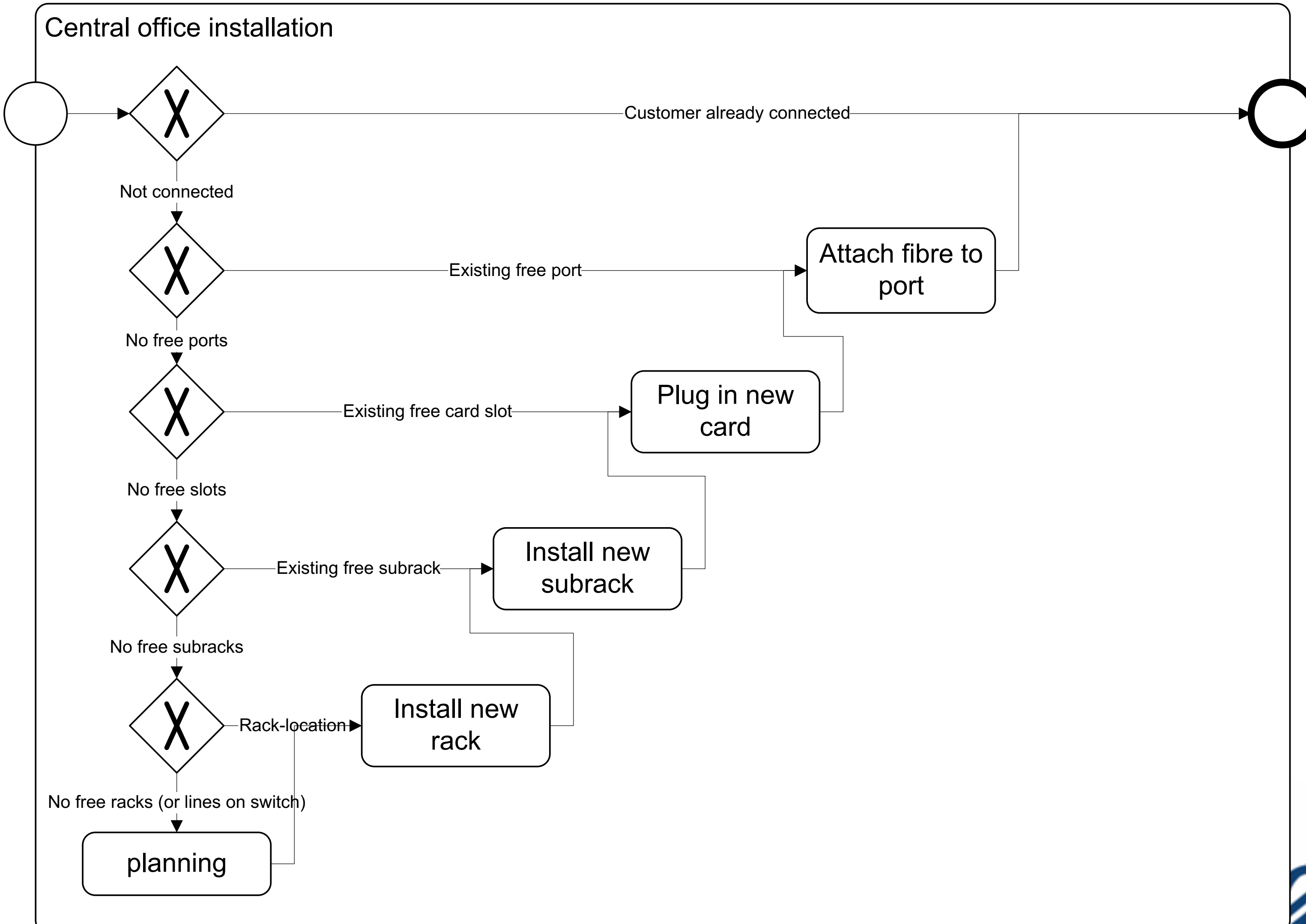
Processes



Installing the central office

Model

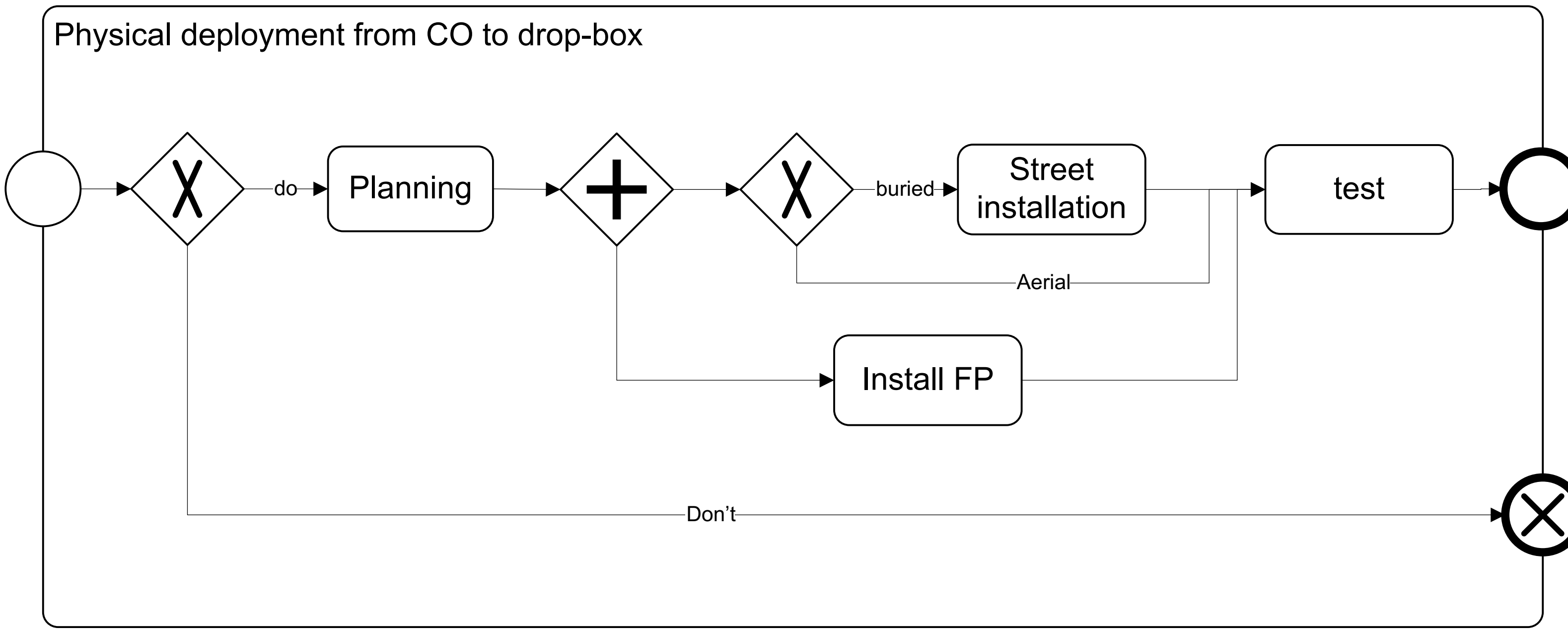
Processes



Deployment
up to the drop box

Model

Processes



Repair

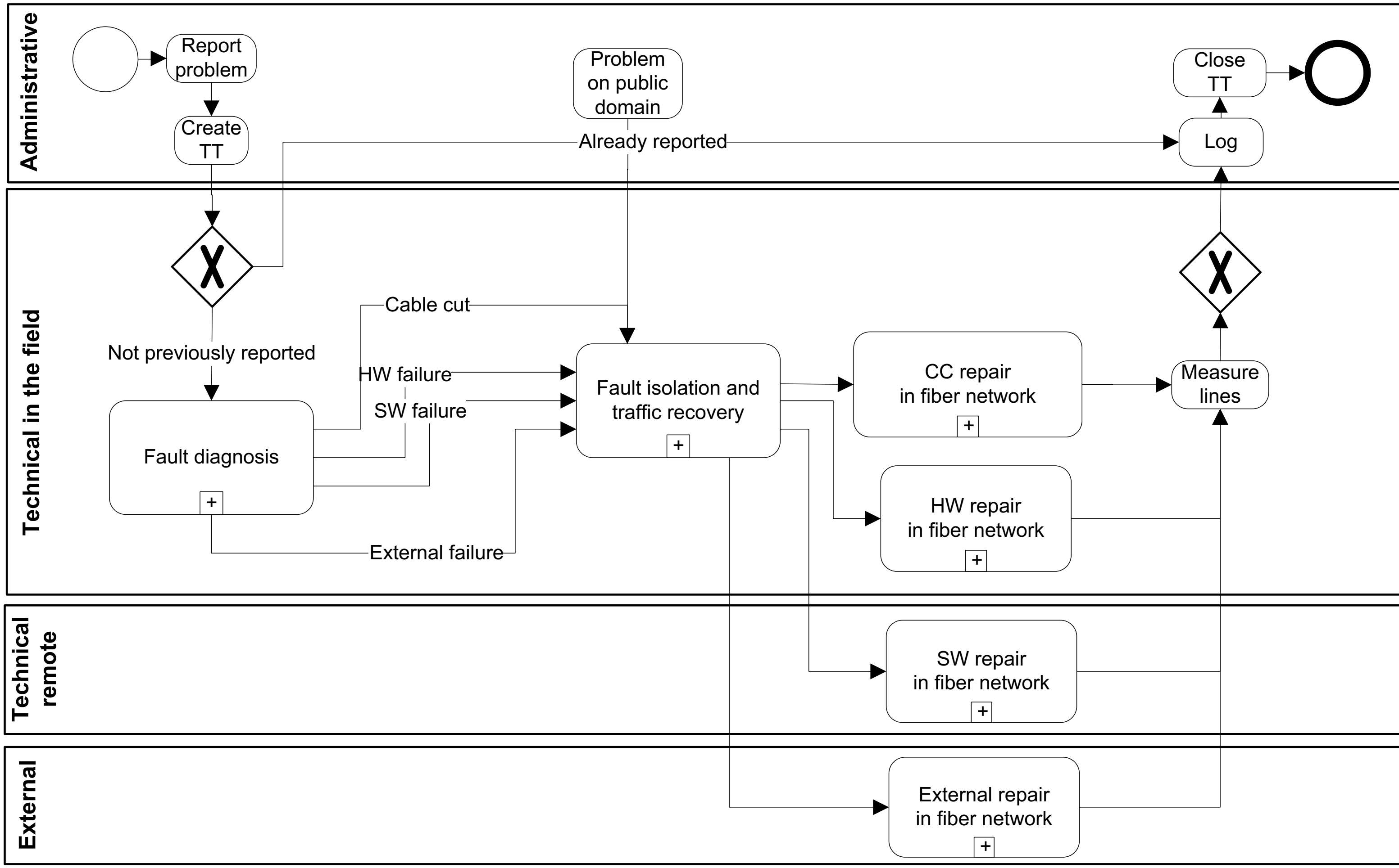
Model

Processes

Repair process

Model

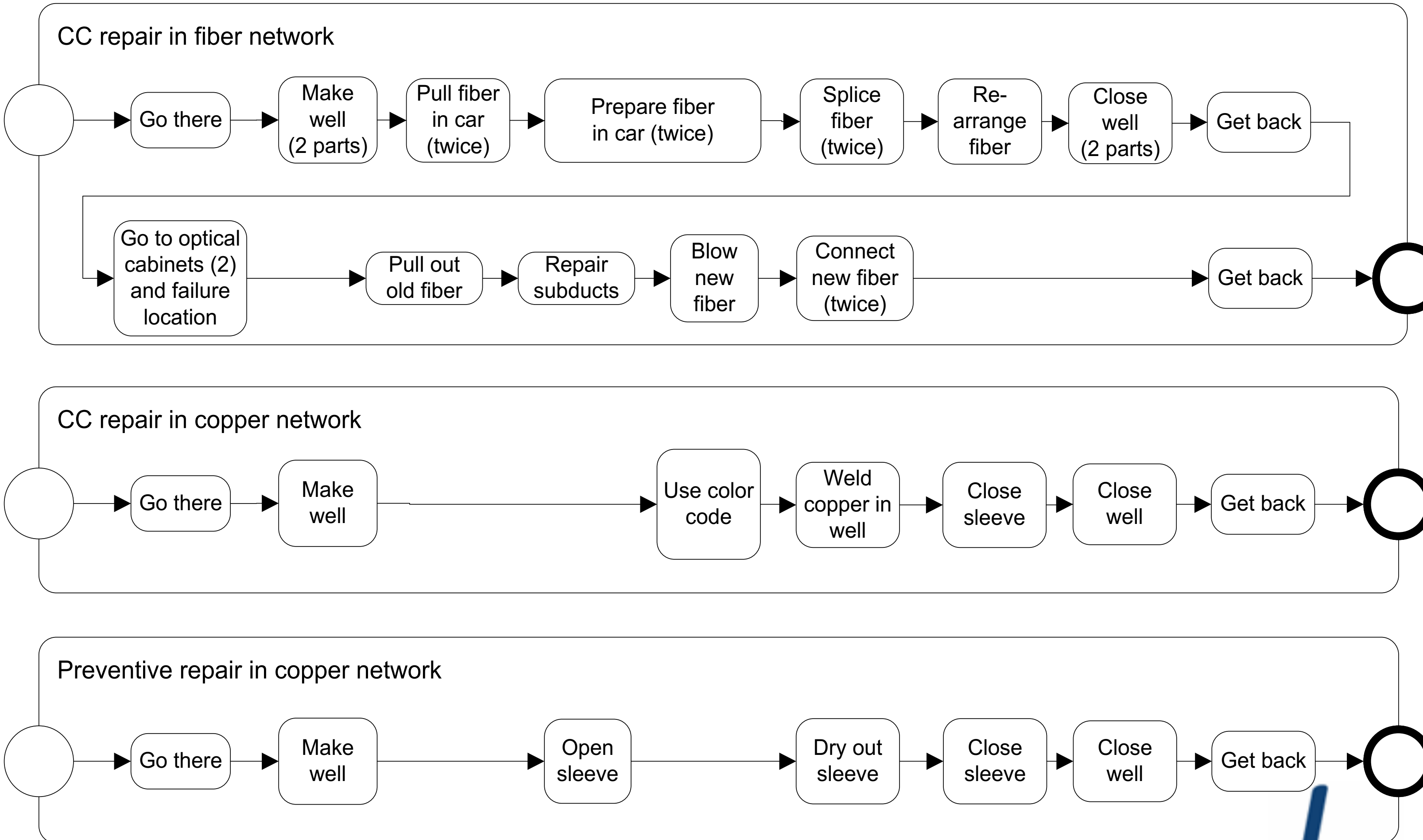
Processes



Cable cut repair subprocess

Model

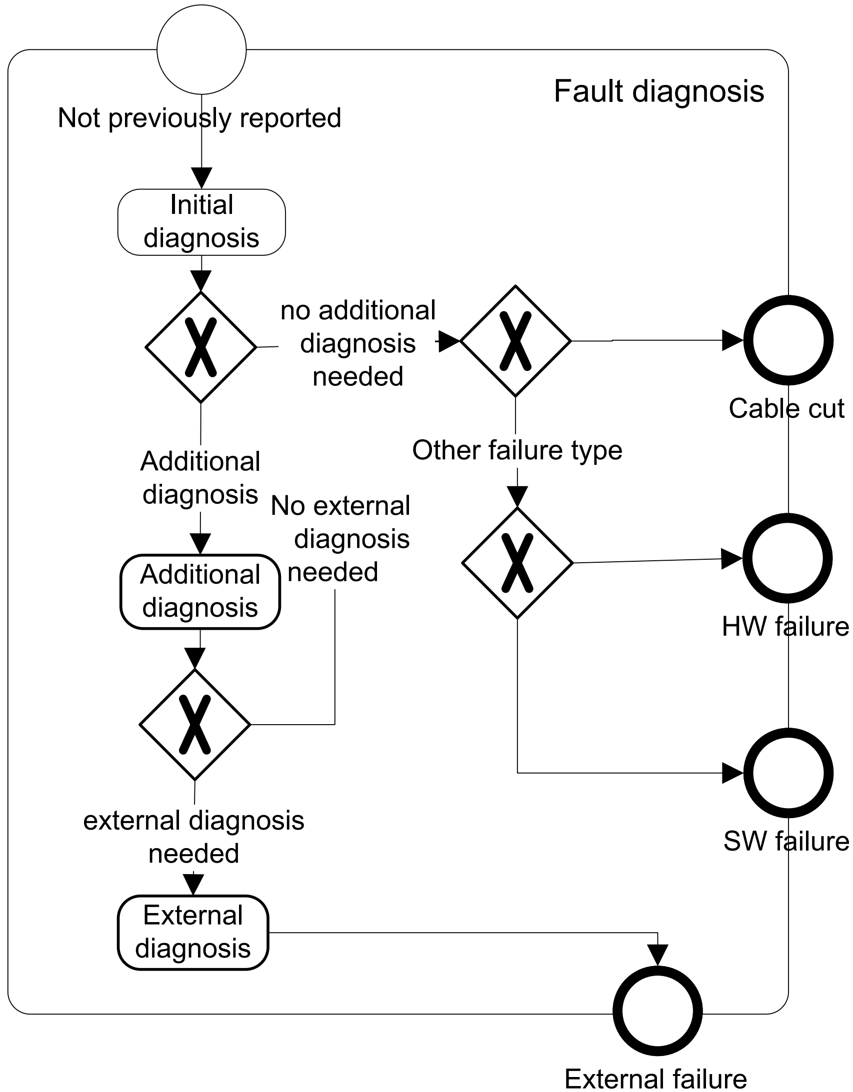
Processes



Diagnosing the failure location

Model

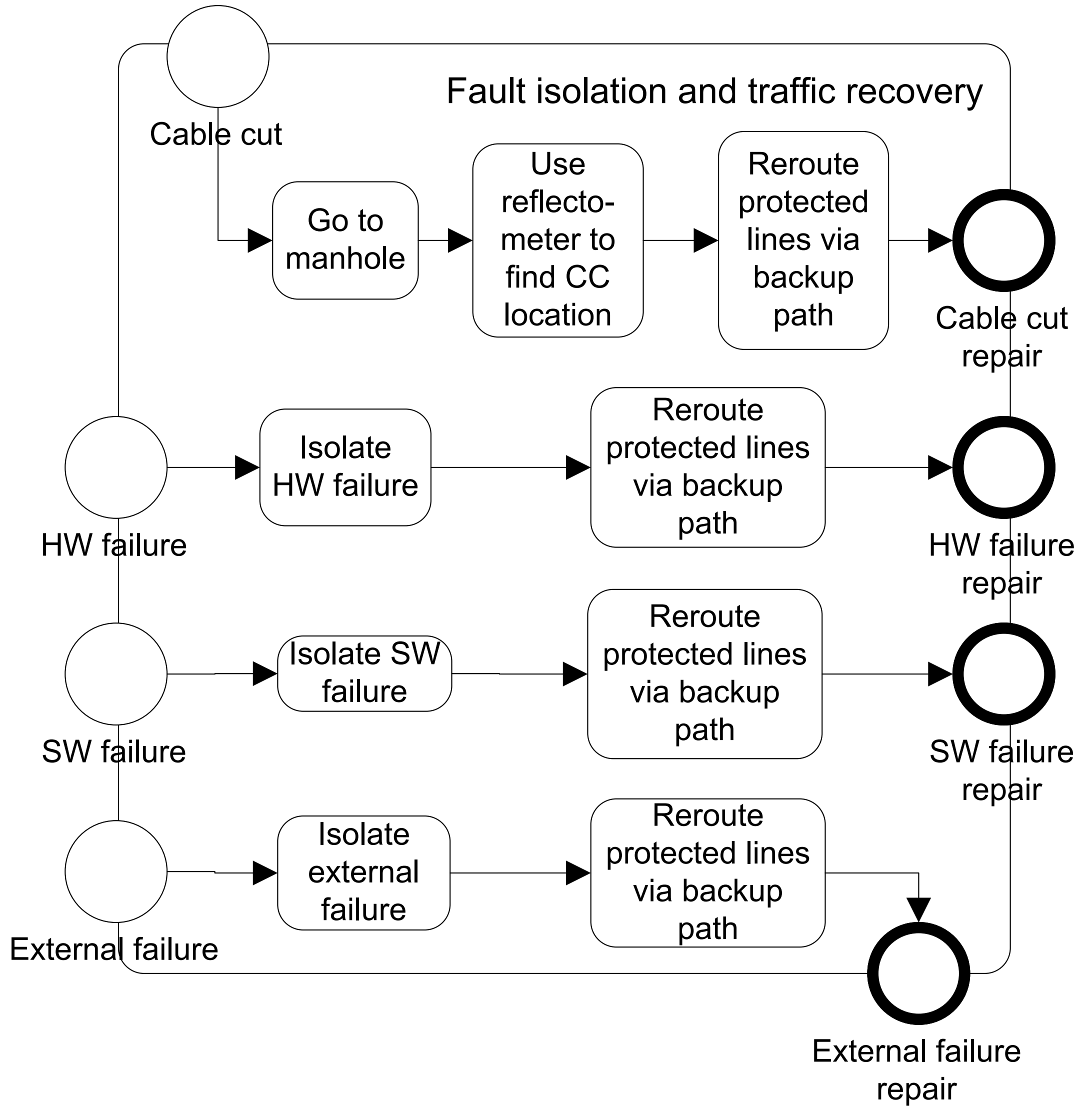
Processes



Recovery actions

Model

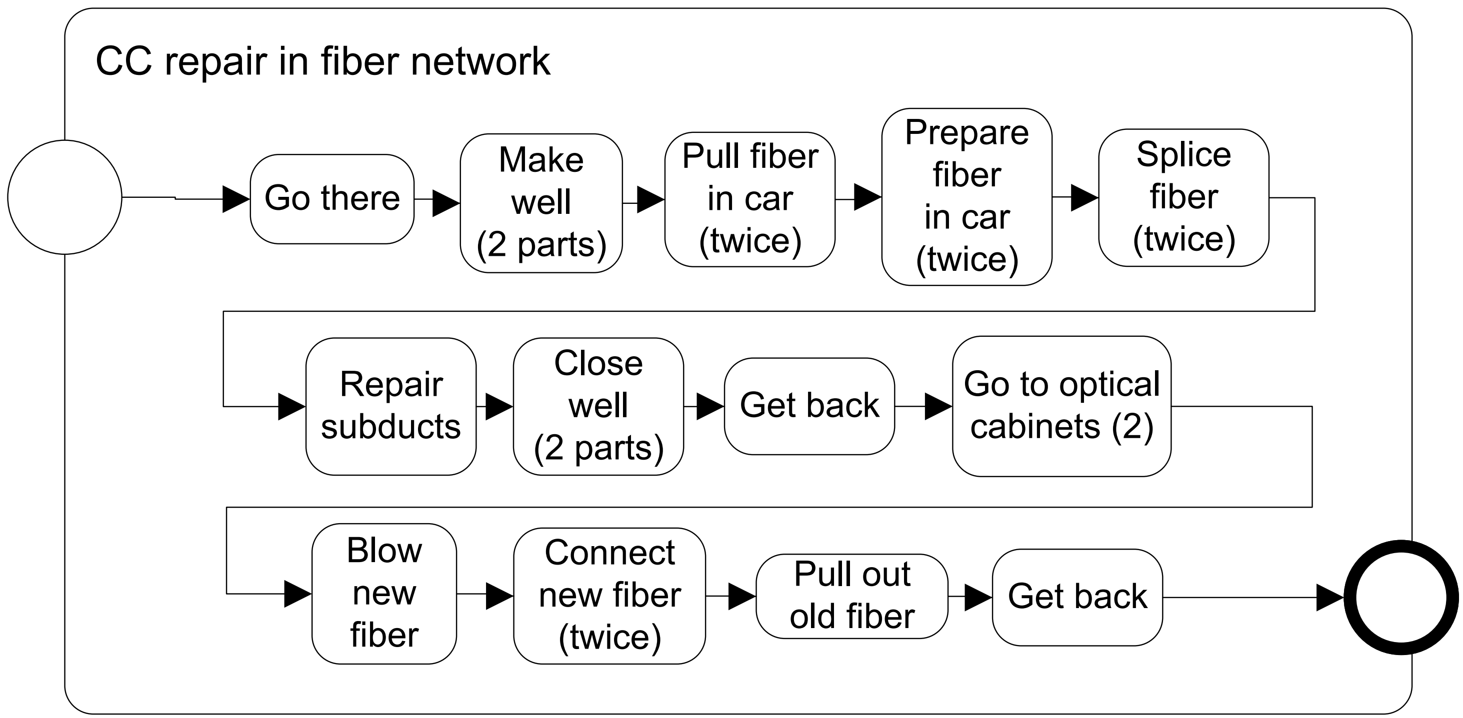
Processes



Repairing the actual fibre

Model

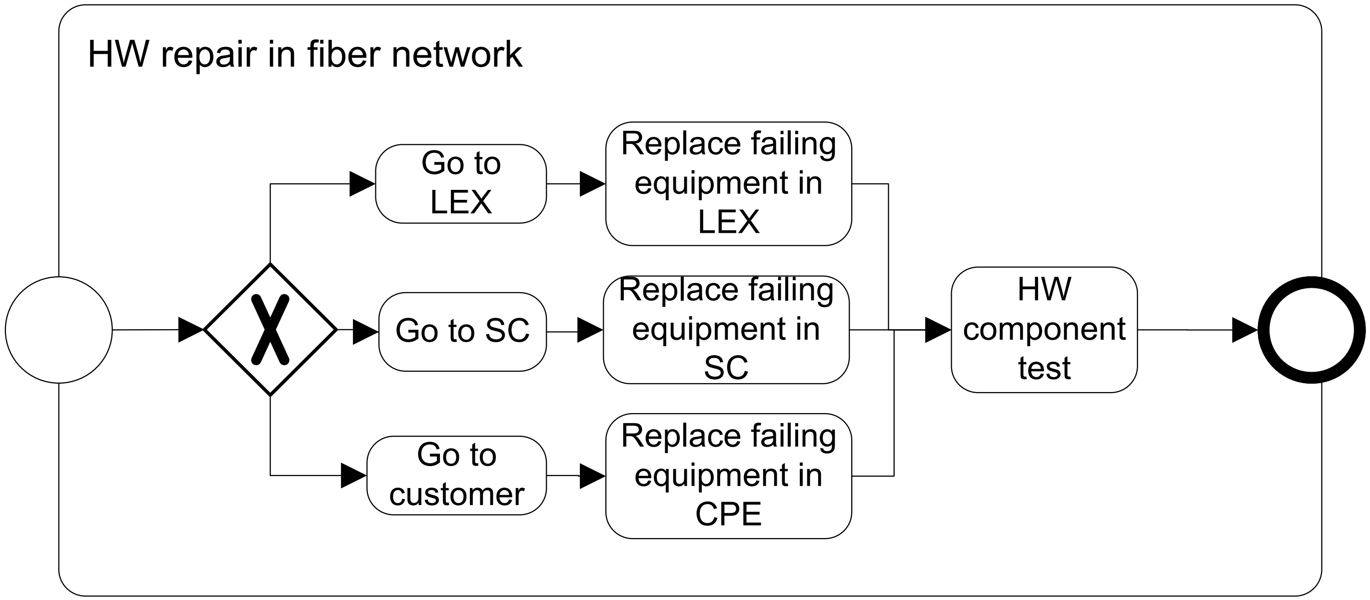
Processes



Repairing the hardware

Model

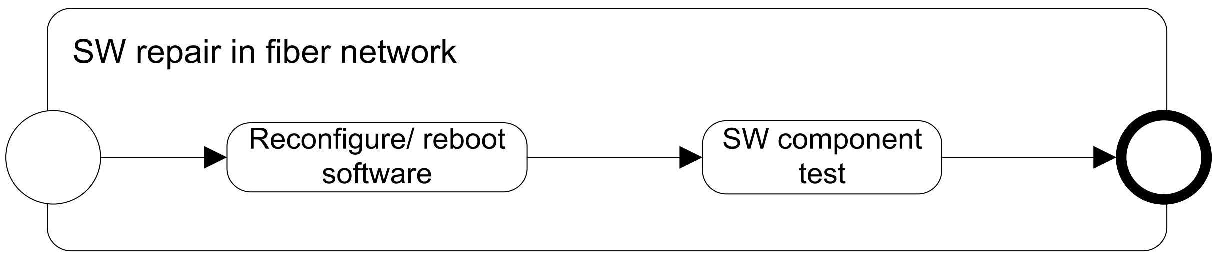
