Forecasting models for cost evolution of network components

and

Risk analysis based on uncertainties in demand forecasts and cost predictions

Kjell Stordahl
Telenor Networks
kjell.stordahl@telenor.com
Forecasting models for cost evolution of network components

Kjell Stordahl
Telenor Networks
kjell.stordahl@telenor.com
Agenda

- Write and Crawford’s learning curve model
- The extended learning curve model
- Discussion of different type of parameters in the models
- Examples
- Conclusion on cost prediction models
Learning curve

T. P. Wright proposed the concept of learning curves:

\[ T_n = n^{-\alpha} T_0 \]

where \( T_n \) is the average production time for \( n \) units, and \( T_0 \) is the time to complete the first unit.

J.R.Crawford applied the same formula, but interpreted \( T_n \) to be the completing time for the \( n^{th} \) unit in a series.

Let us assume that the component cost (price) \( P_n \) is proportional to the production time \( T_n \).
Learning curve coefficient $K$

$$P_n = n^{-\alpha} P_0$$

$P_n$ is the average cost for the $n^{th}$ unit.

The learning curve coefficient is defined by:

$$P_{2n} = K \cdot P_n$$

Then

$$K = (2)^{-\alpha}$$

$$\alpha = -\log_2 K$$
Relevant K values of different network components

<table>
<thead>
<tr>
<th>LearningCurveClass</th>
<th>K_Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>CivilWorks</td>
<td>100,00%</td>
</tr>
<tr>
<td>CopperCable</td>
<td>100,00%</td>
</tr>
<tr>
<td>Electronics</td>
<td>80,00%</td>
</tr>
<tr>
<td>SitesAndEnclosures</td>
<td>100,00%</td>
</tr>
<tr>
<td>FibreCable</td>
<td>90,00%</td>
</tr>
<tr>
<td>Installation (constant)</td>
<td>100,00%</td>
</tr>
<tr>
<td>AdvancedOpticalComponents</td>
<td>70,00%</td>
</tr>
<tr>
<td>Installation (decresing)</td>
<td>85,00%</td>
</tr>
<tr>
<td>OpticalComponents</td>
<td>80,00%</td>
</tr>
</tbody>
</table>
Learning curve prediction

\[ K = 0.8 \text{ or } \alpha = 0.32 \]
What we need:

Cost as a function of time
The answer

To combine the learning curves with volume forecasts of components.

\[ P(t) = n(t)^{-\alpha} P(0) = n(t)^{-\log_2 K} P(0) \]
The answer

To combine the learning curves with volume forecasts of components.

\[ P(t) = n(t)^{-\alpha} P(0) = n(t)^{-\log_2 K} P(0) \]

(Olsen, Stordahl 1993) Extended learning curve model is given by inserting a Logistic model into the learning curve model

\[ n(t) = M \cdot [1 + e^{(a+b \cdot t)}]^{-\gamma} \]
Parameters in the model

- **K** or **α**: Learning curve coefficient
- **P(0)**: Production cost, unit no 1
- **M**: Saturation
- **a**: Parameter in the Logistic model
- **b**: Parameter in the Logistic model
- **γ**: Parameter in the Logistic model
Reformulation of the parameters

The normalized Logistic model is:

\[ n_r(t) = \frac{n(t)}{M} \]

The aggregated production volume the reference year, 0:

\[ n_r(0) \]

The growth period:

\[ n_r(t_1) = 0.1, \quad n_r(t_2) = 0.9 \]

\[ \Delta T = t_1 - t_2 \]
Interpretation of the parameters

\[ n_r(0) \]

\[ t_1 \quad \Delta T \quad t_2 \]
The extended learning curve (γ = 1)

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

- **P(0)**: Production cost the reference year (0)
- **n_r(0)**: Relative accumulated production volume the reference year
- **ΔT**: Time for the accumulated volume to grow from 10% to 20%
- **K**: Learning curve coefficient
Cost as a function of $K$

$n_r(0)=0.1$, $\Delta T=5$
Cost as a function of $n_r(0)$

$\Delta T = 5, K = 0.8$
Cost as a function of $\Delta T$

$n_r(0) = 0.1, K = 0.8$
Historical diffusions of selected goods in Canada.
Historical diffusions of selected goods in Finland.

