Short-Run Cost model

Supplied traffic

Per RAN configuration: number of cells in the region, number of base stations , typical cell capacity (data rate).

Demanded traffic

Per RAN configuration: cell throughput (downlink) is generated randomly
Assumptions: 1. The network has been built to serve the current traffic plus some extra traffic during busy hour. Thus, the demanded traffic in a cell is its capacity (minus the capacity room), considering the traffic characteristics.
2. The traffic in a cell follows an exponential distribution.

Network dimensioning

Find the positions of the sites/base stations for each RAN configuration separately to meet the territory coverage percentage. Then, calculate the number of sites and find their positions by grouping them based on the nearest neighbor (clusters' center). Finally, the multi-technology sites are created randomly based on co-location rules.

Total cost of ownership

Fixed assets: current-cost accounting values the assets at their current replacement cost. The spectrum value is allocated to cells based on service usage shares and the population. Direct and indirect operating cost: the variable energy consumption and cost are calculated from zero to maximum traffic the cell can carry.

Short-Run Cost model | Demand model | Long-Run Cost model | Outputs

Short-Run inputs

Groups of variables:
- Market and industry
- Technology
- Costs
- Finance

Build network infrastructure

Two options:
- From the scratch, using variable from the short-run inputs
- By importing files with actual network infrastructure

Extract network information

Network analytics:
A list of important key performance indicators is created at the cell and network level.

Calculate asset value

Replacement cost, depreciation, amortization and book value for all fixed assets per network technology at cell and network level.

Calculate operating cost

Cost of good sold and Operating expenses (OPEX) at cell, site and network level (with a focus on energy consumption and cost).

Demand model

Market definition

Operators sell mobile data traffic (GB/month) via mobile data transmission subscriptions to households and business.

Regression analysis

1. Demand: A log-linear equation represents the inverse demand curve (market and individual). The coefficients are estimated by fitting the quantity - price points with multiple regression. The coefficient of determination R is calculated. 2. Mobile data traffic: power, exponential and geometric mathematical forms represent the growth.

Revenue analysis

The network evolution, reflected by the experienced user data rate factor, and the mobile data traffic usage have a strong impact on the price of mobile data traffic unit and finally the revenue.

Demand extra inputs

- market shares (past and future)
- traffic volumes (past)
- determinants of demand, such as unit price (past) and experienced user data rate factor (past and future)

Demand estimation

- Market Demand: More determinants of demand show the shift in demand curve (from 3G to 4G).
- Individual Demand for a local operator: The quantity depends on operator's market share. Data weighting factor gives the quantity in region

Data traffic forecast

Several traffic growth scenarios are studied (low, medium, high)

Demand forecast

The future mobile data traffic volume and experienced user data rate factor give the future inverse demand curves (from 4G to 5G).

Revenues

The future price-quantity equilibria determine the revenues. The marginal revenue and annual revenues are estimated

Long-Run Cost model

Initialization

The network evolution scenario is determined by the log-run inputs (e.g., territory coverage of specific RAN configuration). The maximum target network capacity and the traffic growth rate give the network capabilities and the speed of reaching congestion.

Connection with the Demand model

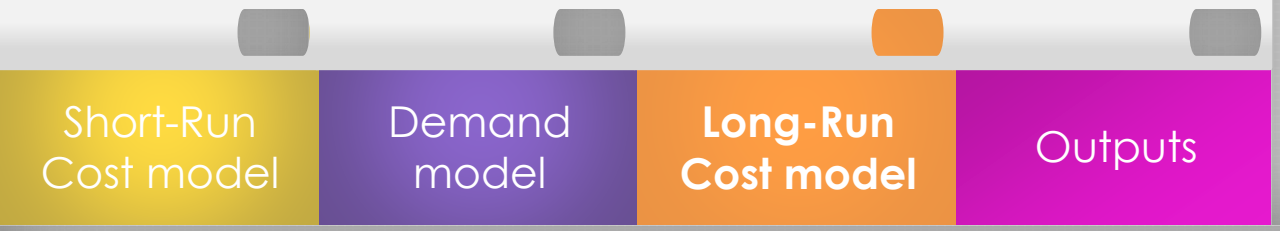
The long-run model runs after selecting the traffic growth rate. Based on the demand model, the traffic growth is linked to time (year, depends on the granularity). Also, the price of GB per month and the marginal revenue are estimated for the selected traffic/time.

