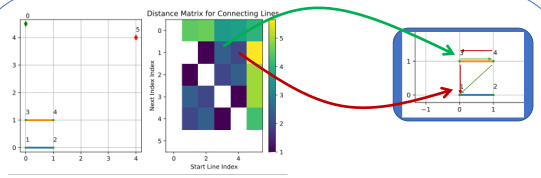
A Solution to TSP for Survey Line Segments

University of New Hampshire
Center for Coastal & Ocean Mapping
Joint Hydrographic Center

Val Schmidt
val.schmidt@unh.edu

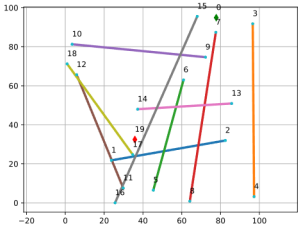
Abstract:
When conducting seafloor mapping operations from a vessel at sea, a plan of parallel lines spaced to ensure adequate overlap in the mapping data are laid out in advance and then systematically followed by human or robotic survey vessels. During the course of survey, it is not uncommon to omit portions of lines, for example, to deviate from the line to avoid other vessels or hazards to navigation, or to need to re-run portions of lines, for example when the INS-aided GPS navigation uncertainty is temporarily too large to meet the uncertainty requirements of the project. These events cause "holidays" or holes in bathymetric surfaces created from the data collection effort if not remedied. Therefore, at the end of several days of systematic survey, an effort is made to repeat the survey lines that have been omitted. To do so in an optimal way, a routine has been developed to solve the Traveling Salesman Problem for a set of arbitrary survey lines. The algorithm extends an existing approximate solution to the standard point-wise TSP problem, so-called "two-opt swap". The routine considers each step as the length of a line segment plus the path length to an arbitrary next line segment. In addition, the routine allows for the traversal of each line segment in either direction. The strategy for development of the algorithm will be presented along with simulated results.



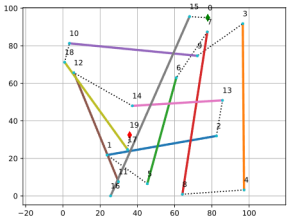
A 2-line test case (left), along with the distance matrix for all combinations of line traversal. Reversed lines are considered separate candidates because the distance traveled to the next line is different.

TSP Line Segment Algorithm:

- Calculate the distance between all pairs of points.
- Calculate the distance for each candidate step, where a step traverses a line and then to the next line segment. Traversing a line in the reverse direction is a separate candidate (because the total path length is different) (green path != red path)
- Propose a candidate route (sequence of steps), where the index of each step indicates the start of the line (and the direction to traverse it). No lines are traversed twice.
- Calculate the route's total distance.
- Implement the "Two-Opt Swap" algorithm to perturb the route iteratively until a threshold of improvement is reached.



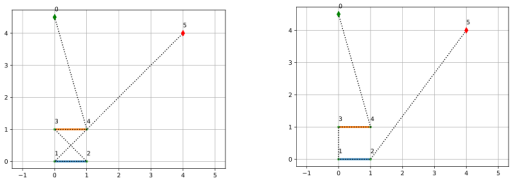
An example with 20 line segments.



And its solution.

"DriX-8" (DriX vehicle manufactured by iXblue) and "ASV-BEN" (C-Worker 4 vehicle manufactured by ASV Global/L3Harris), are two robotic vessels operated by the Center for hydrographic survey missions.

A typical "Boustrophedon" type survey plan run by human and robotic systems for hydrographic survey. Malfunctions and interfering traffic often leave irregularly spaced gaps in the survey, that must be efficiently covered in subsequent work.



An initial candidate route for the two-line TSP problem (left) and its solution (right).

Two-Opt Swap [1]

Systematically removes loops in candidate routes to iterate toward a solution to the Traveling Salesman Problem:

- Calculate the total distance of the candidate route.
- Reverse the order of a subset of the route.
- Ensure a valid route is produced from the new candidate by ensuring lines are always traversed and not repeated.
- Calculate the total distance of the new candidate route. If it is less, accept it.
- Calculate an improvement factor.
- Systematically repeat for all subsets of the route.
- Repeat entire process until the improvement factor < threshold

Conclusion

The best efforts at systematic survey of the seafloor with either robotic or crewed vessels often result in gaps in coverage. These gaps are typically not filled as they occur, but covered in subsequent operations, often by another vessel. The traveling salesman problem for line segments algorithm presented here provides operators a quick method to determine the most efficient path for coverage.

The algorithm can be extended to cover additional scenarios. For example, any single line segment can be replaced with multiple lines that are to be run sequentially as a group, or any other task whose distance can be calculated. These tasks can then replace standard line segments with appropriate modifications to their length estimation. Further, the although the distance calculation is made explicitly here, the distance calculation could be further generalized, specifying a speed of vessel travel along each line. Specifying the speed could, for example, be useful when some lines must be run slowly due to proximity to other hazards. In this case the algorithm would find the sequence of actions that require the least time.

References:

[1] G. A. Croes, "A Method for Solving Traveling-Salesman Problems," *Operations Research*, vol. 6, no. 6, pp. 791–812, 1958.

This work was supported by NOAA Grant NA20NOS4000196.