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AVAILABILITY, RELIABILITY AND CONTINUITY IN NAVIGATION AND HYDROGRAPHY– TERMINOLOGY DISCUSSION

ABSTRACT The problem of positioning for maritime navigation and hydrography purposes, seen only from the categories of the position error point of view, seems to have been solved on a global scale. In such a situation characteristics of radio-navigation systems such as: availability, reliability, continuity, integrity and ambiguity of position, which are equally important but often neglected, turn out to be essential. One may risk a claim that integrity and characteristics of reliability theorem origin: availability, reliability, continuity, treated on various levels of structures of radionavigation systems, now seem to be one of the main areas of research.
This article presents an analysis of meanings like: availability, reliability and continuity based on navigation literature in the last twenty years. Its changeable nature and ambiguous definition of continuity have been discussed here.

THE COMPARABLE CRITERIA OF NAVIGATION SYSTEMS

The parametric assessment of navigation systems during the last decade has been the most common way of their classification according to their quality. Within the scope of this evaluation critical space is given. This space is very closely related to the navigation requirements faced by its various forms. The comparable criteria of navigation systems are often presented in world literature [ERP, 1996] [FRP, 1999] as well as in polish works [Kopacz, 1996]. These criteria have been overestimated as a result of technological development and the needs of navigation process, but are accompanied by the change of the rank of each of them. This overestimation reflects the technical development by choosing the appropriate way and increasing number of research held by various research institutions that based their work on diverse aspects leading to underling the given exploitation features.

The analysis of the criteria allows to distinguish three main groups, which are identical with particular phases of positioning systems development over the years and they are as follows:

- Positioning criteria - characteristics for the system in quality of position fixing. They have in their scope 3 types of accuracy (predictable, repeatable, relative) as well as fix rate, ambiguity and position dimension.
- Reliability criteria – they form a separate group of indicators with reference to characteristics of exploitation systems. Reliability, availability and continuity are among them.
- The safety of exploitation criteria – their task is to give the user current information about the quality (state) of operating system allowing for the proper level of their utility. So far integrity, the only criterion belonging to this group, has been characterised by a wide range of variables such as: time to alarm, the probability of false alarm etc. [RTCM, 1993].

By observing the changeable nature of the comparison criteria, it is difficult not to notice their direct relationship with each of the phases of the evolution of satellite positioning systems (GPS, Glonass), which have been dominating in the contemporary navigation and hydrography. The first of these groups –positioning criteria – were the main exploitation characteristics till the 1990s. [IALA, 1990].

The previous systems were usually of poor precision as well as fix rate (Omega, Loran,Decca, Transit) and they lacked the full ambiguity of measurement (Loran, Decca).Consequently these positional measurements were the main, if not the only, characteristics of such systems. When, in the mid-1990s, the GPS system became the fully operating system fulfilling almost all navigation requirements of the users looking for precision of positioning, then the research connected with positioning criteria was combined into the group of criteria of reliability theorem origin.

The availability and reliability [IALA, 1989] and then continuity [FRP, 1999] described with reference to various systems of structures of functional systems, allowed to evaluate the capacity of the systems to non-failure working. By doing so, they also made its characteristics able to be compared with efficiency and economic factors.

The third group to do with safe of exploitation seen as a very quickly developing part of research of the beginning of the 21st century in the navigation and hydrography. No doubt can the integrity be compared with current functional diagnosis which seems to be synonymous with modernity in all of the contemporary branches of technology.

RELIABILITY AND AVAILABILITY

The analysis of the terms: reliability and availability in navigation literature shows that there are two periods with distinctive limits:

LITERATURE TILL THE YEAR 1990

The term reliability till the end of the 1980s was present in the navigation usually as the indicator of the evaluation of the operating condition of appliances both in Eastern (Zarudny, 1973) as well as in Western literature. In the most extensive elaboration [IALA, 1989] being in force also in all country and concerning reliability and availability of the system of aids, the following information can be read:

