DEVELOPMENT AND APPLICATION OF THE ANALYTICAL METHOD FOR PLANNING DEPENDABILITY (RELIABILITY)

Peter Dirke and Per Lindberg

Televerket Networks, S-123 86 Farsta, Sweden

The analytical method for planning dependability (reliability, maintainability and maintenance support) is recommended by the CCITT [4] and has been used by Televerket since 1987. The level of dependability is dimensioned according to cost-benefit analyses, rather than by beforehand stated objectives. Due to deregulation and increasing risk of competition, there has been a growing demand for an estimate of the business economic benefits of dependability. A simple method for predicting the impact on revenue (i.e. income for the operating company) is derived, taking the market situation (competition or monopoly) and different principles for setting rates and charges into account.

The method is applied to a national fibre network, giving conclusions both for the optimal protection level and protection measures to be used. The network model is based on data from the Swedish national network. It has 248 nodes and includes three metropolitan areas. The protection measures include different network infrastructures, i.e. more or less meshed networks, diverse routings and standby protection. The study is made by the use of a number of computer programs for network optimisation. These include network structure optimisation, circuit routing and multiplexing optimisation, as well as of standby capacities. The revenue evaluation of the network dependability is compared to the network costs and the optimal network can be selected.

1. THE METHOD FOR PREDICTING REVENUE

Network revenue
The annual revenue, \( R \), from a teleservice is determined by the number of customers, \( N \), the price, \( P \), for access to and use of the service \(^1\) and the traffic carried and charged by the network. A rise in price level increases the revenue per customer, but generally decreases the number of customers and the traffic carried, depending on the responsiveness of demand to price changes. This responsiveness is measured by the price elasticity of demand \( e \). \(^2\)

Revenue evaluation of dependability
A rise in the quality of service (QoS) is expected to increase the demand for the service. A price increase, \( \Delta P_{\text{o}} \), without losing customers, and thus a revenue increase of \( \Delta R = N \Delta P_{\text{o}} \), is made possible.

![Figure 1. Revenue if price increase is equal to \( \Delta P_{\text{o}} \) - the marginal customers' willingness to pay for a higher QoS.](image)

However, since teleservices are often provided in a competitive or regulated environment, the operating company is seldom free to set prices at will. We therefore assume more realistic models:
1) prices are regulated by the government and
2) prices are optimised, taking the market reaction into account.
1) Revenue if prices are regulated
This model is often applicable if the operating company has a monopoly of the services (generally telephony). Revenue is given by \( \Delta R = P \Delta N \).

Figure 2. Revenue if the price is unchanged.

In order to derive expressions for \( \Delta R \), useful in network planning, we make two assumptions:

- **Assumption 1:** The customers' willingness to pay for dependability, \( \Delta P_w \), is related to the saved traffic volume, in accordance with the model suggested by CCITT recommendation E.862.

- **Assumption 2:** The change in demand is small. The demand functions, \( N(P) \), can be considered linear and parallel in the studied interval and the average demanded traffic per customer remains unchanged.

These assumptions can be used to derive an analytical expression for predicting the revenue change, \( \Delta R \) (SEK/year), due to a change in the expected mean accumulated down time, \( \Delta U \) (h/year), of a certain part of the network:

\[
\Delta R = -\Delta U E A (x t - e(c - x t))
\]

\( E \) - average blocking during a fault
\( A \) - average traffic during a fault (Erlang)
\( x \) - fraction of traffic lost
\( t \) - traffic dependent charge (SEK/Eh)
\( e \) - price elasticity of demand for the service
\( c \) - the marginal customers' valuation of saved traffic (SEK/Eh).

\( \Delta R \) is normally positive since \( \Delta U \leq 0 \) and \( e \leq 0 \) in most cases. \( -\Delta U E A \) is the saved traffic volume (Eh/year) and thus

\[
r = xt - e(c - xt)
\]

is the revenue of saved traffic (SEK/Eh). The first term represents the instantaneous loss off traffic charges, the second the value to the customers resulting in an increased demand for the service. For regulated services price elasticities are often low (\( e = 0 \)). The instantaneous loss of traffic charges dominate:

\[
r = xt
\]

2) Revenue if prices are optimised
Prices are set to maximise net return (profit). This model is used for unregulated services, i.e. if they are provided in a competitive environment. Revenue is given by \( \Delta R = P \Delta N + N \Delta P \).

Figure 3. Revenue if the price is changed.

