SEA SURVEYING
A PROBABILITY MODEL

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SUMMARY

The ambition to optimize all hydrographic work has today become very important. This is the logical outcome of the increased demand for closely spaced lines of soundings and the high cost of all operational work. This probability model is presented in order to make planning easier and analysing of the surveying operations more accurate. To the best of my knowledge such a model has never been constructed. By introducing some of the variable parameters in hydrographic surveying into the model a probabilistic analysis is achieved.

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Background

When dealing with hydrographic work today, it is essential to plan the use of all vessels in an optimal way. With the present density of sea transport in some areas and the dramatic increase, in the recent past, in ships' sizes, the safety margins at sea are severely reduced. Where, in earlier days, in a very wide channel, ships passed with several meters of underkeel clearance, today the ships are limited to a very narrow area with bottom often dangerously close to the keel. This calls for a denser and a more accurate surveying today than in the past. As hydrographic surveying is a very costly operation, it is essential to optimize the work as far as possible.

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Influencing parameters

The cost of surveying of a given area is influenced by several parameters. These parameters can be divided into logical groups. One of the groups consists of the uncontrollable parameters such as remoteness from land, tides and currents. To this group we can often also add such parameters as type of vessel or vessels used, type of positioning equipment and seasonal weather conditions, as we are not always free to make a choice in these matters.

One group is of special interest to us. This is the group containing the parameters that control, or are at least involved in, the spacing of the surveying lines. The reason for this is that the spacing of the surveying lines is by far the most cost-increasing factor. This group consists of parameters such as the general depth of the area, type of bottom topography, maximum draft of traffic frequenting the area and the opening angle of the transducer beam. For a side-scanning sonar the latter will be replaced by the sweep angle of the sonar beam.

The bottom coverage along a surveying line is a direct function of the speed of the vessel and the PRF (Pulse Repetition Frequency) of the echosounder and the sonar beam width (vs. water depth) or the angle velocity of a sonar beam. In this model it is assumed that the speed of the vessel allows complete, or almost complete, bottom coverage along the surveying lines.

The principle of echo sounding allows echoes from the edge of the beam to remain unnoticed although the responding object might be closer to the surface than the recorded object. This indicates that, for accuracy, it is better to survey more lines with narrower beams. On the other hand, this will of course increase the cost. This special feature of the echo sounding principle is not represented in the model today.

The difficulties in creating a realistic model containing all influencing parameters are obvious. As the line spacing is the most cost-demanding factor, a model based on the parameters related to this factor should be sought. An optimum solution for the parameters could then be found through this model.

The model parameters

Before creating the model some kind of probability statement must be formulated. For this model the following one has been chosen.
"The probability of finding an underwater obstacle".

The parameters affecting this statement will be :
m = the probability of finding an underwater obstacle
s = theoretical spacing between surveying lines
α = angle between two sets of parallel lines
D = water depth
e = depth of echo sounder transducer
ω = opening angle of echo sounder beam
d = diameter of a circular underwater obstacle
c = offset of a line from its theoretical position.

The parameter c is later split into four sub-parameters.

Although being of indisputable influence, the type of bottom topography is not included in this set of parameters. As it is more or less impossible to model it effectively, it must be brought into the model by experience as an inclusion in parameter d.

Construction of the model

In this section the model will gradually be expanded from the most simple one to the full model containing all parameters.

Consider first a simple model containing only the parameters m, d and s. This gives :

$$m = \frac{d}{s} \qquad (1)$$

m will be defined for all values of d and s although $0 < d < s$ giving $0 < m < 1$ are the interesting ones. For $d > s$, there will be a probability larger than 1, indicating a waste of time and money.

Introduce now the parameters D, ω and e. As a direct function of these can be found the width b of the surveyed line as indicated in figure 1.
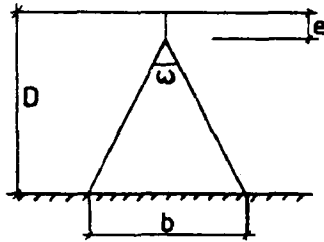

FIG. 1

b as a function of D, ω and e is given by :

$$b = 2(D - e) \tan \frac{\omega}{2} \qquad (2)$$

Incorporating b in the simple model (1) will give :

$$m = \frac{d + b}{s} = m_p \qquad (3)$$

This expression will give $0 < m < 1$ for $0 < d + b < s$.

This index p indicates that (3) is valid for parallel lines. Introducing the parameter α for crossing lines (line patterns) gives an expression for m_c as :

$$m_c = m_p(2 - m_p) \qquad (4)$$

for $0 < \alpha < 90°$. The probability m_c is consequently totally independent of α as long as the lines actually cross each other.

