S100WG01-10.7A

Paper for consideration by NIPWG/S-100 WG/DQWG

Spatial Model – Approximate Areas for Nautical Information Specifications

Submitted by:	Jeppesen/BSH
Executive Summary:	Describes problems and possible approaches to the representation of approximate areas for product specifications in nautical publications information, maritime safety information, and other domains.
Related Documents:	(1) NIPWG1-21.3
Related Projects:	(1) S-100; (2) S-122, S-123, S-124, S-126, etc.

1 Introduction/Background

The work on the S-122 (Marine Protected Areas) data sample revealed shortcomings in the ability to represent approximate areas (or "fuzzy areas") in S-100. Approximate areas are relevant to several NIPWG data products. Further, similar issues arise in S-124 (Marine Safety Information), and are likely to arise in other product specifications. This paper describes the issue and approaches to solutions.

The scope of this paper is limited to areas. Approximate points or curves are not addressed.

How will the mariner assess the nautical information in an S-100 environment?

For ships sailing under the SOLAS requirements their exist an information entity which combines charts and publication. That means no mariner can navigate a ship safely without having consulted the associated nautical publications. Both charts and publications can be available in digital or printed format. Some HOs provide their publications in digital format but the majority of HOs is issuing their nautical publications in printed format.

In an S-100 based ECDIS system and with the existence of Data Products which either interact with each other or which overlay each other, the Mariner will have access to the information only by the system. The intuitive calculation of the presence of an effect or service is no longer possible. The areas where such effect might occur or a service is available must be indicated visually or by a characteristic which indicated the "fuzziness" of the existence of an effect or service.

Publications provide information which is currently not available from the chart, e.g. traffic regulations, effects on the passage during different environmental conditions. The mariner has to compare the charted situation with the environment and the associated publication information.

Publications are often not able to determine the exact location where different effects might occur. Rather they provide more abstract locations, e.g. "in front of the harbour entrance". In theory the area "in front of the harbour entrance" can be extended thousands of miles. In practice the mariner calculates intuitively to which distance off the harbour entrance the effect might occur.

In addition to the hydrographic environment, sailing directions for the passage of islands or headlands are often descripted in a way that mariners have to take their ships condition into account. That may have effects on the area where a ship can navigate. The navigable area (recommended passage) may have specific limits to the area where the water depth is less than allowed but has an uncertain extend (a fuzziness) to the open sea. This spatial extent to the open sea cannot be determined by fixed values. Further, some areas might be passed by vessels carrying specific cargo in a defined distance. The outer limits of the passage are often unspecified. Mariners have to create a route which does not touch the inner limits and which keeps a certain distance to this defined inner limits. The "definition" of the outer limits, which in fact don't exist, depends on the mariner's interpretation. A certain level of fuzziness would be helpful in defining such uncertain limits and would avoid unnecessary deviations.

2 Analysis/Discussion

While this paper draws on academic research in fuzzy spatial objects, it does not attempt to provide a comprehensive survey of the literature. Further, its scope is limited to the types of approximate areas which have been (or are likely to be) encountered in maritime information domains and which it would be useful to represent in S-100-based data sets.

2.1 Examples

Examples of approximate areas follow.

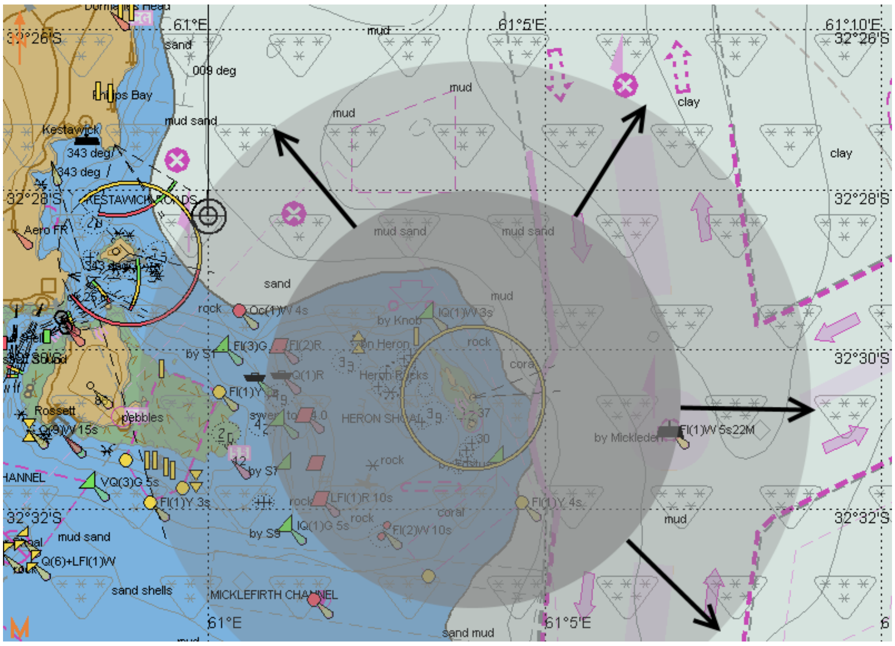
1) North American right whale sighting areas off the U.S. Atlantic coast are described in general terms as, variously “year round in the north-eastern region from Cape Code to Nova Scotia”, “during winter and early spring, calving area in the coastal waters off the Southeast Atlantic coast,” and “during fall, the migration route from the northern zone to the calving area, which runs through near-shore waters along the mid-Atlantic coastline”. “Crisp” restricted areas have been designated in regulations as seasonal management and critical habitat areas, but they are at best substitutes for the approximate areas described above. The approximate areas are depicted on fact sheets from NOAA Fisheries [FS1, FS2].

