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Information Capabilities of Integrated Bridge Systems

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Clod Shannon's fundamental works in the field of Theory of Information are well known and used in many different fields of science and practice. The Theory provides good criteria to evaluate equipment, systems, different effects and situations from the point of view of the necessary information. This article uses the Theory to attempt to create an information model for a "Ship-Danger to Navigation" system, which can evaluate an Integrated Bridge System in critical situations.

KEY WORDS

1. Theory of Information. 2. Integrated Bridge System.

1. INTRODUCTION. During the last decade Integrated Bridge Systems (IBS) have proved to be the major information system on the navigation bridge. They are the integrating unit for the separate aids to navigation such as GPS, radar, ARPA, the electronic chart and information system (ECDIS), echo-sounder, log, anemometer, etc. The information from all the sensors is collected and processed by the processing unit of the IBS and can be displayed by means of separate menus. In this way the navigator obtains data about the position of dangers to navigation, both under- and above-water, their characteristics and their movement relative to the ship [1, 2]. However, the following questions arise – 'How is the available information co-ordinated?' and 'Is there sufficient information to make the correct decision to avoid a close quarter situation?' Theoretically, the co-ordination of the data from almost all navigation aids into a single system would in principle solve the problem of the availability of information about the situation around the ship. This fact allows the theory of information to be used to create an information model for the evaluation of IBS by applying the abstract notions of entropy, traffic capacity and the additional information, which are typical of this theory.

Clod Shannon created his works on the theory of information at the beginning of the 20th century. His main goal was to establish a quantitative evaluation of the abilities of communication systems. Due to its fundamental character however, this theory found a wider application in other fields of science and practice. So far no information model for the "Ship-Danger to Navigation" system has been created through which the effectiveness of IBS can be evaluated. Therefore this paper and its conclusions will be based on the information theory as applied to communications channels, taking into account the peculiarities and needs of navigation.

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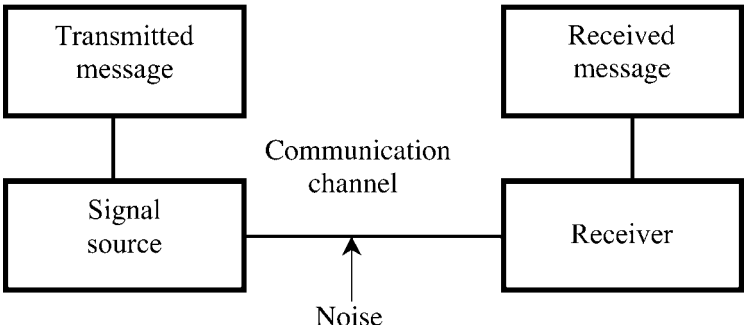


Figure 1. Flow diagram of the general communication scheme.

2. PRINCIPLE INFORMATION SCHEME OF THE SHIP-DANGER TO NAVIGATION SYSTEM. The communications system, to which the theory of information [3] was initially applied, generally comprises the elements shown in Figure 1. The transmitted message is any object (figures, text, speech, image, etc.) that could be transmitted via the signal source, which transforms the transmitted message into a signal carried in a communication channel to a receiver that transforms the received signal into the received message where the transmitted message is reproduced with a certain degree of preciseness. The transmission of messages and signals without any loss of information and at the fastest possible speed requires co-ordination among all units of the system. This means that the following conditions should be carried out:

1. The transformation of the message into a signal and vice versa (encoding and decoding) should be a simple quantity in the two directions.
2. The quantity of the information produced by the source should not be less than the quantity of information contained in the transmitted message.
3. The traffic capacity of the channel should be sufficient to contain the rate of the incoming signal information.

Let us relate the performance of these three conditions to the "ship-danger to navigation" system.

The messages about the location of the under- and above-water dangers to navigation are usually of a discrete character. The signals produced by the radar and echo sounder, due to measurement errors or a variety of different technical reasons, can be discrete or continuous. Therefore, when noise in the channel exceeds a certain level, the information from a given message is often contradictory and illogical. It will be assumed, for the needs of the present analysis, that the message and the signal are discrete, i.e. of single quantity. The quantity of the information contained in the signal and the message is determined by the entropy H [4]:

$$H_i = -\log_2 P_i \tag{1}$$

where P_i is the probability that the ship is at a safe distance from the danger to navigation. Consequently, the performance of condition 2 would mean that the entropy of the signal source H_{sig} should not be less than the entropy of the message

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source H_{msg}:

$$H_{sig} \geqslant H_{msg} \tag{2}$$

If $H_{sig} > H_{msg}$, then the signal provides more information about the message (the object of observation) than the particular navigational sensor actually measures. For example, ARPA takes bearings and distances to a target but data about the movement of the target are also presented on the information display of the IBS. As it was assumed that the message and the signal are of discrete character, their entropy will be determined by the formula:

$$H = \sum_{1}^{n} P_i \,.\, H_i = -\sum_{1}^{n} P_i \log_2 P_i \tag{3}$$

where $P_i = V_i / V_0 = 1/n$ denotes an equally probable possibility the danger to navigation to be in any area V_i of the total area V_0, located at a safe distance to the ship and n is the number of these areas.

