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SERIES E: OVERALL NETWORK OPERATION, TELEPHONE SERVICE, SERVICE OPERATION AND HUMAN FACTORS

Quality of services; concepts, models, objectives, dependability planning – Use of quality of service objectives for planning of telecommunication networks

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DEPENDABILITY PLANNING OF TELECOMMUNICATION NETWORKS

Reedition of CCITT Recommendation E.862 published in the Blue Book, Fascicle II.3 (1988)

NOTES

1 CCITT Recommendation E.862 was published in Fascicle II.3 of the *Blue Book*. This file is an extract from the *Blue Book.* While the presentation and layout of the text might be slightly different from the *Blue Book* version, the contents of the file are identical to the *Blue Book* version and copyright conditions remain unchanged (see below).

2 In this Recommendation, the expression "Administration" is used for conciseness to indicate both a telecommunication administration and a recognized operating agency.

Recommendation E.862

DEPENDABILITY PLANNING OF TELECOMMUNICATION NETWORKS

Introduction

This Recommendation is concerned with models and methods for dependability planning, operation and maintenance of telecommunication networks, and the application of these methods to the various services in the international network.

The CCITT,

considering

(a) that economy is often an important aspect of dependability planning;

(b) that the ability of achieving a certain level of dependability differs between network providers;

(c) that network providers often operate in a competitive environment;

(d) that Recommendations E.845, E.850 and E.855 establish objectives for serveability performance;

(e) that objectives for dependability performance are deducible from Recommendations Q.504, Q.514, and X.134 to X.140;

(f) that these objectives have been established in an intuitive manner rather than based on analysis of user needs;

(g) that there exists no unambiguous way of implementing these objectives in planning;

(h) that there is a need of establishing a method for dimensioning and allocating dependability in the telecommunication network;

(i) that terms and definitions relevant to concepts used for dependability may be found in Recommendation E.800,

recommends

that the procedures defined in this Recommendation shall be used by Administrations to plan, design, operate and maintain their networks.

1 General

Dependability planning may be accomplished by using essentially two different methods.

Intuitive method

The level of dependability is determined by making a synthesis of objectives and procedures presently used. It is a pragmatic method in absence of an analytical method or in the case when necessary data for a thorough analysis is not available.

This method reflects the present status, but is inconsistent in achieving what Administrations actually want to attain: the most economic level of dependability taking into account customer needs and inconvenience.

Analytical method

The analytical method is based on principles defining the object of dependability planning. The principles are realized through a quantitative model. The level of dependability is deduced by applying the model, taking into account all relevant factors in each planning case.

– Basic principle: The main object of dependability planning is to find a balance between the customers' needs for dependability and their demand for low costs.

– Model: Fault consequences are expressed in terms of money and are included as additional cost factors in planning and cost-optimization. The cost factor reflects the customers' experience of faults in the network, quantified in terms of money, as well as the Administration's costs for lost traffic revenue and corrective maintenance.

– Application: The Administration is provided with a method to integrate dependability as a natural part of planning, taking local information from the actual planning case into account. This method enables the preparation of simplified planning rules.

The application of the analytical method gives, economically, the best-balanced level of dependability, seen from the customer's point of view. This reduces the risk of customer complaints and loss of business to competitors as well as the risk of unnecessary investments. It is therefore considered to be the best general way of planning dependability for the Administration, as well as for the customers.

Recommendations for operational dependability objectives are needed in order to discover impairments and to check and compare dependability performance in the national and international network. Experience from the application of the analytical method may give reason to revise existing Recommendations.

2 Generic measures for dependability planning

The dependability is described by measures defining the availability performance, the reliability performance and the maintainability performance of the network and its constituent parts as well as the maintenance support performance (for the maintenance of the network). The recommended measures are:

Availability performance

Mean accumulated down time

Reliability performance

Mean failure intensity

Maintainability performance

Mean undetected fault time

Mean time to restoration

Mean active repair time

Maintenance support performance

Mean administrative delay

Mean logistic delay

Note – The definitions of these measures are given in Recommendation E.800 and Supplement No. 6.