2) Radio services may be received in a certain distance from ashore for sure and with decreasing reliability of the service at increasing distances beyond this distance. That would require a graduation of the service reliability which could fuzzy out at the outer edge.

   That means in practice that the chart should provide an area where the service is 100% available and an extended area where the presence of the service is likely but not guaranteed.

   This extended area cannot be presented with the currently existing or the planned functions to portray uncertainties of services (CATZOC or the planned replacement of CATZOC). Limiting the portrayal to only one area might result in an insufficient access to the information. The reality will show the mariner that the information is either valid or not.

   The example below shows the hypothetical decrease of a radio service reliability broadcasted from the island. The arrows are only placed for presentation purposes. The lighter the colour will become the more unlikely is the reliability of the service.



3) Sailing Directions often describe passages where the recommended path is a corridor and the limits are not specified. That would require a fuzzy spatial limit.

4) On the Norwegian coast, the Norwegian Maritime Authority has charted dangerous wave areas (example attached). These areas have no exact boundaries. They will vary with the speed and direction of the wind and also the current will affect. The chart places a warning text in the area.

5) Locations described in terms of a range of distances off the coast: "A dense concentration of fishing gear lies off the coast of Vesteralen. The fishing gear is set from 4 miles off the coast to between 15 and 30 miles offshore."

6) Terms used to delineate certain maritime territorial claims: Continental Shelf--The Limit of Exploitation, the Continental Margin, and the 200 meter curve have been used by various nations to describe the limit of the Continental Shelf off their coastline.

7) Similar to Radio coverage and whale sighting areas, a “Mine danger area” is an area within which mines are more likely to be found.

8) Normal seasonal ice coverage (seasonal ice zone) is an area that will vary a lot by time and season. Hurricane danger areas are another example of “more likely to be found within” areas, without well-defined borders.

9) General areas or localities in navigational warnings are identified by name or description but not represented by a polygon: “THE SOUND SOUTH OF THE BRIDGE,” “NW OF NAKATSU KO,” “WIDER SEA AREA BETWEEN KOS AND KALOLIMNOS ISLANDS.” This is generally within a larger area which is either explicitly named (BALTIC SEA, WESTERN BALTIC AND THE SOUND) or implicitly identified (as the NAVAREA).

2.2 The problem with crisp areas

Some current data products already represent fuzzy areas approximately by encoding them as crisp[1] areas, sometimes with masked boundaries, or accompanied by notes that warn that the locations and extents may vary. This is not considered satisfactory because:

- There is no way to portray the steepness of variation of likelihood of being “in” or “out” of the condition indicated by the areas.
- Visual indications of approximate areas still look like crisp areas with well-defined boundary; the mariner must expend extra cognitive effort on analysing the fuzziness aspects.
- Software can only make binary in/out determinations since probability distributions are not available.
- Variability of location and extents depending on time of day, tide, or other conditions cannot be encoded.
- Magnitudes in the current model of uncertainty are too small for the approximations needed. For the existing system of Zones of Confidence, even CATZOC “C” corresponds to positional uncertainty of ±500m, all uncertainties larger than that are classified as D.

2.3 Representation of fuzzy areas

Fuzziness in two spatial characteristics of the areas must be represented: location and extent. In theory for areas it is always the boundaries that are approximate, but in practice it is sometimes useful to distinguish between location and extent (examples below). Location means a nominal *location* of the area in terms of (for example) a centroid, center of mass, center of a circle, or centroid of bounding box, or convex hull, and the extent of the area, i.e., *where* the transition from interior to exterior occurs. Either or both of location and the boundary may be fuzzy.

Some approaches to representation are, described below.

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[1] “Crisp areas” is a retronym coined in the research literature to differentiate ordinary, well-defined, non-approximate spatial primitives from fuzzy or approximate areas.

2.3.1 Likelihood functional gradients

The likelihood of a specific location being in or out of the area is described by a mathematical function over a spatial region, either geo-referenced by means of lat/lon coordinates and extent, or referenced to a base curve. The domain of the function or the area of the distribution would be a geographical region (not necessarily a rectangle) and the range a real interval (say [0.05, 1.0] for 5% to 100%) representing the likelihood of a specific location being in the area.

