Capacity and Capability for Hydrographic Missions

Authors; Rune Axelsson
Marketing and Business Development
Optronics and Land Systems
Saab Dynamics AB

Mats Alfredsson
Marketing and Business Development
Optronics and Land Systems
Saab Dynamics AB

1 INTRODUCTION

Saab Dynamics has developed a computer software tool to assist hydrographic survey organisations, when evaluating alternative configurations of survey equipment based on modern technologies including airborne Laser Bathymetry Systems (LBS).

The Saab Dynamics' tool models the capacity and capability of the considered equipment.
The model for the total task calculates the needed time and capacity of entered survey equipment configurations. It also includes the impact of economical factors. Thus the model makes it possible to compare alternatives and to indicate optimal solutions. In addition the tool indicates the requirement on the equipment and staff for processing and storage of depth data for creating hydrographic data bases.

Depth accuracy's shall be adopted to the requirements for different water areas according to their importance for the safety of navigation or other use of depth data. This means that a number of considerations have to be taken when planning for a survey mission and the post processing of data. These kind of considerations are reflected in IHO's Standards for Hydrographic Surveys, S44; 4th edition (1998). Low S44 Orders (Special or 1) are very demanding to fulfil and more time consuming the more shallow the water is.

The required input parameters are normally available or possible to estimate in the hydrographic offices. The results of the analysis should only be used as guide lines, which means that a full truth is not required for the input data either. For some of the input parameters a sensitivity analysis is included in the model.

2 STATE OF THE ART TECHNOLOGIES FOR DEPTH MEASUREMENTS

The model analyses configurations of survey systems based on the following technologies:

- Multibeam echo sounders; offers great potential for accurate and total seafloor coverage if used with proper procedures and provided that the resolution of the system is adequate.
- Airborne laser sounders, a technology which offers substantial productivity gains for surveys in shallow water. Airborne laser systems are capable of measuring depths down to 40 metres or more. Depth range is depending on water transparency.

When comparing Multibeam and LBS based on adequate S44 Order and average depth the conclusion are two: Low S44 Orders (Special or 1) are very demanding and expensive to fulfil with any system even if most pronounced for Multibeam systems in very shallow water (<20 m). For very shallow water LBS is very competitive, the model assign LBS for the survey when ever possible. For deeper water (>40-50 m) and turbid waters Multibeam is a good method.

3 DATA ENTRIES

3.1 Mission Scope and Classification

The mission is to survey a water area with its sub-areas surveyed to required accuracy and bottom coverage. This has to be done in a cost efficient way and within a required period of time. Depth accuracy and bottom coverage shall be adopted to the requirements for different sub-areas according to their importance for the safety of navigation or other use of depth data. To handle this different requirement on survey capacity the model uses a classification of sub-areas. Sub-areas are classified by the required accuracy and their nominal depth.

The survey mission volume is divided into depth intervals used to classify the water areas for a fair comparison or choice between different Multibeam platforms and LBS configurations. It will also give a prediction of the time needed for the whole survey mission. In a sense it’s also a depth estimate for planning a survey mission to achieve high survey efficiency.

Survey Class; The analysis of the model are based on a classification of the Survey Mission Volume into 13 Survey Classes. Each Survey Class is characterised by the required S44 order and the nominal depth (“Class depth”). To classify the Survey Mission Volume properly into Survey Classes may be difficult. However, the model allows for three parallel classification runs and it will recommend survey equipment configurations for all three.

Parallel classification; The model allows for three parallel classifications and it will recommend survey equipment configurations for all three. The three classifications are called Best, Shallow and Deep. All three variants will be analysed by the tool.

Share suitable for LBS; LBS feasibility and capacity is dependent on transparency of the water. Each Survey Class shall therefore be classified according to the transparency. Assuming a homogenous water column the transparency can be established by using a Seechi disc. The measure of transparency is the Seechi depth in meter. Existing water transparency data for different areas are useful, else estimates has to be used.

