MEASURES OF EFFECTIVENESS PERFORMANCE
APPLIED TO TELECOMMUNICATION

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ABSTRACT
Various measures combining the aspects of the reliability, maintainability and maintenance support performances with the traffiability and operability performances have been proposed and applied during the years.

It is shown that the measures of these combined aspects are suitably arranged under one performance concept, effectiveness performance, defined as

the ability of an item - under the combined aspects of its availability performance and traffiability performance and of the operability performance - to fulfill user service demands under stated use conditions

where use conditions refer to conditions of traffic as well as maintenance, environment and other conditions.

This definition is considered generally applicable to telecommunication items and gives with a proper arrangement of measures an efficient linking to the quality of service concept.

INTRODUCTION
The various properties of a telecommunication function (service) from the user point of view have been described (measured) in terms of grade of service, quality of service, call loss etc. These properties depend on a number of subproperties.

The subproperties included in a study differs from study to study - sometimes without a clear indication to which are included and which are not. There may be several reasons for this negligence, one is that there have been only few attempts made to develop and standardize a suitable terminology.

The existing literature on the dimensioning of telecommunications systems is mainly devoted to the description of systems consisting of devices in a fully functioning state, i.e. the effects of failures are not treated more than indirectly.

The applications of traffic modelling have not - until recently - been directed towards systems with failed equipment. The seventies have, however, seen some attempts.

Approaches to the dimensioning taking into account also reliability performance aspects have been published, see e.g. (11) and (15), references in (8) and (15).

Within IEC, the International Electrotechnical Commission, work has been going on since the mid-sixties on the standardization of terms relating to reliability and maintainability performances. In recent years the scope has been somewhat broadened - essentially with a limited aim to put the reliability and maintainability performances in their proper perspective.

Since 1968 the CCITT/CCIR Joint Study Group CMDB (earlier Special C) has had on its work-programme the task to prepare suitable terms and definitions for reliability and maintainability performances. Almost from the start of its study of this question CMDB (Special C) chose to include concepts which also cover properties dependent on the traffic dimensioning, the traffic envirnoment and the subscriber behaviour. The concepts have not been arranged giving a satisfactory distinction, nor have the terms been unambiguously applied. E.g. the word availability has been used in four different terms with quite different meaning.

The simultaneous treatment of technical performance aspects and reliability and maintainability performances is in no respect new. It has been practiced in many areas for a long time - especially by the military people - under the name (system) effectiveness. The term effectiveness, in turn, has had a much broader application. It was maybe first used quantitatively in so-called cost-effectiveness evaluations.

In its more restrictive meaning effectiveness is perhaps known as the measure adopted in the WSEIAC report (16).

The effectiveness concept has also been introduced to the recent discussions of IEC (with the aim to put the reliability and maintainability performances into perspective) and in CCITT (6). It has earlier been proposed for use in the evaluation of telecommunication equipment, see e.g. (1), (8), (15).

Further, several articles have dealt with the quantification of measures of effectiveness of telecommunication equipment without explicitly identifying them as measures of effectiveness performance as such.

A few of the approaches published seem to be of interest for the development of a suitable concept set. Two of them, the WSEIAC approach and the Ebenfelt approach, are reviewed here.

THE WSEIAC APPROACH

The WSEIAC model, (16), is based on a mission oriented system usage approach.

At the start of the mission the system is in one of the possible states in a discrete state space. The probability of the system being in state i is \( a_i \) and the vector

\[
A = (a_i)_{i=1}^n
\]

is called the availability.

During the mission transitions between (at least some of) the states are possible (i.e. failures, and possibly repairs, may occur).

The probability of a transition from state i to state j during the mission is \( d_{ij} \) and the matrix

\[
D = (d_{ij})_{i,j=1}^n
\]
is called the dependability.

The ability of the system to achieve the mission objective, given the system condition during (at the end of) the mission is \( C_j \) and the vector
\[
C = [c_j] \quad j=1,...,n
\]
is called the capability.

The system effectiveness is then defined as
\[
E = A*D*C^T
\]
where * denotes the transpose of C.

For multi-function systems the overall system effectiveness is obtained e.g. by weighting each function's effectiveness by its relative use.

