# Routing ships through the Kiel Canal

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The Kiel Canal connects the North Sea and the Baltic Sea. It is about 100 km long, and ships using it save 460 km compared with the route around Skaw. It is the canal with the highest traffic worldwide and has become too narrow for future and even today's traffic. The problem is caused by ships in opposing directions that together are too large to pass each other, see Figure 2. One of them must then wait in a siding to let others pass. This can happen several times for the same ship along its route, but must in total not be too long so that the passage through the canal is still attractive. Currently, there are 12 sidings of different capacity along the canal, which correspond to the green columns at the top of Figure 3.

This situation bears some similarities with opposing trains on a single track with sidings, but is more difficult since some ships may pass each other, whereas opposing trains cannot.

In a billion Euro project, the German Federal Waterways and Shipping Administration WSV had decided to enlarge the canal in the coming years. They came to MATHEON because of our expertise in routing automated guided vehicles (AGVs, see previous Showcase), and wanted an algorithm to improve current and simulate future traffic such as to recommend suitable measures (new sidings, widening of narrow segments, etc.) for the canal enlargement. The movie [2] illustrates this cooperation.

We started with the AGV routing algorithm and enhanced it to take care of the scheduling decisions, i.e., which ship should wait in which siding for which other ships. In addition, we had to observe the limited capacity of the sidings

Figure 1. *Glimpses of the canal and a siding with traffic lights (*middle*)*

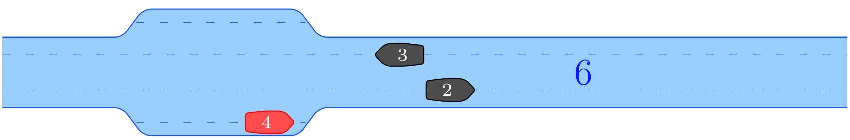


Figure 2. *Ships cannot pass each other when the sum of their sizes (here 3 and 4) exceeds the width of the canal (here 6). The red ship waits in a siding.*

and the lock scheduling at both ends of the canal.

To this end, we enhanced the AGV routing algorithm considerably, see [1]. The problem really is a combination of scheduling (deciding the waiting) and routing (does the scheduling permit a feasible routing). We could show that if we find "good" scheduling decisions, then the routing can be done quickly with the AGV routing algorithm. Other complications occurred with the limited capacity of the sidings, and determining the places for mooring in the sidings. Altogether, we combined the AGV routing algorithm with a rolling time horizon, local search for the scheduling decisions, a suitable modeling of the sidings, and lock scheduling at both ends of the canal.

We calibrated our algorithm on data from 365 days, for which we could show an average daily improvement of 25 % in waiting time for current traffic, and ran it for future traffic scenarios to make our recommendations. These were combined with a cost-benefit analysis done by a different group and have led to the final plan for enlargement, which is currently being prepared by WSV.

*Further reading*


[1] E. Günther, M. E. Lübbecke, and R. H. Möhring. Ship traffic optimization for the Kiel canal. In *Proceedings of the Seventh Triennial Symposium on Transportation Analysis*, pages 326–329, 2010.

[2] W. Höhn and M. Lübbecke. DFG science TV: Discrete Optimisers, Episode 2. URL: http://dfg-science-tv.de/en/projects/discrete-optimisers [cited 08/20/2013].


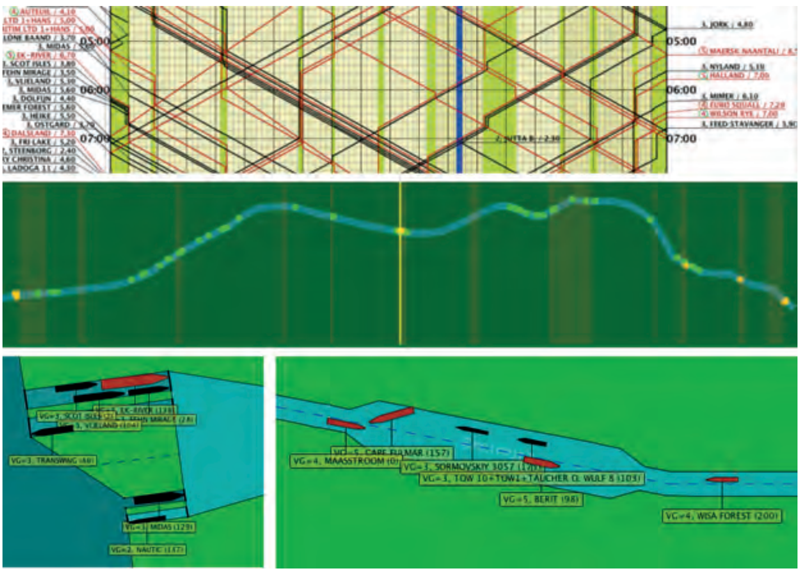


Figure 3. *Glimpses of the algorithm. Space-time diagram (*top*), overview of the current traffic situation (middle), lock scheduling in Brunsbüttel (*bottom left*), scheduling in siding Breiholz (*bottom right*).*