Preplanning survey; In the model is a preplanning survey option included. The purpose is to survey the whole mission area with a low bottom coverage and accuracy (Order 2-3) in a short timeframe to produce adequate planning data. The data will help the Hydrographic Office to plan future surveys and to use the most suitable survey system for sub-areas.

Volume and Classification Table

Survey Mission Volume……………………………………[Km^2]							
Survey Class		**Share of total [%] Best**	**Share of total [%] Shallow**	**Share of total [%] Deep**		**Required min. Seechi depth: S44 cube/flat bottom [m]**	**Share suitable for LBS [%]**
S44 order	**Class depth [m]**						
1	**4**					**2/2**	
Special	**8**					**8/4**	
1	**8**					**6/4**	
2	**8**					**5/4**	
Special	**16**						**0**
1	**16**					**12/7**	
2	**16**					**11/7**	
1	**32**						**0**
2	**32**					**28/16**	
2	**70**						**0**
2	**150**						**0**
2	**300**						**0**
2	**1000**						**0**
Total share; (shall be 100%)		100 %	100 %	100 %			
Preplanning Survey with LBS to be analysed ? …..………**[Yes/No]**							
Bottom coverage for preplanning survey ……………….**[%]**							

3.2 Classification of survey equipment

You are also expected to give nominal capacities of the survey systems. The model will calculate the net capacities by using influencing factors described in the model.

3.2.1 Multibeam Nominal Capacity

For multibeam the apertures for effective surveys and avarage speeds of ships shall be given. It shall be appreciated that the max. possible aperture in a system may not be equal to the aperture effective to use. Multibeam frequency, ping rate, aperture values and foot prints are already estimated for the model but easily changed if necessary.

3.2.2 LBS Nominal Capacity

The capacity of the LBS is mainly dependent on the requirements of S44 and not so much of the depth. The nominal capacity of the LBS for the different orders of S44 shall be given if differs from default.

3.3 Factors Reducing Capacity due to Operational Constrains

The nominal capacity is reduced by operational factors depending on operational constrains on site. Nominal survey time is reduced by turnings, overlaps between swathes, repeated swathes etc. Reduction factor for these operational reductions shall be noted for each Survey Class. The calculated net capacity per hour will be based on this factors multiplied by the nominal capacity.

3.4 Definition of Survey System Configurations

Four alternative configurations of survey equipment and platforms are analysed by the model.

3.4.1 Survey Systems

Three types of ships are possible to specify in the model: large ships, medium ships and small ships. The criteria for the classification of ships (large, medium, small) are endurance and costs. Costs shall be specified in later sections. The model assumes that ships of proper sizes for the actual conditions are chosen.

For LBS a helicopter is the first choice as a platform and part of the comparing analysis, but also fixed wing aircraft can be chosen in the model. However, a fixed wing aircraft can not be used for S44 order Special. Some fixed wing data will anyhow be given as results. The four configurations analysed are:

1. Only medium sized ships for all surveys.
2. Any combination of large, medium and small ships. The type to use for a certain Survey Class are specified in the tables below.
3. A helicopter borne LBS for all surveys possible for LBS and medium sized ships for all other surveys.
4. A helicopter borne LBS for all surveys possible for LBS and any combination of large, medium and small ships for all other surveys. The ship type to use for a certain survey class are specified below.

For LBS configurations helicopter borne LBS will be used where possible and combinations of the three ship types as specified in the table for all other surveys.

3.4.2 System Deficiency Margin

The model will analyse and recommend the optimal number of each system type. However, there will normally be a marginal capacity deficiency to small for utilisation of one extra system. If an extra system is not included the lacking capacity has to be rented from external sources. If an extra system is included the surplus capacity may be sold to external resources. This is taken care of in the model by specified factors.

3.5 Planned / Expected Utilisation

The expected utilisation shall be given by specifying factors affecting the survey capacity and utilisation of equipment. The factors concern staff working conditions, the survey organisation, weather conditions and system transport time for the different types of systems.

