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THE PROCESS OF CREATION OF BATHYMETRIC INFORMATION IN TERMS OF THE SET THEORY

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Abstract

All types of bathymetric information and its properties are presented. The entire process of creating bathymetric information, beginning from the planning of the bathymetric survey to the post-processing of bathymetric measurements, is described. This process is expressed in terms of the set theory. Therefore, the description of this very complicated process has become easier and more understandable.

1. INTRODUCTION

Bathymetric information is considered the main and the most important part of hydrographic information. This subject has been described, in detail, in various works, which are listed in references [1], [2], [3].

By the term "process of creating bathymetric information" we mean all the activities, connected together and mutually dependent, which are performed during all the phases of a bathymetric survey, and which result in obtaining bathymetric information, i.e. bathymetric data. Such process must fulfill all bathymetric standards.

This process is nowadays carried out in a variety of ways. Surveys can be performed by different means, from leadlines and sounding poles to very sophisticated multibeam sounding systems, side-scan sonars, special search sonars, sub-bottom profilers, aerial survey systems, etc.

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Similar differentiation exists also with respect to data processing methods, a bathymetric survey can be performed manually, or by very sophisticated data processing subsystems.

The process of creating bathymetric information, as discussed below, does not take into account any particular method of carrying out the bathymetric survey and the data processing. Only the pure, i.e. the abstract process of creation of the bathymetric information, is considered.

The following activities are presented below :

- the bathymetric information and its properties,
- the process of creation of the bathymetric information, its sub-process and phases,
- the preparation of the bathymetric survey,
- the elaboration of the bathymetric survey.

2. THE BATHYMETRIC INFORMATION AND ITS PROPERTIES

By "bathymetric information" is meant the information describing the sea depth, the sea floor configuration, the types of morphological structure of the sea bottom, and the navigational obstacles situated on the sea floor.

In the past, bathymetric surveys had been carried out, almost exclusively, for the safety of navigation, i.e. for the safety of commercial and naval ships. Therefore, priority was given to survey such as sea areas, harbours, gulfs, sea channels, straits, etc. Leadlines, sounding poles, and subsequently, sounding machines, were employed.

Information concerning the sea floor structure was important, but primarily for anchoring. Information concerning the underwater obstacles became important at the beginning of the present century, i.e. with the development of submarines and mining. This type of information was also useful for fishermen. But only in the 1920s, when echo sounders were introduced, it was possible to better satisfy the growing demands for bathymetric information.

Bathymetric information which fulfill the requirements of the safety of marine navigation, i.e. the safety of commercial and naval ships, yachting, sea fishing, etc, can be expressed as follows :

$$\{Bath\} = \{Dept, Isob, Grou, Uobs\} \quad (1)$$

where Bath is the set of bathymetric information, Dept is the subset of the depths of the sea, Isob is the subset of the isobaths, Grou is the subset describing the type of sea floor structure, and Uobs is the subset describing the underwater obstacles.

However, the quality of the bathymetric information expressed by formula (1) neither satisfies the needs of the present users of this information, nor the needs of modern commercial shipping. Most of today's users of bathymetric information require

such information, which exactly describes not only the sea depths, sea floor configuration, under-water obstacles and types of the bottom material but also the sea bottom morphological structure, i.e. the sea bottom sediments and sub-bottom layers. Therefore, the bathymetric information for today's users can be expressed by the following formula:

$$\{Bath\} = \{Dept, Boco, Bost, Uobs\} \quad (2)$$

where Boco is the data subset describing the sea floor configuration, and Bost is the subset describing sea floor structure, i.e. the sea floor sediments and sub-bottom layers.

The better the information contained in the subset (Bost), the better the bathymetric information (Bath).

The sea bottom classification has many applications. These include:

- ground fish habitat and fish farming areas;
- shellfish distribution areas;
- oil spillage residue mapping;
- oil rig site investigation;
- dredging operations;
- pipeline and cable layouts;
- damage areas of the fishing gears;
- scientific research;
- row materials' exploration;
- submarine and anti-submarine warfare;
- mine counter - measures;
- divers employment, etc.