Investment scenario

Defining several rules and assumptions on how investments are made. For example, load balancing rules, assumption that the number of sites remains constant.

Total cost of ownership

The analysis is made for the network which is a snapshot for the selected traffic growth. The information, operating cost and asset value are processes similar to the short-run model



Long-Run inputs

Groups of variables:
- Market and industry
- Technology
- Costs
- Finance

Target network infrastructure

Understand the supplied traffic of the targeted future infrastructure. Especially the maximum traffic the target network can carry.

Throughput growth

Algorithm for determining the traffic growth rate and identifying the upper limit of the traffic that the cells and network can carry. Assumption: The traffic in a cell increases proportional to the current throughput.

Investments

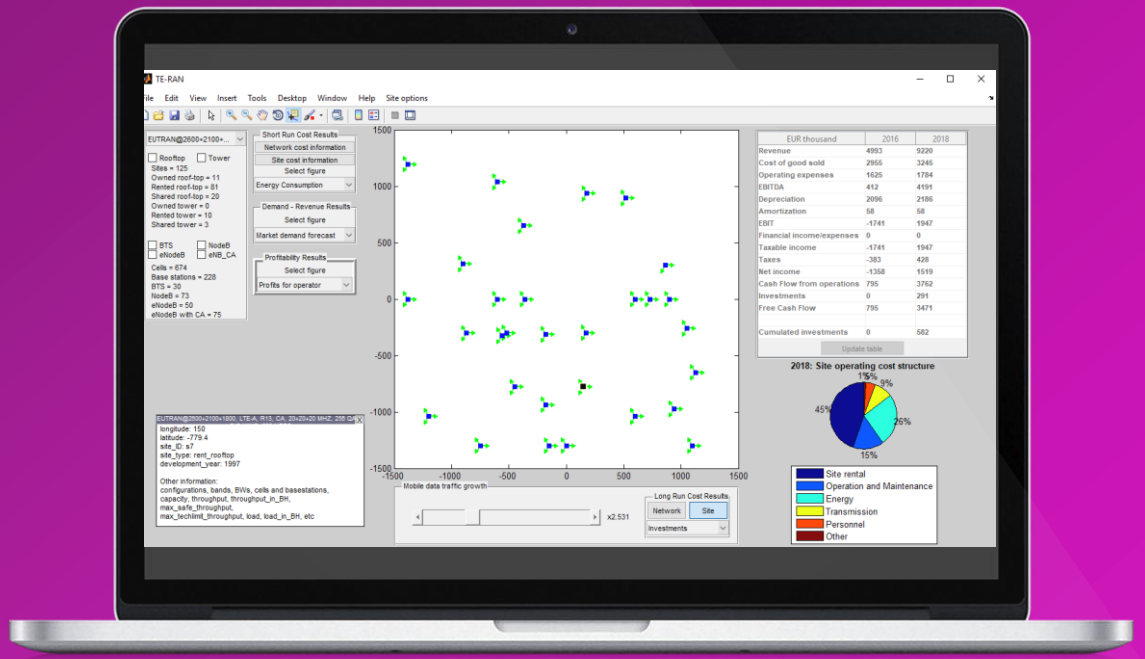
- For the selected traffic growth, find the congested cells.
- Find which of these cells i) belong to potential cells to invest, ii) are inside the range of cells to invest which can carry their traffic, iii) the scenario cannot solve their traffic problem
- Install and unistall equipment
- Recalculate cell thoughput and estimate new territory coverage

Information and costs

Similar to Short-run model. Also, calculate investment cost and disposal value.

Outputs

User interface



Network Information

Sort sites by RAN configuration, site types, technology

Short Run Cost Results

Network cost structure
Site cost structure for selected site
Total operating cost
Unit cost curves
Energy Consumption
Cost per GB and GB per data user

Demand - Revenue Results

Market Demand
Mobile data traffic forecast
Market demand forecast
Annual market revenue
Market marginal analysis (2020)

Profitability

Annual traffic for operator
Profits for operator
Income statement table

Long Run Cost Results

After selecting Mobile data traffic growth:
Cumulated investments
Network cost structure
Site cost structure for selected site
Total operating cost
Unit cost curves
Energy Consumption
Cost per GB and GB per data user