Up till now only the theoretical line spacing has been considered. In reality, it can very seldom be assumed that this value is stable. There are always errors affecting the theoretical pattern. By introducing the parameter c (offset) the

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consequences of a line being offset from its theoretical position can be modelled. This situation is shown in figure 2 :
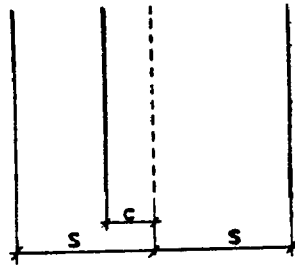

FIG. 2

The offset c is a function of several elementary errors. For this model it has been chosen to study the effect of the following parameters :

p = positioning system accuracy

h = steering accuracy (ability to follow the line designated by the positioning system)

k = side boat steering accuracy (ability of side boat to hold its position with respect to the leader vessel or, for example, the ability of a towed paravane to follow the towing vessel)

r = roll.

Contrary to the parameters used earlier, which can be regarded as more or less stable figures, these are best expressed as statistical values, usually as standard deviations. Their values must therefore be treated with a certain amount of consideration as the total offset in the model is created by simply adding them together.
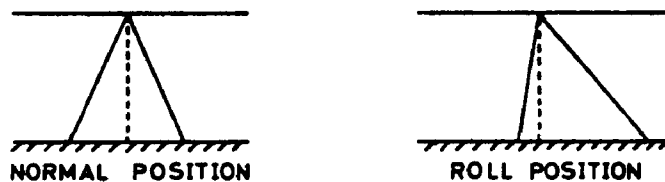
The influence of r is shown in figure 3.

NORMAL POSITION   ROLL POSITION

FIG. 3

The parameter b is of course affected by r but as the change in b is less than seven percent for r = 15°, no consideration of this has been taken in the model. Due to the earlier mentioned feature of echoes from the edge of the beam, this increase in b, which at first might appear as a positive effect, is in reality a negative effect.

One possible effect of the offset is that, for closely spaced lines, parts of the bottom will be covered twice. This is also the only case when the offset has a negative effect as m remains unaffected if this situation doesn't occur. It must be remarked that the neighbouring lines to the one influenced by the offset are

considered to be free from offset. In reality this is seldom the case and the probability of significant offset therefore higher.

c can now be expressed as :
$$c = p + h + k + (D - e) \tan r \qquad (5)$$
c is only significant if $b + d > s - c$. If this is the case, m_o (o for offset) can be expressed as :
$$m_o = \frac{d + b + s - c}{2s} \qquad (6)$$

This formula is only valid if the offset is less than the spacing. Should the offset be larger than the spacing, something is completely wrong with the surveying technique. If this is the case, the model will yield negative probabilities as a warning.

The complete model can now be summarized for the three different main situations.

Parallel lines without significant offset :
$$m_p = \frac{d + 2(D - e)\tan \omega/2}{s} \qquad (7)$$

Parallel lines with significant offset :
$$m_o = \frac{d + 2(D - e)\tan \omega/2 + s - (p + h + k + (D - e)\tan r)}{2s} \qquad (8)$$

Crossing lines :
$$m_c = \frac{d + 2(D - e)\tan \omega/2}{s} \; (2 - \frac{d + 2(D - e)\tan \omega/2}{s}) \qquad (9)$$

Using the model

The model can be used in various ways and for different purposes. To facilitate the use of the model, a program has been written for the HP-41 pocket calculator. Figures 4 and 5 show the flow chart and the program lines respectively.

By introducing the known values of performed surveys, analyses can be made. For planning purposes, the model can be used to establish the optimal mode of operation, parallel or crossing line patterns. It can be used to establish the optimal spacing between the lines for complete coverage or for a certain value of m. The effects of altering the beam angle can be studied together with a lot of other things.