The hydroacoustic method is, nowadays, the almost exclusive method used for bathymetric surveys. Other methods, such as wire sweeping, diving, use of leadlines, sounding poles, etc, are only historical or complementary. Aerial survey methods, such as photogrammetry and laser technology, may be considered as additional methods.

Frequencies from 10 kHz to 500 kHz are used for hydroacoustic measurements. This band of frequencies is sufficient for the creation of the two main subsets of the bathymetric information, i.e. the subsets (Dept) and (Isob) or (Boco).

The creation of the subset (Grou) needs the use of one of the following means: armed leads, bottom samplers, side-scan sonars, or echo sounder with two transducers. In the last case, one of the transducers usually uses frequencies below 50 kHz while the second is usually above 180 kHz.

The creation of the subset (Uobs) needs the use of one of the following means: diving, wire sweeping, sonar sweeping, or special search sonars.

The creation of the subset (Bost) requires the use of side-scan sonars, or echo sounders using two or more frequencies. However, the above both methods provide only identification of the sea bottom sediments. For identifying the sub-bottom

layers, special sub-bottom profilers are needed. They use two or more frequencies in the band - 0.5 kHz to 20 kHz, - and special software for data processing.

Bathymetric information has the properties of geographical information. It means, that each element of the information, contained in the set (Bath), has the following structure:

$$bath = obcl \wedge attr \wedge valu \wedge lalo \wedge time \quad (3)$$

where bath is an element of the bathymetric information; obcl is the object's class, i.e. the type of the information; attr is the attribute of the information, i.e. the characteristic of the information; valu is the value of the attribute; lalo is the latitude, longitude and height of the elementary information; and time is the time of acquisition of the elementary information.

3. THE PROCESS OF CREATION OF BATHYMETRIC INFORMATION, ITS SUB-PROCESSES AND PHASES

The process of creating bathymetric information can be divided into three phases (Fig. 1):

- preparation of the bathymetric survey,
- execution of the bathymetric survey,
- elaboration of the bathymetric survey.

The above process is composed of several sub-processes. Each sub-process transfers one or some set of information into another set of information. There are also the measurement sub-processes. Each sub-process transforms the information in accordance with the function of transformation. Therefore, each sub-process, and the function connected with it, is given the same name, e.g. "Pos", indicates the sub-process of positioning and, at the same time, indicates the function of the transformation which is carried out in this sub-process.

Figure 1 illustrates the process of creating bathymetric information.

The names of the sub-processes are listed below:

pla - planning of the bathymetric survey,
ste - steering the ship in accordance with the sounding plan,
poş - positioning of the ship,
sta - stabilizing the ship on the line of sounding,
sou - sounding sea depths,
ame - acquisition of additional measurements,
rec - recording of surveyed row data and the additional measurements,
pro - processing of the measured row data into the bathymetric data,
ppr - postprocessing of the bathymetric data into the fair sheet or into the set of the fair sheet data.

The process of creating bathymetric information can be expressed as follows (Fig. 1):

$$bat = pla \wedge ste \wedge pos \wedge sta \wedge sou \wedge ame \wedge rec \wedge pro \wedge ppr \quad (4)$$

where bat is the function which carries out the process of creation of the bathymetric information.