Reliability [IALA, 1989] – is the ability of an aid, or system of aids, to perform a required function under stated conditions for a stated period of time. A wide range of other standard documents also used the recommendation given here. The technical approach to the reliability criterion made the MTBF (Mean Time Between Failure) the unique parameter used hereafter to characterise the reliability which is also the parameter used in data collecting by most Lighthouse Authorities (page 1-2-1). The suggested reliability calculating method was based on a range of examples of evaluating MTBF of navigation appliances combined in series and parallel structures, for which the reliability indicators of combined structure MTBFS were respectively [IALA, 1989]:

In the case of connection in series of structure system:

$$\frac{1}{MTBFS} = \frac{1}{MTBF_1} + \frac{1}{MTBF_2} + \ldots \frac{1}{MTBF_i} \tag{1}$$

where:

MTBF - Mean Time Between Failure,
MTBFS - Mean Time Between Failure of the System.

as well as for two-element system of parallel structure without – restoration:

$$MTBFS = MTBF_1 + MTBF_2 \tag{2}$$

It should be noted that, despite limiting the term reliability to single indicator – MTBFS, in this document there are also formulas towards reliability function and the failure rate indicator (page A3 –3) for n- block connection in series structure:

$$R(t) = e^{-\sum_{i=1}^{n} \lambda_i t} \tag{3}$$

$$\lambda_s = \sum_{i=1}^{n} \lambda_i \tag{4}$$

where:

$R(t)$ - reliability function,
λ_s - failure rate of the system,
λ_i - failure rate of the element.

In the case of parallel structure - the doubled (two-element) system, reliability function was analysed

$$R(t) = 2e^{-\lambda t} - e^{-2\lambda t} \tag{5}$$

The whole document refers to appliances of optical aids to navigation, including technical elements of known characteristics (MTBF or λ).

The second of the terms discussed here –availability [IALA, 1989] is seen as the probability that an aid or system of aids performs the required functions in the stated conditions at a specified time. It is shown by the following formula:

$$A = \frac{MTBF}{MTBF + MTTR} \tag{6}$$

where:

$MTTR$ - Mean Time To Repair,
A - system availability.

In the authors' of this recommendation opinion, the availability is the system evaluation criterion, allowing for stating how well its functions are performed. Thanks to such an understanding of definition system categories, from the availability point of view, were established. Their evaluation is carried out by taking into account the formula (6) based on numerous enough measurement test. The method of determining this indicator is obvious as far as single technical appliances or groups of such appliances are concerned. But with reference to navigation systems, which are strongly influenced by the environment factors (propagation circumstances, weather impact etc), this methodology can not be accepted.

LITERATURE AFTER THE YEAR 1990

The beginning of the nineties in maritime navigation and hydrography is the time of the satellite navigation systems domination in positioning. Together with their implementation many documents describing their exploitation appeared. Such a demand was because of the necessity of providing the users of the systems with precise information about the properties of the systems. The comparison criterions suggested in [IALA, 1990] including both positional characteristics (accuracy, fix rate, ambiguity, fix dimension) as well as exploitation ones (coverage, reliability, availability and integrity) became an introduction for multi-criteria assessment of the radionavigation systems.

Taking into account the analysis carried out, the document called 'Global Positioning System (GPS) Standard Positioning System, Signal Specification' [SPS, 1993] seems to be the most interesting comparable material. This document presents the exploitation characteristics of GPS system made accessible for civilian users. It was modernised over the years to appear in 2001 in its final form [SPS, 2001] with selective availability excluded. When comparing the definitions of reliability and availability of GPS service taken from the two references mentioned above, one can read that:

- Service availability [SPS, 1993] – the percentage of time over a specified time interval that a sufficient number of satellites are transmitting a usable ranging signal within view of any point on or near the Earth.
- Service availability [SPS, 2001] – defined to be the percentage of time over any 24 hours interval that the predicted 95 % positioning error is less than its threshold for any point within the service volume.
- Service reliability [SPS, 1993] given coverage and service availability, the percentage of time over a specified time interval that the instantaneous predictable horizontal error is maintained within a specified reliability threshold at any point on or near the Earth.
- Service reliability [SPS, 2001] – the percentage of time over a specified time interval during which a healthy GPS satellite's ranging signal exceeds the Not – to – Exceed (NTE) SPS SIS URE tolerance

