Multi-Objective Optimization of Voyage Planning for Ships

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If you were the captain of a ship, which route would you take: The fastest one, the most fuel efficient one or the safest one? Take an intermediate route!

When planning a path, we usually have an objective in mind that we try to optimize. That objective could be time, energy, safety, money and much more. For instance, the everyday commuter usually wants to take the path that takes the least amount of time. The rock climber might choose the path that wastes the least amount of energy. The pilot obviously want to take a safe route, but also have an estimated arrival time to meet. This last example is a little different than the others: It has two objectives, while the others only had one.

Having several objectives when planning a voyage for a ship is quite common. The freight company obviously wants a fuel efficient and fast route, but also a safe journey for the ship crew and the freight. Planning a voyage for a ship is thus a quite complex problem involving several objectives. A demand of a sophisticated voyage planning tool is therefore understandable.

In general, there is no single optimal solution to such a multi-objective optimization problem. For example, minimizing the time for a voyage and minimizing the fuel consumption of the vehicle are conflicting objectives. Since a shorter trip time requires more power, which in turn yields higher fuel consumption. Therefore, there can not exist a single solution that is optimal in regard to both objectives.

Thus, one needs to find all the solutions that might provide relevant compromises among the possibly conflicting criteria. For a compromise to be relevant, there should not exist another solution that improves any of the objective functions without deteriorating at least one of the other. Such a solution is called a *Pareto optimal* solution and the set of all such solutions is called the *Pareto front*.

In Figure 1 we have calculated some Pareto optimal solutions for a voyage from Gothenburg, Sweden to New York, USA. The objectives where precisely the arrival time, fuel consumption and safety (in the form of wave heights). In Figure 2 the corresponding Pareto front can be seen. Note the conflict between the fuel consumption and the arrival time.

Now back to our original question, after being presented with all the Pareto optimal solutions, which one should we take? We know that they all are optimal, it is now just a matter of taste!

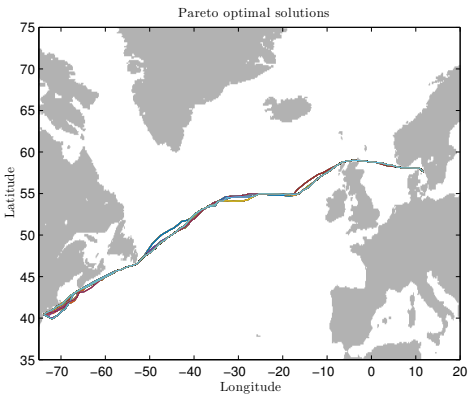

Figure 1: The Pareto optimal solutions for a voyage between Gothenburg and New York.

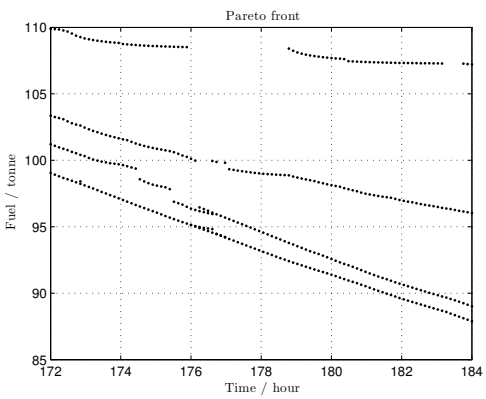

Figure 2: The Pareto front. The x-axis shows the arrival time and the fuel consumption on the y-axis. Every dot represents a Pareto optimal route.