# Hydrographic Survey with Autonomous Surface Vehicles:

A Best Practices Guide

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## Abstract:

Increasingly, hydrographic offices are turning to robotic, unmanned, and "autonomous" surface vehicles (ASVs) to conduct systematic seafloor surveys for hydrographic applications. The practice of hydrographic survey is categorically different from general navigation of transiting commercial vessels whose operation may fall under other guidance. In establishing best practices for operation of ASVs for hydrography, environmental and other risks are considered, and practical levels of autonomy are defined. Environment and level of autonomy are then evaluated to establish a suitable level of supervision to meet the intentions of the Convention on the International Regulations for the Prevention of Collisions at Sea (COLREGS) and other Navigation Rules.

## Overview

Increasingly, hydrographic offices are turning to robotic, unmanned, and "autonomous" surface vehicles (ASVs) to conduct systematic seafloor surveys for hydrographic applications (nautical charting) (Figure 1.). The term "autonomous" is set in quotes to acknowledge the spectrum of capability of these vessels, which varies from those that are remotely piloted (but possibly either manned or unmanned), to those that have some auto-pilot capability, to those that have the ability to react to their local environment, for example to avoid hazards and other ships while optimizing data collection. Data on which these reactions are based may be provided to them or sensed on their own.

**Figure 1. The Center for Coastal and Ocean Mapping's *Bathymetric Explorer and Navigator (BEN)* conducting seafloor survey within the U.S. Thunder Bay National Marine Sanctuary, Lake Huron, 2018.**

The practice of hydrographic survey is categorically different from general navigation of transiting commercial vessels whose operation may fall under other guidance. Hydrographic survey involves the systematic ensonification of the seafloor, usually in "lawnmower" patterns whose lines extend along contours of constant depth. During survey, launches do not often follow prescribed or traditional transit lanes but often operate within those lanes. Survey launches may operate in tandem or independently, covering separate areas within a region; their base of operations may be on shore or a parent survey vessel.

This document seeks to provide a set of best practices for operation of ASVs conducting hydrographic survey, and whose operations are focused on this unique application. The intent of this document is to propose guidance for safe operation and good seamanship based on real-world experience and by complying with the intent of the Rules set forth by the 1972 International Regulations for the Prevention of Collisions at Sea (COLREGS)[1] and other

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[1] In the United States, rules pertaining to safe navigation from COLREGs and other U.S. provisions are provided for mariners in a single document titled "Amalgamated International & U.S. Inland Navigation Rules", the authoritative version of which is available in text form online and within the *U.S. Coast Pilot* (See References).

provisions that may be in force in U.S. or other State regulations. In a few cases, recommendations made here may conflict with existing regulations, either because those regulations do not explicitly address autonomous systems or because in our experience the capabilities of autonomous systems, and the expectations of other mariners, are such that additional caution is warranted. Organizations should augment or modify these recommendations to ensure safe operation and comply with regulations as necessary.

## Levels of Environmental Risk, Autonomy and Supervision

To provide a framework for operation of ASVs one must define some basic terminology. Not all scenarios and conditions can be covered practically, but from these descriptions one may extrapolate best practices as capabilities and conditions change.

### Environment:

Operational environments range geographically from harbor areas in which navigation hazards, fishing gear, and other vessels are sure to be encountered, to the remote areas in which it is unlikely that an autonomous vessel will encounter either obstacles or other vessels at all. Similarly, areas with high currents require different considerations from those without, particularly when the currents may push a vessel not under command into shoal areas or traffic channels. Weather and sea state further complicate these environments, often requiring a reassessment of the levels of autonomy and supervision required to meet a given level of tolerable risk. Low, Medium and High risk environments are defined here to guide decision making when operating ASVs.

**Low Risk Environment:** A low risk environment is one in which other vessels, fishing gear, and navigational hazards are unlikely to be encountered. Weather and seas are benign.

**Medium Risk Environment:** A medium risk environment is one in which other vessels may be encountered, but neither recreational boaters, which do not typically carry AIS and are difficult to detect, nor fishing gear are expected. Other navigation obstacles, such as rocks, reefs, and kelp, may be encountered but are unlikely, or can be avoided through careful mission planning. Weather may include winds to 25 knots, and chop and swell conditions that require additional caution when deploying and retrieving the vehicle, either normally or manually.