Short-Run Cost model | Demand model | Long-Run Cost model | **Outputs**

Model inputs

Market and industry

DEMOGRAPHICS

Land area
Population

MOBILE MARKET

Penetration
Market share
Data subscriptions

SERVICE

Mobile data traffic
Traffic distribution among sites
Busy hour ratio
Uplink-to-downlink ratio

Technology

SPECTRUM

Paired per frequency
Unpaired per frequency

EUTRAN/UTRAN/GERAN

Configuration per technology
Band
Bandwidth
Bandwidth efficiency
Cell range
Territory coverage
Development year
Base station max power
Power share in idle mode
Carrier aggregation config.
Reuse factor
BSC and RNC capacity

CORE

HSS, VLR, EIR capacity
EPC capacity (MME,SGW,PGW)
PS capacity (SGSN,GGSN)

SITES

Types:
  rooftop, tower
  owned, rental, shared
Share per type
Oldest development year
Newest development year

EXTRA

GSM channel
TRx data usage share
UMTS data usage share
Transmission overhead
Owned RAN transmission share
Owned core transmission share
Core data usage share
Operation share for data service
Core energy consumption
Controlers energy consumption
Default sectors number
Sites-to-Base station ratio
Extra built capacity room
Antenna directions
RAN and core labor

Model inputs

Costs

OPERATING COSTS

Cost of good sold

Site rental per type
Energy MWh price
Personnel
RAN/RANtoCore/Core:
- Network and operation maintenance
- Leased transmission lines
- Other

Interconnection and other fees

Selling, general and administrative

CAPITAL EXPENDITURE

RAN

Site per type
BTS
NodeB
eNodeB
eNodeB with CA
BSC
RNC
Owned transmission line
Other tangible fixed assets

RANtoCore

Owned transmission line
Other tangible fixed assets

Core

Packet switch core
Evolved packet core
Common core entities
Other tangible fixed assets

Non-network tangible fixed assets

Intangible fixed assets

Site development
Other fixed asset's development
Other intangible fixed assets

SPECTRUM

Per frequency:
Cost
Acquisition year
Licence duration

Finance

Weighted Average Cost Of Capital

Current year

Tax rate

Interest

Economic asset life

Buildings and construction
Machinery and equipment in buildings
Telecom networks
Exchanges and concentrators
Equipment for network and exchanges
Other machinery and equipment
Other

Network Infrastructure import file

Different files for each network technology (EUTRAN, UTRAN, GERAN)

Site information

Site ID
Site type
Longitude
Latitude
Development year

Cell information

Cell ID
Configuration type
Band
BW
Cell range
Cell direction
Cell capacity (Mbps)
Cell throughput (Mbps)
Development year
Owned transmission lines

Initial Site information structure

- **Site_infrastructure**
  - site_ID
  - site_type
  - longitude
  - latitude
  - development_year

- EUTRAN_s
  - sector
    - cell_ID
    - configuration
    - band
    - BW
    - cell_range_km
    - cell_capacity_Mbps
    - cell_throughput_Mbps
    - development_year

- EUTRAN_CA
  - sector
    - cell_ID
    - configuration
    - band
    - BW
    - cell_range_km
    - cell_capacity_Mbps
    - cell_throughput_Mbps
    - development_year

- UTRAN
  - sector2100
    - cell_ID
    - configuration
    - band
    - BW
    - cell_range_km
    - cell_capacity_Mbps
    - cell_throughput_Mbps
    - development_year
  - sector900
    - cell_ID
    - configuration
    - band
    - BW
    - cell_range_km
    - cell_capacity_Mbps
    - cell_throughput_Mbps
    - development_year

- GERAN
  - sector900
    - cell_ID
    - configuration
    - band
    - BW
    - cell_range_km
    - cell_capacity_Mbps
    - cell_throughput_Mbps
    - development_year
  - sector1800
    - cell_ID
    - configuration
    - band
    - BW
    - cell_range_km
    - cell_capacity_Mbps
    - cell_throughput_Mbps
    - development_year

- transmission
  - owned_transmission_lines
  - leased_transmission_lines
- configurations
- cell_directions