Processes



Repairing the software

Model

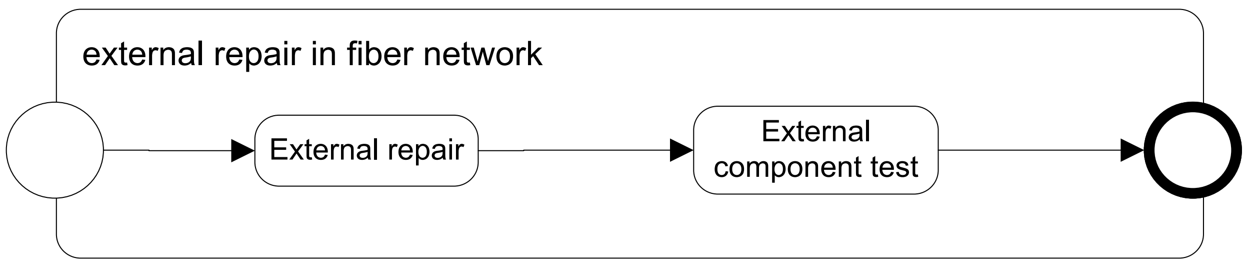
Processes



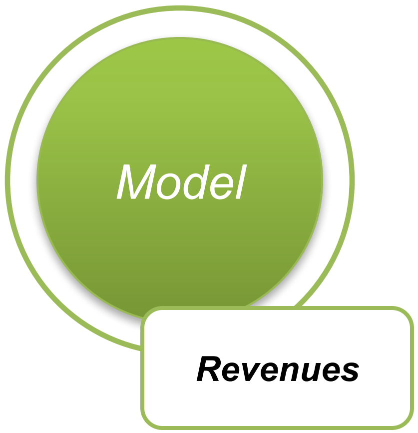
External repair
where no actual actions are taken

Model

Processes



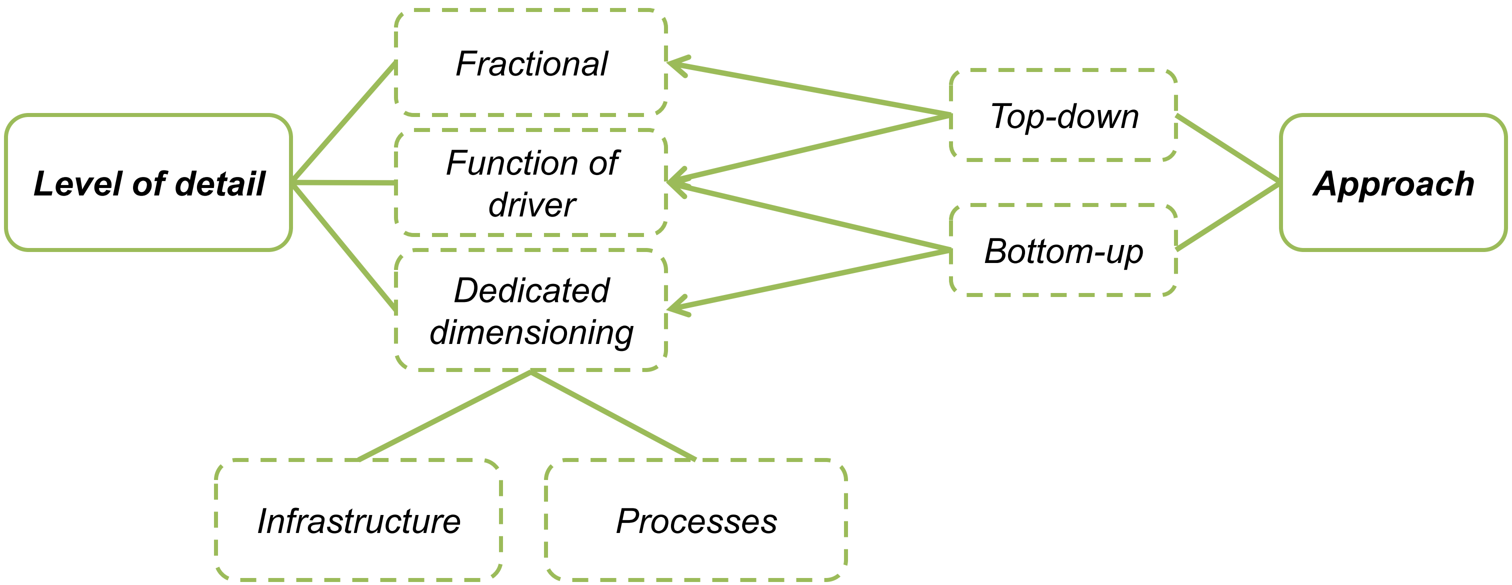
Model revenues
in a similar way as costs



Approach versus level of detail

Model

Revenues



Revenue models

Model

Revenues

Direct revenues (subscriptions)

Driver based — **customers x subscription fee**

Indirect revenues

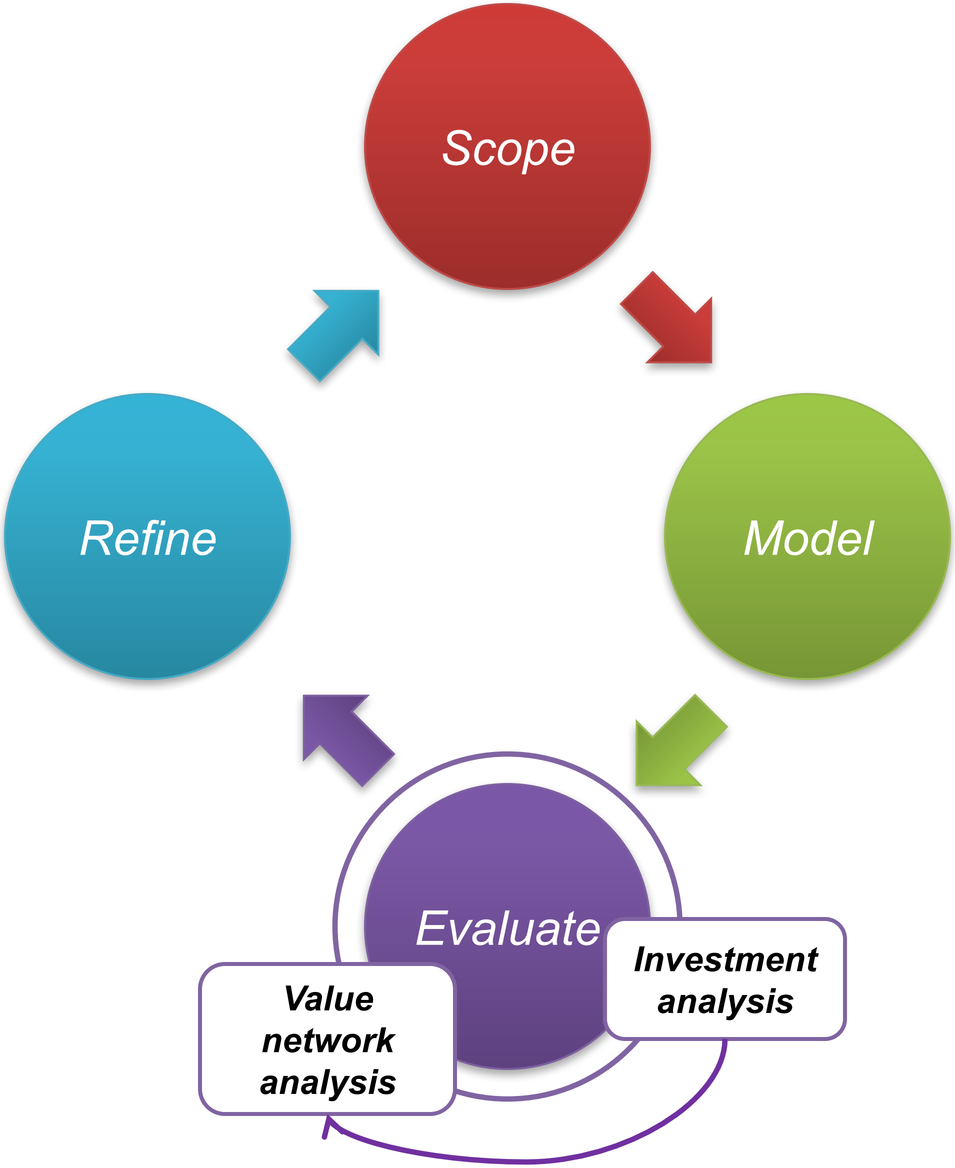
Dedicated model — **network value model (Odlyzko)**

monetary value related to existing studies

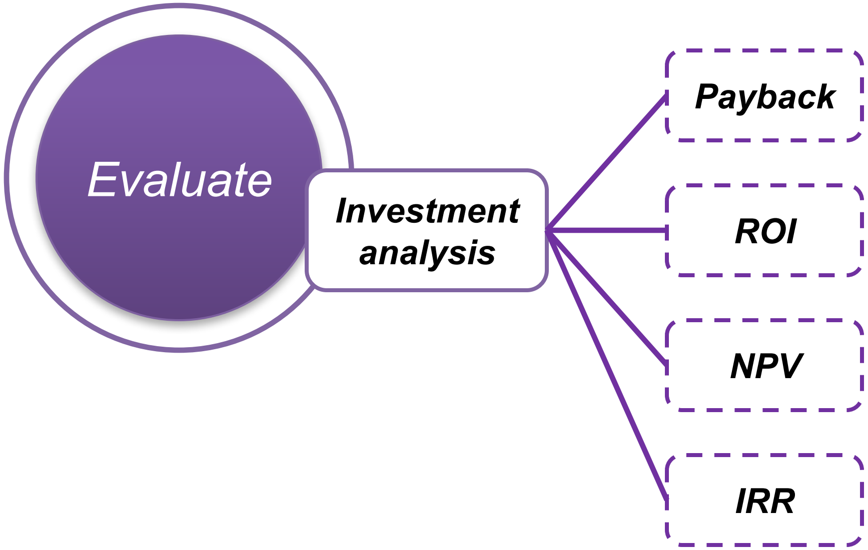
Practical steps in techno-economic evaluation of network deployment planning