**High Risk Environment:** A high-risk environment is one in which other vessels and/or fishing gear are likely to be encountered, possibly including recreational boaters. Other navigation obstacles such as shoals, rocks, reefs and kelp may be present and unavoidable to achieve the survey objectives. While unforeseen conditions do arise, weather and sea state conditions that are considered high-risk should simply be avoided, period.

## Levels of Autonomy

In 2015, NOAA's Hydrographic Systems and Technologies Branch (HSTB) hosted a workshop to explore and evaluate the state of the art of autonomous systems. Although definitions of autonomy have been proposed in other communities, attendees at this workshop defined a set of *practical* levels of autonomy to provide a common understanding through the discussions. The group envisioned levels of autonomy for navigation, sensors (payload sonars and subsystems) and vehicle self-awareness. An abbreviated version of these are adopted here. Note that the capabilities of a given ASV do not always fall cleanly into one level or another. For example, an ASV might be equipped with a lidar based collision avoidance system (Level 4 – Advanced Autonomy) but is unable to monitor the depth beneath the keel to keep from running aground (Level 1 – Piloting). These nuances become important during operations to ensure a proper level of supervision is applied for the available level of autonomy.

**Level I - Remote Piloting:** Remote piloting of a vessel is the act of manually controlling thrust and rudder movements through a telemetry link to the vessel. It involves no autonomous behavior.

*An ASV attains Level 1 Autonomy through "manual mode" with a joystick control interface.*

**Level 2 - Basic Autonomy:** Basic Autonomy involves the ability to follow a pre-planned fixed mission consisting of a sequential list of waypoints, lines, loiter points and combinations of these without operator interaction. With some exceptions the only inputs are the vessel's position and heading (from onboard sensors) and the desired point to reach. Generally, the only outputs are thrust and control surface (rudder) angles.

*An ASV provides Level 2 (Basic Autonomy) through the layout of a multi-point track-line on a graphical user interface. In addition, in hydrographic survey applications line files created in other software such as Hypack and exported in the "L84" format or in Qinsy through other mechanisms might be loaded into the ASV mission planner. These track lines are then "executed" programmatically through the interface and the ASV will follow these lines, automatically.*

**Level 3 - Intermediate Autonomy:** Intermediate Autonomy involves the ability to adjust a pre-planned mission in a reactionary way to fixed (i.e. not dynamically sensed) input according to fixed rules, for example, to avoid shallow water, charted hazards to navigation, or a polygon of prohibited operational area.

*An ASV provides Level 3 (Intermediate Autonomy) by providing the ability to specify a "geofence" within which the ASV will not enter when in any autonomous mode, or to load a chart and use it to avoid hazardous areas.*

*An ASV may also have the ability to follow the path of the operator's vessel at a fixed distance astern and with optional fixed athwartships offset.*

**Level 4 - Advanced Autonomy:** Advanced Autonomy involves the ability to adjust a pre-planned mission in a reactionary way to dynamically sensed conditions, for example, to detect and avoid previously unknown buoys, lobster pot floats, other vessels, to follow and/or track another vessel and to moor by anchor or pier without user intervention.

*An ASV provides Advanced Autonomy when it can dynamically avoid AIS contacts, or contacts detected in radar or lidar. Note that these sensors can "detect" obstacles at different ranges and vehicles that can detect and avoid objects at one range but not another can only be said to have limited advanced autonomy.*

**Level 5 - Planning:** Planning involves the ability of an ASV to make a major adjustment or totally create a mission based on a deliberative consideration of objectives, fuel/power physical constraints, and both previously known fixed obstacles, and real-time sensed, possibly dynamic ones as well as sensor states and other parameters.

*No ASV can yet provide autonomy at this level.*

## Levels of Supervision

**Attended:** Attended operation involves continuous supervision of an autonomous vehicle by vigilant watch-standers, ready to take action in the event of any untoward event. Remote piloting (Level 1 autonomy) is attended operation, by definition. However, any other level of autonomy may be attended or not. Operations without constant telemetry cannot be "attended" operation, but rather qualify as "Monitored" or "Independent".