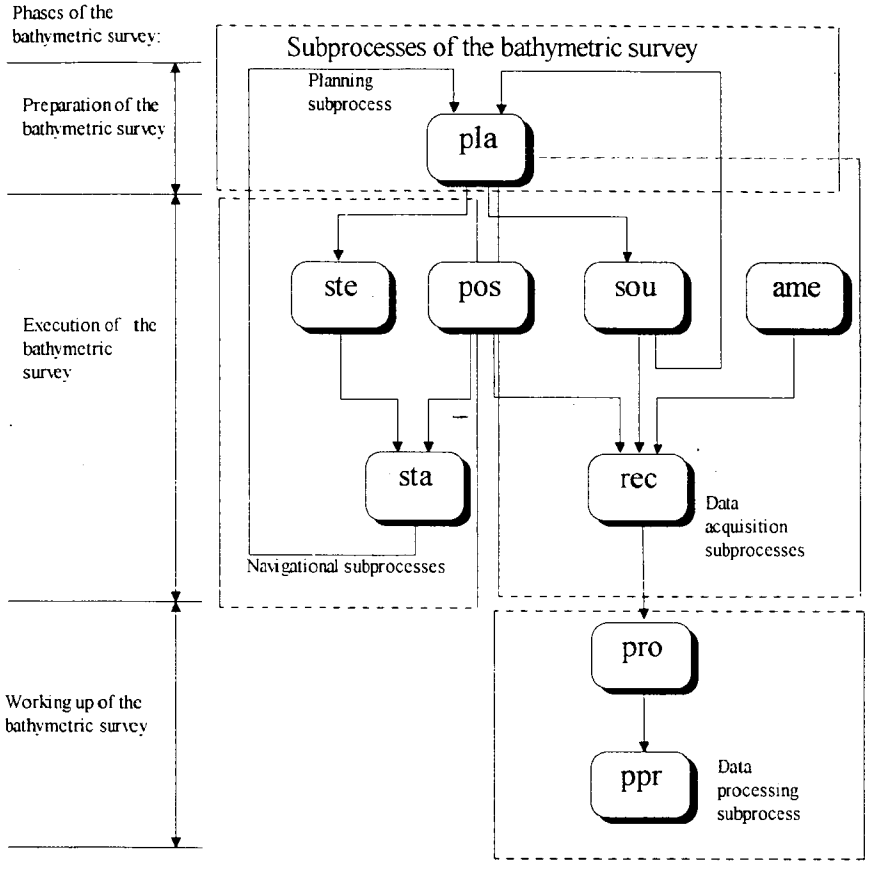

FIG. 1.- Process of the bathymetric survey, its sub-processes and phases [1]

The formula (4) can be written as follows (Fig. 1):

$$bat = pla \wedge nav \wedge acq \wedge dpr \quad (4a)$$

or as follows $$bat = pla \wedge exe \wedge dpr \quad (4b)$$

where nav is the group of navigational sub-processes, acq is the group of acquisition sub-processes, dpr is the group of data sub-processes, and exe is the group of all sub-processes which are being performed during the execution phase of the bathymetric survey.

Notation in Figure 1:
pla, etc., are the names of the sub-processes and related functions of the transformation or measurement.

As it is shown in Figure 1, these group sub-processes can be expressed as follows:

$$nav = ste \wedge pos \wedge sta \quad (5)$$

$$acq = sou \wedge ame \wedge rec \quad (6)$$

$$dpr = pro \wedge ppr \quad (7)$$

The sub-process pos is common to the two first groups of the sub-processes, i.e. nav and acq (Fig. 1).

The information which is involved in the process of creation of bathymetric information can be divided into four different types of information:

- primary bathymetric information, i.e. the whole measured information which is the subject of transformation (Pbin),
- bathymetric standards, i.e. the hydrographic standards concerning the bathymetric survey (Bas)
- bathymetric procedures (Bapr),
- bathymetric data, i.e. the transformed bathymetric information which is the product of the data processing sub-processes (Bada).

The above can be expressed as follows:

$$bat: (Pbin, Bast, Bapr) \rightarrow Bada \quad (8)$$

where bat is the function which transforms the information within the whole process of a bathymetric survey (4).

4. PREPARATION OF THE BATHYMETRIC SURVEY

The first phase of the bathymetric survey is carried out by the sub-process "planning" (pla). As a result of this sub-process, the plan of preparation and execution of the bathymetric survey should be worked out. This plan can be expressed by the set of information (Plan). Such set should contain the subsets describing the following topics:

- geodetic and cartographic framework of the bathymetric survey, i.e. the survey sheets, working scale, sounding datum, etc,
- lay-out of the sounding lines in compliance with the type of survey and features of the surveyed area (harbour, coast area, etc),
- navigational procedures concerning the conducting of the ship and her positioning,
- data acquisition procedures,
- methods of elaboration of the bathymetric survey,
- record of the special activities which should be done before and during the surveying,
- schedule for carrying out each step of the plan.