THE EBENFELT APPROACH

In (10) the following model, applied to an anti aircraft fire control system, is used.

The states of the system span a discrete state space. The probability that the system is in state \( i \) at time \( t \) is denoted \( p_i(t) \). If the number of states is \( m \) we thus get
\[
p(t) = [p_i(t)]_m^1
\]
called the system dynamics vector.

The benefit of the system is considered to be dependent on the tactical environment, assumed to be possible to describe by a discrete environment state space, containing \( n \) elements. The probability of state \( j \) at time \( t \) is \( r_j(t) \) and thus get
\[
r(t) = [r_j(t)]_n^1
\]
is the environment dynamics vector.

For each pair of system state and environment state the system has a value or benefit, called capability. If the capability in system state \( i \) and environment state \( j \) is denoted \( c_{ij} \), we thus get a capability matrix
\[
C = [c_{ij}] \quad i=1,...,m \quad j=1,...,n
\]
The (instantaneous) system effectiveness is then defined as
\[
E(t) = p(t)*C*r^T(t)
\]
It is said that in most cases an asymptotic value of \( E(t) \) may be used.

MEASURE OF THE BASIC PERFORMANCES

Before we start to discuss measure concepts for the effectiveness performance we review the principles for measuring the basic performances i.e. the reliability, maintainability and maintenance support performances. These are the performances usually considered to be the determining factors of availability performance.

All these performances are generally dependent, mutually and on external factors (such as the environment).

RELIABILITY PERFORMANCE

The reliability performance is the ability of an item to perform a required function under stated conditions for a stated period of time, (6).

The fundamental measure of reliability performance of non-repaired and repaired items is the instantaneous failure rate defined as
\[
\lambda(t) = \lim_{\Delta t \to 0} \frac{P_R(t+ \Delta t)}{\Delta t}
\]
From this all the other measures of interest for an item may be deduced. One of them is the mean failure rate in a given time interval
\[
\lambda(t) = \lim_{\Delta t \to 0} \frac{P_R(t+ \Delta t)-P_R(t)}{\Delta t}
\]
and accordingly
\[
\lambda(t) = \int_{t_1}^{t_2} \lambda(t)dt
\]
Another measure for repaired items is the event density of the point process formed by successive failures, here called the instantaneous failure intensity.

\[
(E(t)) = \lim_{\Delta t \to 0} \frac{N(t+ \Delta t)}{\Delta t}
\]
and accordingly
\[
(E(t)) = \int_{t_1}^{t_2} E(t)dt
\]
is the mean failure intensity.

The fact that for a homogeneous Poisson process
\[
\lambda(t) = \lambda
\]
has been a permanent source of misunderstanding and misinterpretation of these basic concepts.

MAINTAINABILITY PERFORMANCE

The maintainability performance of an item is its ability to be retained in or restored to a state in which it can perform a required function under stated conditions, (6). It is related to the item's ability to detect internal failures and the ease in which it is maintained (preventively and correctively).

The measures of maintainability performance are given under stated conditions regarding the maintenance organization. They are usually in terms of the time components of down time of an item. As such they are described by probability density functions, distribution functions etc in the usual way.

Also in this case a rate function
\[
\mu(t) = \lim_{\Delta t \to 0} \frac{P_F(t+ \Delta t)-P_F(t)}{\Delta t}
\]
is useful. Depending on what the stochastic variable \( T \) represents, it is called (instantaneous) repair rate, maintenance rate etc.
MAINTENANCE SUPPORT PERFORMANCE

This is the ability of the maintenance organization to provide upon demand the resources required to maintain an item, (6). The ability is measured in terms of the delays caused by non-ideal properties of it (delays awaiting personnel, spares, tools etc and as well as probability of not having a resource immediately available etc).

AVAILABILITY PERFORMANCE

When the aspects of an item's reliability and maintainability performances and of the maintenance support performance are combined we get the availability performance. It is related to either an instant of time or to an interval of time (6).

The instantaneous availability is the probability that the item is in an up state at time \( t \), usually denoted \( A(t) \).