**Monitored:** Monitored operation involves cursory supervision of a vehicle, affording an operator the ability to focus on other tasks, but ensuring normal operation at regular periodic intervals and relying to some extent on warnings and alarms from the vehicle in the event operator assistance is required. Monitored operation requires basic (Level 2) vehicle autonomy at a minimum (the ability to follow a sequential mission plan), but also the ability to invoke remote piloting and even physical intervention when necessary. Therefore, monitored operation requires a suitable telemetry link and operation within sufficiently close proximity to intervene if required.

**Independent Operation:** Independent operation involves little direct supervision of a vehicle other than periodic review of operations and status, relying largely on warnings and alarms to notify the operator of faults and events requiring assistance. Independent operation also requires a complete mission plan composed of a sequential list of mission objectives and/or vessel behaviors under various circumstances, autonomously executed (Levels 2-3 or above), for both the vessel and its payload sensors. When under independent operation, telemetry links may be inadequate to support remote piloting and distances may be too far for any timely physical intervention.

## Levels of Risk

For any given operation, the environment, level of autonomy, and level of supervision of the system determines a level of risk, where risk is broadly defined as risk to property and personnel as well as risk of not successfully achieving the mission. No operation is risk free, and these recommendations are designed to mitigate the different kinds of risk involved in operating unmanned systems.

Many hydrographic offices are already familiar with the practice of Operational Risk Management (ORM) and the application of those procedures to small boat operations. These procedures are particularly suited to ASV operations, and we recommend the adoption of this kind of model. However, because ASVs are complex robotic systems in early stages of development, additional consideration must be paid to the health of the system and the operator's ability to respond to failures of the system should they arise.

## Best Practices

### ASV Color, Lights, and Signals

These items can be controversial because there remains no explicit guidance for unmanned systems within the Navigation Rules (including COLREGs). What is proposed here is a common sense approach designed to adhere to existing guidance where possible and to mitigate risks otherwise.

1. **The ASV should be conspicuously marked with bright yellow, orange, or red paint.**

   Such paint schemes are atypical for other vessels and will serve to make the ASV clearly visible and distinguish it from others.

2. **The ASV should operate navigation lights at all times, day and night.**

   Although not required from sunrise to sunset, the shape of some ASVs can be so different from manned vessels that their apparent heading can be difficult to discern. Operation of navigation lights can aid other mariners in discerning the ASV's heading.

3. **Operate an alternately flashing red and yellow light signal aboard the ASV at all times, located so that it does not interfere with other navigation lights.**

   Operation of a red and yellow flashing light clearly signals to other vessels the unusual nature of the ASV. In our experience, safety is increased when other mariners recognize an unmanned vessel conducting survey operations as out-of-the-ordinary. This particular light configuration is recommended by the U.S. "Inland Rules" for public safety operations, and it is in the spirit of that provision, namely to provide special indication for a vessel conducting a public safety activity (seafloor survey) that it is recommended here, for both inland and international waters. The recommendation to also adopt this configuration for international waters comes with careful regard to guidance provided by "Rule 20" of COLREGS, which generally discourages "alternative" lighting configurations so as not to cause confusion with those required by the Rules. Alternating flashing red and yellow lights do not otherwise exist in the international rules and would be highly unlikely to be mistaken for other configurations.

The exact text for this lighting configuration and its precautions warrants repeating verbatim:

*Annex V, Section 88.12 "Public Safety Activities":*

> (a) Vessels engaged in government sanctioned public safety activities, and commercial vessels performing similar functions, may display an alternately flashing red and yellow light signal. This identification light signal must be located so that it does not interfere with the visibility of the vessel's navigation lights. The identification light signal may be used only as an identification signal and conveys no special privilege. Vessels using the identification light signal during public safety activities must abide by the Inland Navigation Rules, and must not presume that the light or the exigency gives them precedence or right of way.

By adopting the guidance for public safety activities when operating in both inland and international waters one can increase the awareness of other mariners to the peculiar behavior and appearance of ASVs conducting those operations. ASV Operators are warned to heed the cautionary statements above; that such a light configuration conveys no privilege.