CONCLUSIONS

This model should be a valuable tool for all hydrographic work. To meet future demands the model could be refined as indicated earlier. The model could also easily be re-arranged so that the spacing s could be given as a function of the other parameters including the chosen probability m.
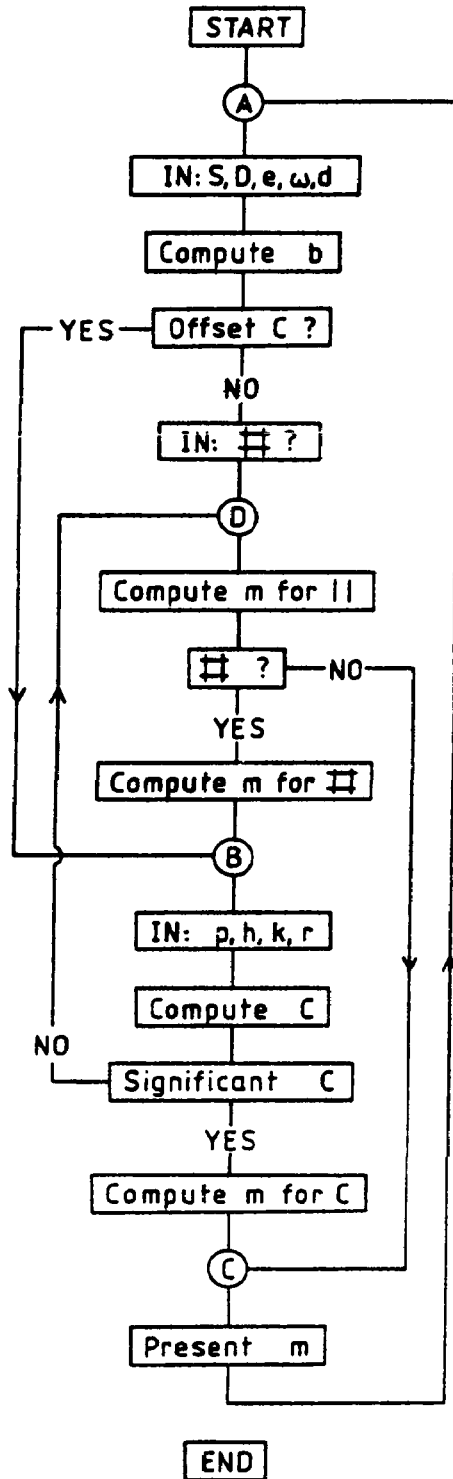
FIG. 4

SSP - SEA SURVEYING PROBABILITY

0	1	LBL SSP	5	1	0	10	1	RCL 12
	2	FIX 0		2	RCL 01		2	+
	3	DEG		3	X = Y ?		3	RCL 00
	4	LBL A		4	GTO C		4	+
	5	SPACING = ?M		5	2		5	RCL 11
	6	PROMPT		6	ENTER		6	-
	7	STO 00		7	RCL 06		7	2
	8	W-DEPTH = ?M		8	-		8	÷
	9	PROMPT		9	RCL 06		9	RCL 00
1	0	STO 02	6	0	+	11	0	÷
	1	FIX 1		1	STO 06		1	STO 06
	2	E-DEPTH = ?M		2	GTO C		2	LBL C
	3	PROMPT		3	LBL B		3	RCL 06
	4	STO 03		4	POS ACC = ?M		4	FIX 2
	5	FIX 0		5	PROMPT		5	PROB OF FIND
	6	E-ANGLE = ? DEG		6	STO 07		6	PROMPT
	7	PROMPT		7	STEER ACC = ? M		7	STOP
	8	STO 04		8	PROMPT		8	GTO A
	9	DIAMETER = ? M		9	STO 08		9	END
2	0	PROMPT	7	0	SIDE ACC = ?M			
	1	STO 05		1	PROMT			
	2	2		2	STO 09			
	3	ENTER		3	ROLL = ? DEG			
	4	RCL 02		4	PROMT			
	5	ENTER		5	STO 10			
	6	RCL 03		6	RCL 07			
	7	-		7	RCL 08			
	8	*		8	+			
	9	RCL 04		9	RCL 09			
3	0	2	8	0	+			
	1	÷		1	RCL 02			
	2	TAN		2	ENTER			
	3	*		3	RCL 03			
	4	STO 12		4	-			
	5	OFFSET? NO = 0		5	RCL 10			
	6	PROMT		6	TAN			
	7	ENTER		7	*			
	8	0,5		8	+			
	9	X ≤ Y ?		9	STO 11			
4	0	GTO B	9	0	0			
	1	CROSS? NO = 0		1	STO 01			
	2	PROMPT		2	RCL 12			
	3	STO 01		3	RCL 05			
	4	LBL D		4	+			
	5	RCL 12		5	RCL 00			
	6	RCL 05		6	RCL 11			
	7	+		7	-			
	8	RCL 00		8	X > Y?			
	9	÷		9	GTO D			
	0	STO 06	10	0	RCL 05			

Registers

00	S	spacing
01	0=11, 1=#	
02	D	water depth
03	e	echo depth
04	ω	opening angle
05	d	diameter
06	m	
07	p	pos acc
08	h	steer acc
09	k	side acc
10	r	roll
11	c	offset
12	b	width

FIG. 5

By a proper use of the model, the cost of hydrographic surveying could be diminished and/or the efficiency increased. It is the hope of the author that this model will help hydrographic surveyors to optimize their work in the best possible way.