Processing network infrastructure

Information per site and RAN technology

Configurations
Configuration per site
Bands per site
BWs per site
Cells per site
Cells
Base stations per site
Base stations
Capacity per cell
Capacity per site
Total capacity
Average cell capacity
Throughput per cell
Throughput per site
Throughput in BH per site
Max safe throughput per cell
Max safe throughput per site
Max safe throughput in BH per site
Max technical limit throughput per cell
Max technical limit throughput per site
Max technical limit throughput in BH per site
Total throughput
Total throughput in BH
Total max safe throughput
Total max safe throughput in BH
Total max technical limit throughput
Total max technical limit throughput in BH
Average cell throughput
Average cell throughput in BH
Average cell max safe throughput
Current load per cell
Current load per site
Current load per site in BH
Average cell load
Average cell load in BH

Total Network Information

Configurations
Configuration per site
Bands per site
BWs per site
Cells per site
Cells
Base stations per site
Base stations
TRx per BTS
TRx
Sites
Owned towers
Owned rooftops
Sites rent towers
Sites rent rooftops
Sites shared rent towers
Sites shared rent rooftops
Data subscriptions
Average site data subscriptions
Capacity per site
Total capacity
Average cell capacity
Throughput per site
Throughput in BH per site
Max safe throughput per site
Max safe throughput in BH per site
Max technical limit throughput per site
Max technical limit throughput in BH per site
Total throughput
Total throughput in BH
Total max safe throughput
Total max safe throughput in BH
Total max technical limit throughput
Total max technical limit throughput in BH
Average cell throughput
Average cell throughput in BH
Average cell max safe throughput
Current load per site
Current load per site in BH
Average cell load
Average cell load in BH

Asset value & Operating cost

Value per cell and RAN technology
Total Network Value

REPLACEMENT COST, DEPRECIATION AND VALUE

RAN

Site development
Site equipment
Base stations
Controllers
Owned transmission lines
Other tangible fixed asset

RANtoCORE

Owned transmission lines
Other tangible fixed asset

CORE

PS network elements
Common network elements
Owned transmission lines
Other tangible fixed asset

Non network

Tangible fixed assets
Intangible fixed assets

SPECTRUM

Allocation
Amortization
Value

Cost per cell and RAN technology
Total Network Cost

COST OF GOOD SOLD

RAN

Site rental
Network operation and maintenance
Fixed energy consumption
Current energy consumption
Variable energy consumption
Leased transmission lines
Personnel
Other

RANtoCORE

Leased transmission lines
Network operation and maintenance
Other

Core

Fixed energy consumption
Current energy consumption
Variable energy consumption
Network operation and maintenance
Personnel
Other

OPERATING EXPENSE

Interconnection and other fees
Selling, general and administrative

Matlab files

M-files

Existing network (Short-run model)

SR1_inputs_market_industry
SR2_inputs_technology_spectrum
SR3_inputs_costs
SR4_inputs_finance
SR5_supply_cell
SR6_demand_cell
SR7_site_infrastructure_positions
SR8_site_infrastructure_layout
SR9_network_information
SR10_assets_value
SR11_operating_costs

Future network (Long-run model)

LR1_inputs_market_industry
LR2_inputs_technology_spectrum
LR3_inputs_costs
LR4_inputs_finance
LR5_supply_cell
LR6_demand_cell
LR7_sites_to_invest_due_to_traffic
LR8_investments_scenario
LR9_network_information
LR10_investments_cost
LR11_assets_value
LR12_operating_costs
LR_D_marginal

Demand model

D1_input
D2_demand_estimation
D3_data_traffic_forecast
D4_demand_forecast
D5_revenues
D6_marginal

teran
teran_SR
teran_D
teran_LR_initial
teran_LR

Functions

teranGUI
number_of_cells
cell_capacity_Mbps
cell_throughput_Mbps
basestations_initial_position
number_of_sites
define_site_infrastructure_struct
distribute_RAN_to_sites
io_write_site_infrastructure_to_file
io_read_site_infrastructure_from_file
extract_network_information
extract_network_information_all_RAN
number_of_TRx
fixed_assets_cost_cells
fixed_assets_cost_all_RAN
operating_cost_cells
operating_cost_all_RAN
calculate_inverse_demand
cell_throughput_progression_Mbps
convert_trafficGrowth_to_time
invest_to_sites
network_territory_coverage
cell_throughput_LR_Mbps
cell_throughput_correction_LR_Mbps
investment_cost_cell
investment_cost_all_RAN
disposal_value_cell
disposal_value_all_RAN

other functions:
kmeans
rangesearch

txt files:
cells_EUTRAN_CA
cells_EUTRAN_s
cells_UTRAN
cells_GERAN