The following types of information are needed for the realization of the plan:

- information describing the tasks related to the bathymetric survey, i.e. the type of survey means and methods, scale of sounding sheets, spacing of sounding lines, etc (Task),
- information describing the survey area, i.e. the character and location, navigational properties of the area, etc (Area),
- special geodetic, cartographic and navigational requirements (Gkna),
- bathymetric standards (accuracies, spacing of the lines of sounding, etc)(Bast);
- bathymetric procedures (Bapr).

With respect to (8) the sub-process of the planning can be expressed as follows:

$$\text{pla: (Ship, Task, Area, Gkna, Bast, Bapr)} \rightarrow \text{Plan} \qquad (9)$$

where pla is the function transforming the subsets of the planning information into the plan (Plan).

Figure 2 illustrates the sub-process (pla), which is expressed by formula (9).

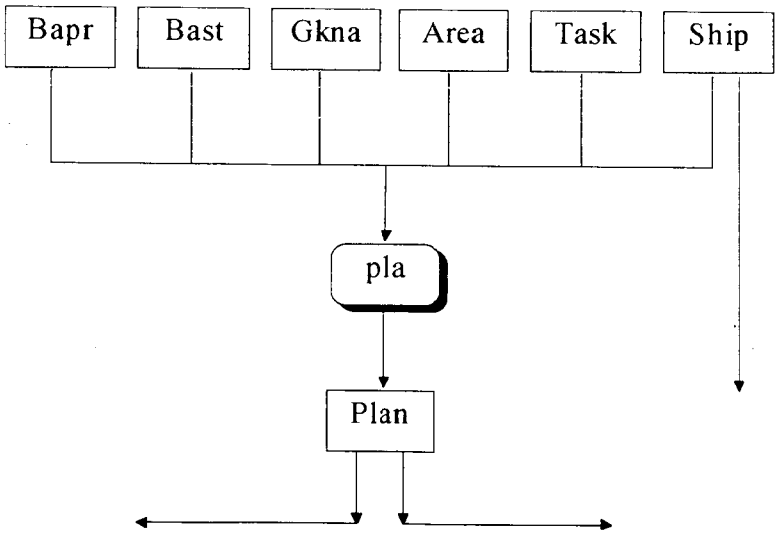

FIG. 2.- Different types of information which are included in the planning sub-process (pla).

The types of information contained in the set (Plan) can be expressed as follows:

$$\{\text{Plan}\} = \{\text{Geka, Liso, Napr, Acpr, Spac}\} \qquad (10)$$

where Geka is the subset describing the geodetic and cartographic framework of the bathymetric survey, Liso is the subset describing the layout of the sounding lines, Napr is the subset describing the navigational procedures, Acpr is the subset describing the

acquisition procedures, Spac is the subset describing the special activities which should be carried out before and during the bathymetric survey.

$$\{Plan\} = \{Nhme, Acpr\} \tag{10a}$$

where Nhme is the subset describing the additional navigational and hydrographic measurements which fulfill all the requirements and standards of the bathymetric survey.

Comparing the (10) with (10a), we get

$$\{Nhme\} = \{Geka, Liso, Napr, Spac\} \tag{10b}$$

The computerized bathymetric and navigation systems of the modern hydrographic ships enable the planning sub-process to be performed shortly before the beginning of the bathymetric survey.

5. THE EXECUTION OF THE BATHYMETRIC SURVEY

During the execution phase of the bathymetric survey, two groups of sub-processes are carried out, i.e. the navigational sub-process (nav) (5) and the acquisition sub-process (acq) (6). The function of the transformation of information during this phase can be expressed as follows:

$$exe = nav \wedge acq \tag{11}$$

or in full form

$$exe = ste \wedge pos \wedge sta \wedge sou \wedge ame \wedge rec \tag{11a}$$

Figure 3 illustrates the execution phase of the bathymetric survey.