19. okt. 2004

Telenor
Recommended values on the parameters when cost time series are not available

<table>
<thead>
<tr>
<th>LearningCurveClass</th>
<th>K Value</th>
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</thead>
<tbody>
<tr>
<td>CivilWorks</td>
<td>100,00%</td>
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<td>CopperCable</td>
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<tr>
<td>Installation (constant)</td>
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<td>AdvancedOpticalComponents</td>
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<td>OpticalComponents</td>
<td>80,00%</td>
</tr>
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</table>

<table>
<thead>
<tr>
<th>VolumeClass</th>
<th>$n_i(0)$</th>
<th>$\Delta T$</th>
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</thead>
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<td>5,00</td>
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<tr>
<td>Emerging_Medium</td>
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<td>Emerging_Slow</td>
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<td>Emerging_VerySlow</td>
<td>0,001</td>
<td>40,00</td>
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<td>Mature_Fast</td>
<td>0.1</td>
<td>5,00</td>
</tr>
<tr>
<td>Mature_Medium</td>
<td>0.1</td>
<td>10,00</td>
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<tr>
<td>Old_Fast</td>
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<tr>
<td>Old_Medium</td>
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<td>10,00</td>
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<tr>
<td>Old_Slow</td>
<td>0.5</td>
<td>20,00</td>
</tr>
<tr>
<td>Old_VerySlow</td>
<td>0.5</td>
<td>40,00</td>
</tr>
<tr>
<td>Straight Line</td>
<td>0.1</td>
<td>1000,00</td>
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</table>
Forecasts for ADSL line costs. Estimation: P(2000)= 212 Euro, ΔT=8, n(2000)=0,1%, K=0,736
Logistic model with different $\gamma$ values
The extended learning curve (diff $\gamma$)

$$P(t) = P(0) \cdot n_{r}(0)^{-1} \cdot \left(1 + e^{-\frac{1}{\gamma} \cdot \left[\ln n_{r}(0)^{\gamma} - 1 + \frac{\ln \delta}{\Delta T} \cdot t\right]}\right)^{-\gamma \log_2 K}$$

- $P(0)$: Production cost the reference year (0)
- $n_{r}(0)$: Relative accumulated production volume the reference year
- $\Delta T$: Time for the accumulated volume to grow from 10% to 20%
- $K$: Learning curve coefficient
- $\gamma$: Parameter asymmetry
Use of the the Extended learning curve model

- AC364/TERA 1998-2000
- ECOSYS / CELTIC 2004-
- Many Eurescom projects
  - P306, P413, P614, P901 etc
- Within Telenor and other project partners organizations
Advantages with the extended learning curve model

- The model makes forecasts of component costs (predictions as a function of time)
- The model has the possibility to include both a priori knowledge and statistical information at the same time
- The model can be used to forecast component costs evolution even if no cost observations are known
- The model can be used to forecast component costs based on estimation of the parameters when historical costs are available
Risk analysis based on uncertainties in demand forecasts and cost predictions

Kjell Stordahl
Telenor Networks
kjell.stordahl@telenor.com
Agenda

- Business case: Roll out of ASDL2+/VDSL
- Adoption rate forecasts
- Evaluation of 6 different roll out scenarios
- Calculation of net present values for the roll out scenarios
- Framework for risk analysis
- Modelling dependency between variables in risk analysis
- Results from risk analysis
- Conclusions
Important factors for ADSL2+/VDSL roll out

- Broadband demand forecasts
- Substitution effects between broadband technologies
- Competition (Same technology and other technologies)
- Size of the access area
- Distribution of the copper line length
- Standardisation of network technology/components
- Component price and functionality
- Maintenance costs
- Expected ARPU (Average revenue per user)
Adoption rate forecasts for ADSL2+/VDSL

