Possible point distance approach as coverage requirement

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Table 1 in Edition 6

Reference	Criteria	Order 2	Order 1b	Order 1a	Special Order	Exclusive Order
Chapter 1	**Area description** (Generally)	Areas where a general description of the sea floor is considered adequate.	Areas where underkeel clearance is not considered to be an issue for the type of surface shipping expected to transit the area.	Areas where underkeel clearance is considered not to be critical but features of concern to surface shipping may exist.	Areas where underkeel clearance is critical	Areas where there is strict minimum underkeel clearance and manoeuvrability criteria
Section 2.6	**Depth THU** [m] + [% of Depth]	20 m + 10% of depth *Ba5, Bb2	5 m + 5% of depth *Ba8, Bb3	5 m + 5% of depth *Ba8, Bb3	2 m *Ba9	1 m *Ba10
Section 2.6 Section 3.2 Section 3.2.3	**Depth TVU** (a) [m] and (b)	a = 1.0 m b = 0.023 *Bc7, Bd4	a = 0.5 m b = 0.013 *Bc8, Bd6	a = 0.5 m b = 0.013 *Bc8, Bd6	a = 0.25 m b = 0.0075 *Bc10, Bd8	a = 0.15 m b = 0.0075 *Bc12, Bd8
Section 3.3	**Feature Detection** [m] or [% of Depth]	Not Specified	Not Specified	Cubic features > 2 m, in depths down to 40 m; 10% of depth beyond 40 m *Be5, Bf3 beyond 40m	Cubic features > 1 m *Be6	Cubic features > 0.5 m *Be9
Section 3.4	**Feature Search** [%]	Recommended but Not Required	Recommended but Not Required	100% *Bg9	100% *Bg9	200% *Bg12
Section 3.5	**Bathymetric Coverage** [%]	5% *Bh3	5% *Bh3	≤ 100% *≤ Bh9	100% *Bh9	200% *Bh12

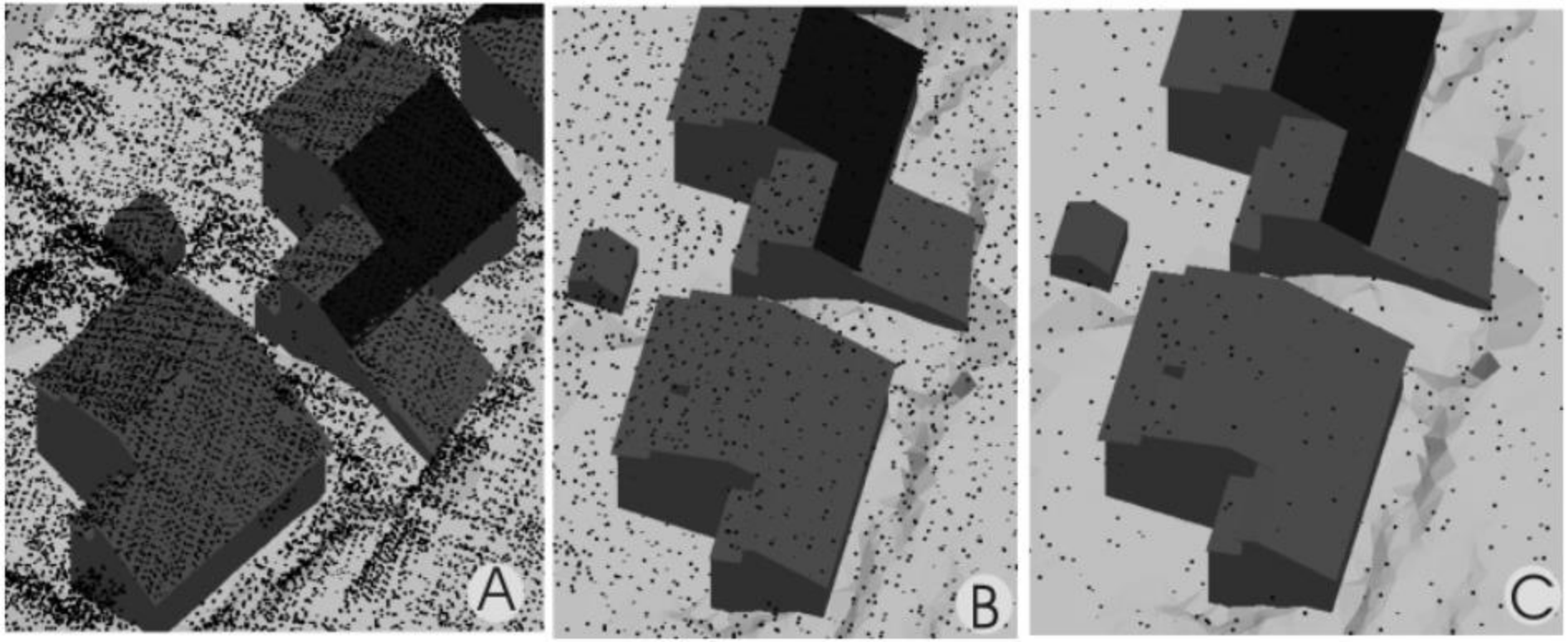
Q: What is the driving factor for the bathymetric coverage requirement for Special and Exclusive Orders?