EVALUATION

Evaluate the project



Investment analysis
for static case uses traditional techniques



Revenue results

Evaluate

Investment analysis

REVENUES

PLAYER 1

subscription	rate	percentage
eco	25	25%
standard	40	65%
premium	60	10%

PLAYER 2 - FTTH

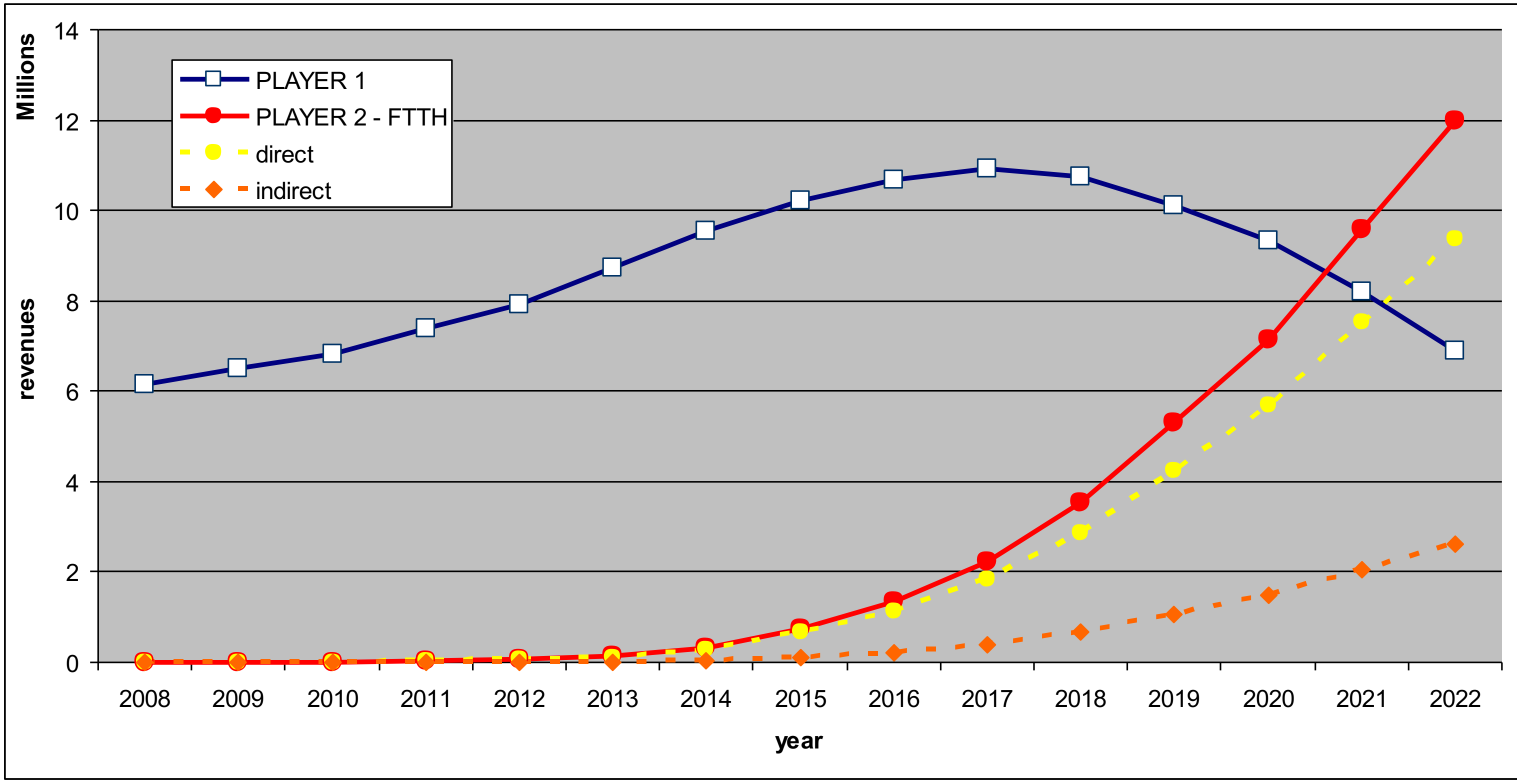
subscription	rate	percentage
eco	25	25%
standard	40	65%
premium	60	10%

year	PLAYER 1 TOTAL	PLAYER 2 - FTTH direct	PLAYER 2 - FTTH indirect	PLAYER 2 - FTTH TOTAL
2008	**6157773**	0	0	**0**
2009	**6503221**	851	20	**871**
2010	**6833276**	10740	387	**11127**
2011	**7375486**	37422	1846	**39269**
2012	**7923136**	64707	4807	**69514**
2013	**8722181**	117788	12580	**130367**
2014	**9546351**	281578	34307	**315886**
2015	**10230701**	654490	99667	**754157**
2016	**10691899**	1121464	207121	**1328585**
2017	**10928099**	1838946	388799	**2227745**
2018	**10749264**	2875682	662601	**3538282**
2019	**10107652**	4254038	1048433	**5302471**
2020	**9331582**	5675984	1471567	**7147551**
2021	**8195515**	7533869	2045148	**9579017**
2022	**6878243**	9366638	2604597	**11971235**

Revenue results

Evaluate

Investment analysis



Deployment cost results

Evaluate

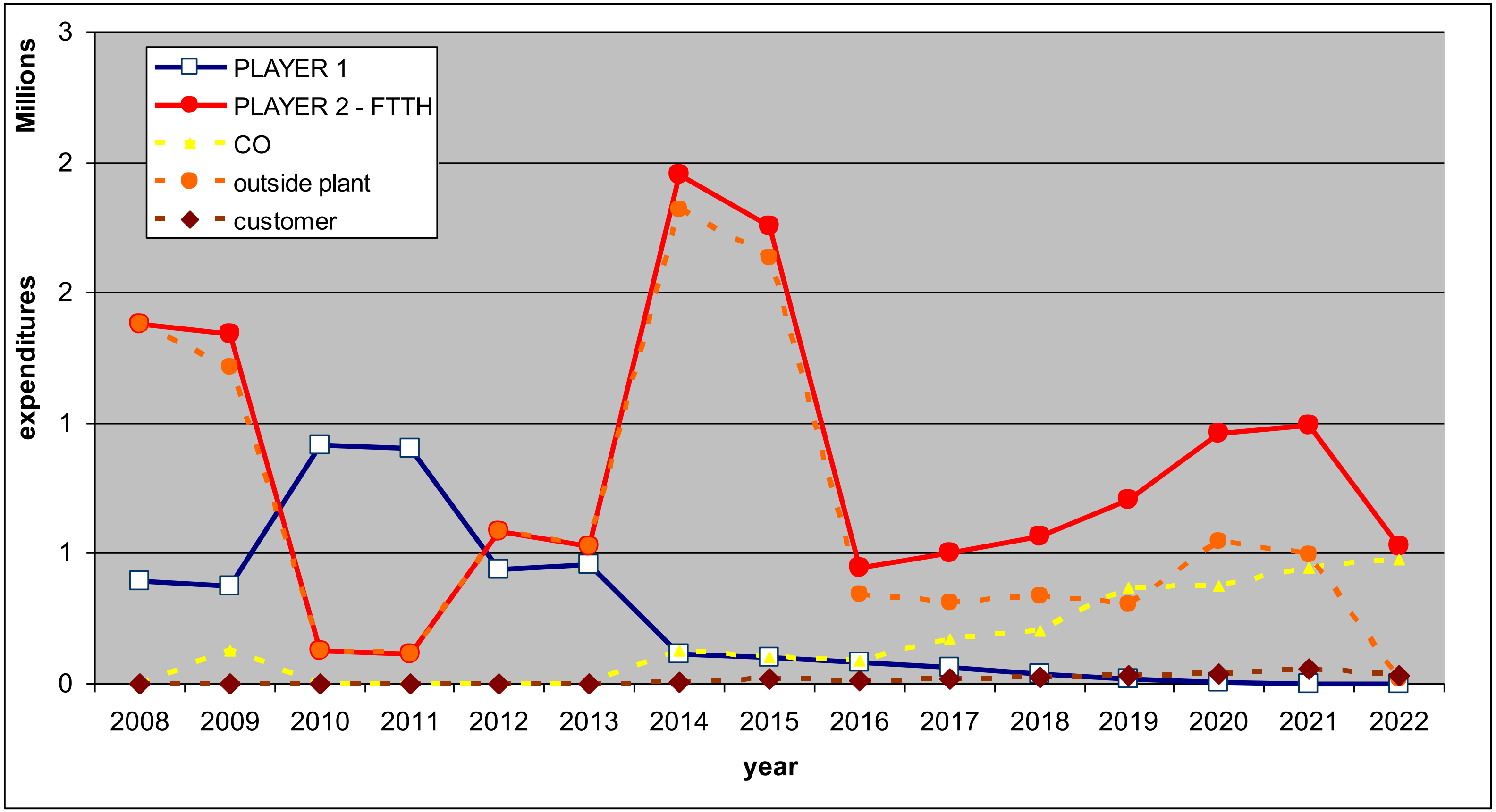
Investment analysis

year	DEPLOYMENT COSTS					
	PLAYER 1	PLAYER 2 - FTTH				
	TOTAL	CO	outside plant	customer	TOTAL	
2008	**393841**	0	1378349	0	**1378349**	
2009	**374976**	125885	1217833	70	**1343788**	
2010	**916004**	0	126263	406	**126669**	
2011	**901678**	0	114784	851	**115636**	
2012	**437564**	0	585698	1026	**586724**	
2013	**459027**	0	524856	2435	**527291**	
2014	**112376**	126074	1818595	6767	**1951435**	
2015	**101009**	101173	1636672	16381	**1754225**	
2016	**81779**	91448	345139	11682	**448269**	
2017	**65824**	170599	311848	18353	**500800**	
2018	**37444**	201234	339952	22606	**563792**	
2019	**17427**	366724	308418	31251	**706393**	
2020	**5800**	376047	544244	37564	**957855**	
2021	**0**	444297	494209	56727	**995234**	
2022	**0**	474801	19059	33111	**526971**	

Deployment cost
results

Evaluate

Investment analysis



Operational expenditures
results

Evaluate

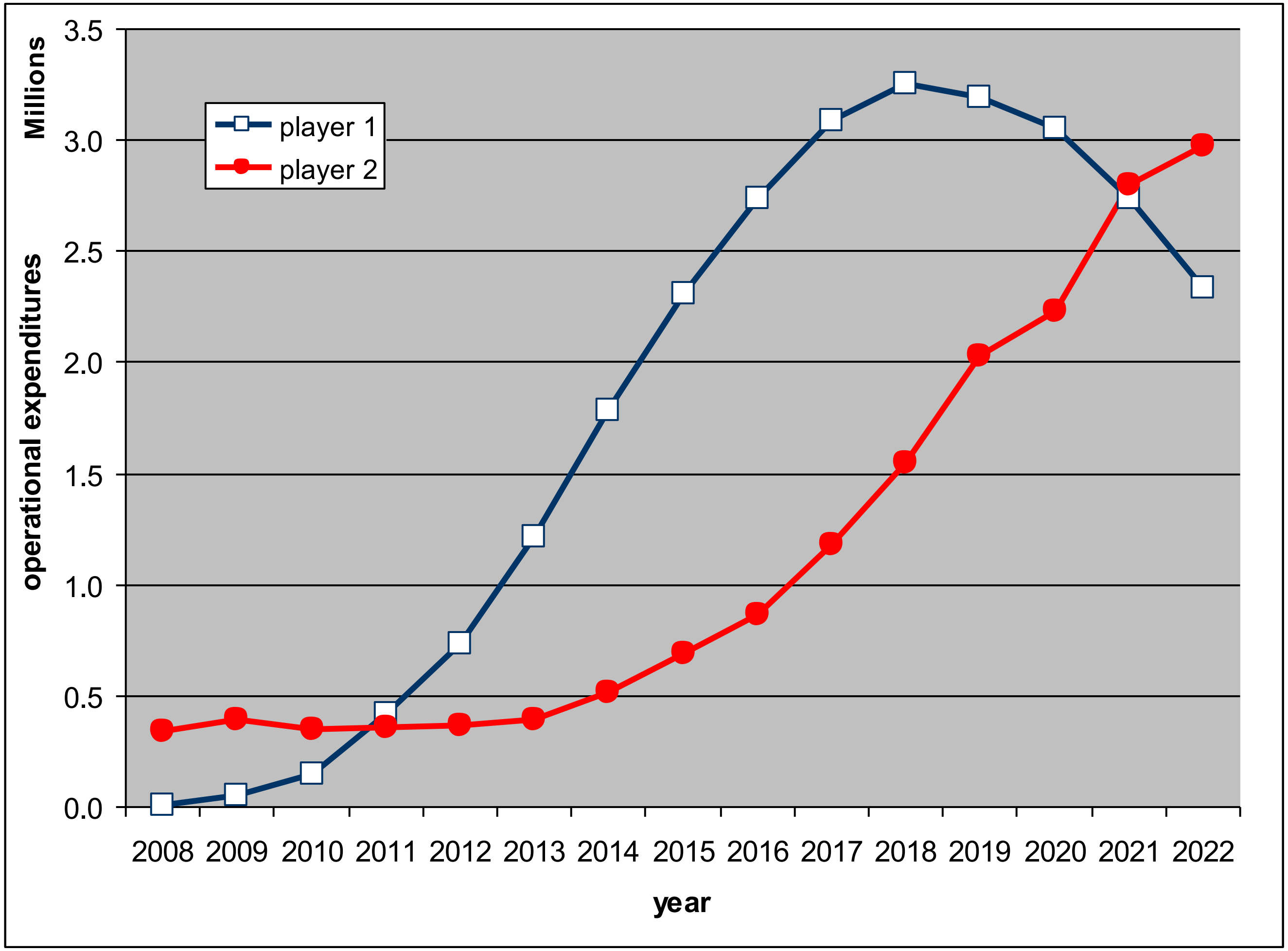
Investment analysis

year	OPERATIONAL EXPENDITURES								
	PLAYER 1	PLAYER 2 - FTTH							
	TOTAL	repair	maintenance	service provisioning	pricing and billing	marketing & operational planning	helpdesk	power	TOTAL
2008	**6039**	4004	0	0	0	336000	0	0	**340004**
2009	**48592**	7674	45825	718	34	336000	48	6	**390304**
2010	**151720**	8674	0	3679	201	336000	290	38	**348882**
2011	**416849**	9675	0	10119	659	336000	949	123	**357526**
2012	**731308**	12344	0	16540	1425	336000	2052	266	**368627**
2013	**1220061**	15013	0	36835	3172	336000	4567	593	**396180**
2014	**1788745**	25356	46273	89120	7459	336000	10741	1394	**516342**
2015	**2311699**	35698	37341	233707	18853	336000	27149	3523	**692272**
2016	**2742245**	38034	33763	367016	35932	336000	51742	6715	**869202**
2017	**3092924**	40036	62600	576319	62920	336000	90605	11758	**1180237**
2018	**3253362**	43038	73779	827177	101425	336000	146051	18954	**1546424**
2019	**3190410**	46375	135371	1109093	153303	336000	220756	28649	**2029547**
2020	**3050418**	51379	137952	1160907	208263	336000	299898	38920	**2233319**
2021	**2741953**	56384	163329	1509149	280660	336000	404150	52450	**2802122**
2022	**2336210**	56717	174426	1489736	349625	336000	503460	65338	**2975302**