3.5.1 Time Horizon for Mission and Planned Spare Capacity

The number of years to carry out the total mission shall be given and also reserves for unknown tasks.

3.6 Organisational and Operational Costs

Investments, maintenance costs, crew costs, operational costs (fuel etc) shall be given. Also expected income for extra capacity/costs for lack of capacity.

3.7 Pay-Off Calculation Data

A Pay-Off calculation is carried out for the two transitions below:

1. Configuration 1 (only medium ships) ⇒ Configuration 3 (LBS + medium ships)
2. Configuration 2 (mixed ships) ⇒ Configuration 4 (LBS + mixed ships)

The two transitions analyses the shift from configurations with only survey ships to configurations including LBS. To do this calculation properly the residual values and costs for liquidation of ships are needed.

4 RESULTS OF THE MODEL

The model calculates capacity of the systems, operational configurations and costs for four different configurations, costs for transition between configurations and expected data flow in the hydrographic office.

System capacities; For the different types of survey systems, large Multibeam ship, medium Multibeam ship, small Multibeam ship and LaserBathymetry System (LBS) in helicopter:

- Net survey capacities
- Number of survey hours for the systems in the specified mission.

Operational configurations and costs; Calculated for the four system configurations below:
(1) only medium ships,
(2) large, medium and small ships,
(3) as (1) but including LBS,
(4) as (2) but including LBS

- Number of operational years for each type of system in the survey mission
- Number of systems of each type in the configurations to manage the mission within given time period.
- Cost per Km^2 per system and S44 order. Costs are equally spread per survey hour.
- Marginal cost per Km^2 and S44 order (only operational costs included)
- Annual costs for each configuration.

Costs to change between configurations; Estimation of the cost to change from a configuration without LBS to a configuration including LBS:

- Pay off calculation to change from configuration (1) to (3) and to change from configuration (2) to (4).

4.1 Results of example

As an example a mission area of 160000 Km^2 is used. The area is to be surveyed within 50 years. The nominal depths and needed IHO orders are given in Figure 4-2.

The figures below shows some parts of the results and how it is presented. Figure 4-1 shows the survey capacity for Multibeam and LBS for the survey classes. The model clearly indicates that the LBS system is very efficient in the shallow areas. When the areas are deeper the multibeam is the method.

Figure 4-3 shows the cost per Km^2. You can see that the cost for the Multibeam survey mainly depends on the depths of the waters you are surveying. The cost is very high for shallow waters but decreases a lot for deeper waters. This is in correspondnance with Figure 4-2.The cost for surveying with a LBS system is mainly dependent on the IHO order and not on the depths.
The cost is very competitive for shallow waters up to 50 meters.

Figure 4-4 shows the annual cost for the four configurations. For each of the configurations the number of systems are given and the Annual Cost for the systems ("Basic Cost"). In the table is also given the Total Cost (Basic Cost + Marginal Cost). The annual cost for the four configurations shows that using LBS where possible is very cost effective. The configurations using combinations of Multibeam platforms and LBS systems has much lower annual costs. In these configurations there are less Multibeam platforms as the LBS system covers most of the shallow waters.