Adoption rate as a function of delayed introduction

- Alone
- 0 Year delay
- 1 year delay
- 2 year delay
- 3 year delay
- 4 year delay
- 5 year delay
- 6 year delay

0,0 %
5,0 %
10,0 %
15,0 %
20,0 %
25,0 %
30,0 %
35,0 %

2004 2005 2006 2007 2008 2009 2010
## Market segmentation

<table>
<thead>
<tr>
<th>Market segment</th>
<th>Exchange size N</th>
<th>Percent households</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area 1</td>
<td>$15.000 &lt; N$</td>
<td>10 %</td>
</tr>
<tr>
<td>Area 2</td>
<td>$10.000 &lt; N &lt;= 15.000$</td>
<td>15 %</td>
</tr>
<tr>
<td>Area 3</td>
<td>$5.000 &lt; N &lt;= 10.000$</td>
<td>20 %</td>
</tr>
<tr>
<td>Area 4</td>
<td>$2.000 &lt; N &lt;= 5.000$</td>
<td>20 %</td>
</tr>
<tr>
<td>Area 5</td>
<td>$N &lt;= 2.000$</td>
<td>35 %</td>
</tr>
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</table>
### Generic case study

#### Population and coverage

<table>
<thead>
<tr>
<th></th>
<th>Area 1</th>
<th>Area 2</th>
<th>Area 3</th>
<th>Area 4</th>
<th>Area 5</th>
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<tbody>
<tr>
<td>Distribution of HHs</td>
<td>14 %</td>
<td>21 %</td>
<td>29 %</td>
<td>23 %</td>
<td>13 %</td>
</tr>
<tr>
<td>Average number of HHs per CO</td>
<td>12 000</td>
<td>8 000</td>
<td>2 600</td>
<td>1 400</td>
<td>400</td>
</tr>
<tr>
<td><strong>Coverage level</strong></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>HH (in %) within 2 km</td>
<td>10 %</td>
<td>15 %</td>
<td>20 %</td>
<td>15 %</td>
<td>0 %</td>
</tr>
<tr>
<td>Coverage (HP)</td>
<td>75 %</td>
<td>75 %</td>
<td>75 %</td>
<td>75 %</td>
<td>75 %</td>
</tr>
<tr>
<td>Total number of HHs in covered exchanges</td>
<td>2 500 000</td>
<td>3 750 000</td>
<td>5 000 000</td>
<td>3 750 000</td>
<td>15 000 000</td>
</tr>
<tr>
<td>Number of upgraded exchanges</td>
<td>3 333 333</td>
<td>5 000 000</td>
<td>6 666 667</td>
<td>5 000 000</td>
<td>7 038</td>
</tr>
<tr>
<td>Number of HHs in areas without deployment</td>
<td>166 667</td>
<td>250 000</td>
<td>583 333</td>
<td>750 000</td>
<td>3 250 000</td>
</tr>
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</table>
The 6 scenarios studied

- Scenario 1 – Market equality, no overlap
- Scenario 2 – Market equality, 50% overlap
- Scenario 3 – Market equality, 75% overlap
- Scenario 4 – Incumbent 2 years delayed
- Scenario 5 – Incumbent 1 year delayed
- Scenario 6 – Incumbent offensive roll out
Scenario 1
"Market equality, no overlap"

<table>
<thead>
<tr>
<th>Year</th>
<th>Incumb.</th>
<th>Other</th>
<th>Overlap</th>
<th>Incumb.</th>
<th>Other</th>
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<tbody>
<tr>
<td></td>
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<td></td>
<td>Area 1</td>
<td></td>
<td>Area 2</td>
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<td>Area 3</td>
<td></td>
<td>Area 4</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>2004</td>
<td>2,5 %</td>
<td>2,5 %</td>
<td>0,0 %</td>
<td>2,5 %</td>
<td>2,5 %</td>
<td>2,5 %</td>
<td>2,5 %</td>
<td>2,5 %</td>
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<td>2,5 %</td>
<td>2,5 %</td>
<td>2,5 %</td>
<td>2,5 %</td>
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<tr>
<td>2005</td>
<td>7,5 %</td>
<td>7,5 %</td>
<td>0,0 %</td>
<td>2,5 %</td>
<td>2,5 %</td>
<td>2,5 %</td>
<td>2,5 %</td>
<td>2,5 %</td>
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<td>2,5 %</td>
<td>2,5 %</td>
<td>2,5 %</td>
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<tr>
<td>2006</td>
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<td>0,0 %</td>
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<td>2,5 %</td>
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<td>2,5 %</td>
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<tr>
<td>2007</td>
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<tr>
<td>Sum</td>
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<td>5,0 %</td>
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</table>
### Scenario 4