4. **Use of other lights or day-shapes, such as those for vessels "not under command" or "restricted in their ability to maneuver" is not recommended.**

It has been argued that an unmanned vessel, either because no human is aboard, or because the situational awareness can be limited, should fall into the categories of "not under command" or "restricted in their ability maneuver" as defined in COLREGS, Rule 3. COLREGs, indeed, lists vessels engaged in "surveying" in a list of examples of those restricted in their ability to maneuver. Such a designation would afford some right-of-way to ASVs conducting survey operations in meeting situations with other vessels not otherwise encumbered.

However, the utility of such a designation is in practice quite limited and serves to only provide a false of security. ASVs conducting hydrographic survey are typically small relative to other vessels and by the very nature of their nautical charting mission are often traversing relatively shallow waters that place a far greater constraint to navigation others. Any vessel constrained by its draft in a meeting situation with a surveying ASV would have right of way giving no utility to these designations. Experience has also shown that the lights and shapes for these designations tend to go unheeded by other mariners and can give ASV Operators a false sense of security, when the experimental nature of ASVs and the unfamiliarity on the water with them by other mariners warrants extra caution. Because these designations provide no practical utility and do not invoke the necessary caution that ASV Operators should exhibit it is recommended not to assume these designations.

## Operations

1. **Use a risk management guide to quantify and mitigate the risk associated with each deployment.**

   Prior to each deployment a risk management guide should be evaluated and reviewed by ASV operators, supervisory personnel (the ship's Captain, Officers and Mates when operating from ships at sea, or Operational Supervisors when operating from shore) and support staff (Engineers, Deck Hands and others). Risk management guides often come in the form of score sheets in which various elements of the deployment are evaluated either quantitively or qualitatively, or both. Elements include the capability and proper operation of vessels and equipment, weather and seas, prevalence of navigation hazards and other vessel traffic, experience of the operators, operator fatigue, and the availability of rescue equipment and staff in the event a vessel recovery is required. The scores in such a form provide helpful guidance in identifying risk in any operation and mitigating those risks whenever possible.

   As part of this review ASV operators should explicitly identify the level of supervision (Attended, Monitored, or Independent Operation) required for the operational environment, autonomy level of the ASV and its mapping systems, and capability of the operator's interface to indicate and warn operators of events. ASV operators should note when the appropriate level of supervision is expected to vary.

   For examples of risk management guides for manned vessels ASV Operators are directed to NOAA's Small Boat Standards and Procedures Manual and U.S. Coast Guard Risk Management documentation (*COMDINT 3500.3A* and *Risk Management Fundamentals*) and risk management tools such as the *NOAA Small Boat Operational Risk Assessment (GAR) Form* and the US Coast Guard *PEACE-STAAR-Job-Aid* (see the references for links to these documents). However ultimately it is recommended that ASV Operators generate their own scoring system, borrowing from these documents, tailoring the categories to their own systems and tuning the overall assessment of risk to the risk tolerance of the organization. (The risk tolerance for Coast Guard search and rescue is likely higher than that for hydrographic survey operations, for example.)

   While the scores in the risk management form provide a useful guide, ASV Operators are cautioned not to place undue emphasis on the numeric result. Studies by the National Academy of Sciences have noted that non-quantitative information is often as important as quantitative measures of risk to decision makers. Further the study found that attempts to aggregate widely disparate sources of risk with a common metric is likely to be misleading. (See "A Review of the Department of Homeland Security's Approach to Risk Analysis", National Academy of Sciences, pg 10.) **The most important function of the form is the candid discussion that it facilitates.** A cursory scoring without thoughtful deliberation can provide a false sense of the real risks involved and be even more dangerous. The scoring requires judgement for which no single point of view is likely to see all the implications, therefore ASV operators should seek to give voice to all involved and provide adequate time for this review.

Because decisions made with regard to risk mitigation are rarely black and white some examples are provided here to illustrate useful ways of thinking for ASV Operations.