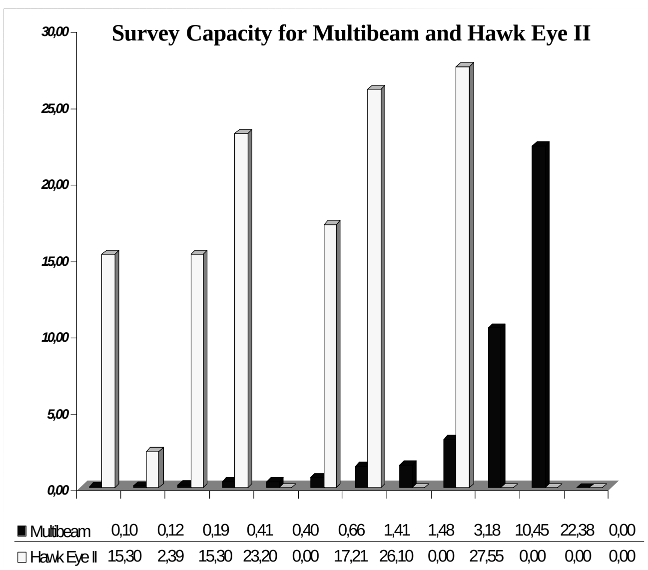

Figure 4-1 Survey Classes from Order 1; 4 metres up to Order 2; 150 metres.

			Classification of Survey Mission										
Survey accord.to S44	**Order 1**	**Special**	**Order 1**	**Order 2**	**Special**	**Order 1**	**Order 2**	**Order 1**	**Order 2**	**Order 2**	**Order 2**	**Order 3**	**Ord. 3**
Controlling depth [m]	**4**	**8**	**8**	**8**	**16**	**16**	**16**	**32**	**32**	**70**	**150**	**300**	**1000**
Share in the class; %	5,0	1,0	15,0	10,0	1,0	28,0	7,0	16,0	12,0	3,0	2,0	0	0
Ackumulated	*5,0*	*6*	*21*	*31*	*32*	*60*	*67*	*83*	*95*	*98*	*100*	*100*	100
Class Area; Km^2	7750	1550	23250	15500	1550	43400	10850	24800	18600	4650	3100	0	0
Ackumulated	*7750,0*	*9300*	*32550*	*48050*	*49600*	*93000*	*103850*	*128650*	*147250*	*151900*	*155000*	*155000*	155000

Figure 4-2

		Cost per Km^2, systems used to 100%, costs equaly spread per survey hours.											
Survey accord.to S44	**Order 1**	**Special**	**Order 1**	**Order 2**	**Special**	**Order 1**	**Order 2**	**Order 1**	**Order 2**	**Order 2**	**Order 2**	**Order 3**	**Ord. 3**
Controlling depth	**4**	**8**	**8**	**8**	**16**	**16**	**16**	**32**	**32**	**70**	**150**	**300**	**1000**
Large Ship; **USD/Km^2**		22172	14243	6620	6929	4173	1939	1855	862	263	123	58	17
Medium Ship; "		12622	8108	3768	3944	2375	1104	1056	491	150	70	33	10
Small Ship; "	16434	12791	8217	3819	3997	2407	1119	1070	497	152	71	33	
Hawk Eye+Hcp; "	378	2413	378	249		336	221		210			61	
Hawk Eye+fixed Wing "				151			134		127			37	
			Marginal Cost per Km^2, only operational costs										
Large Ship; **USD/Km^2**		1616	1038	483	505	304	141	135	63	19	9	4	1
Medium Ship; "		808	519	241	253	152	71	68	31	10	4	2	1
Small Ship; "	519	404	260	121	126	76	35	34	16	5	2	1	
Hawk Eye+Hcp; "	26	167	26	17		23	15		15			4	
Hawk Eye+fixed Wing "				17			15		15			4	
Estimated market price per Km^2					Total "Market costs" for the specified Mission:						**1272**	MUSD	
"Norm" USD / Km^2	2000	25000	20000	10000	15000	10000	4000	2500	1700	600	250	125	40
MAX USD / Km^2	15000	50000	20000	12000	20000	12000	6000	3500	2200	800	350	150	60
Min USD / Km^2	200	10000	500	500	500	500	300	500	200	100	100	30	10
Market Costs; MUSD	**15,50**	**38,75**	**465,00**	**155,00**	**23,25**	**434,00**	**43,40**	**62,00**	**31,62**	**2,79**	**0,78**	**0,00**	**0,00**