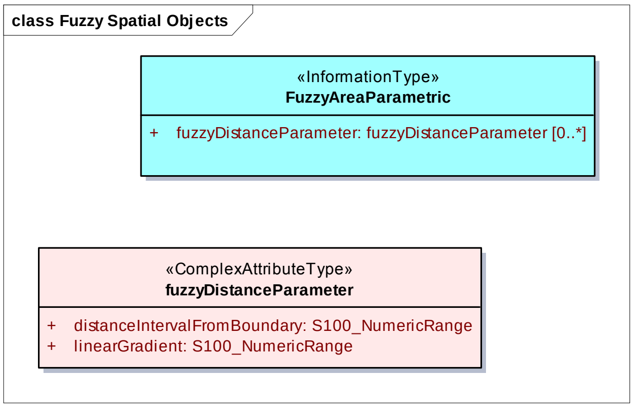

Figure 1. Model of likelihood functional gradient by distance from boundary

[Insert figure depicting functional gradients over space and parametric gradient.]

2.3.2 Likelihood grids

These are similar to likelihood gradients, but described by a grid of likelihood values instead of a mathematical function. Values can be interpolated to form a likelihood surface. In general a TIN or Riemann grid (S-100 Figures 8-10, 8-11) is likely to be used but regular grids are not excluded.

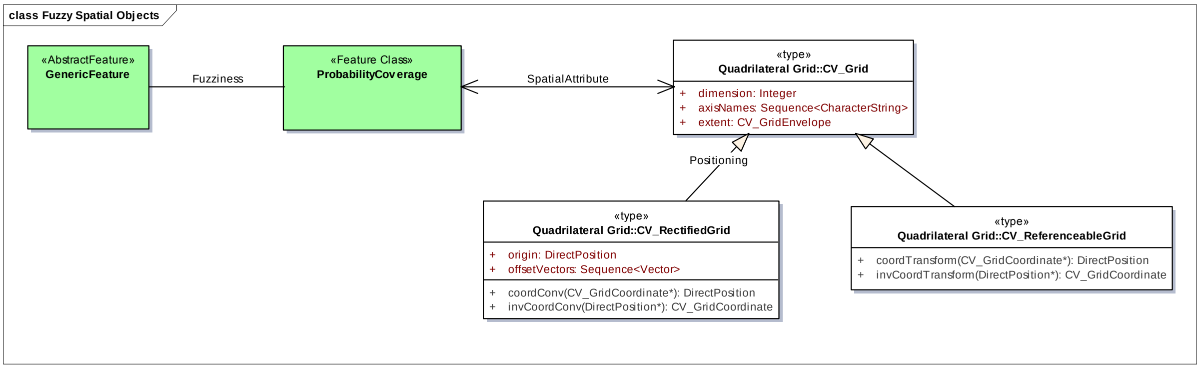

Figure 2. Model of grid-based approach

2.3.3 Likelihood zones and contours

This approach just defines a set of touching polygons representing stepwise likelihood of a location being within the areas, ranging from (say) 5% to 100%. The number of steps would have to be determined by NIPWG but 2-5 intermediate levels may be appropriate.

Likelihood contours around areas might be encoded in datasets, computed from one of the above approaches on the production side. This would add some curve features associated to the base feature and is almost the same as the zones method only with curves representing contours instead of polygons representing zones.

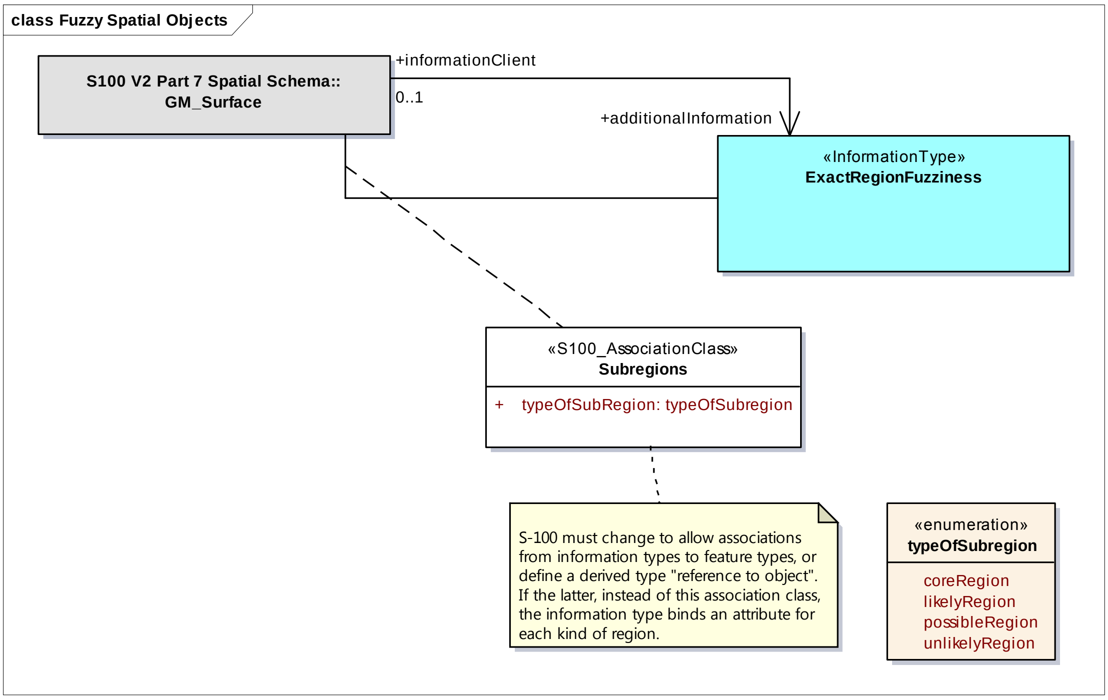

Figure 3. Feature-independent model of zones. This approach does not require any change to the feature model in individual applications schemas