- Even fully Attended operation may not be a high enough level of supervision, particularly if the ASV's sensors and operator interfaces do not provide good situational awareness. In this case additional monitoring can be provided by limiting operations to within visual line of sight or with other ancillary systems. In some cases, any ASV operation may be deemed too risky altogether.
- ASVs with little to no ability to automatically detect and identify hazards in their environment (Basic Autonomy and below) incur too much risk to be operated in Monitored or Independent levels of supervision when these hazards are likely to be present. In this case a human operator must be attentively monitoring telemetered sensor feeds to ensure vehicle safety.
- ASV's with no ability to autonomously maneuver to avoid hazards in their environment (Intermediate Autonomy and below) incur too much risk to be operated at an Independent level of supervision when those hazards are likely to be present.
- When considering the appropriate level of supervision it is important that the ASVs sensors, detection capability, and ability to autonomously react to those detections are matched to the hazards an operator expects to encounter. For example an ASV with no depth sounder and no autonomous ability to avoid shoals requires a higher level of supervision when operating near shore than when operating on the open ocean.
- User interfaces and data collection systems with no ability to audibly alarm may warrant fully Attended operation to ensure faults within these systems do not go unnoticed.

2. **When operating in the likely presence of other vessels, issue a Notice to Mariners, and VHF Sécurité calls at 4-hour intervals to provide indication of your operations.**

Notice to Mariners or Navigational Warnings will notify local commercial mariners and Coast Guard facilities of your operations. VHF Sécurité calls will provide more immediate warning to your presence. Use the following or similarly concise script:

"SÉCURITÉ" x3

"ALL STATIONS IN THE VICINITY OF [Local point of Interest]" x3

“THIS IS [Your ship/station identification]”

“UNMANNED VESSEL OPERATIONS ARE UNDERWAY IN THE VICINITY OF [or WITHIN X NM OF] [Local point of interest] FOR SEAFLOOR SURVEY. OPERATORS ARE STANDING BY CH 16”

“OUT”

3. **Follow COLREGS’s guidance for good seamanship, and follow the *spirit* of COLREGS when you cannot comply with Rules intended for manned vessels.**
   Simply put, no ASV can comply with the requirements set forth by COLREGS as they were envisioned for human vessel operators. The nuanced rules, which require the ability to properly detect and interpret lights, signals, day shapes, vessel type, vessel size, and many other conditions in addition to proper application of the “rules of the road” are beyond the capability of artificial intelligence for the foreseeable future. However, every ASV and its operator can comply with the spirit of COLREGS, namely, *the proactive prevention of collisions at sea*.

   Rules regarding Look-out (Rule 5), Safe Speed (Rule 6), Risk of Collision (Rule 7) and Action to Avoid Collision (Rule 8) are simply good practice for any mariner and should be adhered to by ASV Operators and provided for manually when warranted and not otherwise provided through automated technologies. While there may be no human look-out aboard the vessel, cameras, lidar, radar, audio monitoring equipment and other sensor systems can allow an operator or its artificial intelligence counterpart to “make a full appraisal of the situation and the risk of collision”. Similarly, an ASV operator should navigate the ASV “at a safe speed so that it can take proper action to the prevailing circumstances and conditions” (Rule 6). Rule 6 also specifies that vessels should adjust their speed accordingly based on the state of the wind, sea and current, the proximity of navigation hazards and shallow water, the “efficiency and limitations” of its sensing equipment, and the number and extent of hazards. These considerations remain good guidance for any ASV Operator. Rule 7 cautions the mariner to assume the worst when assessing the risk of collision, advises them to interpret sensor data skeptically, particularly when little information exists, and warns mariners of conditions indicating a possible collision situation such as a constant bearing rate to other vessels. Finally, Rule 8 states plainly that any action to avoid collision shall be “made in ample time”, “large enough to be readily apparent to another vessel”, “result in a safe passing distance”, and to “slacken speed” to allow more time to assess the situation. These same actions should be adhered to by ASV operators and provided for manually when the autonomy level of the vehicle is insufficient to do so for the anticipated risks.

4. **Never impede the passage of another vessel.**

ASVs for hydrographic survey remain small vessels whose capability and intent are difficult to interpret for other mariners. Thus, to ensure safety, always consider the ASV to be the “give-way” vessel in any crossing situation.