Figure 4-3

		Annual Cost; for all Configurations											
Factors	Level of capacity defiency for capacity increase:				0,3		Costs and numbers are based on :			**50**	years for the Mission		
	Annual Cost, no external income				**Shallow**	**Deep**	**Free survey capacity**			**Expected external sell**			
Configuration 1.	**Vessels number**	**Basic Cost MUSD**	**Marignal Cost MUSD**	**Total Cost MUSD**	**Vessels / Cost [No/MUSD)**	**Vessels / Cost**	**Hours/y**	**Cost Nominel USD/h**	**Margin. USD/h**	**Hours/y**	**Pris/h USD/h**	**"Incom." MUSD**	**Own Cost MUSD**
Medium Sips	5	13,30	0,83	14,13	6	4	819	1562	100	400	1600		
Sum		13,30	0,83	**14,13**	**16,95**	**11,35**						0,60	***13,53***
Configuration 2.													
Large Ships	0	0,00	0,00	0,00	0	0	0	2744	200	0	2500		
Medium Ships	2	5,32	0,40	5,72	3	2	-403	1562	100	0	1600		
Small Ships	7	6,95	0,21	7,17	9	5	299	1583	50	100	1400		
Sum		12,27	0,62	**12,89**	**17,63**	**10,83**		Order 1				0,14	***12,75***
Configuration 3.													
Hawk Eye (Hcp)	1	2,41	0,06	2,46	1	0	307	5778	400	300	5000		
Medium Ships	1	2,66	0,13	2,79	1	1	557	1562	100	0	1600		
Sum		5,07	0,18	**5,25**	**5,25**	**2,84**						0,30	***4,95***
Configuration 4.													
Hawk Eye (Hcp)	1	2,41	0,06	2,46	1	0	307	5778	400	300	5000		
Large Ships	0	0,00	0,00	0,00	0	0	0	2744	200	0	2500		
Medium Ships	1	2,66	0,09	2,75	1	1	888	1562	100	500	1600		
Small Ships	1	0,99	0,02	1,01	1	1	318	1583	50	0	1400		
Sum		6,06	0,17	**6,23**	**6,23**	**3,82**						2,13	***4,10***

Figure 4-4

5 DESCRIPTION OF A LASER BATHYMETRY SYSTEM

By the very nature of laser bathymetry technology and built-in features, LBS surveys offer the ideal complement to sonar surveys. The key words are survey efficiency, survey accuracy, bottom area coverage, survey safety and versatility.

- Survey efficiency, LBS provides in shallow waters outstanding productivity with minimum crew requirements. High velocity of the carrier and a large swath width give fast coverage of the sea bed. Narrow passages, archipelagos, reefs and the coast line can be surveyed in just one mission.
- Survey accuracy, LBS gives full bottom coverage in all areas even in very shallow areas where other methods is very expansive to use. Local variations in salinity and/or temperature present no problem to LBS.
- Survey safety, The survey platforms of an LBS is airborne and readily clears narrow passages, shoals and reefs. Unknown waters and areas subject to mine hazards are no safety problems for the survey crew or the survey equipment.

- **Versatility**, a LBS may be adapted for environmental control, e.g. erosion, contamination or reef growth/breakdown periodical surveys. In its environmental control role, the LBS also benefits from the carrier's short re-deployment time.

The airborne system is normally installed in a helicopter or fixed wing and the ground equipment is located in a Mobile Base Station, together with field level support equipment and space for spares.

The operational sequence consists of three steps, **mission planning** where the extent and purpose of the missions are transformed to flight line patterns and settings for the fly missions **airborne operation** during which data are gathered and the **post processing** where mission data are enhanced and converted into specified formats.

During mission planning maps over the planned survey areas are digitised and stored. For the areas optimal system parameters are set and stored. The survey areas are divided into strips, called flight lines.

In the figure the pattern of the laser soundings on the water surface is shown. The parameters have the following meanings: **a** is the distance between the centre of two adjacent laser spots on the water surface. **V** is the helicopter speed over ground. **S** is the swath width. **H** is the flight altitude and ∅ is the off nadir angle.