The mean availability is defined as:

\[
\bar{A}(t_1,t_2) = \frac{1}{t_2-t_1} \int_{t_1}^{t_2} A(t)\,dt
\]

In addition, when it exists,

\[
A(\infty) = \lim_{t \to \infty} A(t)
\]

is called the asymptotic availability.

Further, the asymptotic mean availability is

\[
\bar{A}(0,\infty) = \lim_{t \to \infty} \bar{A}(0,t)
\]

Predictions and other analyses are often made under assumptions, see e.g. (3), such that

\[
\bar{A}(0,\infty) = A(\infty)
\]

Another set of measures with practical applications are those in terms of accumulated times e.g. the mean accumulated down time in a given time interval.

THE TRAFFICABILITY PERFORMANCE

"Grade of service" criteria have been successively extended to cover not only the nominal (busy hour) traffic conditions but also high load conditions. For some purposes also certain failure states (e.g. single-failure states of common equipment) are taken into account at dimensioning. The measures used are either related to delays or loss probabilities.

An exchange or a network dimensioned according to these criteria will have a certain behaviour under the various conditions of traffic and of failures occurring.

This behaviour may be measured - in addition to the measures used for dimensioning - by convential measures from the traffic theory.

It seems practical to restrict the grade of service concept to the normal network and equipment reactions to traffic in the ideal situation with no failures in equipment or transmission media. When other states are also covered we use the concept trafficibility performance, cf. (6), (15). It is then understood that these measures are only quantified for each given state.

It is obviously so, that the measures of trafficibility performance exist in an instantaneous and a mean version, possibly also in asymptotic and asymptotic mean versions.

FURTHER ELEMENTS OF EFFECTIVENESS PERFORMANCE

The success of a call attempt (or a similar service request) is dependent not only on the availability performance and the trafficiblity performance of the equipment but also on equipment-user interaction.

We call these latter aspects the operator adaption performance (the equipment part) and the operator performance (the user part), (6). They may then be combined into one concept, operability performance, (7).

THE OPERATOR ADAPTION PERFORMANCE

The operator of a system is the person using the system for some purpose, the user. The user or a telecommunication system is essentially the subscriber although some functions have other users e.g. operations personnel. In either case there exists a man-machine relationship between the telecommunication system and the user. E.g. the telephone subscriber is met by the system in different ways, tone messages, time outs etc. The design of the telephone instrument, including the dial or pushbuttons etc. All these factors influence the possibility to be successful in making calls and thus contribute to the effectiveness performance.

THE OPERATOR PERFORMANCE

Being designed in a given way the system shows a certain operator adaption performance. Still, the successful outcome is dependent on how the operator (user) acts, i.e. if he dials the correct number, obeys the handling rules (e.g. to wait for second dial tone) etc.

The operator performance may be measured by different kinds of measures, expressed as human error probabilities or related to time (delays).

OPERABILITY PERFORMANCE

The combined aspects of the item's operator adaption performance and of the operator performance is the operability performance.

GENERAL MEASURES OF EFFECTIVENESS PERFORMANCE

Before we discuss explicit measures of effectiveness performance we establish, in analogy with the definitions of availability, the following definitions.

Instantaneous effectiveness is denoted \( E(t) \).

The mean effectiveness in an interval of time \([t_1,t_2]\) is

\[
\bar{E}(t_1,t_2) = \frac{1}{t_2-t_1} \int_{t_1}^{t_2} E(t)\,dt
\]

and, when it exists, the asymptotic effectiveness

\[
E(\infty) = \lim_{t \to \infty} E(t)
\]

The asymptotic mean effectiveness is then

\[
\bar{E}(0,\infty) = \lim_{t \to \infty} \bar{E}(0,t)
\]

It seems useful not to restrict the application of the effectiveness performance concept to success or failure related events (usually calls), but also permit measures based on the other measures used for the description of trafficibility performance.
It is thus to be observed that the value of a trafficability performance measure is dependent on whether it is time related (e.g. mean waiting time) or is a probability. This means that a measure of effectiveness performance has the same range as that of the trafficability performance measure used.

MODELLING EFFECTIVENESS PERFORMANCE

For the modelling of the effectiveness performance of telecommunications systems we could e.g. apply an adjusted version of Ebenfelt's approach.

Let the state of the system at time \( t \) be \( S(t) \).