In doing so, give other vessels a wide berth, anticipate the effects of control failures when considering maneuvers, and hail other vessels in the immediate vicinity of the ASV to arrange passage when necessary. When hailing other vessels via VHF use the terms “unmanned vessel” or “robotic vessel”. Do not use the term “autonomous” to describe the ASV on the radio, as it is difficult to understand.

Experience has shown that it is extremely difficult for ASV Operators viewing a map display, radar, or camera feed to apply the appropriate amount of caution for a given range to another vessel (or even stationary hazard). The difficulty results in part from displays that represent the ASV or other vessels with an icon whose size is a fixed number of pixels regardless of zoom level. Other contributing factors include misperception that comes with varying map zoom levels, camera lens distortion and a general inability to translate 2D representations provided by maps and cameras into the mariner’s intuition afforded by a 3D environment. Great care should be made in determining safe passing distance from these interfaces with additional consideration for Rules 6 (Safe Speed) and 8 (Action to Avoid Collision).

5. **Mitigate the risks of near-shore operations.**

   Near-shore operations afford little room for equipment failure, as any untoward event can put the ASV into shoals or surf and lead to equipment loss. Therefore, carefully consider the health of telemetry and control systems, prior knowledge of the seafloor (or lack thereof) and prevailing winds, waves and currents. Navigate the vehicle over mapped portions provided by previous survey swaths that have been shown to be hazard free. Prepare and pre-position recovery teams such that they can field a recovery in a timely manner if necessary. Operate only in an Attended level of supervision.

## Telemetry

1. **Operate at least two independent telemetry systems.**

   Failed connectors, heavy rain or system failures can drop a telemetry link unexpectedly. Having a backup mechanism is important to keep any unmanned vehicle safe. These systems need not have the same range and bandwidth capability, but any backup system should afford the ability to establish a second connection to the vehicle (possibly repositioning operators to do so) and retask (at a minimum) or pilot the vehicle to safety.

2. **Operations outside real-time telemetry range should be done with caution, and routine monitoring.**

   Operation outside the range of real-time telemetry systems can increase flexibility by tasking vehicles to complete a survey without attended supervision. However, because of the difficulty in reliably detecting and avoiding navigation hazards and other vessels autonomously, these operations should only be conducted in areas in which encounters with these hazards and other vessels are unlikely. Routine monitoring can be achieved either by non-real-time telemetry updates, such as Iridium messaging, or by design of survey tasking such that portions of the survey are in sufficient proximity to operators to periodically re-establish real-time telemetry.

3. **Understand and anticipate the effects of a loss of telemetry.**

   No telemetry installation is perfect, and most have relative bearings in which the link is likely to be degraded or lost. Measure the quality, in terms of SNR and bandwidth, of telemetry links as a function of bearing and range to the operator station, so one can anticipate their loss.

   Some ASVs secure the vehicle's engine on loss of telemetry, others may station keep, and others may continue their last navigation tasking until that tasking is complete. It is important that operators understand the expected behavior and consider the implications of that behavior operationally. For example, an unexpected telemetry loss that causes the ASV's engine to shut down and sets it adrift can place the ASV in danger when operating near shore. Similarly, a loss of telemetry when the ASV is operating in the presence of nearby or moving hazards can prevent operators from intervening to redirect or pilot the ASV. Operators should select the behavior most appropriate to their operating environment when possible.

4. **Ensure survey data transfers over telemetry links shared by command and control do not compromise control of the ASV.**

   Often it is desirable to transfer the acquired survey data over the telemetry link to operators for troubleshooting or processing during survey operations. Care must be taken to ensure the increase in bandwidth consumed by the transfer does not preclude an operator's ability to monitor or interact with the ASV when an Attended level of supervision is necessary.

   Some ASVs operate dual telemetry links for the purpose of protecting command and control messaging from sensor payload bandwidth usage. When this is the case, it is important to continue to provide redundancy for the command and control link (item 1 above), which may be provided through the payload's telemetry system or through another system altogether.