Operational expenditures
results

Evaluate

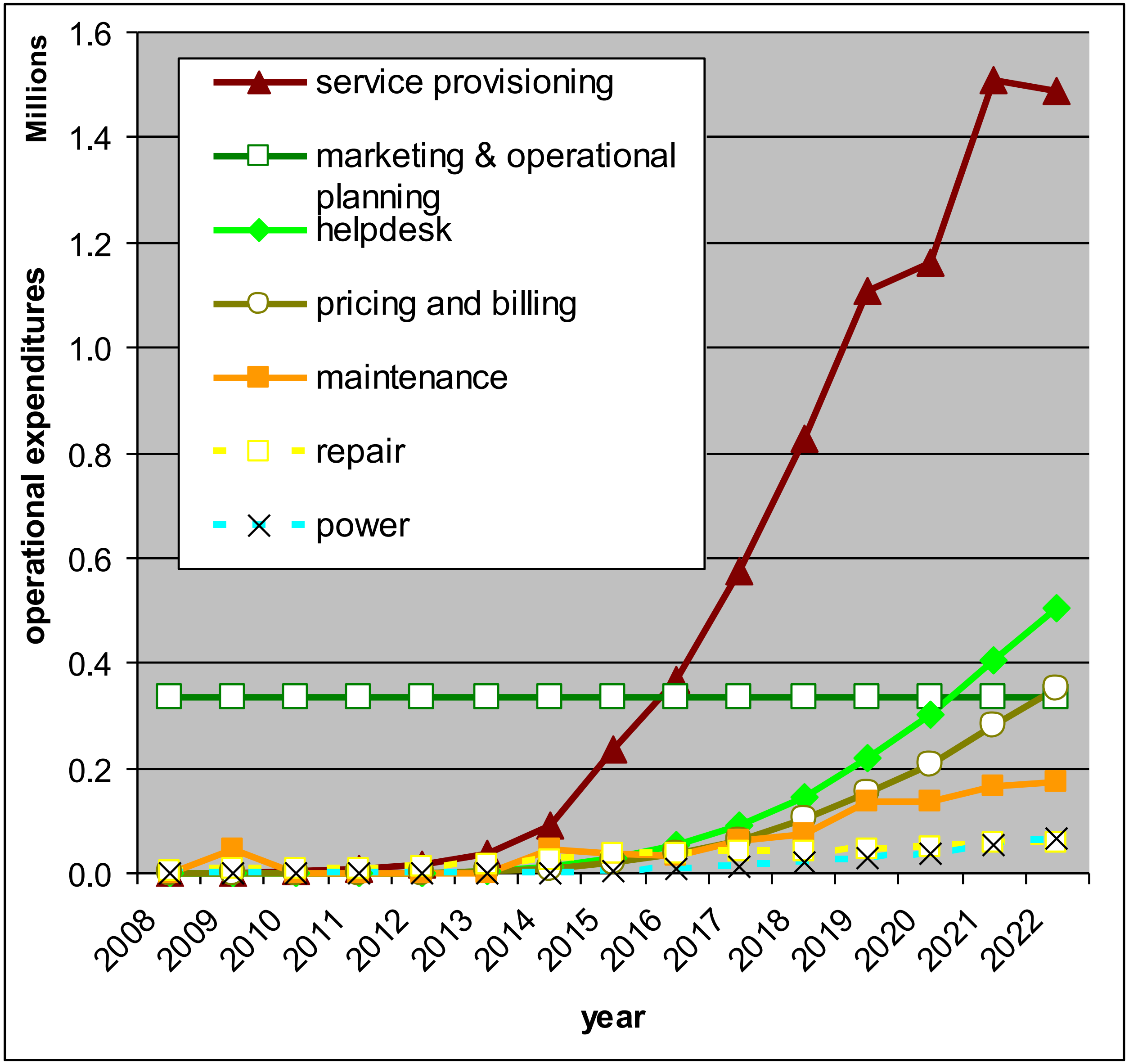
Investment analysis



Operational expenditures
results

Evaluate

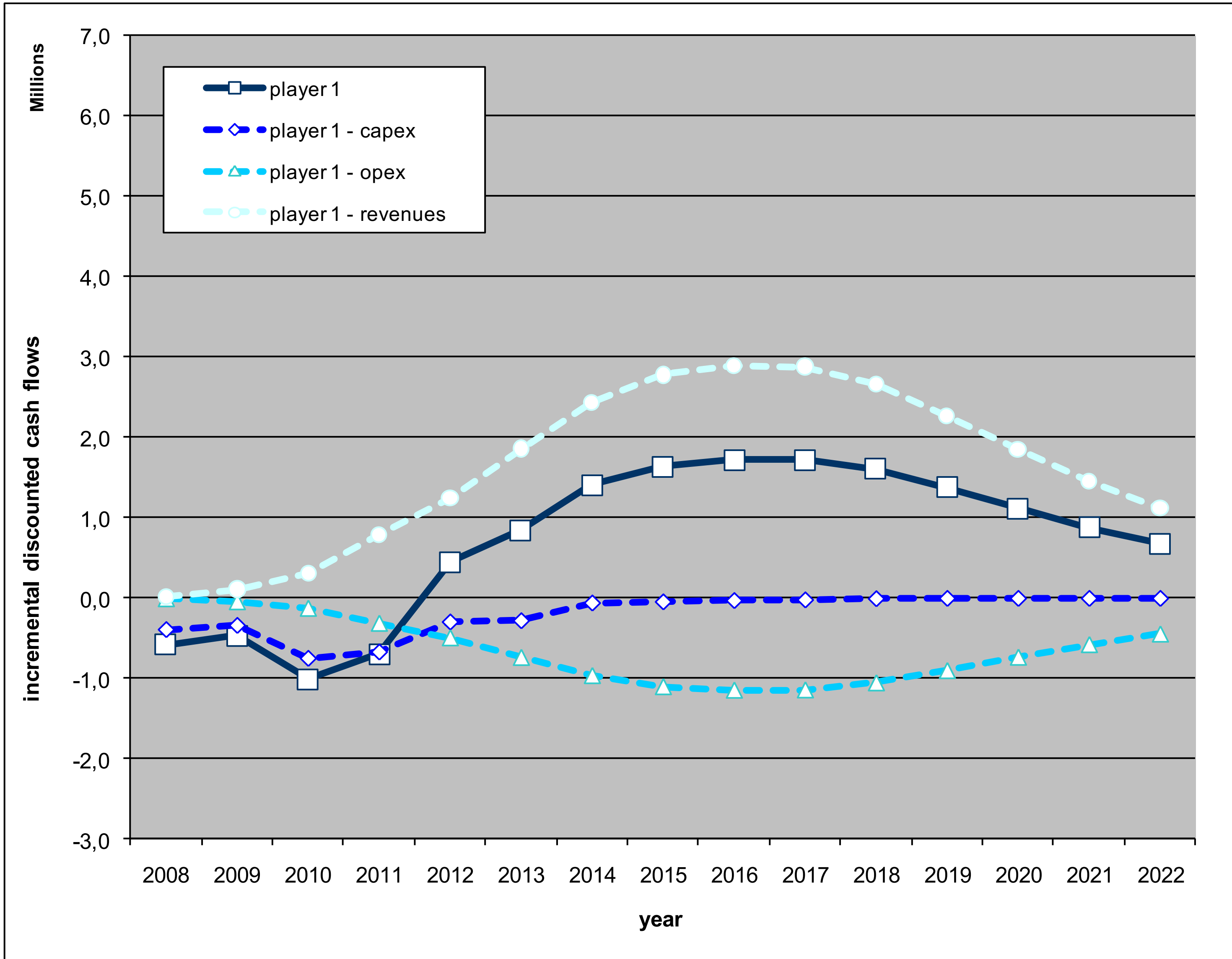
Investment analysis



Cash flows player 1
results

Evaluate

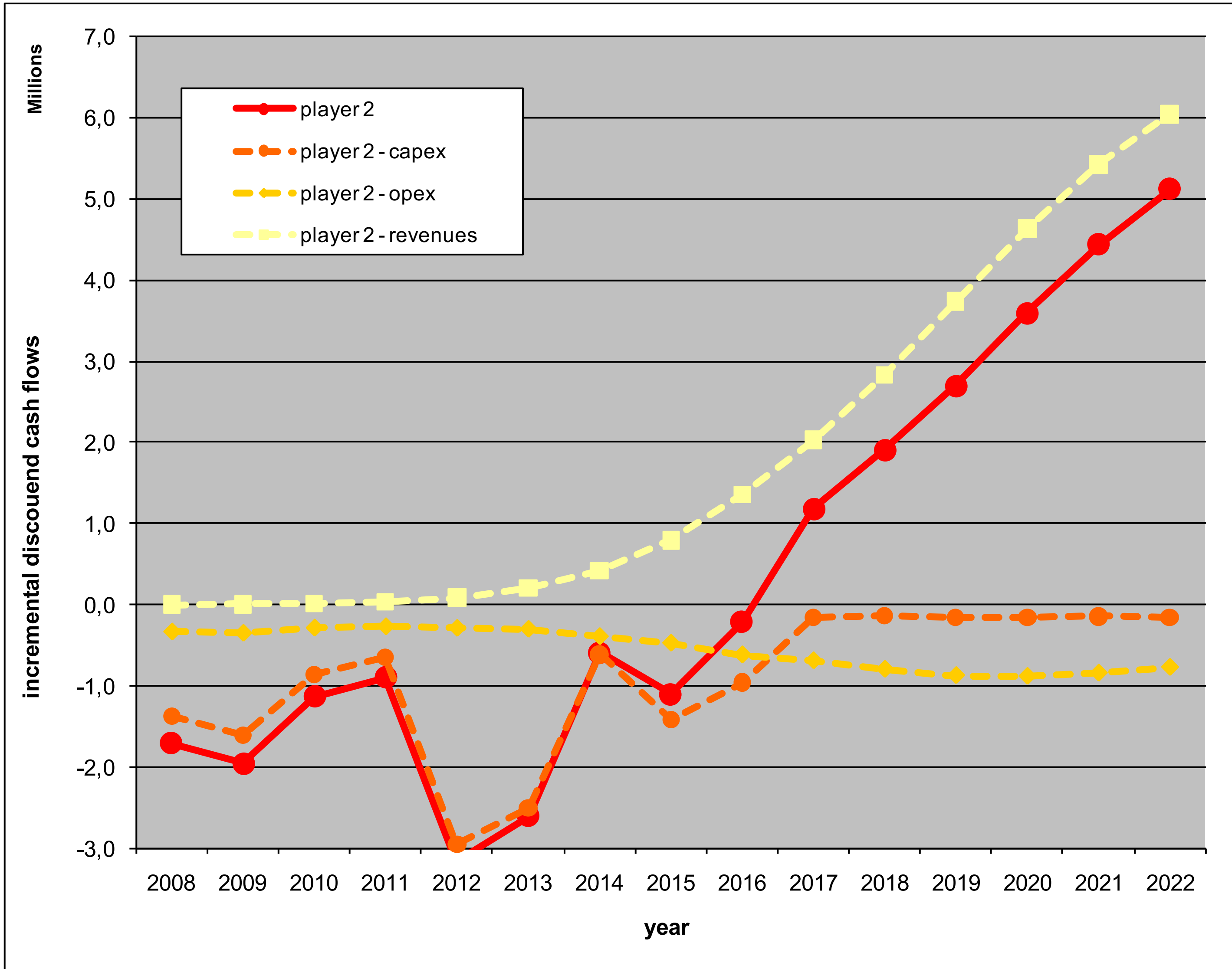
Investment analysis



Cash flows player 2
results

Evaluate

Investment analysis

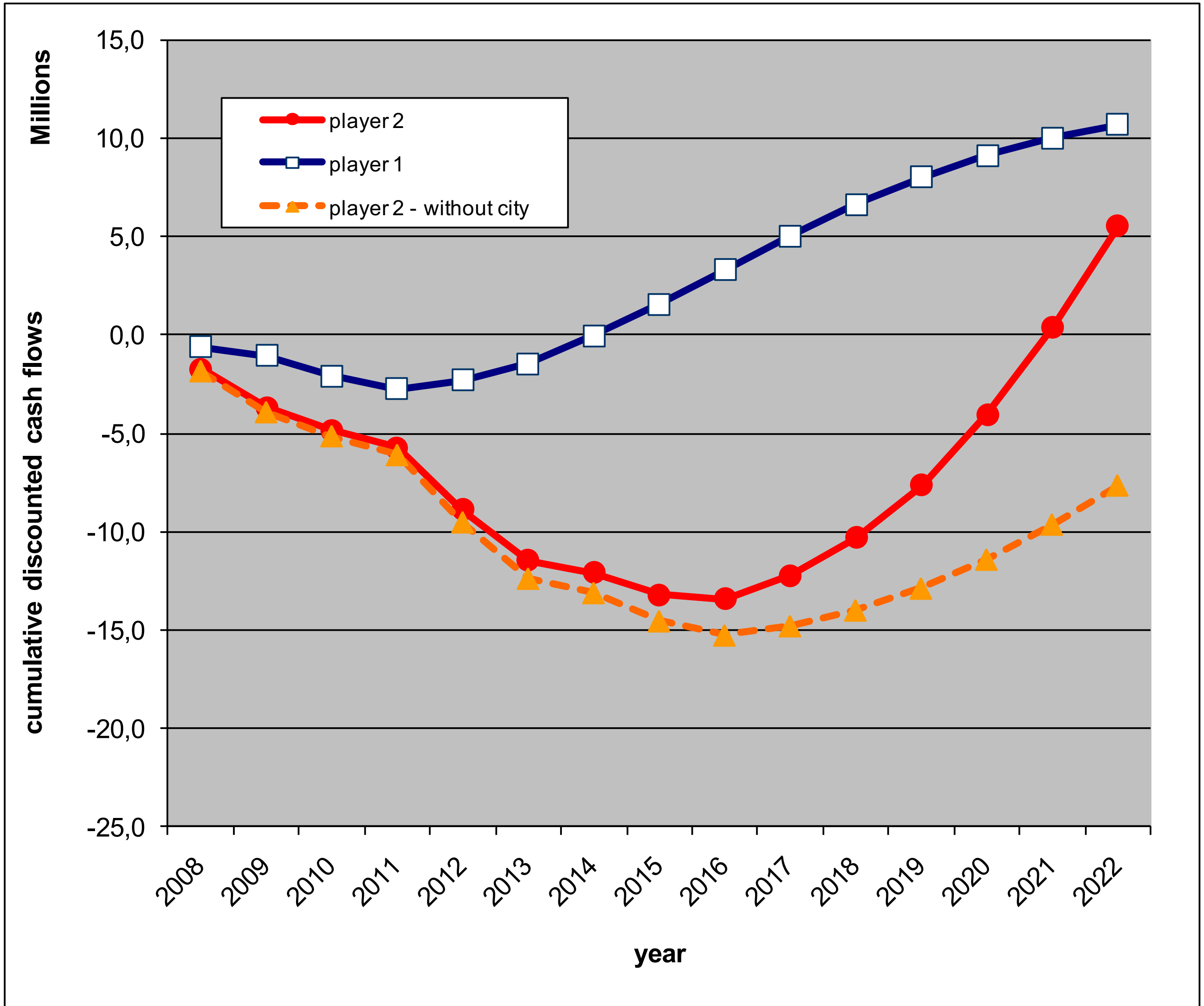


Total NPV
results

Evaluate

Investment analysis

NPV

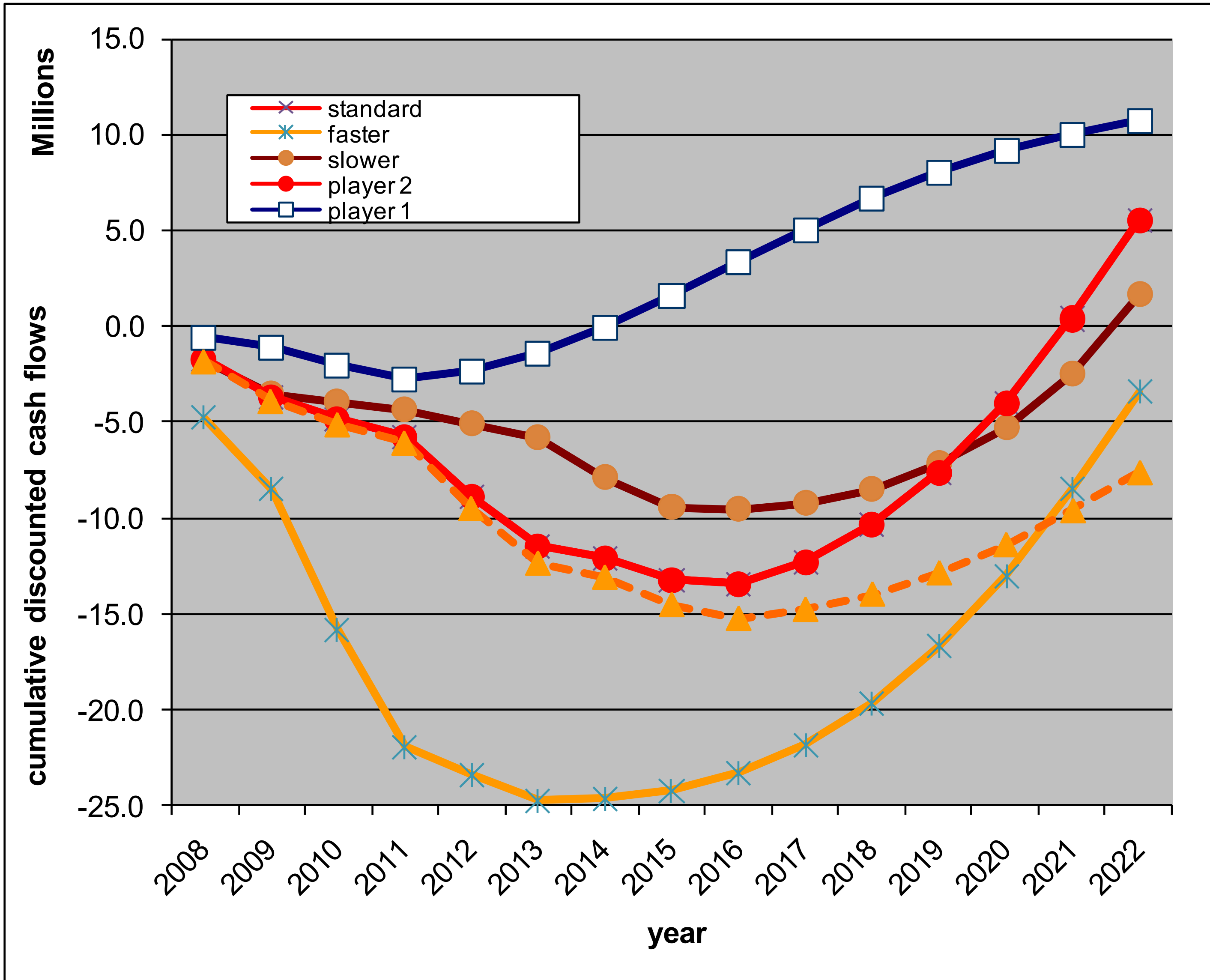


Total NPV for considered variations
results

Evaluate

Investment analysis