From such a comparison of definitions, the conclusion may be drawn that during almost seven years the definitions have been significantly changed. In the case of reliability the lack of system usability was at first described as positioning error [SPS, 1993] being geometrical (DOP's) and precision of the pseudorange accuracy measurement function, but later it became the term referring only to one of its two components - pseudorange measurement error. Consequently, this new definition is not influenced by satellite configuration represented by DOP factors. The term: availability was also affected by similar change. In the definition of 1993, availability is only related to utility of radio signals reaching the user. Whereas the new meaning of this term refers to position solution.

Trying to establish the cause of such a change of the meaning of these two terms, it should be noted that essence of both definitions – the probability or the ratio of functional times to total time being in fact the measurement of probability, have not been changed. But the definition of the conditions which are taken as fulfilled to name the system a correctly functioning one, has been changed considerably. Similar conclusions can be drawn by analysing many standard documents referring to satellite navigation where different forms of availability and reliability are defined. These forms include: reliability and availability of: transmission broadcast, reference station,signal and the user [USCG, 1993] and as for availability we can name: PDOP factor, horizontal and vertical service availability [SPS, 2001].

CONTINUITY

At the end of the 90s a new criterion appeared - namely the service continuity, which is connected directly the navigation task carried out and the system used to support it. Continuity is the probability that the specified system performance will be maintained for the duration of a phase of operation, presuming that the system was available at the beginning of that phase of operation [FRP, 1999]. Seeing it as a navigation task, it seems to be a very essential criterion because the scope of its usage refers to specified period when a navigation object is to use the navigation structure (system) to perform a set task provided that at the beginning of it (t - time) the system was available. It should be noted that as it happens in the navigation (maritime or air navigation), the task starts when the system is available.

Taking the practice into account, the navigator or hydrographer starts the process (of survey, landing, docking etc.) when the appropriate navigation structure (navigation system) is available after a short operating interval. The definition presented here might seem non-ambiguous as far as its meaning is concerned,but it can be found in European literature as 'continuity is the ability of a system to function within specified performance limits without interruption during a specified period (normally short term).There is no need to include the availability at the beginning of the time period of the operation because if there is no service then the operation will be not commence.' [IALA 2001].

Consequently:

$$C = e^{\frac{CTI}{MTBF}} \tag{7}$$

If $MTBF >> CTI$ then

$$C = 1 - \frac{CTI}{MTBF} \tag{8}$$

where:

C - service continuity,
CTI - Continuity Time Interval. For maritime applications CTI- 3 hours [IALA, 2001].

The definitions presented here are definitely diverse. The main difference is connected with determining the operating condition (availability or lack of it) at the beginning. It is hard not to criticize the view presented in [IALA, 2001] - as it states that reliability and continuity are equal. The criticism is because the low failure rate present in contemporary navigation systems cause that reliability function very quickly reaches '1' and as a result of this the differences in the numerical value of both of these probabilities may be very hard to notice.

CONCLUSIONS

The synthesis of the meaning of notions discussed in this article: reliability, availability and continuity was carried out by taking into account the most extensive and formal (standards and recommendations) pieces of navigation literature. The following conclusions are the result of the procedure:

(literature till the year 1990)

- the reliability term was discussed only in their technical aspects of the appliances with the result being the acceptance of the numerical value of MTBF and MTBFS as reliability factors,
- the reliability function and the failure rate are determined by including identical technical elements,
- the literature lacks analysis of other reliability factors,
- the analysis was carried out with the appliances of zero time of restoration,
- the usage of simplified models of operating systems (exponential distributions of lifetimes and times of failures),
- the suggested calculating methodology lacks modification into more complex processes (e.g. alternative with restoration).

(literature after the year 1990)

- reliability and availability refers to different functional structures,
- the definition of continuity is ambiguous,
- the lack of mathematical connection between availability, reliability and continuity,
- vague procedures and methods of determining each of the criteria,
- the measurement of the criteria is based on statistic analysis of empirical measurement data.

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