A: The Feature Detection criteria!

Point Density Examples

High fidelity of representation and **high** probability of feature detection

Adequate fidelity of representation and **low** probability of feature detection



Examples of different LiDAR point densities: A) 20 points/m^2, B) 10 points/m^2 and C) 1 point/m^2 (Triglav Cekada *et al.,* 2010)

Let’s look at a possible adaptation of S-44 Table 1 to a point distance approach…

…step-by-step:

Distinction between criteria and requirement

Criteria	Requirement	Order 2	Order 1b	Order 1a	Special Order	Exclusive Order
	Area description (Generally)				Areas where underkeel clearance is critical	Areas where there is strict minimum underkeel clearance and manoeuvrability criteria
Feature Detection	Feature Size [m] or [% of Depth]				Cubic features > 1 m	Cubic features > 0.5 m
Fidelity of Representation	Maximum Point Distance [m]				0.5	0.25

Assumptions:

- A distance measurement system (e.g. SBES, MBES, ALB) generates an unstructured point cloud of depths.
- The Nyquist-Shannon sampling theorem is used as basis for minimum feature detection.

Criteria	Requirement	Order 2	Order 1b	Order 1a	Special Order	Exclusive Order
	Area description (Generally)				Areas where underkeel clearance is critical	Areas where there is strict minimum underkeel clearance and manoeuvrability criteria
Feature Detection	Feature Size [m] or [% of Depth]				Cubic features > 1 m	Cubic features > 0.5 m
Fidelity of Representation	Footprint Size [m]				1	0.5
	Maximum Point Distance [m]				0.5	0.25

Since spatial resolution also limits the feature detection capability, a **Footprint Size** requirement needs to be added. This was recognized by Miller et al. (1997).

Criteria	Requirement	Order 2	Order 1b	Order 1a	Special Order	Exclusive Order
	Area description (Generally)				Areas where underkeel clearance is critical	Areas where there is strict minimum underkeel clearance and manoeuvrability criteria
Fidelity of Representation	Footprint Size [m]				1	0.5
	Maximum Point Distance [m]				0.5	0.25

The feature detection requirement is redundant and can be removed.

Criteria	Requirement	Order 2	Order 1b	Order 1a	Special Order	Exclusive Order
	Area description (Generally)	Areas where a general description of the sea floor is considered adequate	Areas where underkeel clearance is not considered to be an issue for the type of surface shipping expected to transit the area.	Areas where underkeel clearance is considered not to be critical but features of concern to surface shipping may exist.		
Fidelity of Representation	Footprint Size [m]	Not specified	Not specified	2		
	Maximum Point Distance [m]	4 x average depth [recommended]	25 or 3 x average depth, whichever is greater [recommended]			

Q: What is the driving factor for the bathymetric coverage requirement for Order 2, 1b?

A: A sufficiently accurate portrayal of the bottom topography!

Q: What is the driving factor for the bathymetric coverage requirement for Order 1a?

A: A sufficiently accurate portrayal of the bottom topography and the Feature Detection criteria!