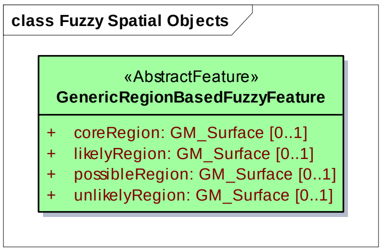

Figure 4. Alternate model. Each fuzzy feature carries attributes for each of its fuzzy sub-regions

Another alternative is to define a generic "FuzzyZone" feature with a single attribute for the strength of the association to the core (either a percentage or a ordered list of predefined intervals of strength). Instances of this feature are associated with the core feature to define the less likely outlying zones.

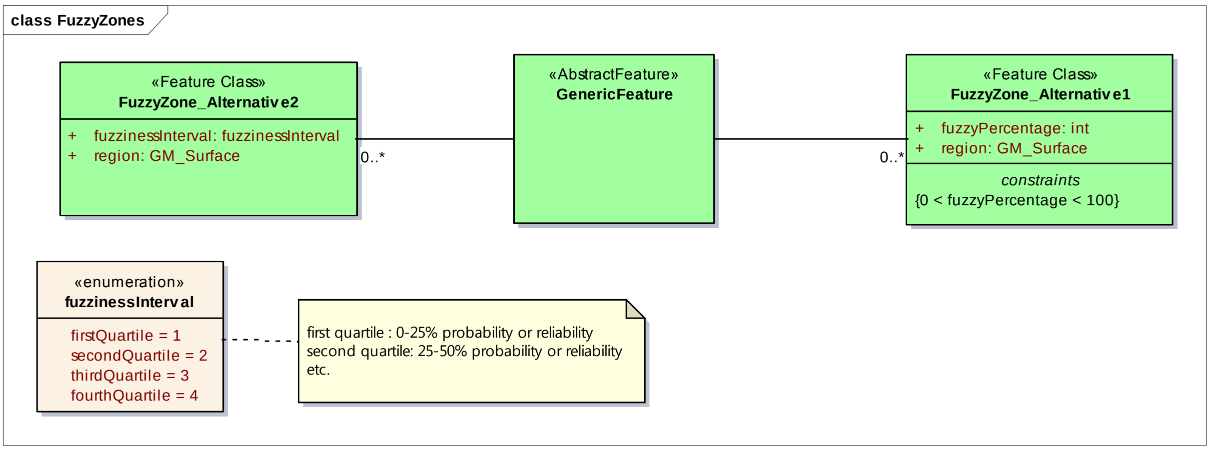

Figure 5. Another alternate model - generic zone features carrying attributes for the degree of fuzziness

2.3.4 Smooth curves for estimated boundaries, zones, or contours

Since the areas are approximate, it is generally not necessary to define crisp boundaries for their sub-regions. Estimated or approximate boundaries could be represented by smooth curves offset from the nominal boundary, circles, annular rings or sectors, smooth offset curves. Existing curve primitives could probably suffice since the encoder can draw smooth curves at the appropriate distance.

2.3.5 Areas whose boundaries are definite but unknown

Depending on the amount of uncertainty, the most suitable approaches may be portrayal-based (e.g., a shadowed curve) or zone/contour-based.

2.3.6 Fuzzy terms

Fuzzy terms include, example “in the vicinity of”, “near”, etc., relative to a specific feature, landmark, or location coordinates. Formalization of a restricted vocabulary of such terms and what they mean in terms of fuzziness would go a long way here.

Another approach would be using an association class to link the subject and object of such terms, with the term itself encoded in an attribute of the association class. An enumeration or codelist of such terms should be developed.

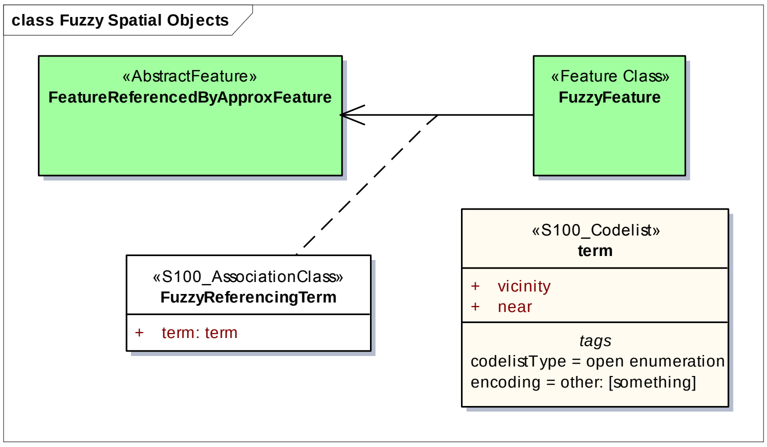

Figure 6. Association-based model of fuzzy terms referencing a fuzzy area to a base feature