3 Characteristics of network faults

The faults occurring in the telecommunication network are characterized mainly by their impact on the service provided by the network, i.e. by the traffic disturbance they cause. Important measures determining the traffic disturbance due to a fault are:

Duration of the fault (mean down time), T in hours (h)

Mean traffic intensity affected by the fault, A in Erlangs (E)

Mean probability of congestion during the fault, P

The seriousness of a fault also depends on how the customers experience the fault, and on the Administration's loss of revenue. In order to express this fact, the value of a unit of traffic volume (Eh) disturbed by the fault is quantified in economic terms.

Measure: the economic valuation of affected traffic volume is c (monetary units per Eh).

A number of factors may influence this variable such as:

– the category of customers and services affected,

– the degree of congestion or transmission disturbance during the fault,

– the duration of the fault,

– the accessibility to alternative communication means for the affected customers,

– time of day, week or year when the fault is in effect,

– how often faults have occurred in the past.

Additionally, the Administration's costs for corrective maintenance also contribute to the assessment of fault consequences.

Measure: the maintenance cost per fault is c_m (monetary units per fault).

4 Planning for economic optimum

4.1 *Economic dimensioning and allocation method*

Mathematically expressed, the main principle of dependability planning is to find actions that minimize the total cost of the network:

$$\min\{ C_I + C_m \cdot d + C_t \cdot d + \ldots\}$$

where

C_I is the investment costs to achieve a certain degree of dependability,

C_m is the expected annual costs for corrective maintenance,

C_t is the expected annual traffic disturbance costs,

d is the discount factor for calculating the present value of the annual cost over the lifetime of the investment.

C_t reflects the annoyance caused by faults and should be regarded as the basic service parameter which dimensions and allocates dependability in the network under given conditions.

An action is optimal if the following two conditions are met:

1) The benefit of the action (e.g. lower traffic disturbance cost) is larger than the cost, i.e. the action is profitable.

2) The action is the best in the sense that the ratio benefit/cost is maximal. There are no alternative actions that give a higher profit.

The method points out a profit seen from the customer's point of view, i.e. the actions are not necessarily profitable for the Administration in the short run. Rates and charges might therefore have to be increased to finance the actions. However, satisfying the customer's needs is recommended as the generally most profitable policy for the Administration in the long run.

This method is applicable for planning all parts of the national and international network and for dimensioning the dependability of network components and the level of the maintenance support. It may be used in short term planning as well as in long term optimization and strategic planning.

The method does not become out of date with technological advances, changes in cost structure etc. Dependability is converted to one clear-cut measure (money) which makes it easier to evaluate actions to promote dependability and to compare and choose between different alternatives.

4.2 *A model for traffic disturbance costs*

The annual traffic disturbance cost is obtained by multiplying the disturbed traffic volume (lost, delayed or affected by transmission impairments) by the monetary valuation of disturbed traffic volume c and the mean failure intensity z which gives:

$$C_t = PAzTc$$

where

T is the duration of the state of increased congestion or transmission disturbance due to the fault, mainly the down time. Congestion due to traffic overload after the fault has been repaired might however also have to be included.

A is the intensity of offered traffic.

P is the portion of the offered traffic volume over the time *T,* delayed or lost.

z is the mean failure intensity.

c is the monetary valuation of disturbed traffic volume. c may be dependent on any number of factors, *i.e. c = c(P, T, A, ..).*

Assuming traffic variations, $A(t)$, and consequently variations of congestion, $P[A(t)] = P(t)$, then A and P are calculated as follows:

$$P = \frac{\int_0^T A(t)\, P(t)\, dt}{\int_0^T A(t)\, dt} \qquad A = \frac{1}{T}\int_0^T A(t)\, dt$$

Normally it is not possible to predict the instant of time when a failure will occur. In this case *A* is a long time average incorporating yearly variations and long time trends. *P* is calculated by using an average traffic profile. Recommendations E.506, E.510 and E.520 to E.523 deal with methods for traffic calculations.

4.3 *Economic assessment of disturbed traffic volume, c*

The factor *c* reflects the level of ambition of an Administration or Operating Company in dependability planning. A high valuation of *c* will give a high level of dependability and vice versa. The values used by an Administration are related to the society's dependence on telecommunications which in turn might be dependent on standard of living, national economy, price level, etc. The establishment of c on the national level is therefore a national matter.