6 INSTALLATION IN A CARRIER

The Airborne Equipment which is mounted inside the helicopter or aeroplane consists mainly of a Control and Monitoring Subsystem, a Sensor Subsystem and an Integration Subsystem. The figures show the Sensor Subsystems and distributed parts from the Control and Monitoring Subsystem in helicopter (figure 6-1) and aeroplane (figure 6-2).

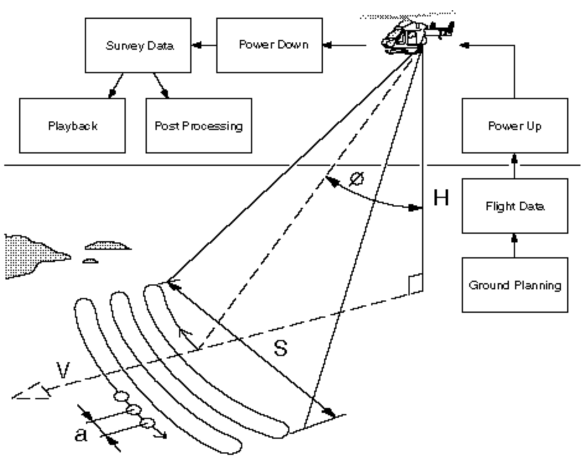

Figure 5-1

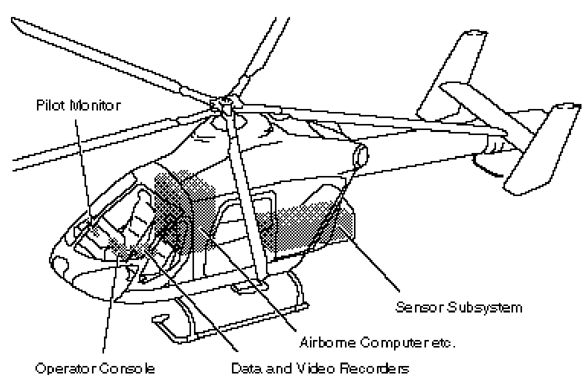

Figure 6-1 Airborne Equipment Lay-Out

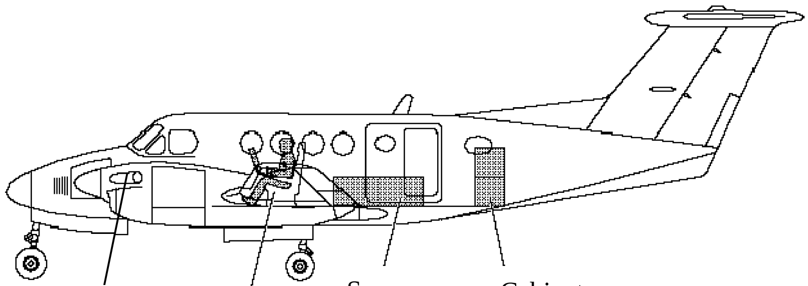

Figure 6-2 Outline of aeroplane integration

7 CAPABILITIES

The Hawk Eye II system will be a 1000 Hz system. The maximum depth capability is dependent on the water turbidity. A Secchi disk can be used to approximately determine the vertical visibility in the water. For flat bottoms (reflectivity greater than 5 %) the maximum depth capability (D_{max}) under normal operating conditions is greater than or equal than 3.5-4,5/K, where K is the green light attenuation coefficient for the water. For water with good visibility the maximum depth is expected to be up to 40-50 meters in very clear waters. The minimum depth measuring capability is better than 1 m, but may be as good as to 0.3 m. However, the waterline is separately discriminated.

Post processed and quality checked depths data will fulfil the requirements of IHO Standards for Hydrographic Surveys, S44, Fourth Edition, 1988.

For low S44 Orders, to secure detection and positioning of (small) cubes on the bottom, a reduction of the maximum depth is compulsory.