In this case we need to make two additional assumptions:

- **Assumption 3:** Investments to promote dependability only affect the fixed costs, not the variable costs of providing the service.

- **Assumption 4:** The result of strategic market interaction can be described by what economists call the Cournot equilibrium.\(^3\)

The revenue change (SEK/year) is then given by:

\[
\Delta R = -\frac{1}{2} \Delta U E A (1 - e/s)c
\]

where \( s = N / \Sigma N \) is the market share and the other parameters are the same as in expression (1). \( e/s \) can be interpreted as the price elasticity facing the network operator. With this interpretation the expression (4) holds even if assumption 4 does not hold.

The revenue of saved traffic (SEK/Eh) is given by

\[
r = \frac{1}{2}(1 - e/s)c
\]

In a competitive environment dependability thus becomes increasingly important as competitors enter the market and the market share, \( s \), gets smaller. However, if the operator dominates the
market, and the marginal costs of providing the service are low, optimal pricing implies that \( e/s = -1 \) and thus the revenue of saved traffic equals the customers' valuation:

\[
 r = c 
\]

(6)

**Parameter estimation**

In order to predict future prices, \( t \), price elasticities, \( e \), and market shares, \( s \), models of market competition can be applied to different market scenarios. The fact that services compete and are substitutes for each other, as well as the fact that postal and transport services etc. are substitutes for some teleservices, should be taken into account.

The customers' valuation of saved traffic, \( c \), is the most difficult parameter to predict. In order to assess the valuation of dependability today, studies have been made of what customers actually have paid for service contracts concerning dependability, as well as studies by use of customer interviews and questionnaires concerning the costs of interruption and the valuation of dependability. The society's dependence on telecommunications in the future is analysed in order to predict future values.

**Parameters used**

The following services and parameter values are assumed to be valid for the Swedish long distance network by the year 1995:

- **Telephony** (regulated service)
  \( e = 0 \), \( x = 0.3 \) and \( t = 100 \text{ SEK/Eh} \)
  Revenue of saved traffic: \( r = xt - e(c - xt) = 30 \text{ SEK/Eh} \)

- **ISDN** (unregulated service)
  \( e/s = -1 \) and \( c = 3000 \text{ SEK/Eh} \) (total failure)
  Revenue: \( r = 1/2(1 - e/s)c = 3000 \text{ SEK/Eh} \)

- **Data and mobile services, leased lines etc.**
  (unregulated and competitive market)
  \( e = -1.8 \), \( s = 0.2 \) and \( c = 1000 \text{ SEK/Eh} \)
  Revenue: \( r = 1/2(1 - e/s)c = 5000 \text{ SEK/Eh} \)

**2. APPLICATION OF THE METHOD**

**Network strategy**

We give an example of using the analytical method for setting the policy for the network protection. The main questions are whether to use standby protection, multirouting or both.

The policy adopted by Swedish Televerket is to install a standby protection network to protect all capacity in case of a single link failure in the long-distance digital network. This decision was supported by the analytical planning method. The circuits between each pair of nodes are diversified on two paths as well. However, this multirouting rule is based on intuitive considerations rather than on economic analyses.

**Evaluation of network dependability**

A transmission network carries all different types of services. To evaluate the reliability one has to estimate an average of the revenues of saved traffic for the different services. Taking into account also the mean utilisation per circuit (64 kbit/s) the parameter can be recalculate to a monetary value per circuit/hour. The figure used in the study is 300 SEK/ctchour, and is based on the estimations for the different services made above.

In this study the revenue of saved traffic is compared to the network costs. The amounts are compared to an ideal network having no traffic losses due to failures. A loss of revenue due to failures is calculated, which is added to the network cost to find the optimal network. Only the difference between network solutions, not absolute values, are of interest.

**Partial failures**

The evaluation of the loss of revenue at partial failures is essential for the policy of multirouting. It is critical how the network behaves at a severe reduction of capacity. Provided that there is sufficient overload protection to prevent the network from degeneration, a partial failure is much less serious than a total failure. There are many reasons for this:

- Traffic utilization is lowest on the last trunks.
- Trunk groups are dimensioned for busy hour traffic, and most of the time the traffic is lower.
- Trunk groups are provided in modules of 30 circuits, so there will always be a number of overprovided trunk groups.
- For sensitive services such as data networks the diversity can be combined with a planned overprovision.