The speed of creating the information by the source of the message or signal is called source efficiency (R). It is calculated by the formula [5]:

$$R = \frac{I}{T} \tag{4}$$

where I is the necessary quantity of information for solving a particular practical problem and T is the time taken to obtain, receive, process and transmit the message. For a system to be capable of transmitting information which is obtained at speed R, the system's information capacity C should be the greater, i.e. $C > R$.

In his theory Clod Shannon showed that the theoretical limit of the information transmission speed is determined by the system's traffic capacity. The mathematical expression for C is:

$$C = W \,.\, \log_2\left(1 + \frac{P_{sig}}{P_{noi}}\right) \tag{5}$$

where W is the width for information transmission of the system's traffic capacity with P_{sig} the signal power and P_{noi} the power of the noise in the system.

With $C > R$, the transmission of information with a low probability of the mistakes is theoretically possible. The maximum possible amount of information, which can be theoretically transmitted without mistakes for time T is:

$$I = C \,.\, T = W \,.\, T \,.\, \log_2\left(1 + \frac{P_{sig}}{P_{noi}}\right) \tag{6}$$

The situation in which $C < R$ determines condition 3. In the case of discrete messages and signals, as well as taking into account formula (5), the condition will be expressed by:

$$\frac{H}{T} \leqslant W \,.\, \log_2\left(1 + \frac{P_{sig}}{P_{noi}}\right) \tag{7}$$

The information scheme of the "ship-danger to navigation" system, presented in such a way, shows that the theory of information is applicable for the creation of a

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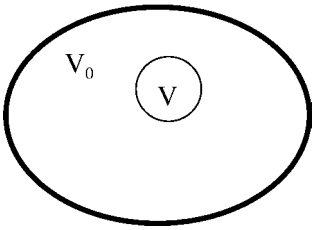


Figure 2. Choosing a particular area V from the whole area V_0.

model, which could solve the degree of the uncertainty of critical situations. The system has its own peculiarities and they are different from those to which Clod Shannon's theory was originally applied. The specific technical solution of part of the system in Figure 1, as displayed by IBS, will be discussed later in this paper.

3. INFORMATION CONTENT OF THE IBS OPERATION. In the general case the particular goal of the IBS operation is to provide sufficient information about the location of the ship relative to a certain danger to navigation, A, in order to take controlled deviation action in a close quarter situation. Consequently, the ultimate aim of IBS is to provide an area around A, to which the ship should not enter. The role of the main analysing and controlling unit, the subjective factor, will not be discussed here because of the different professional abilities resulting from the level of training, the experience, the current physical and mental state.

The information model of IBS in the context of Figure 1 contains the blocks from the transmitted message to the end. In this sense, the model could be identified as ships in general in the "ship-danger to navigation" system, since it performs all the functions in detecting the danger, encoding and decoding the signal and displaying the information [6]. In this case the message would mean choosing a particular area V from the whole area V_0 (see Figure 2), in which there are different other targets (moving, fixed, under-water, above-water). The final value of V determines the discrete character of the message. The choice of the area V is made by an operator who evaluates the degree of danger of the target A within it, the main criterion being the relative movement of the target A to the ship.

The signal reflected by the target carries information about the target parameters. The transformation of the target parameters in a signal, i.e. the encoding, is performed by the target itself. This is the transformation of the parameters of the target state – distance, speed, direction of movement, depth, etc. The amount of the information borne by the signal should not be less than the quantity of information contained in the message for the choice of area V. That means that the signal entropy should not be less than the entropy in the choice of V (formula 2). However, since the IBS transmits definitive information about the targets, the performance of this condition is possible only up to a certain distance and with particular meteorological states.

The channel for communication between the target and IBS is formed by the electromagnetic or acoustic oscillations reflected by A. In the normal situation, the quantity of information that is transmitted along the channel, should not be less

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than the quantity of information required for the exclusion of the entropy from the choice of the area V. The receiving unit gets a signal from the output of the channel, transforms it into a received message and displays it in the form of an object or digits characterizing the target parameters (the ARPA display, ECDIS, echo-sounder).

So far, from the point of view of information, the operation of the IBS is analogous to that of the communication system. However, there are some operational peculiarities. The main ones are characterized by the fact that the transmission and processing of the information are performed under the conditions of limited time t, which is observed as noise in the channel. These peculiarities are determined by restricted visibility, bad hydrological and hydro-meteorological conditions, peculiarities of the signal reflected by the target, etc.