Referring to (8) and (9) and to figures (2) and (3), the function of the navigation sub-process can be written as

$$nav: (Ship, Plan, Stee, Posi, Napr) \rightarrow Navi \tag{12}$$

where Navi is the set of information describing the navigation sub-process.

The process of the ship's navigation, and its sub-processes, are described, in detail, in [5]. Therefore, the navigational sub-processes, are not discussed below.

All sub-processes of the acquisition process (acq), except the sub-process rec, are the measurement's sub-process. They can be expressed as follows:

$$\text{The sounding sub-process: sou: } (Sopr) \Rightarrow Some \tag{13}$$

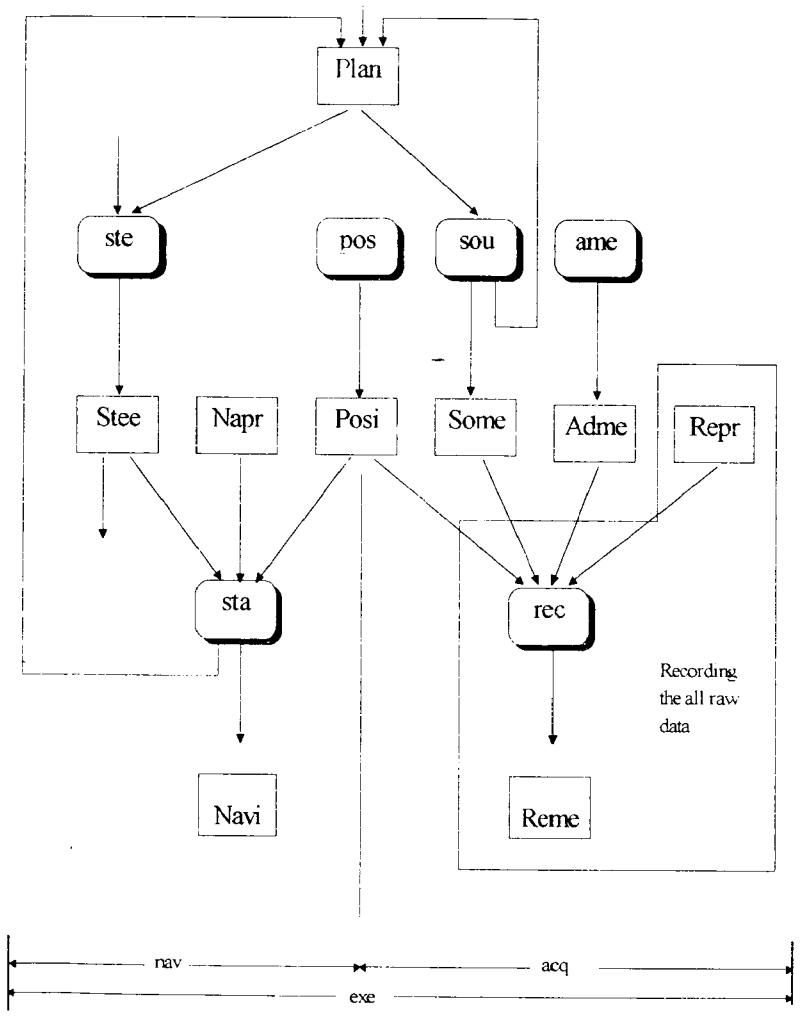

FIG. 3.- The illustration of the sub-processes and the relevant sets of information created during the execution phase of the bathymetric survey.

where sou is the measurement's function of the sounding sub-process, Sopr is the set of sounding procedures which controls the soundings' measurement, and Some is the set of soundings.

$$\text{The additional measurement's sub-process: ame: (Ampr)} \Rightarrow \text{Adme} \qquad (14)$$

where ame is the function of measurement of the additional parameters for computing corrections, Ampr is the set of procedures which controls the measurement of additional parameters, Adme is the set of additional measurements.

$$\text{The positioning sub-process: pos: (Popr)} \Rightarrow \text{Posi} \qquad (15)$$

where pos is the function of the ship's positioning, Popr is the set of positioning procedures which control the positioning sub-process, and Posi is the set of the position's coordinates.