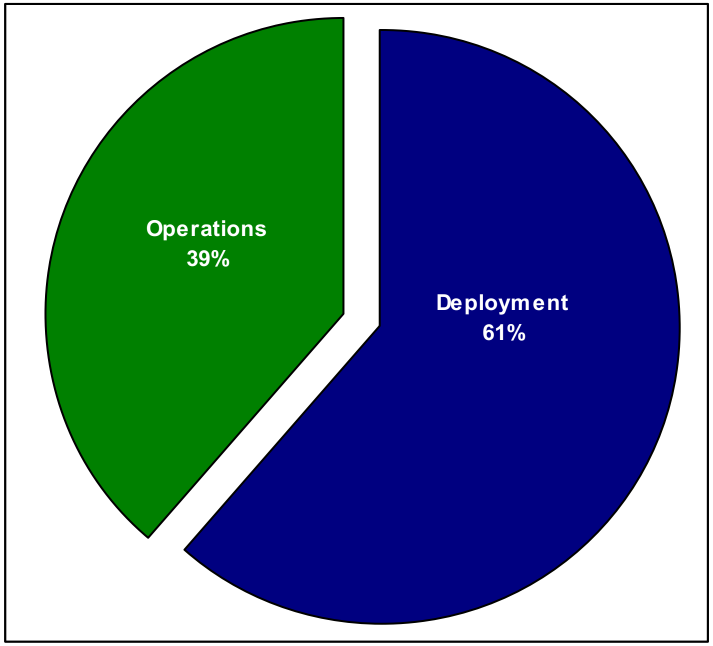
NPV

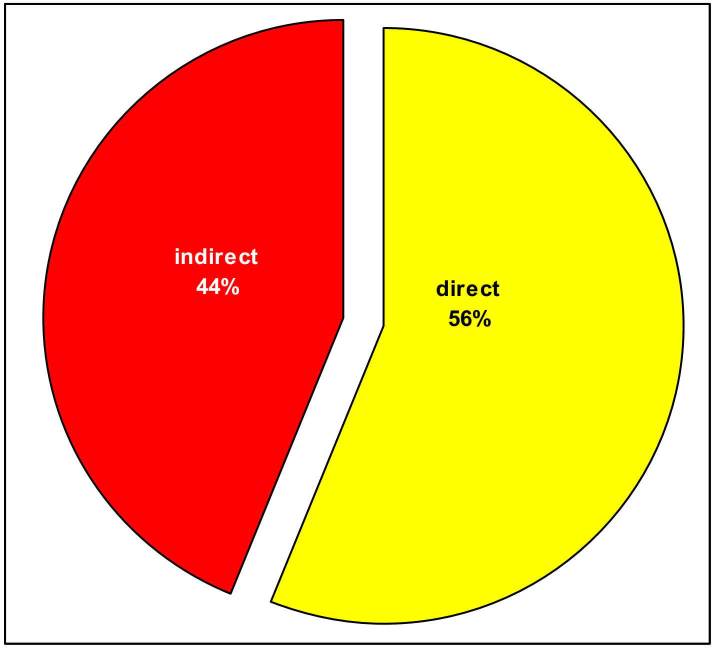


Overview after 15 years
results

Evaluate

Investment analysis

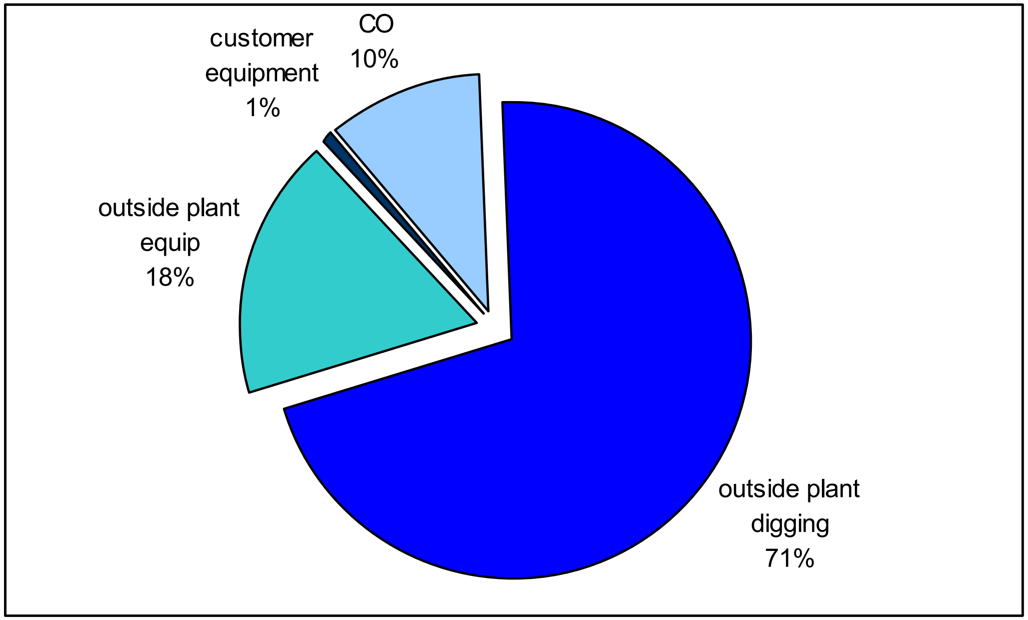


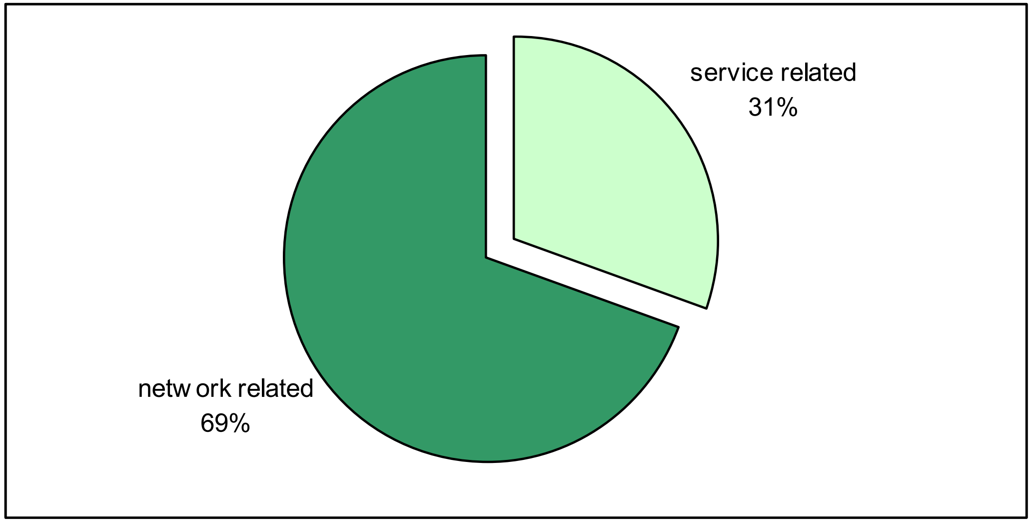


Detailed cost overview
results

Evaluate

Investment analysis

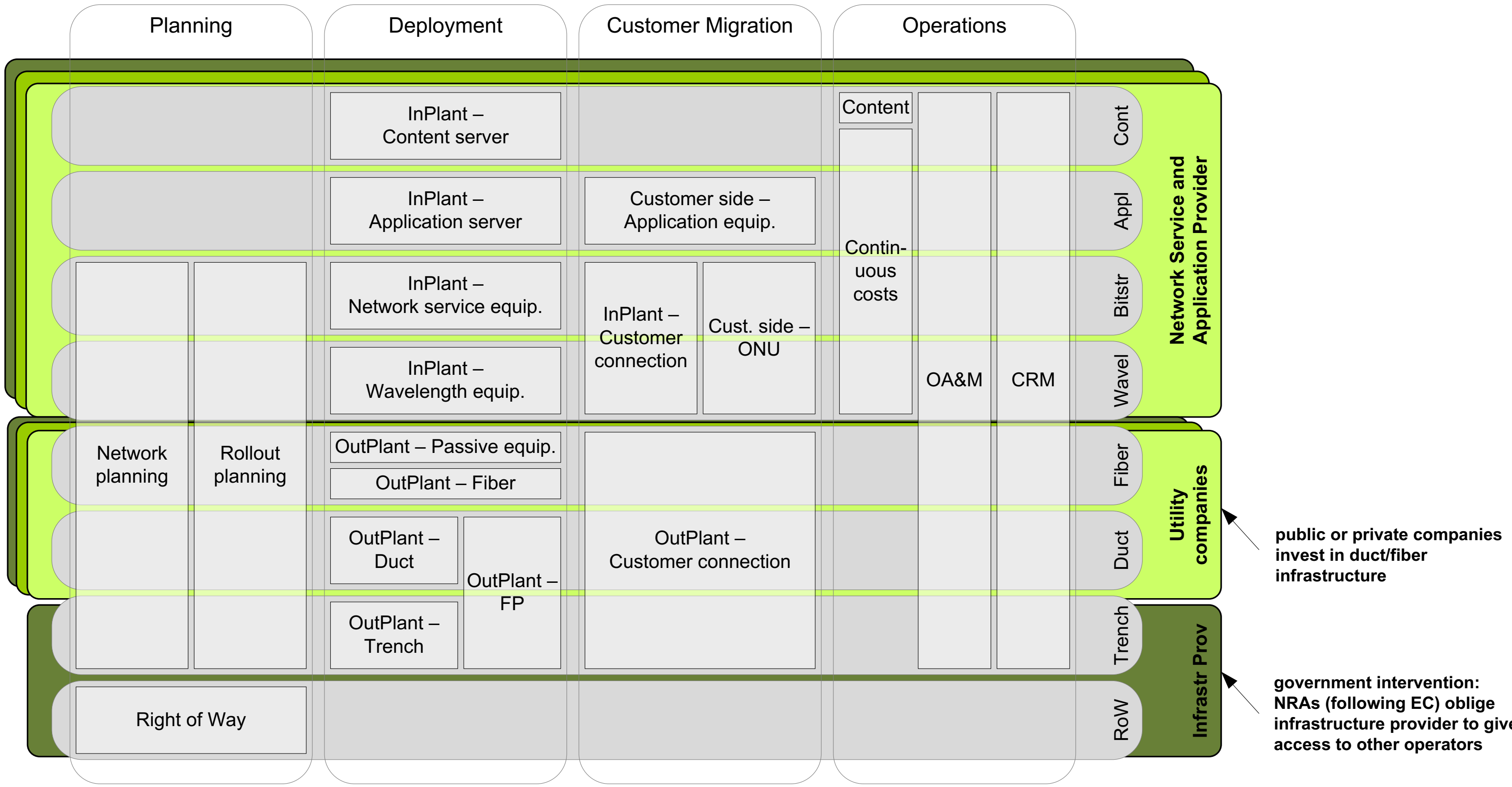




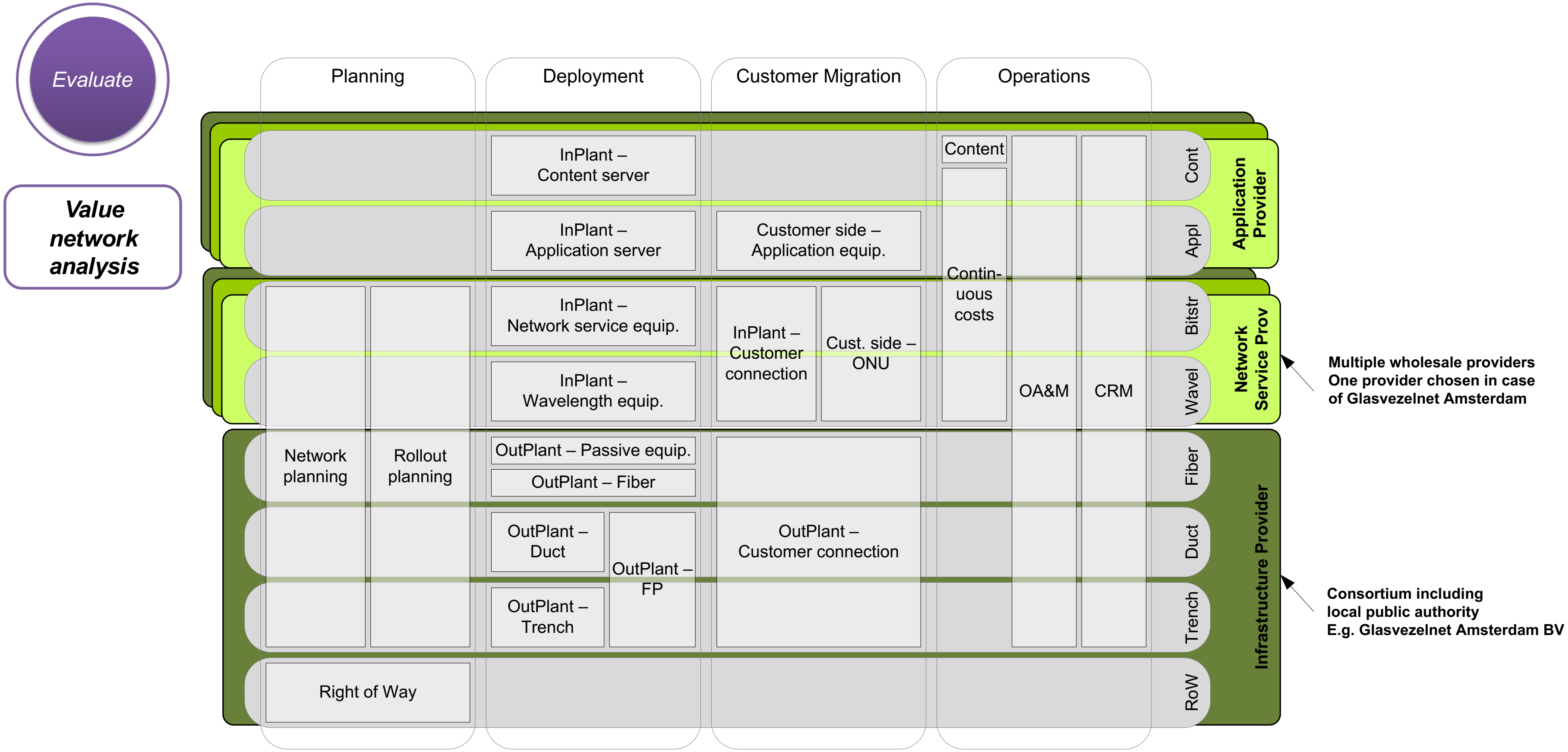
Value network analysis
Physical infrastructure based competition

Evaluate

Value network analysis



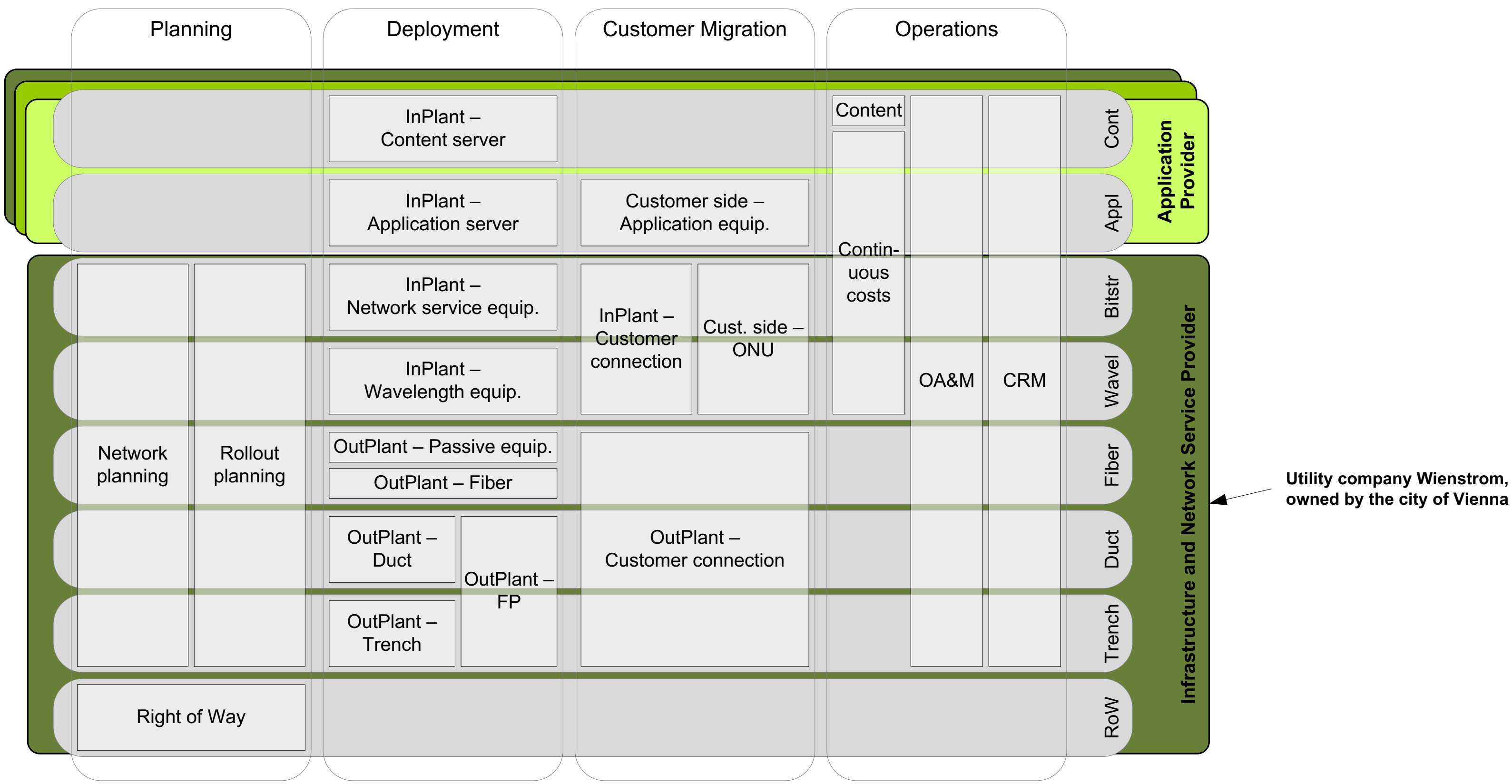
Value network analysis
Network service based competition