2.3.7 Dynamic areas

Dynamic areas are areas whose location or extent varies with time or other factors. In addition, the boundaries of the area may be estimated or unknown. Examples are the areas of dangerous waves identified off the Norwegian coast. Dynamic areas can be represented by one of the other methods plus additional information to describe the variation, e.g., an information type encoding the parameters, variables, and functional form of the variation. The variables would be information like other thematic attributes, time of day, time relative to tide, natural conditions, etc. If spline curves are introduced, it is theoretically possible to define variations by defining trajectories for the control points. Similarly, a parametric primitive such as circle by center point and radius or offset curve can be varied by describing the variation of control points or a parameter, e.g., a circle could be moved by moving its center and a grown or shrunk by varying its radius.

Figure 7. Hypothetical portrayal of dynamic dangerous wave area

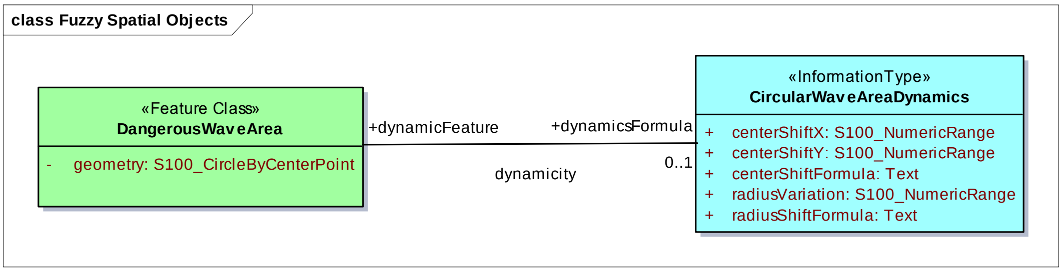

Figure 8. Dynamic fuzzy area modelling - hypothetical example

2.3.8 Use or extension of data quality information

Applying the attribute **quality of position** to the relevant boundary on the spatial attribute with value 4 (approximate) indicates that the boundary is approximate but provides no indication of the magnitude or extent the uncertainty.

Use a positional uncertainty value attached to the boundary curve is in principle feasible, but the magnitudes of uncertainties would need to be appropriate and the precise semantics of uncertainty for curves need to be defined (e.g., does it mean displacement of the curve as a whole, radial uncertainties for each individual point in the segments, or something else?)

2.3.9 Observations about the approaches

2.3.9.1 Similarity to bathymetric surfaces

Several of these approaches amount to defining a likelihood surface, analogous to the bathymetric surface. The "zones" approach is analogous to depth contours. Bathymetry portrayal concepts should transfer to fuzzy objects with some adaptations. This direction should be further explored especially for portrayal.

2.3.9.2 Complexity

The problem with likelihood gradients and functional representations of dynamics is mainly that S-100 was not designed for representing dynamic data, e.g., it does not allow operations in UML application schemas, and therefore encoding functional dependencies in an object/attribute model can get unnecessarily complicated.

2.3.9.3 Provisions in S-100

The S-100 GFM and application schema rules allow features to have more than one spatial attribute. This is in S-100 3-6.5.2 ("Spatial characteristics of a feature shall be described by one or more spatial attributes".) E.g., an Administration Area with location indicated by the usual Surface spatial primitive and another attribute "authorityOfficeLocation" of type Point giving the location of the administrative office of the controlling authority. Data formats, in particular the ISO 8211 format, may need to be updated to accommodate this.

2.4 Zones of fuzziness

To avoid a proliferation of slightly different definitions of fuzziness, NIPWG and other interested working groups (S-124?, S-100?, DQWG?) could define a system for categorizing positional uncertainty similar to the CATZOC system, but limited to positional uncertainty (CATZOC considers depths too), and with break points at values that are more realistic for the types of fuzziness encountered in nautical information, as in the examples above. (The current CATZOC system appears too fine-grained in distinguishing categories by meters and 10's of meters.)

Possible criteria and examples are in the table below (BB = bounding box; ZOF = zone of fuzziness).

ZOF	Location Accuracy	Boundary uncertainty	Temporal variability	Other variability	Reliability or Probability	Terms

X	±1NM to ±2NM	5% of BB diagonal	(dependency on time of day, season, etc.)	(dependency on wind, water level, tides, etc.)	90%	in the vicinity of
Y	±2NM to ±5NM	10% of BB diagonal			75%	near

2.5 Portrayal

Portrayal of fuzzy areas should be addressed in detail later, but in general depiction of a likelihood shadow, e.g., by a thicker line, shadows, solid or gradient colours, or thinner or grey line or lines at specific likelihood contours.