However, it is recommended that *c* should reflect the combined experience of the Administration and the customer, i.e. it should consist of:

1) the Administration's loss of revenue due to traffic not recurring after the fault,

2) an assessment of the average customer's economic loss due to a unit of traffic volume *(Eh)* being affected by a fault,

3) a symbolic price tag reflecting the annoyance experienced by the average customer.

The sum of 2) and 3) should reflect the price the average customer is willing to pay to avoid one Erlang-hour of offered traffic, delayed or lost due to a fault. The result will then be a level of dependability the customers are satisfied with and prepared to pay for.

Administrations are recommended to make their own investigations among their customers in order to determine the values to be used for planning. Annex B gives an example of such an investigation.

If this is not possible, rough estimates may be obtained from information about actions taken in the present network. The cost of an action is compared to the amount of traffic it saves. Actions that intuitively are regarded as reasonable give a lower limit of c, actions that obviously are unreasonable give an upper limit. The values derived this way are then used in optimization under the assumption that they are valid also for planning the future network.

If *c* is not possible to estimate at all, the method may still be used to find an optimum allocation of a given amount of resources. The level of dependability attained in this case does however not necessarily satisfy the customers.

4.4 *Planning procedure*

Traffic disturbance costs are included as additional cost-factors in economical calculations for planning, thus integrating dependability as a natural part of planning.

The procedure of dependability planning is performed in four steps:

Step 1: Plan a network attaining functional and capacity requirements.

The starting point is a network planned and dimensioned in order to comply with the functional and capacity requirements, but without special consideration of dependability (zero-alternative). The second step is to identify what changes may be necessary to promote dependability.

Step 2: Search for actions to promote dependability.

There is a need for actions to promote dependability if traffic disturbance costs are high or if the actions can be taken at a low cost. A non-exhaustive list from which actions could be identified is given below:

- Protection of equipment in order to prevent failures
- Choice of reliable and maintainable equipment
- Modernization and reinvestment of worn out equipment
- Redundancy
- Overdimensioning
- Increase in maintenance support
- Network management actions to reduce fault effects.

Step 3: Analyse the actions.

Express improvements in terms of changes in traffic disturbance and maintenance costs ($\Delta C_t + \Delta C_m$) for each action. It is only necessary to calculate costs that differ between the alternatives. Annex A gives examples of dependability models for network design, maintenance support planning and for determining requirements for network components.

Compare $\Delta C_t + \Delta C_m$ to the increased investment cost *(ΔC_I)* for each action, e.g. by the present value method.

Choose the best set of actions, i.e. which gives the lowest total cost.

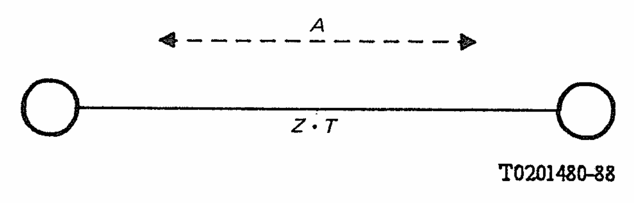
Step 4: Check that minimum requirements are complied with.

A minimum service level may be stipulated by governmental regulations, by CCITT Recommendations, for commercial or for other reasons. The establishment of any minimum requirements on the national level is a national matter. For planning of the international network the Administration is recommended to check if dependability objectives deducible from existing CCITT Recommendations are met. If not, the reasons for non-compliance should be examined more closely. If it is justified, the level of dependability should be adjusted.

4.4.1 *Numerical example based on the above*

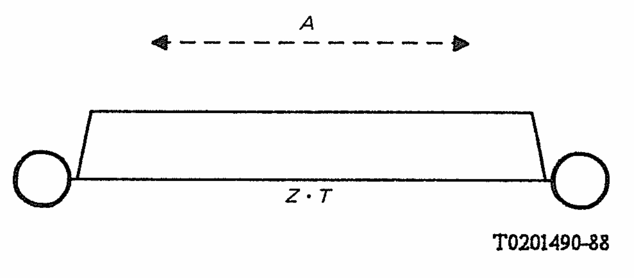
Step 1: Network planned without special consideration of dependability.