Value network analysis
Open access based competition

Evaluate

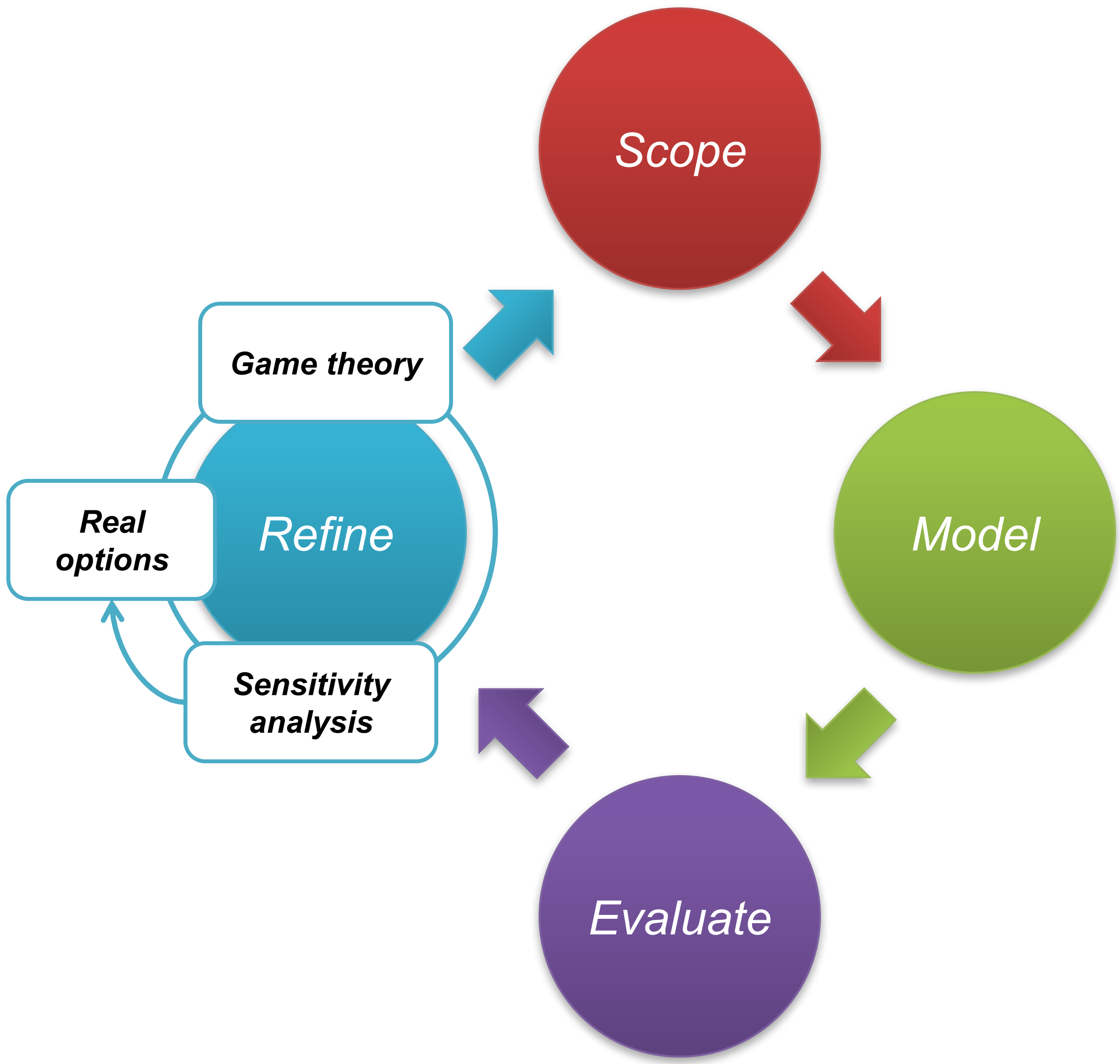
Value network analysis



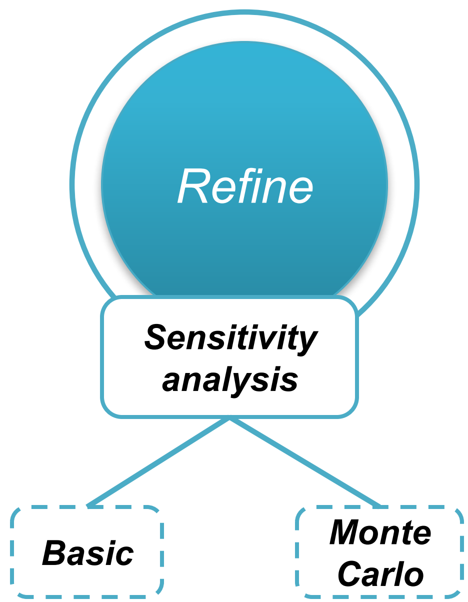
Practical steps in techno-economic evaluation of network deployment planning