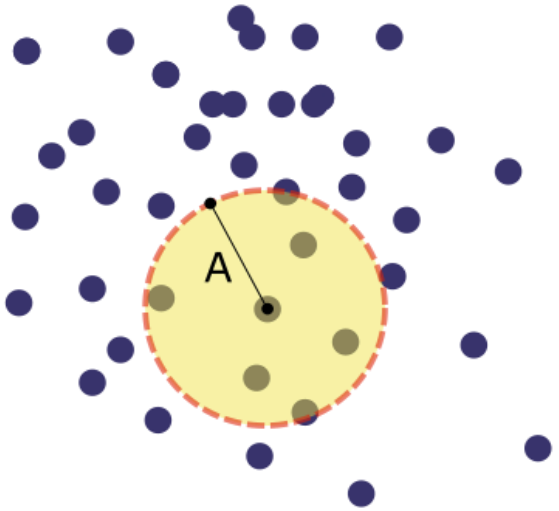
Criteria	Requirement	Order 1a		Special Order		Exclusive Order	
		Distance measurement systems	Imaging systems	Distance measurement systems	Imaging systems	Distance measurement systems	Imaging systems
Fidelity of Representation	Footprint Size [m]	Not specified	Not specified	1	Not specified	0.5	Not specified
	Maximum Point Distance or Maximum Sample Distance [m]	25 or 3 x average depth, whichever is greater	0.5	0.5	0.25	0.25	0.1

Imaging systems and a ground sampling distance (GSD) requirement are introduced in order to:

1. Accommodate the Feature Detection criteria of 2m for Order 1a (i.e. using a sidescan);
2. Accommodate systems that are not distance measurement systems, measure signal intensity and may infer bottom topography (e.g. SDB, PBMS)

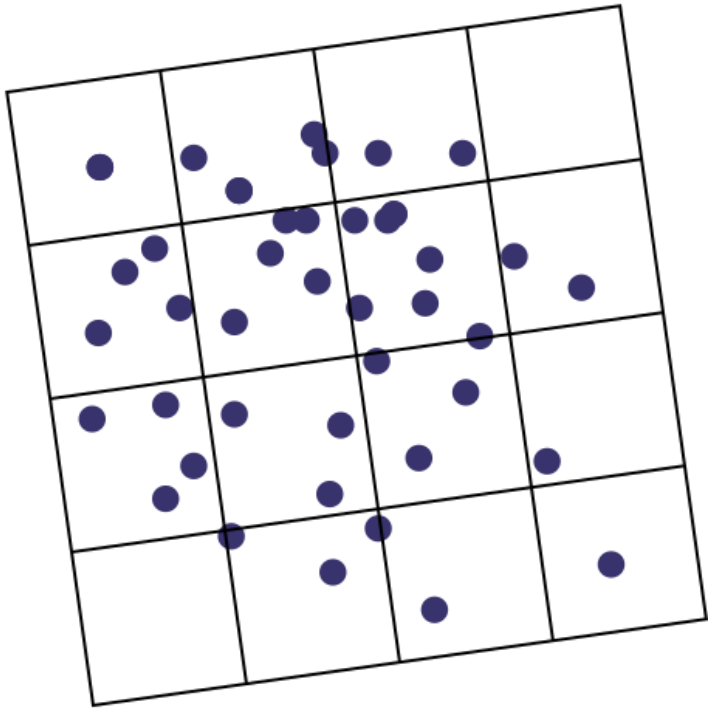
Measuring the maximum point distance

Radial Approach



Number of points inside a circle of radius A defining the maximum point distance

Raster Approach



$$average\ point\ distance\ per\ cell = \sqrt{\frac{1}{cell\ density}}$$

Some pros and cons

Advantages:

- Simple metric (i.e. the meter) that is easy to understand
- Practical metric that makes software calculations unambiguous
- More consistent with survey specification in Geodesy
- Data from non-acoustic techniques can be validated with S-44

Disadvantages:

- How to specify the footprint size? Should it be based on a beam angle specification?
- How to deal with multiple soundings per beam (from interferometry or high-resolution methods)?
- How to deal with beamforming applied to PBMS?
- Can we assume that all imaging systems produce structured dataset?

References

Miller, J., Hughes Clarke, J. E., & Patterson, J. (1997). How Effectively Have You Covered Your Bottom? *Hydrographic Journal*, *83*, 3–10.

Triglav Cekada, M., Crosilla, F., & Fras, M. (2010). Theoretical LiDAR point density for topographic mapping in the largest scales. *Geodetski Vestnik*, *54*, 403–416. https://doi.org/10.15292/geodetski-vestnik.2010.03.389-402