The network studied is the trunk between two exchanges.



Step 2: Search for actions to promote dependability.

The action considered is to introduce a physically redundant cable. It is assumed to be dimensioned to carry the whole traffic load, i.e. a single failure will not disturb the traffic.



Step 3: Analyse the action

Assumptions

Failure intensity	z	= 0.1 failures/year
Mean down time	T	= 24 h
Mean offered traffic	A	= 100 E
Congestion	P P	= 1 (without redundancy) = 0 (with redundancy)
Monetary valuation of disturbed traffic volume	c	= 400 monetary units/Eh
Discount factor (lifetime 25 years, interest 5% per year)	d	= 14
Maintenance cost per failure	c_m	= 1000 monetary units/failure
Cost of redundant cable	C_I	= 400 000 monetary units

Calculations

Traffic disturbance costs for network without redundancy:

$$C_I = P \cdot A \cdot z \cdot T \cdot c = (1)\,(100)\,(0.1)\,(24)\,(400) = 96\,000 \text{ per year}$$
$$\text{Present value } C_t\, d = (96\,000)(14) = 1\,344\,000$$

Traffic disturbance costs for network with redundancy (the possibility of simultaneous faults is negligible):

$$C_t = 0$$

Change in traffic disturbance costs:

$$\Delta C_t d = 0 - 1\,344\,000 = -1\,344\,000$$

Maintenance costs without redundancy:

$$C_m = zc_m = (0.1)(1000) = 100 \text{ per year}$$
$$\text{Present value } C_m d = (100)(14) = 1400$$

Maintenance costs with redundancy:

$$C_m = 2zc_m = (2)(0.1)(1000) = 200 \text{ per year}$$
$$\text{Present value } C_m d = (200)(14) = 2800$$

Change in maintenance costs:

$$\Delta C_m d = 2800 - 1400 = 1400$$

Cost reduction:

$$\Delta C_t d + \Delta C_m d = -1\,344\,000 + 1400 = -1\,342\,600$$

Change in total cost:

$$\Delta C_I + \Delta C_m d + \Delta C_t d = 400\,000 - 1\,342\,600 = -942\,600$$

Conclusion

Since $\Delta C_I + \Delta C_m d + \Delta C_t d < 0$, the action is profitable. Whether or not it is optimal depends on whether there are alternative actions that are more profitable.

Step 4: Check minimum requirements

Any additional actions to meet governmental requirements (for defence reasons, emergency, etc.) should be taken.

5 Applications to the international network

5.1 *Value of c for international traffic (for further study)*

In order to dimension and allocate dependability to different parts of the international network a uniform way of evaluating affected traffic should be established. It is recommended that the following values (c_i) be used as a guide in the planning of the international network

$$c_i = x_i \; SDR : s/Eh \qquad \text{(values to be determined)}$$

The values refer to a particular reference year. Price increase due to inflation, society's increasing dependence on telecommunication etc., should be taken into account.

5.2 *Planning recommendations (for further study)*

When values of c have been established, it is possible to make economic dependability analyses of the international network. These studies may be done in a similar manner and using partly the same data as for cost studies of charging and accounting.

The object of the studies is to arrive at planning recommendations, e.g. for the amount of redundancy, maintenance support, etc., in different parts of the international network.

5.3 *Operational objectives for dependability (for further study)*

The result of the economical dependability analysis of the international network is presented in terms of reliability, maintainability and maintenance support performances of different parts of the network. This will help Administrations monitoring and checking their networks to discover impairments, misplanning, etc.

ANNEX A

(to Recommendation E.862)

Simplified models for dependability planning

A.1 *General*

The object of this annex is to show simple examples of how different models of dependability may be used to calculate traffic disturbance costs and how the calculations can be used in planning. A list of actions is given in § 4.4. The applications may be divided into:

– Network planning (§§ A.2 and A.3)

– Dimensioning dependability of network components (§ A.4)

– Maintenance support planning (§ A.5).