The sub-process of recording of soundings and additional parameters can be expressed as follows (Fig. 3):

$$\text{rec: (Some, Adme, Repr)} \rightarrow \text{Reme} \qquad (16)$$

where rec is a function of the recording sub-process, Repr is the subset of the recording procedures, and Reme is the set of the recorded bathymetric measurements.

The function which carries out the sub-process of the data recording of all measurements, is performed to-day, usually, by the data logging subsystem. This function has a technical character.

6. ELABORATION OF THE BATHYMETRIC SURVEY

The sub-processes which are being realized during the elaboration phase, are expressed by the formula (7) (Fig. 3):

$$dpr = pro \wedge ppr$$

The elaboration of the bathymetric survey is finished when the fair sheet, or sheets, are prepared and delivered to the Hydrographic Office.

The transformation of the measurements into the fair sheet, or into the set of the fair sheet data, can be performed in many ways. These ways change, mainly following the amount of computerization involved in the data processing sub-processes. Because no particular way of the data processing is discussed, some assumptions must be made:

- the necessary number of soundings and additional parameters have been measured in order to obtain all types of bathymetric information, i.e., the following subsets:

Dept, Isob or Boco, Grou, Uobs and Bost

- the sub-process of data processing (pro) performs the transformation of the soundings and additional parameters into the proper subsets of the set (Bath), expressed by formula (1) or (2). Therefore, there are as many modifications of this sub-process as subsets of the set (Bath),

- the sub-process of the bathymetric data postprocessing (ppr) prepares the fair sheets or their equivalent, i.e. the set of fair sheet data (Fsda).

Figure 4 illustrates the sub-processes of the bathymetric data processing.

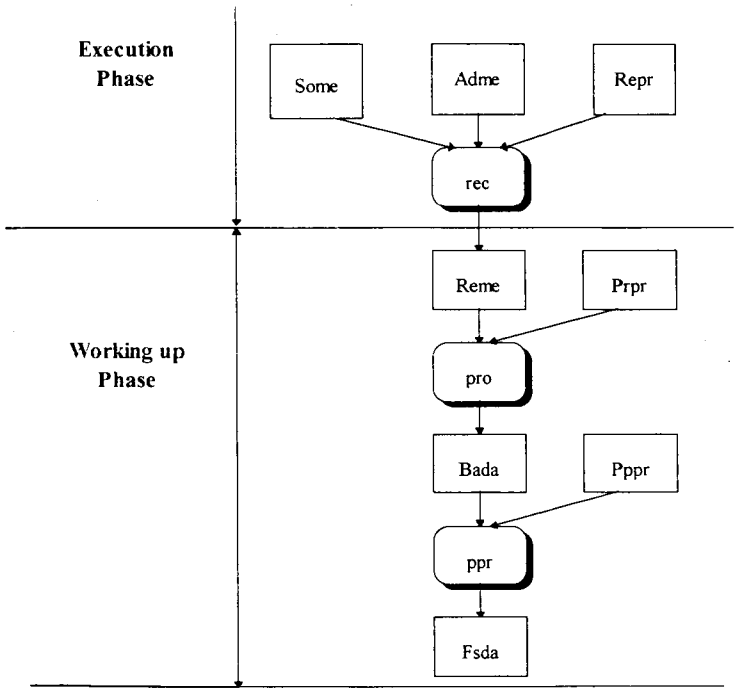

FIG. 4.- Sub-processes of the elaboration phase of the bathymetric survey. [2]