"Incumbent 2 years delayed"

<table>
<thead>
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<th>Year</th>
<th>Incumb.</th>
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<th>Overlap</th>
<th>Incumb</th>
<th>Other</th>
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<th>Incumb</th>
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<tr>
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<td>2,5 %</td>
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<td>10,0 %</td>
<td>15,0 %</td>
<td>15,0 %</td>
<td>20,0 %</td>
<td>20,0 %</td>
<td>7,5 %</td>
<td>7,5 %</td>
<td></td>
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</table>
The business case approach:

Demand for the Telecommunications Services

Risk Assessment

Services

DB

Architectures

Revenues

OA&M Costs

Investments

Cash flows, Profit & loss accounts

Year 0

Year 1

Year n

... Year m

Economic Inputs

Geometric Model

First Installed Cost

Life Cycle Cost

NPV

IRR

Payback Period

In the business case approach, economic inputs such as demand for telecommunications services determine the services, which in turn influence revenues. DB (possibly referring to database) and architectures are part of the service offer. Revenues and operating costs (OA&M) lead to cash flows and profit & loss accounts. The life cycle cost and first installed cost affect financial metrics like NPV, IRR, and payback period. The geometric model provides a structured approach to assessing risks associated with these inputs and outputs.
Net present values for the roll out scenarios
Conclusions

- A framework for analysing ADSL2+/VDSL rollout has been developed
- The first step is to enter the market with a cherry picking strategy
- Delay in roll out causes significant loss
- The best strategy is to enter the areas as the first operator starting with the largest areas
- But what about the uncertainty and the risks?
Risk analysis principles
Evaluation of the output distribution

Suppose Net Present Value is the output distribution

Alternative measures:

- Mean value
- Confidence interval
- 10% percentage
- 5% percentage
- Percentage of observations below NPV=0
Fitting of probability densities for the input variables

The probability densities have the ability not to give negative values.

The following input are convenient for defining the probability densities:
- Default value
- Minimum value
- 5% percentile
- 95% percentile
- Maximum value
Beta function and the fitting

\[ p(y) = \frac{1}{B(\alpha, \beta)(b-a)^{\alpha+\beta-1}} (y-a)^{\alpha-1} (b-y)^{\beta-1} \]

\[ B(\alpha, \beta) = \frac{\Gamma(\alpha)\Gamma(\beta)}{\Gamma(\alpha + \beta)} \]

- The parameters/variables a, b, \( \alpha \) and \( \beta \) in the Beta function are found base on the shown input
- Solver is used in the calculations
- The distribution is multiplied with the default value to map the real distribution
### Definition of probability functions for critical variables