It is assumed that the revenue loss per hour of a failure affecting the circuits between a pair of nodes can be approximated by a function

\[
 n c p^\alpha 
\]

(7)

\( n \) - the number of circuits
\( c \) - the estimation of total failure per circuit/hour
\( p \) - the fraction of circuits out of function
\( \alpha \) - a parameter > 1. In the study is used \( \alpha = 3.5 \)
Network model
The study is made for an all fibre network covering Sweden. The forecasted number of 2 Mbit/s blocks is about 30000 and the network includes all 248 nodes expected to have at least 25 terminating 2 Mbit/s blocks. It could be considered as a combination of long-distance and medium-distance networks. The network is built entirely with SDH equipment, where 63 2 Mbit/s blocks by add/drop multiplex or cross-connect systems DXC4I1 are fitted into a STM-1 of 155 Mbit/s. The STM-1 is carried on an optical system of either 155 or 620 Mbit/s or 2.5 Gbit/s. The standby network works on the STM-1 level and is switched by cross-connects DXC 4/4.

The network failures considered in the study are total link failures. This is the dominant type of failures in the Swedish network. However, there has in fact been an observed improvement with fibre cables as compared to coaxial cables. The figure for unavailability used in the study is 0.02 hours per year and kilometer.

It is not evident how to evaluate additional protection measures if there is 100% standby protection. Here is taken a simple approach, assuming that the standby rerouting will be effective only in a certain percentage of the failure situations. The main reason for failing rerouting is lack of spare capacity, due to unexpected growth, simultaneous failures, maintenance work etc. However, failing DXC 4/4 and failures in the network control system can also contribute to unsuccessful rerouting. In the study it is assumed that standby protection is effective in 95% of the failures.

The different evaluated networks have been constructed by the use of three network optimisation computer programs, each handling a special part of the network.

Network structure optimisation
This program determines the basic network infrastructure, i.e. between which pair of nodes fibre cables should be installed. This is done by a computer program presented in [1]. The program assumes a concave cost function of the capacity of each link. This cost function is not immediately given by the equipment costs. Between major nodes there will be direct high order optical systems (2.5 Gbit/s) not terminating at intermediate nodes. Instead there will also be in the same cables lower level systems that more economically can be terminated at the smaller nodes. Thus the cost function of a link is, except for cost for cable, cable-laying and fibres, based on the cost of regenerators more than the cost of line terminals.

Wherever optical fibre is laid it is also expected to be of use for the short distance network. Therefore the fixed cost of cable and cable-laying should be shared between the two networks, so in the study it is priced at 50 SEK/m instead of the more actual 100 SEK/m.

An initial maximal network structure was constructed, connecting the 248 nodes with 684 links. The program optimises the network structure taking into account the value of network protection by multirouting. Two networks have been generated, the second was optimised with an even lower fixed cost per link of 25 SEK/m. The result is shown in table below:

<table>
<thead>
<tr>
<th>Network</th>
<th>Routing penalty</th>
<th>Biriouting</th>
<th>Cost of fibres</th>
<th>LT,MUX,DXC4/1</th>
<th>Sum in-service network</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>65</td>
<td>129</td>
<td>579</td>
<td>708</td>
</tr>
<tr>
<td>2</td>
<td>0</td>
<td>65</td>
<td>129</td>
<td>579</td>
<td>708</td>
</tr>
</tbody>
</table>

Network 1 is shown in figure 4 on the next page.

Circuit routing and multiplexing
This optimisation program was presented in [2]. In order to evaluate the protection policy used in Sweden, two path multirouting was used. Multirouting is obtained by setting a penalty cost for routing the second half of the circuits between a pair of nodes on the same as the first half. This routing penalty was varied between the values 0, 25, 50 and 100 SEK/cctkm. With the 2 network structures 8 different network solutions was obtained.

<table>
<thead>
<tr>
<th>Network 1</th>
<th>Routing penalty</th>
<th>Biriouting</th>
<th>Cost of fibres</th>
<th>LT,MUX,DXC4/1</th>
<th>Sum in-service network</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>25</td>
<td>50</td>
<td>129</td>
<td>579</td>
<td>708</td>
</tr>
<tr>
<td>0</td>
<td>25</td>
<td>50</td>
<td>129</td>
<td>579</td>
<td>708</td>
</tr>
</tbody>
</table>