The simplest approaches to depict are probably likelihood zones which could be treated as just polygons of different symbol / hash densities, color, etc. Likelihood contours might be depicted as curves either with or without a visual association to the 'core" (on the same principle as limits of territorial seas and the relevant coastline or baseline).

Other options include a decorated boundary e.g. hachures, or broken zigzag lines, etc.

The processing power needed for portrayal should be considered when developing portrayal rules and symbols.

2.6 Application logic

General consequences for application logic are TBD.

3 Recommendations

1) The initial implementation should be focused on likelihood zones/contours and on the "fuzzy terms" association class approach.
2) Dynamic areas can be partially implemented using tractable primitives i.e., circles and rectangles.
3) S-100: Extend the encodings (Part 10a-10b) to allow roles in feature / spatial object bindings (e.g., SPAS in the ISO 8211 encoding).
4) S-100: Update the ATTR field to allow spatial objects or references to spatial objects as attribute values.
5) S-100: Add "annulus" and spline curves to the spatial types in part 7. Part 9 (Portrayal) already defines an "annulus" class in the Graphics package. Spline curves are defined in ISO 19107.
6) S-100: As an alternative to spline curves, define a spatial type for "smoothed offset curve" – this would be a curve that is offset an approximate distance from a base (composite) curve with the shorter segments smoothed. [This type is speculative and might be difficult to implement, details have to be worked out.]
7) S-100: The portrayal catalogue should be reviewed to evaluate whether it allows for desired symbology types, e.g., shadowing.
8) S-100: Allow operations in application schemas, in order to describe area dynamics, or otherwise introduce a model of moving features.
9) NIPWG/DQWG: Define a system for categorizing fuzziness. The initial development of this system may be more suitable for NIPWG since NIPWG members can be expected to be more familiar with the significance of terminology and magnitudes of approximations.
10) NIPWG: Consider options for portrayal of fuzzy areas, including (i) what approaches from bathymetric data are relevant and how they should be adapted, and (ii) what information is needed for different types of portrayal. For example, if a symbolization of a varying area uses arrows to indicate the variation, there must be information which can be converted to magnitude and direction as well as the temporal

dependency. The actual portrayal and symbology in a product specification would be a matter for individual specification development groups.

11) S-100: Whether any changes are needed to part 9 (Portrayal) remains to be evaluated.

Changes to the S-100 GML encoding should be small, or just clarifications, since GML 3.2.1 already allows for multiple spatial attributes, but the ISO 8211 encoding would need to be extended.

The spline and smoothed offset curves should simplify encoding regional boundaries (i.e., of different likelihood zones). They should also allow representation of some variations of position, if simple functions describing the variations in the positions of the control points can be encoded (with tool support). Since they are intended for approximate spatial types, precise coordinates should not be needed in general (this relaxation should be re-evaluated for each data product).

4 Impacts

The recommendations for the S-100WG and the NIPWG should involve a small-to-moderate amount of preparation and group evaluation spread over 2-3 meetings of the S-100WG and NIPWG.

Application software would ultimately have to be updated to process new spatial types. Impacts of different approaches would vary, with "zones" concept having a low impact and functional forms needing more extensions. Backward compatibility would depend on what changes are made to the ISO 8211 encoding. Overuse of the more powerful forms such as gradients and likelihood grids.

The impacts relating to adding support to the GML encoding should be minor. Impacts of the additional spatial types on supporting tools should be low since functionality needed for features already in S-100 could be reused.

5 References

[FS1] North Atlantic Right Whale Fact Sheet, NOAA Fisheries, Southeast Regional Office. Location: <http://sero.nmfs.noaa.gov/protected_resources/outreach_and_education/index.html> (retrieved 12 Jan 2016).

[FS2] North Atlantic Right Whale Seasonal Distribution and Habitat Use (Fact Sheet), NOAA Fisheries, Southeast Regional Office. Location: <http://sero.nmfs.noaa.gov/protected_resources/outreach_and_education/index.html> (retrieved 12 Jan 2016).

[Annex B] Extract from Norwegian sailing directions, describing dangerous wave areas off the Norwegian coast.

6 Conclusion

In the broader universe of maritime information, there are different kinds of approximate or fuzzy areas whose spatial reality or dynamic nature cannot be properly represented by ordinary modeling and "crisp" spatial primitives. This problem has turned up in nautical publications and marine safety information.

The possible approach of representing approximate or fuzzy areas by ordinary spatial primitives which are marked as "approximate" is insufficient because:

- it is not capable of capturing the different types of fuzziness that exist in reality;
- there are too few details about the nature and magnitude of the fuzziness for software to do much intelligent processing or portrayal;
- representing them as ordinary primitives with an "approximate" marking places a heavy cognitive load on the mariner to understand the nature and extent of the fuzziness.

For descriptions which are purely textual (i.e., in a nautical publication or a text note in an ENC or other S-100-based dataset) the latter two points apply with enhanced force, since software cannot even access the details of the fuzzy or approximate nature.