A.2 *Example: Redundancy*

The traffic disturbance cost of a redundancy consisting of two independent items as shown in Figure A-1/E.862 is:

$$C_t = P_1 z_1 T_1 Ac(P_1) + P_2 z_2 T_2 Ac(P_2) + z_1 z_2 T_1 T_2 Ac(1)/8760$$

P_1 is the average congestion when item 1 is faulty,

P_2 is the average congestion when item 2 is faulty.

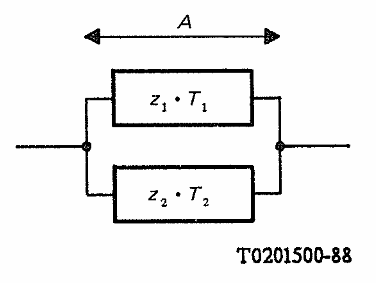


FIGURE A-1/E.862

A simple case is when the two items are identical and each can carry the whole traffic load (see Figure A-2/E.862), then:

$$C_t = z^2 T^2 A c(1)/8760.$$

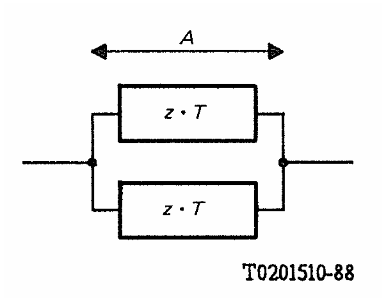


FIGURE A-2/E.862

By installing a redundant item, the traffic disturbance costs are reduced by

$$\Delta C_t = zTAc(1) - z^2 T^2 A c(1)/8760.$$

The second term is often negligible, thus AC, may be approximated by $\Delta C_t = zTAc(1)$.

A.3 *Example: Optimal dimensioning for diversified routes*

The problem is to determine the optimal number of channels, N_1 and N_2 respectively, for which the two redundant routes should be dimensioned, see Figure A-3/E.862.

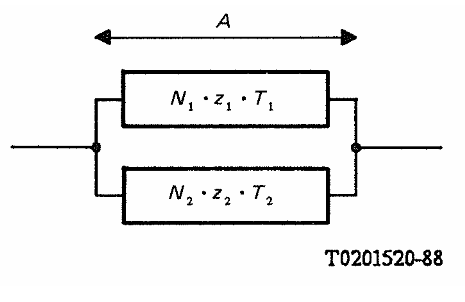


FIGURE A-3/E.862

Denote C_N to be the cost per channel. The optimal allocation of channels each way is found by solving

$$\min_{N_1, N_2} \left\{ (N_1 \cdot C_{N1} + N_2 \cdot C_{N2}) + (P_1 \cdot A \cdot z_1 \cdot T_1 \cdot C(P_1) + P_2 \cdot A \cdot z_2 \cdot T_2 \cdot C(P_2)) \cdot d \right\}$$

This implies an overdimensioning in the fault free condition. The benefit of this is not included in this formula. The effect of simultaneous faults does not influence the optimization.

A.4 *Example: Optimal testing time*

Assume that the failure intensity $z(t)$ after a certain operation time (t) *is* given by

$$z(t) = z_0 + z e^{-bt}$$

where

$z_0 + z$ is the failure intensity at $t = 0$,

z_0 is the constant failure intensity after the early failure period,

b is the factor determining the decrease in failure intensity during the early failure period.

By testing, faults may be corrected before causing traffic disturbance and maintenance costs. Assume that:

$c_m + ATc$ are the maintenance and traffic disturbance costs per fault,

C is the cost per year of testing.

The optimal testing time (t') *is* found by solving

$$\min_t \left\{ tC + \frac{z}{b} e^{-bt} (c_m + ATc) \right\}$$

where

$\frac{z}{b} e^{-bt}$ is the additional number of faults occurring in operation as a function of the testing time.

Optimal test time: $t' = \frac{1}{b} \ln \frac{z(c_m + ATc)}{C}$.

