Authors' Commentary: Searching for Submersibles

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Introduction

On 18 June 2023, the *Titan* submersible went missing in the north Atlantic and became the headlining story for several days [Wikipedia 2024b]. It was carrying five passengers to visit the wreck of the *Titanic*. During the days between first hearing of the lost submersible and learning of its tragic fate, the genesis of this problem was formed.

The *Titan* stopped communicating with its host ship, *MV Polar Prince*, 1 hour and 45 minutes into its two-hour descent to the *Titanic*. Its overall mission was supposed to have lasted 8 hours. When it did not return at its scheduled time, it became the target of a massive search and rescue effort. The *New York Times* reported that "[n]umerous factors could hinder the ongoing rescue operation, including weather conditions, darkness, the state of the sea and water temperature" [Russell 2023].

Additional aspects of deep-sea exploration were reported that provided additional content for this problem [Wikipedia 2024b]. The safety measures on the *Titan* included a balloon, thrusters, and ballasts that could be dropped. It was expected to emit a safety ping every 15 minutes and had very limited text-messaging with the host. Acoustic beacons and other types of devices, found on many submersibles, can greatly accelerate the search process; but they were not present on *Titan*. Because of the lack

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of regulation for deep-sea dives in the open ocean, it was not clear what additional safety measures, if any, should have been considered.

The US Coast Guard, US Navy, Canadian Coast Guard, and other rescue ships arrived days later to assist in the search and rescue using specialized equipment that can reach the depths expected by this expedition [Wikipedia 2024b]. It took four days to find the debris field using modern technology, and the search is estimated to have cost several million dollars. This contrasts greatly with the *Titanic* itself, which sank in 1912 and took 73 years to find, albeit with considerably less emphasis on the "rescue" part. Similarly, the French submarine, *La Minerve*, was lost in 1968 in the Mediterranean and still took 50 years to find [French Minerve . . . 2019].

People's fascination with sunken treasures and shipwrecks is not new, but the ability for humans to see it is. Deep-sea tourism is a growing industry [Aguirre 2023], with safety concerns being one of the largest impediments. Our goal was to write a problem that challenged teams to think about the difficulties of deep-sea search and rescue along with the equipment needed to increase the chances for a successful operation.

Formulation and Intent of the Problem

The struggle inherent in authoring contest problems is to balance the real-world complexities within a tractable scope that enables the teams to focus on the most important aspects. The problem also cannot have a mathematical solution already published and publicly available. While there are many aspects of the *Titan* submersible that are interesting to study, we wanted the teams to think about search and rescue and how to save lives in this new and growing industry. Using the background of tourism, we were able to emphasize how mathematical modeling could be used to plan and create protocols that can ultimately help keep the submersibles and the industry afloat. We also wanted to avoid getting tangled in any of the engineering and other controversies associated with the *Titan*.

We needed to choose a good location. Since the *Titan* was in international waters, the regulations would need to be governed by international law. While it would be an interesting policy problem to consider how to determine regulations on this scale, we wanted to keep the focus on the immediate search-and-rescue aspects and avoid getting tangled in complex politics. One author was also reading Laura Trethewey's book *The Deepest Map* [2023], which includes discussions of mapping the ocean floor and how little is truly known about it. A more general problem would be to consider search and rescue in an environment that, in addition to not being able to use our senses, also does not have proper or complete maps. Again, we felt that this was beyond the scope of the main problem. After considering numerous sites, the Ionian Sea seemed like the best fit. Greece is the clear governing body, the Ionian Sea contains a number of ancient shipwrecks that make it a natural tourist destination, and the seafloor there is fully mapped. Additionally, the Calypso Deep (the deepest point of the Mediterranean Sea at over 16,000 feet [Wikipedia 2024a]) is in the Ionian Sea, which replicates the deep-sea conditions of the open ocean. The Caribbean Sea was included in the problem to have teams consider the adaptability of their methods to other locations.

The main component that we expected the teams to model was the search pattern. Unlike a typical search on land or at sea, a good model would have to account for the three-dimensional aspect, to include consideration of the seafloor and points of neutral buoyancy along with the surface search. We found at least one reference to underwater search-and-rescue patterns [Doornekamp 2021] that could possibly be used as a starting point to build a mathematical model. In considering additional equipment to accelerate the search process, cost is a crucial factor in determining what a company can include. Additionally, we wanted teams to consider how to adapt their models to a future where the submersible tourist industry has grown to a level that can accommodate more traffic. In the end, we felt that the resulting problem provided a good scope for the teams to study in a four-day contest.

Comments on the Results

The teams considered many factors to track and find a lost submersible. There were many quality models to track the currents and buoyancy effects on the submersible's possible location. In general, teams that analyzed a submersible reaching the seafloor, and/or was in neutral buoyancy traveling only with the currents, seemed to have quality approaches. There are other options, such as the submersible rising to the surface (if possible) or having some power for a time after loss of communication, or even others that make this problem rich with uncertainty.

Some teams handled the time component very well. The critical issue, particularly if the submersible carries people, in order to have the best chance of saving lives, is the time elapsed to a successful rescue. This race against the clock is important and what the government would likely care most about. It was nice to see many teams attempt to quantify the time for successful searches.

We were most surprised to see few teams consider the entire issue as a whole rather than three or more individual problems. For example, if a host ship only has sonar scanners, then the search process will be very different from one that has a remotely operated vehicle (ROV) to deploy in the sea. Thus, the search process should be connected with the types (and numbers) of search equipment that is anticipated to be required.

Additionally, there is the opportunity to bring in additional rescue ships in the event of an emergency, as was done with the *Titan*. However, we did not see many teams that considered additional equipment coming to help the search at a significantly delayed time. Such a back-up scenario may be a way to layer response needs.

Overall, the teams did an excellent job of charting the location of a lost submersible and searching for it. We hope this deep-sea exploration taught many students about the difficulty in studying oceans, and ultimately helps to make this growing industry safer.

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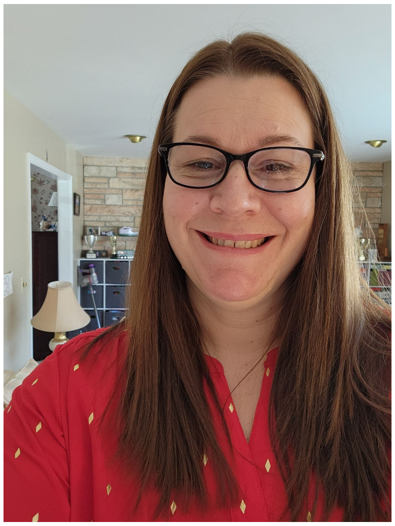

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