REFINE

Refine the results



Sensitivity analysis
indicates impact of uncertainty

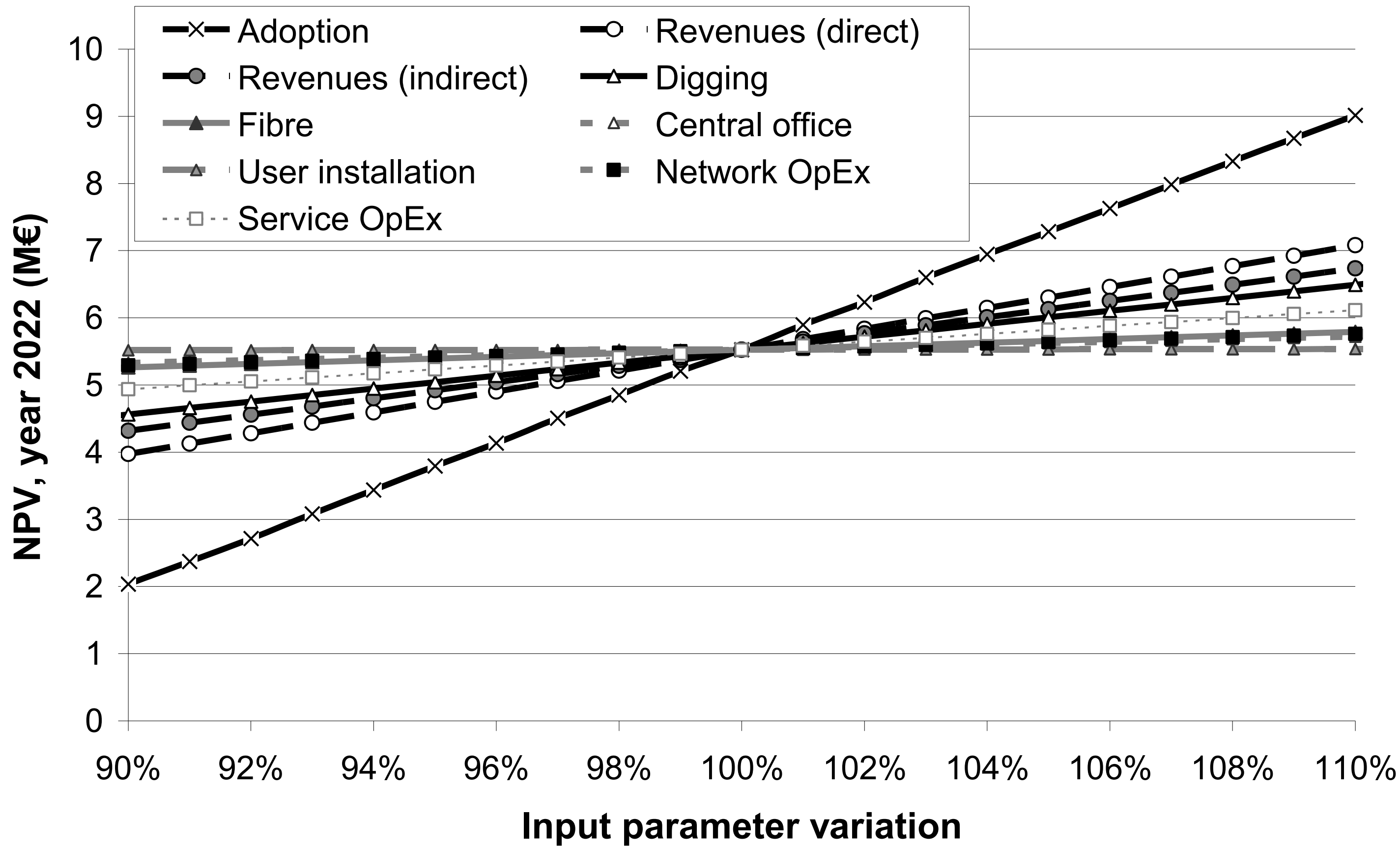


Basic sensitivity analysis

Refine

Sensitivity analysis

Basic

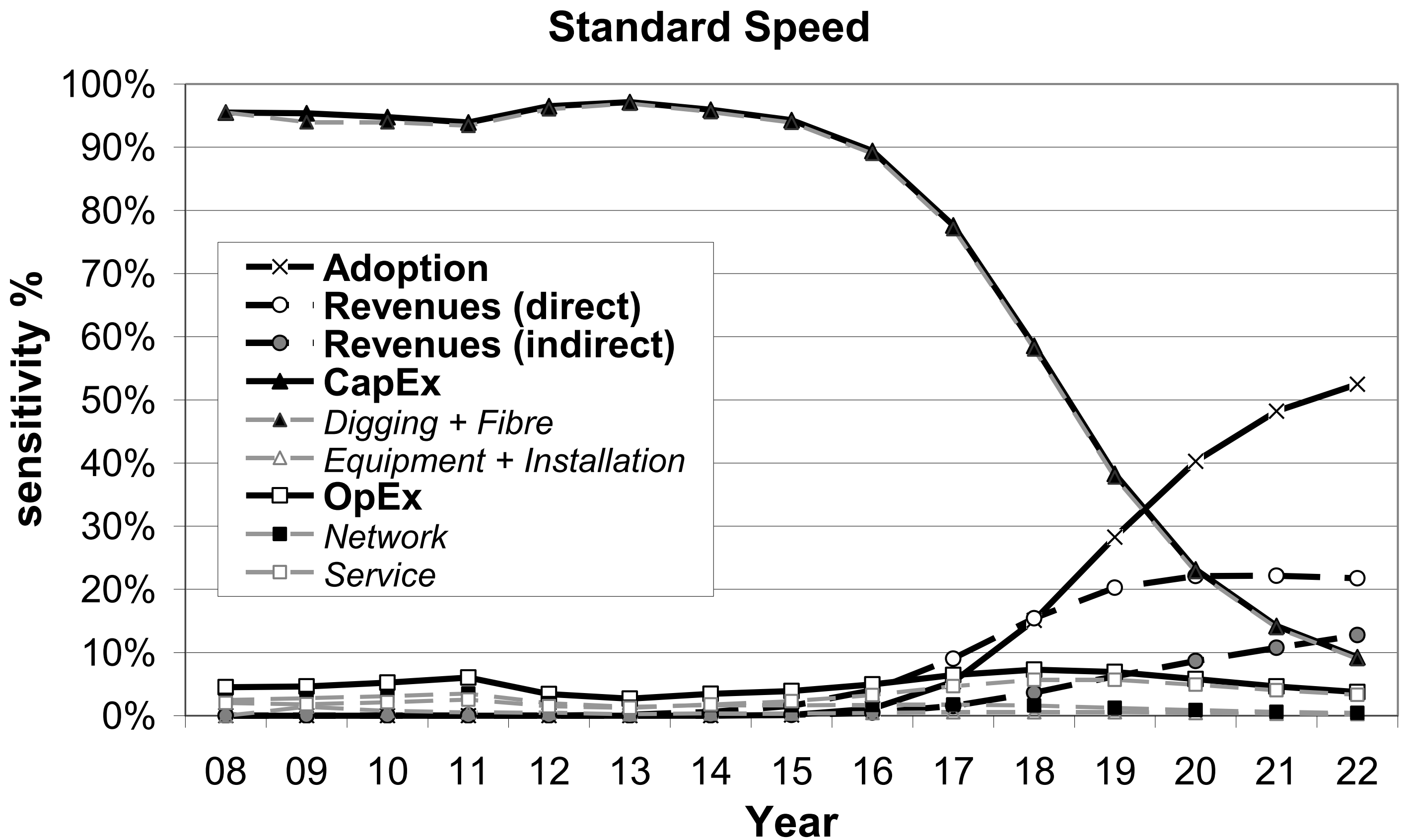


Monte carlo simulations
Parameter sensitivity

Refine

Sensitivity analysis

Basic

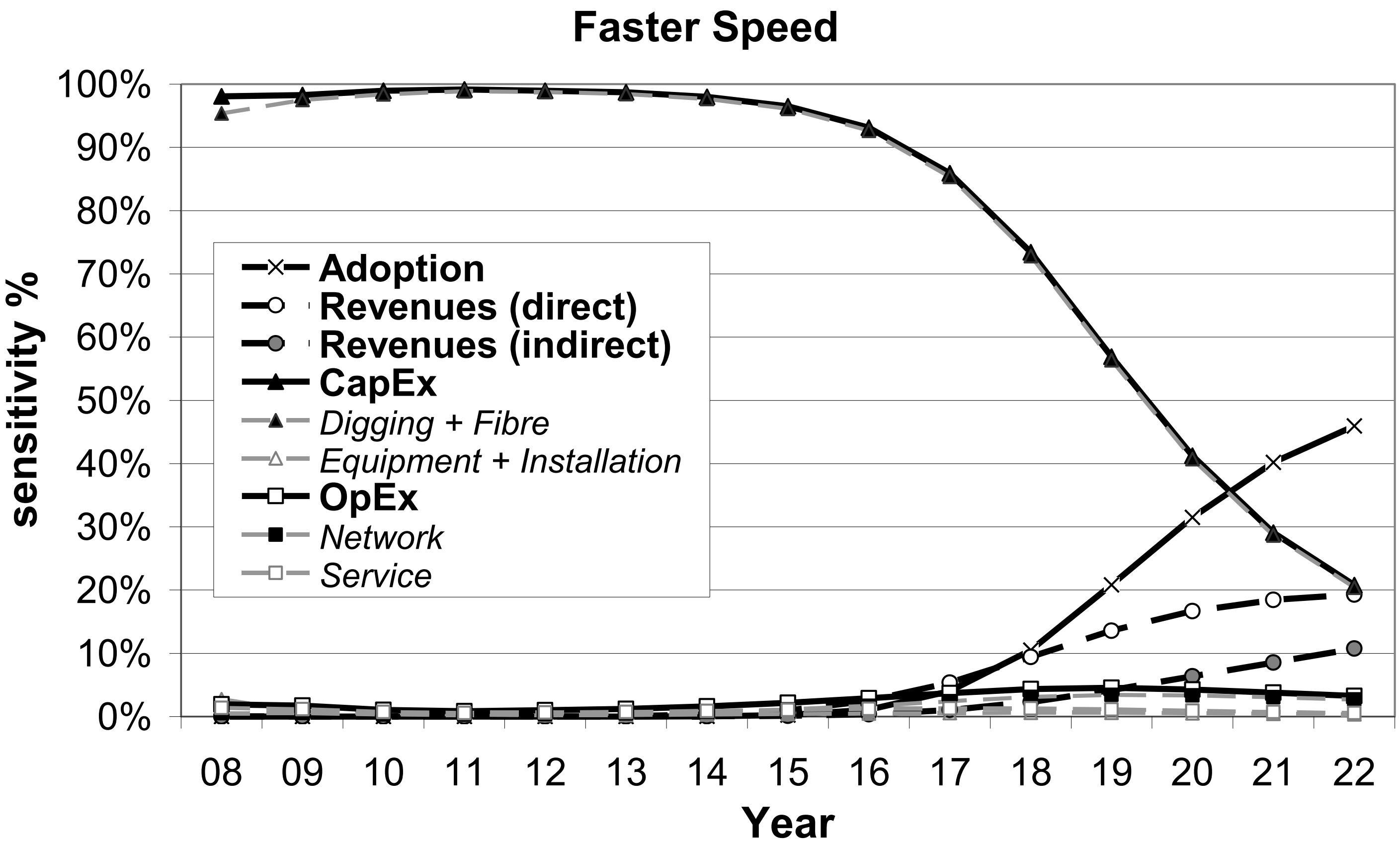


Monte carlo simulations
Parameter sensitivity

Refine

Sensitivity analysis

Basic

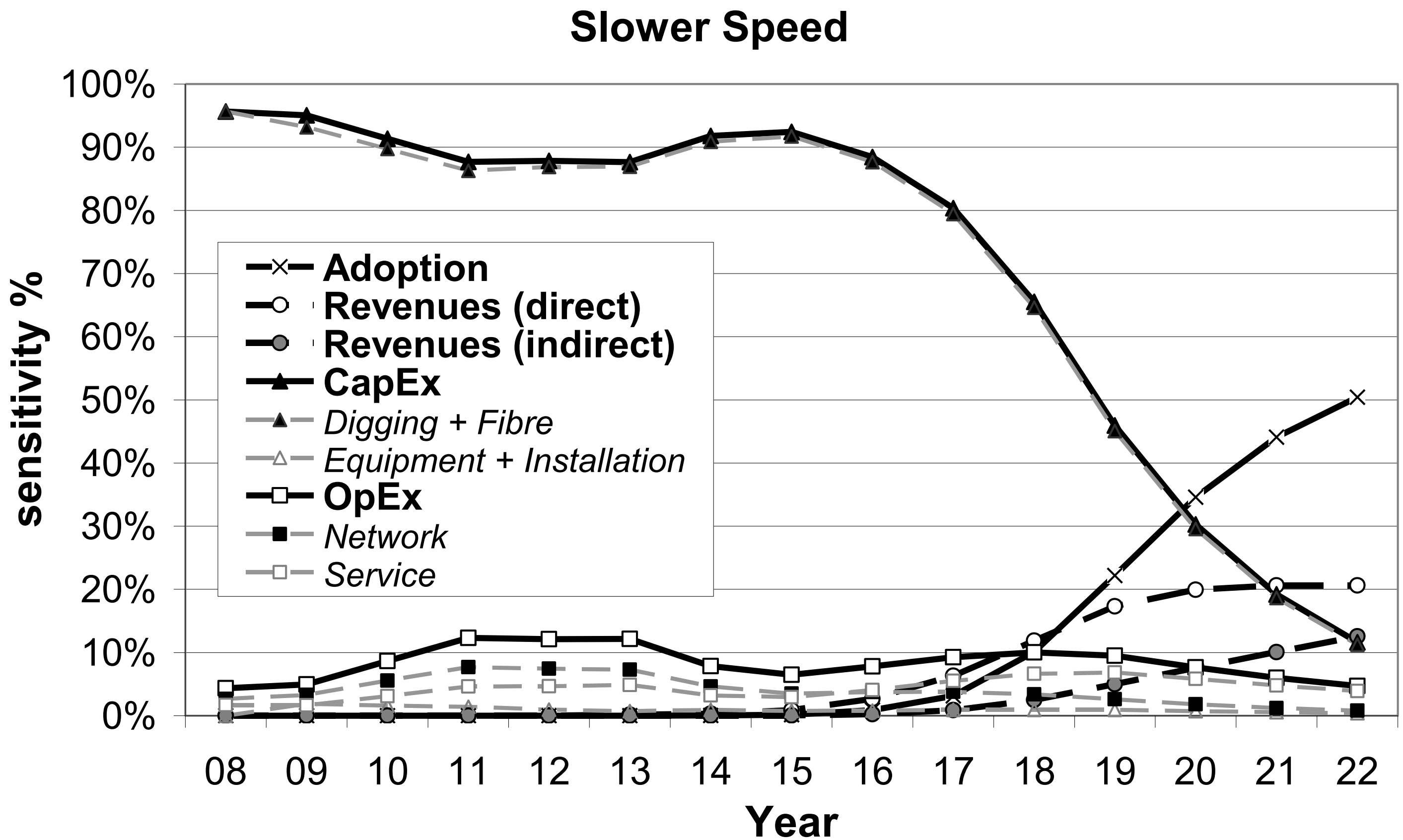


Monte carlo simulations
Parameter sensitivity

Refine

Sensitivity analysis

Basic

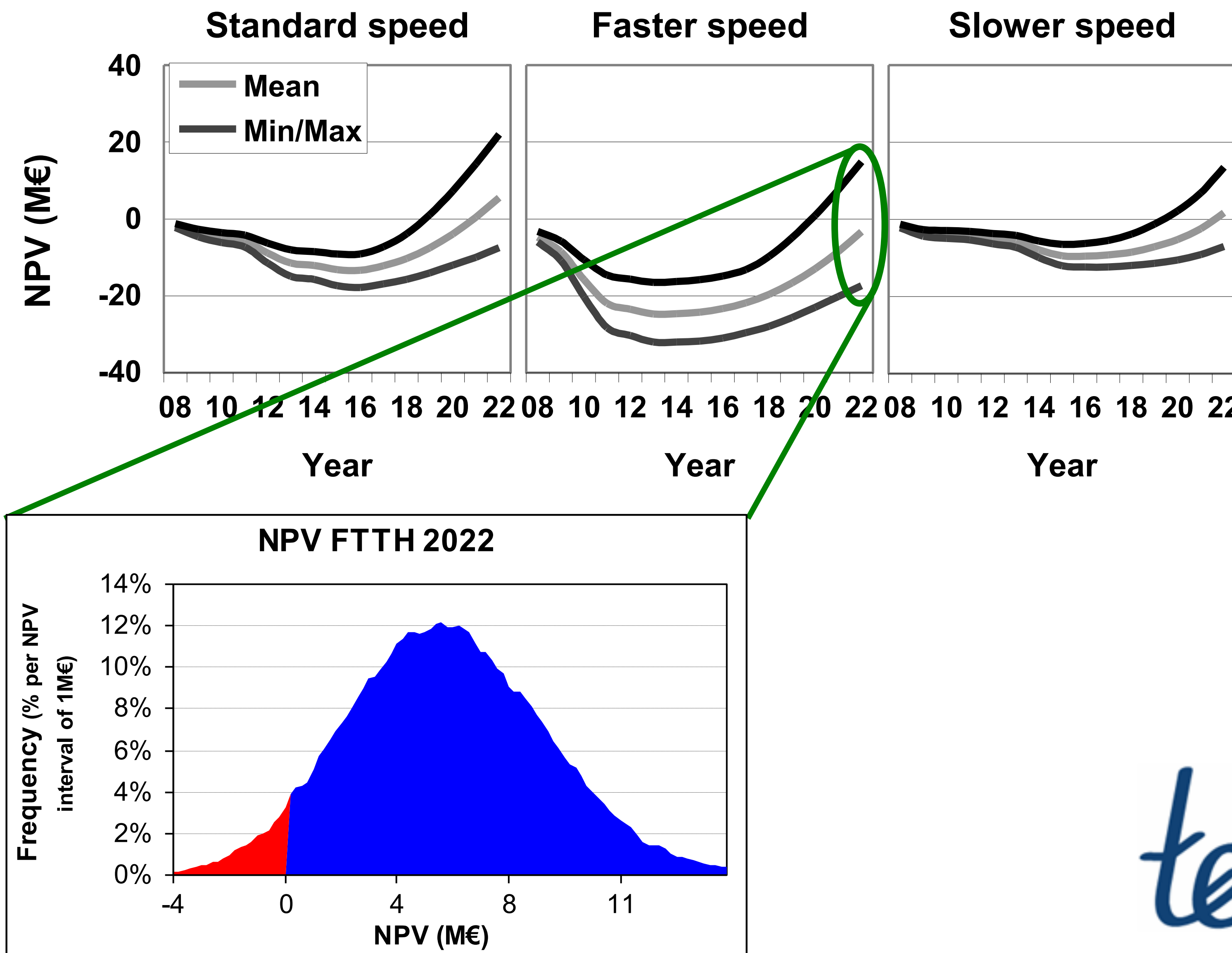


Monte Carlo simulations
Trend analysis & Forecast

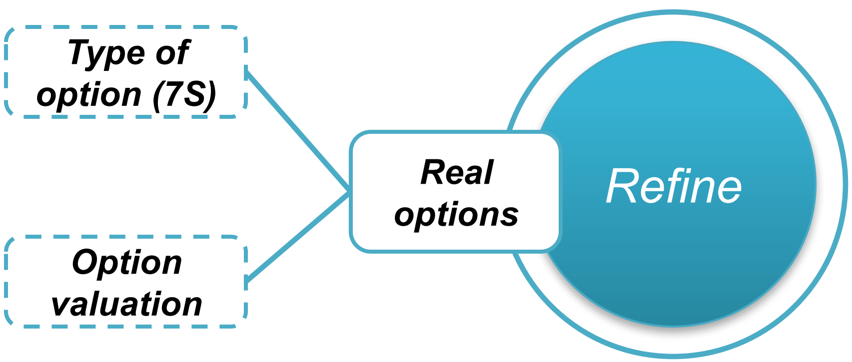
Refine

Sensitivity analysis

Monte Carlo



Real options
allow to value flexibility to react to uncertainty



Real options – possibilities

UNIVERSITEIT GENT

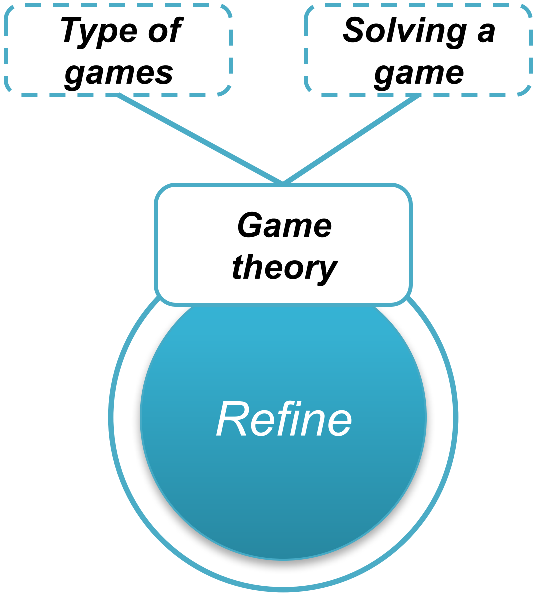
Refine

Real options

Type of option (7S)

Category	*Type*	*Description*
Invest Grow	Scale up	1 – Faster installation of FTTH 2 – Install more regions with FTTH
	Switch up	3 – Switch from PON to ASN or HRN 4 – Install future technology (e.g. WDM PON)
	Scope up	5 – Joint installation with other infrastructure-owners 6 – Install FTTH + Wireless last mile 7 – Provide additional services, content or applications
Learn	Study / Start	8 – Delay or postpone installations 9 – Install test case
Disinvest Shrink	Scale down	10 – Slower installation of FTTH 11 – Install less than initially planned 12 – Sell/lease parts of the network
	Switch down	13 – Switch from HRN or ASN to PON 14 – Delay installation of future technology
	Scope down	15 – Stop providing additional content, services and applications outsource this to a third party.

Game theory
models competition between different players



The reference case
uses following approach

Refine

Game theory

Type of games

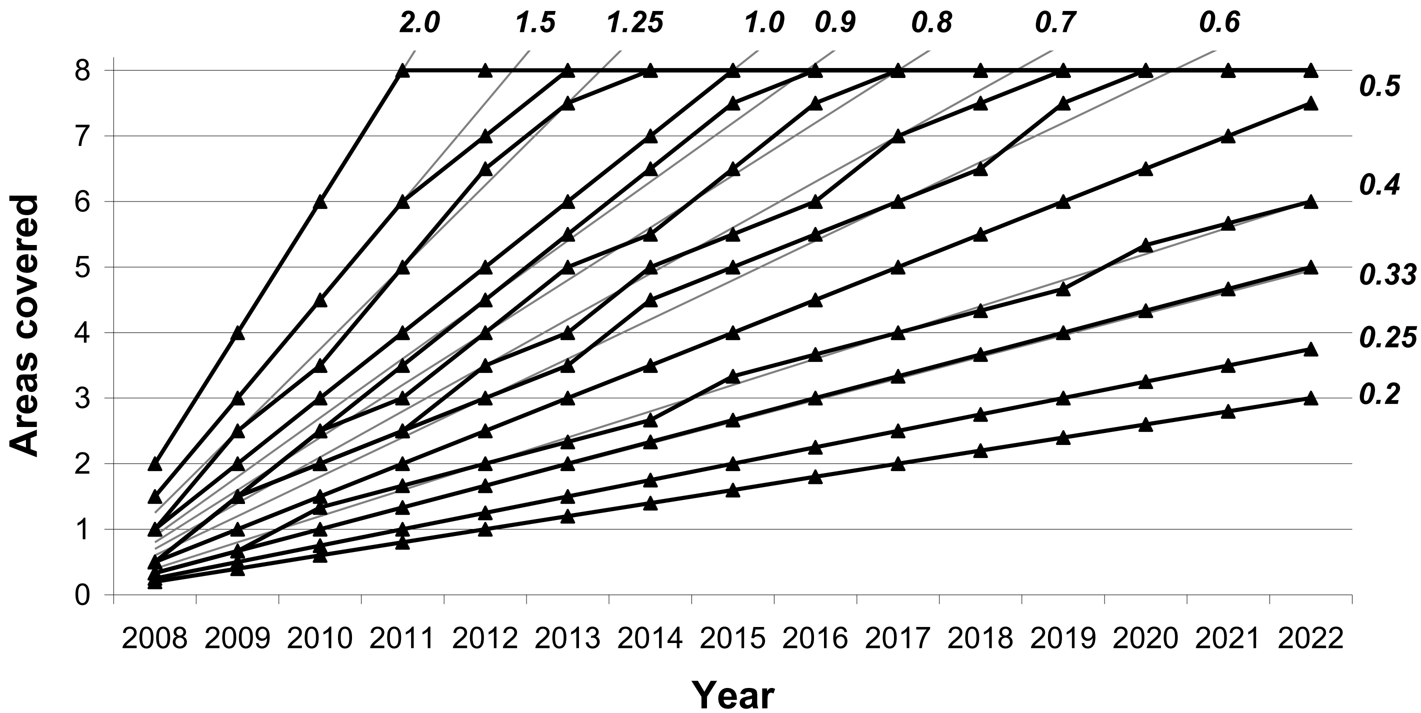
Cooperative	↔	Non Cooperative
Symmetric	↔	Asymmetric
Zero sum	↔	Non Zero Sum
Simultaneous	↔	Sequential
Perfect information	↔	Non Perfect Information
Infinite	↔	Finite
Discrete	↔	Continuous
Static	↔	Multi-stage
Meta Games		

Varying rollout speed
as an input for game theory

Refine

Game theory

Solving a game



Pay-off matrix
as the result obtained by game theory

Refine

Game theory

Solving a game

	1		2		3		4		5	
1	-17758389	8166040	-18030411	10019864	-18140254	9972979	-18502777	9819538	-18624838	9163040
2	-4419268	8209692	-4672096	10051418	-4783478	10004039	-5085165	9817163	-5369412	9241049
3	-1297263	8221360	-1539411	10063978	-1625046	10011094	-2101614	9890862	-2285184	9285241
4	3674401	8499365	3557917	10307558	3481670	10243227	2913255	10139416	2620104	9563192
5	4369139	8566074	4268006	10367731	4215824	10296081	3670082	10189542	3404391	9598189
6	4358976	8925957	4289749	10700868	4247165	10623254	3891460	10455928	3696868	9834836
7	3190003	9676962	3176709	11432764	3174467	11342005	3022545	11082087	2853707	10455453
8	2553035	10187720	2554514	11939482	2556335	11846978	2501637	11555875	2389302	10906220
9	3596362	9676962	3590753	11432764	3591832	11342005	3471156	11082087	3319185	10455453
10	782957	11221947	794121	12970753	800402	12874398	818080	12556340	798473	11883357
11	988780	11221947	999985	12970753	1005802	12874398	1022068	12556340	1008532	11883357
12	63961	12201736	69210	13951408	70193	13855824	74242	13534037	83335	12850949
13	-1671146	13307425	-1671146	15058865	-1671146	14963085	-1668225	14640239	-1671685	13962821
14	-1568758	13307425	-1568758	15058865	-1568758	14963085	-1566007	14640239	-1568579	13962821
15	-3565265	14528862	-3565265	16279824	-3565265	16183664	-3565265	15861358	-3565980	15181891
16	-3171216	15098651	-3171216	16849546	-3171216	16753385	-3171216	16430902	-3171216	15750566
17	-2811207	16344734	-2811207	18099083	-2811207	17999215	-2811207	17683843	-2811207	17003507

Pay-off matrix
as the result obtained by game theory

Refine

Game theory

Solving a game

6		7		8		9		10		11	
-19375834	8140199	-20624789	7045401	-21430522	6173864	-20624789	6939848	-23267660	4804682	-23267660	4684971
-5923502	8121664	-7203103	7043717	-8119590	6173046	-7203103	6938181	-9986542	4804682	-9986542	4684971
-2845024	8165297	-4033789	7042415	-4956901	6171860	-4033789	6936969	-6994032	4804682	-6994032	4684971
2160184	8374263	1381401	7068484	490461	6185096	1381401	6955252	-1364806	4802749	-1364806	4683198
2579750	8545669	1924967	7195402	1318380	6184220	1924967	7069918	-594000	4797759	-594000	4678600
2991400	8732943	2292060	7358294	1541101	6391684	2292060	7216397	95170	4798211	95170	4675931
2338051	9276317	1560714	7876184	778985	6868474	1560714	7698778	187829	4923265	187829	4774586
2049561	9668591	1486519	8180853	827132	7112040	1486519	7996174	-47680	5213955	-47680	5032934
2826653	9276317	2074210	7876184	1308499	6868474	2074210	7698778	651602	4923265	651602	4774586
642739	10583584	406576	8993301	64917	7803686	406576	8796464	-897593	5789316	-897593	5545753
863053	10583584	664412	8993301	354701	7803686	664412	8796464	-558953	5789316	-558953	5545753
49672	11510652	35056	9843989	-118232	8595368	35056	9644570	-596078	6412641	-596078	6134688
-1644457	12593254	-1639867	10914721	-1648081	9608027	-1639867	10714429	-1813021	7327975	-1813021	7044832
-1555095	12593254	-1551121	10914721	-1554765	9608027	-1551121	10714429	-1686931	7327975	-1686931	7044832
-3565980	13823230	-3562033	12140700	-3560851	10825911	-3562033	11940023	-3551871	8473857	-3551871	8189130
-3171216	14389080	-3171216	12708400	-3171216	11389905	-3171216	12507709	-3170978	9037782	-3170978	8752345
-2811207	15642021	-2811207	13960859	-2811207	12642364	-2811207	13759997	-2811207	10290488	-2811207	10004860

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Pay-off matrix
as the result obtained by game theory