On the basis of the analysis so far, the minimum quantity of information, which has to be processed by IBS, equals the entropy H for determining the dangerous target and the area V around it. This is expressed by the equation:

$$I_* = H_0 \tag{8}$$

The entropy equals:

$$H_0 = -\sum_{1}^{N_0} P_i \log_2 P_i \tag{9}$$

where $N_0 = V_*/V$ is the number of single areas V in a inverted space V_* around the ship and P_i is the probability of detecting the dangerous target A in i-th single area V_i.

Determining a target as dangerous is a process which goes though the phases of detection, determining the direction of movement (if a moving target), finding the location relative to the ship, determining the possibilities for deviation according to the area V around the target, separation of the target from the other targets and classifying it as the most dangerous. At each n-th stage of this process, the IBS should exclude the entropy H_n, calculated by formula (9), by obtaining the necessary quantity of information I_{*n}, i.e. at each stage the condition $I_{*n} = H_n$ should be present. Under normal sailing conditions this condition is present and the IBS provides a quantity of information, which even exceeds H_n.

The amount of information, which the system can process, is determined by the expression:

$$I_n = \int_0^{T_n} C_n(t)dt \tag{10}$$

where $C_n(t)$ is the traffic capacity of the channel during the n-th stage of processing the information which depends in the general case on the power of the signal P_{sig}.

The width, W_n, of the channel along which the information is admitted during the n-th stage, according to the order of the value equals:

$$W_n \approx \frac{1}{\tau_n} \tag{11}$$

where τ_n is the time for processing of the signal at the n-th stage.

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The noise power at the n-th stage is:

$$P_{noi_n} = \beta \,.\, W_n \tag{12}$$

where β is the spectral density of the noises.

When substituting formulas (11) and (12) in (5) and thence in (10) we get an expression for the quantity of information (I_n) processed by IBS for time T_n:

$$I_n = \frac{1}{\tau_n} . \int_0^{T_n} \log_2 \left[1 + \frac{P_{sig_n} \,.\, \tau_n}{\beta(t)} \right] . dt \tag{13}$$

Since the traffic capacity C_n of the channel and the efficiency of the signal R depend on the distance between the ship and the target, i.e. on T_n, then, comparing formulas (4) and (13), the conclusion can be drawn that during an approach, the traffic capacity of the system will increase more slowly than the signal efficiency. Consequently, the information characteristics of the system will be determined by the relation between the quantity of information I_n, which can be transferred along the channel for time T_n (formula 13) and the quantity of information i_{*n} (formula 8), which should be processed in order to determine whether a particular target is dangerous.

It can be concluded from (13) that the quantity of information provided by IBS for any particular situation is directly dependent on the noise resistance of the system. This dependence determines the efficiency of IBS in solving the safety of navigation problem. The noise, whose spectral density is generally denoted by β, results from the meteorological and hydrological sailing conditions. With normal visibility, the IBS information for the location and movement of a target is entirely sufficient to determine whether or not it is dangerous. In such a case the condition $C > R$ is always present and the system provides the necessary information for the exclusion of the entropy.

In restricted visibility, however, IBS registers the presence of a target in the area V_* considerably later than under normal conditions. Consequently, the time T_n decreases and τ_n increases due to the necessity of accumulating a greater amount of reliable data. Since the noise in the channel also increases, the information about the target is contradictory, i.e. insufficient for the exclusion of the entropy of the concrete situation. In such a case it becomes necessary to use other sources and evaluation criteria in order to provide additional information about the target. These other sources contain the direction of movement and the need to give way according to the International Regulations for Preventing Collision at Sea, etc.

Such conclusions about the efficiency of the IBS to ensure sufficient information about the situation around the ship are also valid for observation of underwater targets such as shoals, sailing in channels and narrows. Within normal hydrological conditions the echo-sounder registers the distance of the ship's submerged part to the underwater danger directly under the ship. In this case $C = R$, which is still sufficient information for a safe passage. However, when the depth suddenly decreases or when particles from the sea bottom start moving upwards and hamper the operation of the sensor, the time T_n also decreases. This makes the information untimely, or at least insufficient and leads to an impossibility to perform the condition in formula (8).

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4. CONCLUSION. The two examples given above illustrate the applicability of the stated mathematical expressions as an information model for the evaluation of the IBS efficiency. This model evaluates only the information efficiency of the IBS. After processing a sufficient amount of empirical data, a quantitative expression of formula (13) can be given. It will cover different ship-sailing conditions and different close quarter situations, which will serve as a comparison database to evaluate the actual situation. The comparison between results can advise the navigator whether it is necessary to look for additional information in order to solve a particular problem. In the cases when the information is insufficient, i.e. when $C < R$, a sound or a light signal from the IBS could serve as a warning to attain the navigator's attention. ECDIS, with its great information capacity, can serve as a suitable device in the process of accumulating the database.

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