There is no single solution to representing all the different kinds of fuzziness. This paper outlines different methods of approaching the different types of fuzziness. Some approaches can be implemented with the current S-100 framework, others need extensions to current approaches to data quality and portrayal, and others need extensions to the S-100 framework. The problem needs to be discussed by different IHO S-100-related working groups, and different aspects or solution approaches addressed by different groups.

7 Actions Requested

The S-100WG is invited to:-

- discuss the recommended changes to S-100, and make a preliminary endorsement or recommend functional alternatives to each;
- define a plan and schedule for detailed proposals and markup, and their subsequent evaluation and integration into S-100;
- liaise with other relevant working groups to finalize the details of the updates to S-100.

The NIPWG is invited to:

- consider whether and which of the proposed solutions meet the needs of nautical information product specifications;
- determine a priority order for the selected approaches;
- formalize a system for classifying degrees of fuzziness in nautical information, perhaps based on the CATZOC system for ENCs adapted on lines similar to the "zones of fuzziness" proposal in this paper;
- recommend alternate approaches as appropriate;
- liaise with other relevant working groups to finalize the details of the updates to S-100.

The DQWG is invited to:

- consider the recommended changes that pertain to data quality modelling, encoding, and processing;
- define a plan and schedule for detailed proposals and markup and their subsequent submission to the S-100WG;
- liaise with other relevant working groups to finalize the details of the updates to S-100.

Annex A. CATZOC classifications

<table>
<tr><th>ZOC</th><th>Position Accuracy</th><th colspan="2">Depth Accuracy</th><th>Seafloor Coverage</th><th>Typical Survey Characteristics</th></tr>
<tr><td rowspan="3">A1</td><td rowspan="3">± 5 m + 5% depth</td><td colspan="2">=0.50 + 1% depth</td><td rowspan="3">Full area search undertaken. Significant seafloor features[1] detected and depths measured.</td><td rowspan="3">Controlled, systematic survey[2] high position and depth accuracy achieved using DGPS or a minimum three high quality lines of position (LOP) and a multibeam, channel or mechanical sweep system.</td></tr>
<tr><td>Depth (m)</td><td>Accuracy (m)</td></tr>
<tr><td>10
30
100
1000</td><td>± 0.6
± 0.8
± 1.5
± 10.5</td></tr>
<tr><td rowspan="3">A2</td><td rowspan="3">± 20 m</td><td colspan="2">= 1.00 + 2% depth</td><td rowspan="3">Full area search undertaken. Significant seafloor features[1] detected and depths measured.</td><td rowspan="3">Controlled, systematic survey[2] achieving position and depth accuracy less than ZOC A1 and using a modern survey echosounder[3] and a sonar or mechanical sweep system.</td></tr>
<tr><td>Depth (m)</td><td>Accuracy (m)</td></tr>
<tr><td>10
30
100
1000</td><td>± 1.2
± 1.6
± 3.0
± 21.0</td></tr>
<tr><td rowspan="3">B</td><td rowspan="3">± 50 m</td><td colspan="2">= 1.00 + 2% depth</td><td rowspan="3">Full area search not achieved; uncharted features, hazardous to surface navigation are not expected but may exist.</td><td rowspan="3">Controlled, systematic survey[2] achieving similar depth but lesser position accuracies than ZOCA2, using a modern survey echosounder[3], but no sonar or mechanical sweep system.</td></tr>
<tr><td>Depth (m)</td><td>Accuracy (m)</td></tr>
<tr><td>10
30
100
1000</td><td>± 1.2
± 1.6
± 3.0
± 21.0</td></tr>
<tr><td rowspan="3">C</td><td rowspan="3">± 500 m</td><td colspan="2">= 2.00 + 5% depth</td><td rowspan="3">Full area search not achieved, depth anomalies may be expected.</td><td rowspan="3">Low accuracy survey or data collected on an opportunity basis such as soundings on passage.</td></tr>
<tr><td>Depth (m)</td><td>Accuracy (m)</td></tr>
<tr><td>10
30
100
1000</td><td>± 2.5
± 3.5
± 7.0
± 52.0</td></tr>
<tr><td>D</td><td>worse than ZOC C</td><td colspan="2">Worse Than ZOC C</td><td>Full area search not achieved, large depth anomalies may be expected.</td><td>Poor quality data or data that cannot be quality assessed due to lack of information.</td></tr>
<tr><td>U</td><td colspan="4">Unassessed - The quality of the bathymetric data has yet to be assessed</td><td></td></tr>
</table>

Annex B

KAPITTEL IX

Charting of dangerous wave areas on the Norwegian coast

Introduction

Waves and their affect on navigation have been the object of great attention in recent years. Studies have shown that waves in certain circumstances can capsize ships or cause severe damage to them. The studies have, among other things, analysed which conditions contribute to the cause of extreme or dangerous waves.

It is therefore now possible now possible to give a more representative account of wave conditions along the coast and continental shelf.

Description of dangerous areas

Example

Area 18 (58 ° 48 'N 05 ° 26' E)

Skotamedgrunnen. The dangerous area extends about 2 nautical miles around the shoal in SW-NW direction. Depths vary from 40 m to the west, to 16 m east of the given position.