A.5 *Example: Optimal number of maintenance units*

Mean delay $w(N)$ as a function of the number of maintenance men (N) may in some cases be mathematically expressed by using queuing theory. The simplest case is if the times between failures and repair times are exponentially distributed (an *M/M/N* queue model). $w(N)$ is obtained by calculating:

$$w(N) = \left[\frac{(z/\mu)^N \cdot \mu}{(N-1)!\,(N\mu - z)^2} \right] \Big/ \left[\sum_{k=0}^{N-1} \frac{1}{k!} \left(\frac{z}{\mu}\right)^k + \frac{1}{N!} \left(\frac{z}{\mu}\right)^N \left(\frac{N}{N\mu - z}\right) \right]$$

where

N *is* the number of maintenance units,

z is the intensity of failures,

$w(N)$ *is* the mean delay as a function of N,

A *is* the affected traffic intensity,

c is the valuation of affected traffic volume,

μ is the repair rate.

The model may be refined by taking into account classes of priority. It is also possible to let faults of a higher priority interrupt assignments with a lower priority.

If C_N is the annual cost per maintenance unit, the optimal number of maintenance units is obtained by solving:

$$\min_N \{ NC_N + zw(N)Ac \}$$

ANNEX B

(to Recommendation E.862)

Example of an investigation to assess the monetary valuation of disturbed traffic volume, *c*

B.1 The aim is to arrive at cost data to assess c. Different customer groups and their monetary valuation of total and partial failures with respect to typical traffic relations and different services is studied. Investigations are carried out among residential and business customers based on the following assumptions:

a) The customers are affected by telecommunication interruptions in mainly two ways: in terms of annoyance and in terms of direct costs.

b) For residential customers, annoyance is likely to predominate. For business customers, the direct cost may be important.

c) Both costs and annoyance increase by the duration of the interruptions and the amount of traffic disturbed.

d) As a natural consequence of the great variations in dependence on telecommunications there is a great variation of costs and annoyance.

e) Residential customers are not able to quantify their annoyance in monetary terms. Faults on the home telephone mostly result in irritation, and not in direct costs (except in the case of long-time faults).

B.2 *Complete faults*

B.2.1 *Business traffic*

Companies chosen at random are asked to answer the following question: "What is the estimated approximative cost of a total interruption of the telephone or data service in connection with down times of 5 minutes, 1 hour, 4 hours, 8 hours, 24 hours and 3 days?"

Companies with experience of a specific fault are asked the question: "What was the estimated cost of the fault just experienced?"

An estimate of the affected traffic intensity in connection with total interruptions can be made on the basis of the number of exchange lines and the number of data terminals for communication of each company, together with information on how trunks are dimensioned and measurements on the calling intensity of various customer classes.

On the basis of a stated cost, *c* is estimated according to the formula:

$$c = \frac{\text{(cost stated by the customer)}}{\text{(mean traffic intensity) (down time)}}$$

Average values of c for telephony and data traffic are calculated for different trades by means of a market profile (distribution of workplaces by trade).

B.2.2 *Residential customers*

Group discussions on interruptions can be held in order to arrive at a reasonable valuation. If there is little willingness to pay for increased dependability a relatively low value of c is assigned.

B.3 *Partial faults*

A partial interruption of a traffic relation results in costs for the customer mainly in the form of delays to commerce. By using a calculated hourly salary this cost is estimated for business customers. On the basis of information about the amount of business and household traffic, an average value of c for traffic disturbed by partial faults is obtained.

B.4 *Results*

Table B-1/E.862 gives a few examples of figures derived by the Swedish Administration. The figures have been used in various planning cases. The Administration's loss of revenue is included in these figures. The cost figures and exchange rate relate to 1986-01-01 [1 SEK (Swedish Krona) P ≈ 0.1 USD (US Dollar)].

TABLE B-1/E.862

Economic assessment of prevented communication (c)		
Field of application	Class of failure	
	Complete fault ($P = 1$)	Partial fault ($P < 0,5$)
Business customers with a large portion of data traffic	1000 SEK/Eh	250 SEK/Eh
Used in the long distance network	400 SEK/Eh	100 SEK/Eh
Customers in a sparsely populated area. High cost for alternative communication	200 SEK/Eh	50 SEK/Eh
An average value for areas with mostly residential customers	100 SEK/Eh	25 SEK/Eh
Residential area where it is easy to reach essential services. Low costs for alternative communication	30 SEK/Eh	10 SEK/Eh

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