## ASV Safety Features.

1. **Have an Emergency Stop button, in arm's reach of the operator station.**

   In the unlikely event of a control system failure while the ASV is operating in a confined environment, it is important to have a safety mechanism that can secure the ASV's propulsion immediately.

2. **Have an immediate "hover" capability in the ASV Operator's user interface.**

The ability to quickly hover a vehicle at an operator specified location with as few mouse clicks as possible greatly increases the safety of ASV operations. Immediate hover reduces the cognitive loading of the operator by placing the vehicle in a safe navigational state. An operator may then let a complex navigational situation develop or focus on configuration and operation of other systems without incurring additional risk while their attention is elsewhere. Immediate hover also facilitates multi-ASV operations allowing an operator to place one more vehicle in low risk conditions while focusing on the tasking or configuration of another.

**A Note on "Orbit" vs "Hover" behaviors:** ASVs often provide the capability to "orbit" the vehicle, in which the vehicle turns in tight circles at a constant speed around a stationary point. What is less common is the ability to "hover" in which the ASV repositions to a stationary point and maintains that position within some tolerance by drift-and-reposition or through low speed maneuvering to offset the effects of external forcing of wind and current. Both behaviors provide the ability to "park" a vehicle indefinitely while other vessel traffic develops. However, experience has shown that orbit behaviors are confusing and disconcerting to other mariners as they continuously try to anticipate the ASVs next maneuver. Human mariners expect a hover, however, as this behavior is precisely the method used by human operators to maintain position. Hover behaviors are always preferential to orbit behaviors for this reason.

3. **Provide an integrated map display showing ASV and operator station position to supervisory personnel (e.g. on the operator ship's bridge).**

Experience has shown that the mental image of the navigation and environmental situation held by an ASV Operator at their station and supervisory personnel (who may be on a ship's bridge several decks away) is rarely the same. To accommodate, parties must attempt to share sometimes complex information over a radio link between stations. The ability to rapidly convey concise meaningful information from one station to another to gain a shared understanding for both parties over radio communications is exceedingly difficult. The condition is greatly improved when the operator's station is within a short walk of the bridge, affording quick face to face point-and-clarify discussions between stations. But there is no substitute for the benefit of providing a common map display.

A good map display should contain the following:

- Position and heading of the ASV.
- Position and heading of the operator's station. The display of the operator vessel's heading is particularly important, as it allows rapid identification of the relative bearing to the ASV.
- A nautical chart and other background information affording a common perspective and scale to both parties. Without this information individuals are forced to mentally map positions of the ASV, the operator's ship, navigation

hazards, other vessels, and mission objectives between displays. Invariably the displays are not adjacent to each other, not zoomed to the same scale, do not use the same color encoding - the task is almost impossible.

- Basic status of the ASV, including emergency conditions, the status of the radio telemetry link and the ASV's expected track. These indications allow the bridge to anticipate the actions of the ASV, and understand when to inquire about its safety and when an unexpected maneuver is, in fact, normal.

An integrated map display is purposely placed under "Safety Features". Without such a shared view of ASV operations, the Officer on Watch and ASV Operators are tasked with overwhelming cognitive loading as they manage the safety of their respective vessels. A simple display can greatly increase the operational safety of both operations.

## Conclusion

It is an exciting time to be a hydrographer! The advent of unmanned and autonomous survey launches will bring about immense gains in survey efficiency, while increasing the safety of operations at sea and decreasing personal discomfort. New sensors, system interfaces and algorithms are being developed for unmanned systems at an increasing rate and these systems will have positive impacts on manned operations as well.

While there is not yet much in the way of regulations specifically for unmanned systems, there is plenty of guidance. That guidance can be found in all the usual places for manned vessels at sea and can be applied with common sense and an eye toward its intent when the guidance is clearly meant for humans aboard the vessel.

No operation at sea is risk free. Responsible organizations establish protocols and best practices to identify the risks and mitigate them wherever possible. When those risks cannot be mitigated to an acceptable level, one simply does not go to sea. Clear and open communication in this process is extremely important and made more so during the adoption of these new and relatively immature technologies.

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*Surveyor*. Guidance provided by the captain and crew of these vessels and their staffs have been invaluable and are greatly appreciated.

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