The analogy to the system's "tactical environment" is the traffic process, e.g. described by the traffic offered at time \( t \).

The "capability" of the system is described by a trafficability performance measure, e.g. the call congestion.

The measure of the instantaneous effectiveness a time \( t \) is

\[
E(t) = G(S(t), B(t))
\]

where \( G(S(t), B(t)) \) is the value of the trafficability measure of the system in state \( S(t) \) and the traffic offered \( B(t) \).

The asymptotic value of the effectiveness measure does generally not exist in practical cases but under some restrictions the asymptotic mean effectiveness might exist.

\[
Q = \sum_{h(s)} \int_{G(S,A)} f(A) dA
\]

where \( h(s) \) is the density function of the system states \( f(A) \) is the density function of the offered traffic.

A further extension of the effectiveness model is the inclusion of the operability performances.

It is beyond the scope of this paper to extensively discuss modelling techniques.

RELATION TO QUALITY OF SERVICE

In figure 1 is shown the main connections and relationships between the performance concepts previously discussed. The dashed blocks and lines indicate the extension to quality of service, as defined to combine, besides effectiveness performance, the aspects of transmission performance (noise, distortion, interruptions etc, within the acceptable limits), service support performance (the rapidity of commissioning the service etc) and others.

CLASSIFICATION OF MEASURES OF EFFECTIVENESS PERFORMANCE

The measures of effectiveness performance may be grouped dependent on whether they are single-valued or vector-valued, weighted or non-weighted, delay or call oriented etc.

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**Figure 1** Relationship between the performance concepts

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NON-WEIGHTED SINGLE-VALUED MEASURES

Most of the measures presented belong to this category. They may be further grouped dependent on which kind of trafficability performance measure is applied i.e., related to call success, congestion state, delays or traffic.

Call related measures are given for the different call phases, i.e.,

- call establishment
- Probability of successful establishment of a switched connection (6)
- Availability of switched connection (5)
- Call treatment effectiveness (8)
- call retention
- Probability of successful service retention (6)
- Reliability of an established connection (5)
- call release
- Call release efficiency rate (8)

The call related measures are often divided into calls of different categories (local calls, transit calls etc., and different traffic directions).

They may also be combined into

- establishment and retention
- Probability of successful service retention (6)
- retention and release
- Established call effectiveness (8)

State related measures are

- Unserviceable probability (14)
- Figure-of-merit (18)
- Unavailability (8)

Delay related measures are e.g.,

- Dial tone delay (8)
- Signal reception delay (8)

A traffic related measure is

- Service degradation (17)

It may be observed that in the names of the measures presented above the words availability, unavailability and reliability appear. This is a most unlucky condition, since it tends to make the differences between the performance concepts more unclear. The measures should instead be given distinctly different names or, in their absence and where appropriate, be called Probability of (event).

VECTored VA LUEd APPROAcHES

As earlier said, it is usually not sufficient to state a requirement or describe the characteristics by a single effectiveness measure, especially if several services or functions are treated. We thus often need to then state more than one measure, one for each service or function. We could thus say that we have a vector-valued statement.

CONCLUSIONS

Various measures of performance combining the aspects of the reliability, maintainability and maintenance support performances with the trafficability and operability performances have been proposed and applied during the years. They have usually not been properly interrelated and connected in an arrangement scheme so that it may be clearly indicated which properties are actually combined.

It has been shown that the measures of these combined aspects are suitably arranged under one performance concept, effectiveness performance, defined as

the ability of an item - under the combined aspects of its availability performance and trafficability performance and of the operability performance - to fulfill user service demands under stated use conditions.

The use conditions refer to conditions of traffic as well as maintenance, environment and other conditions.

This definition is considered quite general for telecommunication items, applicable to a device group as well as to a whole network.

Since the measures of effectiveness performance combine quite diverse aspects they should be applied with some care. When requirements are written or when telecommunication items are analyzed one should simultaneously also use measures of the subperformances.

The aim of the paper has been to show arrangements of concepts and not to give mathematical models. It is a hope, however, that the document will stimulate work to develop the modelling techniques.

REFERENCES


IEC TC 56 (Secretariat) 106: Overall Ability Concept. September 1977.