Network 2

<table>
<thead>
<tr>
<th>Network 2</th>
<th>Routing penalty</th>
<th>Biriouting</th>
<th>Cost of fibres</th>
<th>LT,MUX,DXC4/1</th>
<th>Sum in-service network</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>25</td>
<td>50</td>
<td>129</td>
<td>579</td>
<td>708</td>
</tr>
<tr>
<td>0</td>
<td>25</td>
<td>50</td>
<td>129</td>
<td>579</td>
<td>708</td>
</tr>
</tbody>
</table>
Standby network optimisation
For the different network solutions a full protection standby network was optimised by use of an improved version of the computer program reported in [3]. The rerouting strategy selected was to reroute each STM-1 between its terminal nodes. This gives a low demand for standby link capacity and at the same time saves DXC 4/4 capacity, since the in-service STM-1:s only have to be connected to cross-connect systems at its ends. The standby STM-1:s are assumed to be connected to crossconnects at all nodes in order to have maximal flexibility. Since a few small nodes were connected with a single cable only, 0.5 % of the capacity was without standby protection in network 1 and 0.2 % in network 2.

Results
For the 8 different network solutions the loss of revenue due to failures was evaluated. This was done for three different classes of circuits, those having neither standby nor diversity, those having standby but not diversity and finally those having both types of protection. The yearly loss of revenue is multiplied by a factor giving a present worth comparable to the network investment costs. The present worth of the loss of revenue is added to the network cost in order to give the optimal network.

The differences between the networks 1 and 2 are small. The higher cost of infrastructure for network 2 is compensated mainly by cheaper standby protection. For both networks the solution using 25 as the routing penalty is optimal, having 62 % and 65 % of the circuits diversified. The conclusion is that also with standby protection it is interesting with multirouting, however this should not be used when the cost of it is too high.
An evaluation was also done for the same network solutions but without the standby network. The result is given in the two tables below. With the parameters used we see that excluding standby protection is bad for all 8 network solutions. If, however, standby protection is not available, then multirouting should be used for almost all circuits.

<table>
<thead>
<tr>
<th>Network 1</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Routing penalty</td>
<td>0</td>
<td>25</td>
<td>50</td>
</tr>
<tr>
<td>NETWORK COST</td>
<td>1201</td>
<td>1247</td>
<td>1307</td>
</tr>
<tr>
<td>REVENUE LOSS</td>
<td>4780</td>
<td>2173</td>
<td>1028</td>
</tr>
<tr>
<td>TOTAL COST</td>
<td>5270</td>
<td>3420</td>
<td>2515</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Network 2</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Routing penalty</td>
<td>0</td>
<td>25</td>
<td>50</td>
</tr>
<tr>
<td>NETWORK COST</td>
<td>1253</td>
<td>1302</td>
<td>1362</td>
</tr>
<tr>
<td>REVENUE LOSS</td>
<td>4757</td>
<td>2017</td>
<td>1033</td>
</tr>
<tr>
<td>TOTAL COST</td>
<td>6010</td>
<td>3319</td>
<td>2395</td>
</tr>
</tbody>
</table>

The results are summarised in figure 5.

![Figure 5. Optimal diversity is about 65 %, which gives maximum profitability.](image)

3. CONCLUSIONS

The use of the analytical method for dependability planning has proved to be beneficial for several reasons.

It has made it possible to take account of dependability in network planning and optimisation in a simple and straightforward way. It is a very difficult problem, technically and practically, to attain objectives for dependability as constraints in network optimisation and planning, which is the aim of the traditional method.

Expressing dependability in terms of revenue has made it easier to discuss the need for actions to promote dependability, with the management and other parties concerned. Although parameter values are difficult to estimate, the method offers a consistent way of analytically analysing the economic implications of different network design strategies.

FOOTNOTES

1 The price is defined by $P = F + at$, where $F$ is the fixed charge for access to the service, $t$ is the traffic dependent charge and $a$ is the average carried traffic per customer. $a$ is dependent on the fraction of lost traffic due to faults, lack of capacity and customer related errors.

2 The price elasticity is defined by $e = \frac{\partial N/\partial P}{P/N}$, where the price is defined as in note (1). Thus, $e$ is a (weighted) average of the elasticity of demand regarding access charge and usage charge. $e$ is normally negative ($e < 0$).

3 In a Cournot equilibrium each operator is maximising its profits, given its beliefs about the other operators' behaviour, and, furthermore, those beliefs are confirmed in equilibrium. The price elasticity facing the operator ($e_r$) may then be written $e_r = e/s$, where $e$ is the price elasticity of the market and $s$ is the market share. The Cournot solution is only one possible. There are other, more sophisticated but more complex, models describing market competition.

4 The values are fictitious since the actual values are either unknown or considered to be confidential.

REFERENCES