Notation of Figure 4

Prpr set of the processing procedures
Pppr set of the postprocessing procedures

6.1 Transformation of soundings and additional measurements into bathymetric data

The sub-process of data processing (pro) can be expressed as follows:

$$\text{pro: (Some, Adme, Posi, Bast, Bapr)} \rightarrow \text{Bada} \tag{17}$$

or in its equivalent form

$$\text{pro: (Reme, Posi, Bast, Bapr)} \rightarrow \text{Bada} \tag{17a}$$

Referring to (3), the set of (Reme) has the following structure:

$$\{\text{Reme}\} = \{\text{Obcl, Attr, Valu, Time}\} \tag{18}$$

The set (Posi); however, has the following structure:

$$\{\text{Posi}\} = \{\text{Obcl, Attr, Valu, Lalo, Time}\} \tag{19}$$

Therefore, the set (Bada) has the structure of geographical information, i.e.:

$$\{\text{Bada}\} = \{\text{Obcl, Attr, Valu, Lalo, Time}\} \tag{20}$$

The sub-process of transformation of the measurements into depths (Dept) can be expressed as follows:

$$\text{dep: (Reda, Posi, Dest, Depr)} \rightarrow \text{Dept} \tag{21}$$

where Dest is the subset of standards concerning the sea depths, Depr is the subset of procedures.

The sub-process of transformation of sea depths into the subset (Isob) or subset (Baco), e.g. 3-D presentation or the colour-coverage sea bottom presentation, can be expressed as follows:

$$\text{iso: (Dept, Isst, Ispr)} \rightarrow \text{Isob} \tag{22}$$

or as follows:

$$\text{bco: (Dept, Best, Bcpr)} \rightarrow \text{Boco} \tag{22a}$$

where iso is the function of isobaths' determination, bco is the function of determination of values for the selected presentation of the sea bottom configuration. The other subsets in formula (22) and (22a) denote the relevant subsets of standards and procedures.

We assume that, in set (Reme), measurements are adequate for the determination of the types of sea bottom grounds (Grou). The sub-process of transformation of measurements into the sub-set (grou) can be expressed as follows:

$$gro: (Reme, Grst, Grpr) \rightarrow Grou \quad (23)$$

where Grst and Grpr are respectively the subset of standards and procedures which should be followed.

The subset (Uobs), like the subset (Grou), needs adequate primary information as contained in the set (Reme). The sub-process of transformation of primary information into the subset (Uobs) can be expressed as follows:

$$uob: (Reme, Uost, Uopr) \rightarrow Uobs \quad (24)$$

where Uost is the subset of standards and Uopr is the subset of procedures of this sub-process.

As it was stated in Section 2, the determination of the subset (Bost) describing the sea bottom sediments and sub-bottom layers, needs adequate primary bathymetric information.

The sub-process of transformation of measurements into the subset (Bost) can be expressed as follows:

$$bst: (Reme, Bsst, Bspr) \rightarrow Bost \quad (25)$$

where Bsst is the subset of standards, and Bspr is the subset of procedures.

The set (Bada) has the following structure:

$$\{Bada\} = \{Bath\} = \{Dept, Baco, Grou, Uobs, (Bost)\} \quad (26)$$

The subset (Bost) is foreseen only for the special users of bathymetric information.

6.2 Transformation of bathymetric data into the set of fair sheet data

By "set of fair sheet data" we mean bathymetric data which form the contents of the fair sheet in a bathymetric survey. The fair sheet data, after having been printed on the plotting sheet (chart) at the relevant scale, become the fair sheet of bathymetric survey. These fair sheets data are stored in the electronic chart data base, or in other similar data base, at the Hydrographic Office.

The fair sheets or the set of fair sheet data are the result of the sub-process of the postprocessing of bathymetric data. This sub-process can be expressed as follows:

$$frd: (bada, Fsst, Fspr) \rightarrow Fsda \quad (27)$$

where frd is a function of transformation, Fsst is the subset of standards, Fspr is the subset of procedures concerning this sub-process, and Fsda is the set of the fair sheet data which after printing on the plotting sheet, create the bathymetric chart (fair sheet).

This concludes the description of the process of creation of the bathymetric information expressed in terms of the set theory.

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