<table>
<thead>
<tr>
<th>Variable Name</th>
<th>Minimum Value</th>
<th>5% percentile</th>
<th>Default Value</th>
<th>95% percentile</th>
<th>Maximum Value</th>
<th>$\alpha$</th>
<th>$\beta$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Monthly ARPU</td>
<td>90</td>
<td>95</td>
<td>100</td>
<td>108</td>
<td>124.7</td>
<td>5.11</td>
<td>11.16</td>
</tr>
<tr>
<td>Line Card Price</td>
<td>1,200</td>
<td>1,400</td>
<td>1,600</td>
<td>1,800</td>
<td>2,000</td>
<td>4.94</td>
<td>4.94</td>
</tr>
<tr>
<td>Sales Costs</td>
<td>25%</td>
<td>27.5%</td>
<td>30%</td>
<td>32.5%</td>
<td>35%</td>
<td>4.94</td>
<td>4.94</td>
</tr>
<tr>
<td>Provisioning Costs</td>
<td>50</td>
<td>60</td>
<td>65</td>
<td>70</td>
<td>80</td>
<td>11.77</td>
<td>11.77</td>
</tr>
<tr>
<td>Equipment Price Reduction Rate</td>
<td>5%</td>
<td>8%</td>
<td>10%</td>
<td>12%</td>
<td>15%</td>
<td>8.02</td>
<td>8.02</td>
</tr>
<tr>
<td>Adoption Rate, final year</td>
<td>26%</td>
<td>29%</td>
<td>32%</td>
<td>37%</td>
<td>42%</td>
<td>4.02</td>
<td>6.04</td>
</tr>
<tr>
<td>Customer Installations Cost</td>
<td>100</td>
<td>110</td>
<td>120</td>
<td>130</td>
<td>140</td>
<td>4.95</td>
<td>4.95</td>
</tr>
<tr>
<td>Content Costs</td>
<td>50%</td>
<td>55%</td>
<td>60%</td>
<td>65%</td>
<td>70%</td>
<td>4.95</td>
<td>4.95</td>
</tr>
<tr>
<td>Smart Card Costs</td>
<td>20</td>
<td>25</td>
<td>30</td>
<td>35</td>
<td>40</td>
<td>4.94</td>
<td>4.94</td>
</tr>
<tr>
<td>Customer Operations &amp; Maintenance</td>
<td>15</td>
<td>20</td>
<td>25</td>
<td>30</td>
<td>35</td>
<td>4.95</td>
<td>4.95</td>
</tr>
</tbody>
</table>
The business case approach:

- Economic Inputs
- Demand for the Telecommunications Services
- Risk Assessment
- Services
- DB
- Architectures

- Revenues
- OA&M Costs
- Investments

- Cash flows, Profit & loss accounts

- Year 0
- Year 1
- Year n
- ... Year m

- NPV
- IRR
- Payback Period

- First Installed Cost
- Life Cycle Cost

- Geometric Model
Net present values for the roll out scenarios
Net present value results from risk analysis. Different simulations

<table>
<thead>
<tr>
<th>Scenario</th>
<th>10 variables simulated</th>
<th>Adoption rate and ARPU simulated</th>
<th>Only Adoption Rate simulated</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>5% perc.</td>
<td>95% perc.</td>
<td>σ</td>
</tr>
<tr>
<td>Sc. 1</td>
<td>-48.5</td>
<td>1 155.7</td>
<td>364.1</td>
</tr>
<tr>
<td>Sc. 2</td>
<td>-70.6</td>
<td>1 138.4</td>
<td>365.7</td>
</tr>
<tr>
<td>Sc. 3</td>
<td>-102.3</td>
<td>1 108.3</td>
<td>366.4</td>
</tr>
<tr>
<td>Sc. 4</td>
<td>-376.4</td>
<td>438.5</td>
<td>264.8</td>
</tr>
<tr>
<td>Sc. 5</td>
<td>-212.0</td>
<td>830.8</td>
<td>315.9</td>
</tr>
<tr>
<td>Sc. 6</td>
<td>-50.6</td>
<td>1 561.9</td>
<td>487.7</td>
</tr>
</tbody>
</table>
5% percentile for NPV for the scenarios for different correlation between demand and ARPU
Conclusions

- The risk framework has been developed through the European programs RACE, ACTS and IST, by the projects RACE 2087/TITAN, AC 226/OPTIMUM, AC364/TERA and IST-2000-25172 TONIC.

- The presentation shows how risk analysis is applied on a specific business case for evaluation of the economic risks.

- The methodology for fitting the probability densities of critical variables in the business case is described.

- The analysis also show the effect by modelling dependency between ARPU and demand in the risk simulations.
Time for Questions & Answers

kjell.stordahl@telenor.com