Waves from SW to NW will create heavy seas in the area. From NW a refraction center will occur in the shoal area and with frequent west going current of 1-1.5 knots, the conditions will worsen. Heavy breakers have been observed in the area.

Area 19 (58 ° 15 'N 06 ° 20' E)

Siragrunnen lies off the channel to Åna-Sira, where the depths vary from 10 to 100 m.

Current conditions in the area are very variable. A little further off shore the current flows northeastwards. There is a tendency to opposite direction between the shore and the coastal current. The outgoing current at the entrance to Åna-Sira is reported to be as much as 3 knots.

Siragrunnen should be avoided bad weather. Together with wind from SE through S to NW, the variable current conditions create rough seas. Even without the current, the bottom configuration will mean that refraction centers will form on the shoal with waves from W to NW.

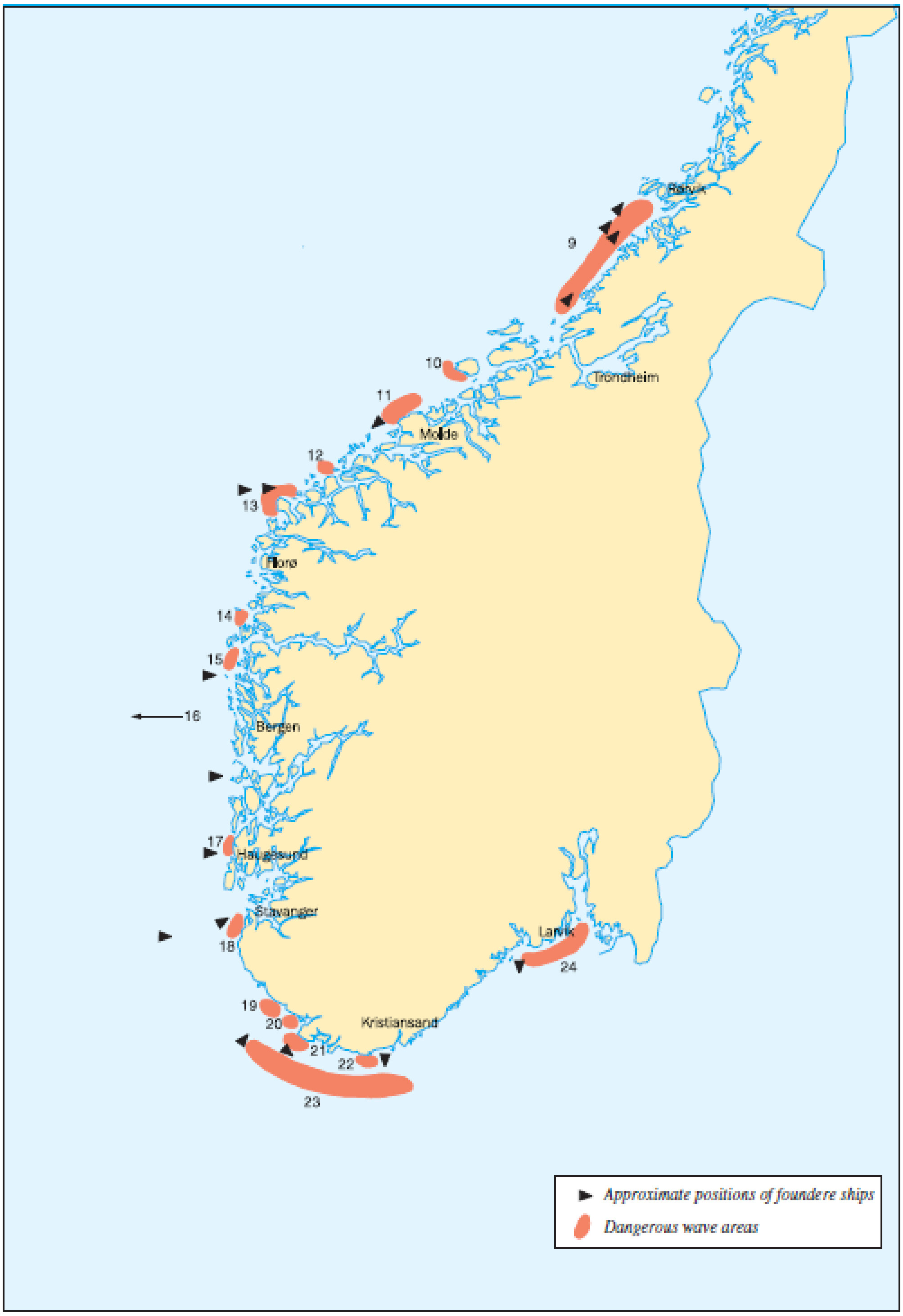

Fig 22a Spesielt utsatte områder langs kysten

Note: FOR REASONS OF ECONOMY, DELEGATES ARE KINDLY REQUESTED TO BRING THEIR OWN COPIES OF THE DOCUMENTS TO THE MEETING