Refine

Game theory

Solving a game

12		13		14		15		16		17	
-25078685	3799915	-27065185	2763561	-27065185	2661606	-29111541	1835810	-30270616	1667941	-31983065	0
-11816490	3799915	-13809890	2763561	-13809890	2661606	-15962744	1835810	-17122980	1667941	-18988767	0
-8943322	3799915	-10930709	2763561	-10930709	2661606	-13162506	1835810	-14232446	1667941	-16090875	0
-3177552	3799716	-5156212	2763561	-5156212	2661606	-7422605	1835810	-8589593	1667941	-10607320	0
-2453833	3799275	-4420352	2763561	-4420352	2661606	-6681774	1835810	-7847325	1667941	-9864855	0
-1733263	3793228	-3701316	2763561	-3701316	2661606	-5972518	1835810	-7140921	1667941	-9156161	0
-1358185	3788403	-3335661	2762659	-3335661	2660775	-5572871	1835810	-6767075	1667941	-8771863	0
-1049064	3812213	-2911339	2754043	-2911339	2652943	-5158671	1835810	-6323067	1667941	-8342747	0
-867853	3788403	-2829437	2762659	-2829437	2660775	-5055376	1835810	-6220153	1667941	-8228295	0
-1579465	4145092	-2685409	2768210	-2685409	2662074	-4806786	1834727	-5975166	1667941	-7947253	0
-1284247	4145092	-2403043	2768210	-2403043	2662074	-4504283	1834727	-5654202	1667941	-7622250	0
-1285943	4503950	-2039286	2922772	-2039286	2787747	-3791042	1829964	-4894028	1667371	-6848580	0
-2146189	5257790	-2932901	3526523	-2932901	3328285	-3615897	1897445	-4486335	1665990	-6391258	0
-1968682	5257790	-2692767	3526523	-2692767	3328285	-3402602	1897445	-4243098	1665990	-6135041	0
-3573937	6300018	-3716045	4338907	-3716045	4094262	-4064415	2215059	-4142330	1686065	-5906374	0
-3166780	6839710	-3176315	4810022	-3176315	4561267	-3240891	2481472	-3336057	1768229	-4834338	0
-2811207	8092818	-2811207	6057057	-2811207	5807050	-2811207	3694235	-2811207	2912859	-2811207	0

Dominance
used to solve the game (1)

Refine

Game theory

Solving a game

	1		2		3		
1	-17750389	8166040	-18030411	10019864	-18140254	9972079	-1
2	-1419268	8209692	-1672096	10051418	-1783478	10004039	-
3	-1297263	8224360	-1539411	10063978	-1625046	10044094	-2
4	3674401	8199365	3557017	10307558	3194070	10243227	2
5	4369139	8566074	4268006	10367731	4215824	10296081	3
6	4358976	8925857	4289749	10700868	4247165	10823254	3
7	3190003	9676862	3176709	11432764	3174467	11342005	3
8	2553035	10187720	2554514	11939482	2556335	11846078	2
9	3596362	9676862	3590753	11432764	3591832	11342005	3
10	782957	11224017	794121	12970753	808402	12874398	3
11	988780	11224017	999985	12970753	1005802	12874398	1
12	63961	12204736	69210	13951408	70193	13855624	
13	-1674416	13307425	-1674416	15058865	-1674416	14963085	-1
14	-1568758	13307425	-1568758	15058865	-1568758	14963085	-1
15	-3565265	14529862	-3565265	16279824	-3565265	16183864	-
16	-3174216	15090651	-3174216	16849546	-3174216	16753385	-
17	-2811207	16344734	-2811207	18099083	-2811207	17999215	-2

Dominance
used to solve the game (2)

Refine

Game theory

Solving a game

	2	
~~5~~	~~4260006~~	10367731
6	4289749	10700868
~~9~~	~~3590753~~	11432764
~~11~~	~~999965~~	12970753
~~12~~	~~69240~~	13951408
~~14~~	~~-1560758~~	15058865
~~17~~	~~-2814207~~	18099083

Dominance
used to solve the game (3)

Refine

Game theory

Solving a game

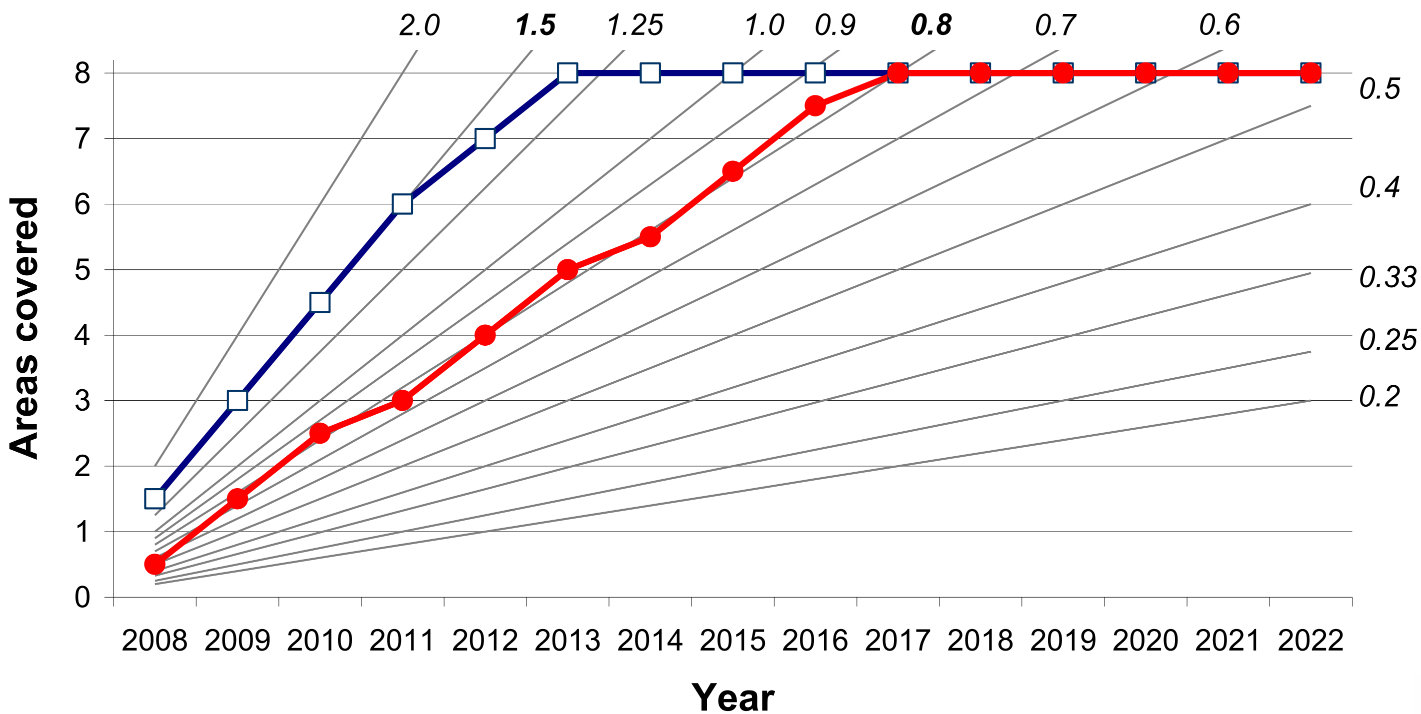
	2	
6	4289749	10700868

Result
obtained by game theory

Refine

Game theory

Solving a game

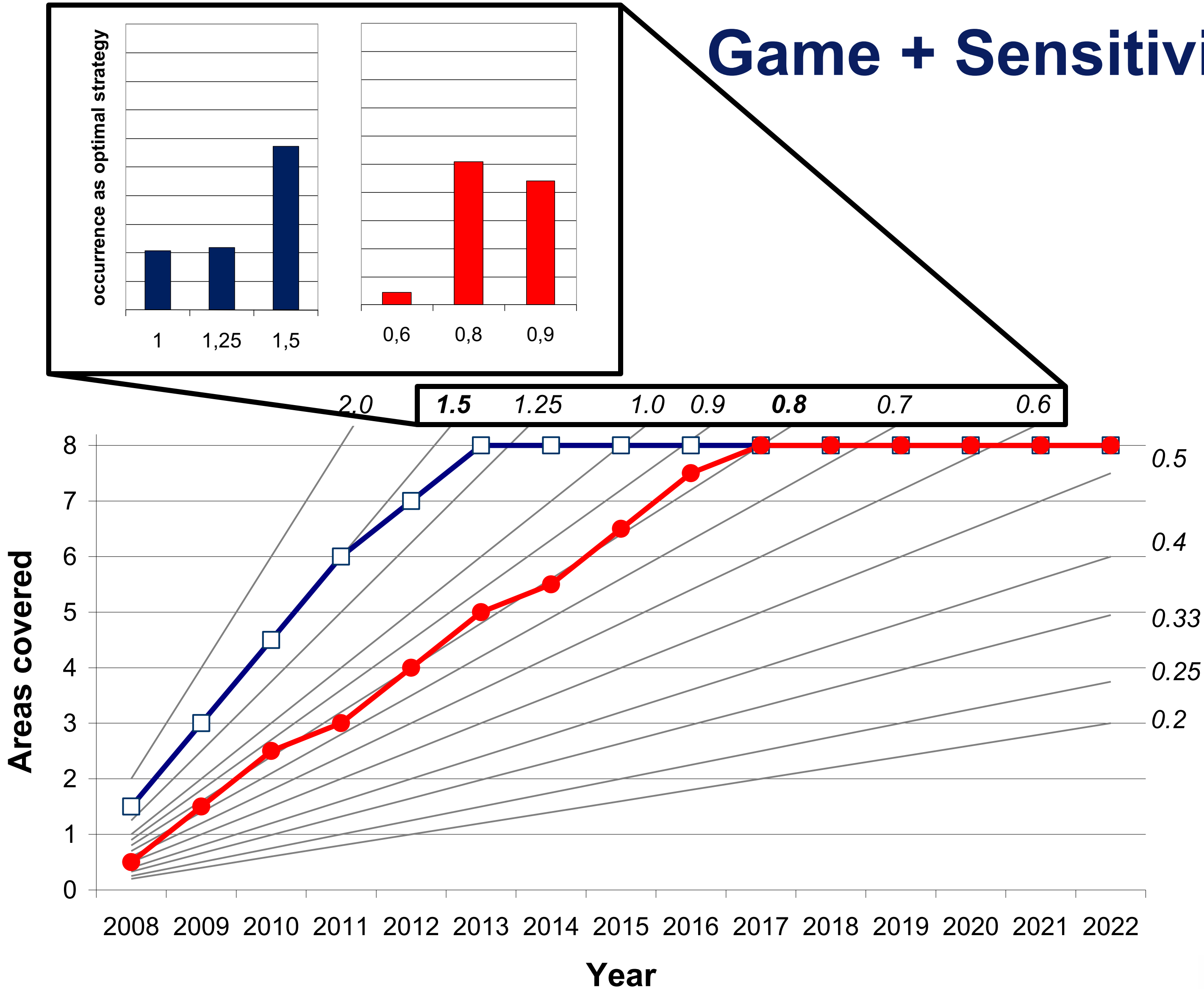


Game + Sensitivity

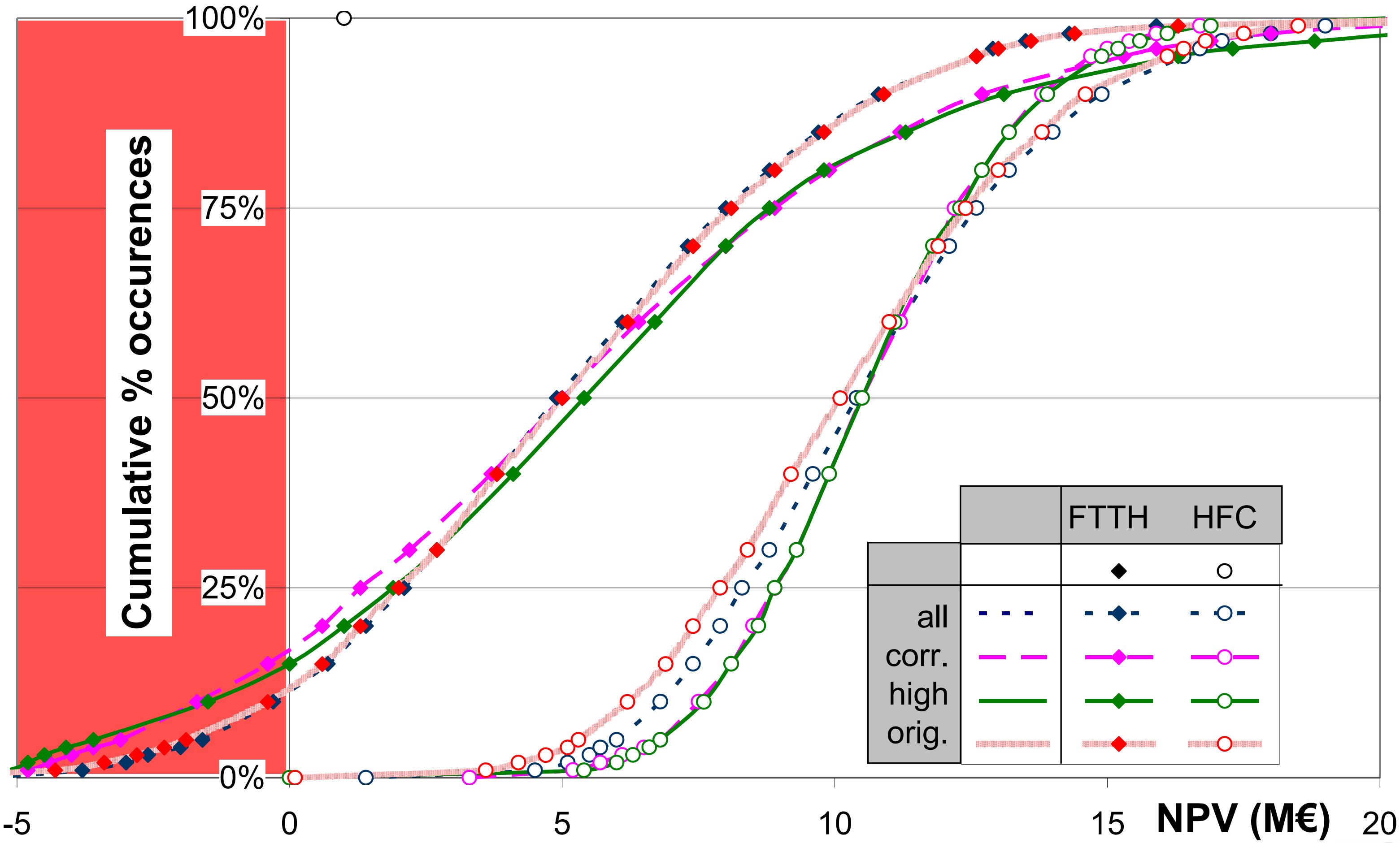
Refine

Game theory

Solving a game



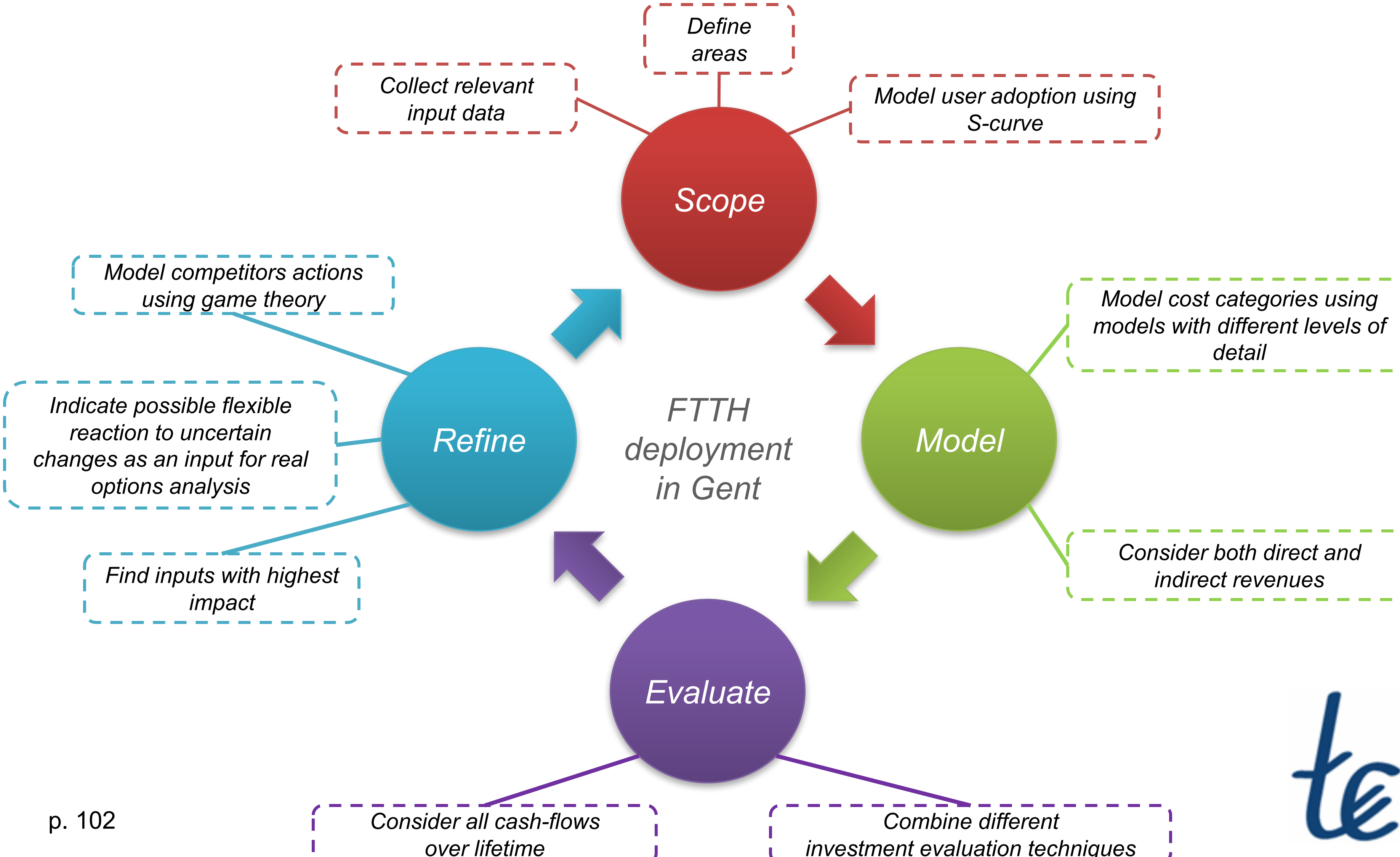
NPV distribution for the games



Practical steps in techno-economic evaluation of network deployment planning

SUMMARY AND CONCLUSIONS

Practical steps in network deployment planning



Practical steps in techno-economic evaluation of network deployment planning

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Thanks for your attention!

Any questions?

koen.casier@intec.ugent.be, sofie.verbrugge@intec.ugent.be

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