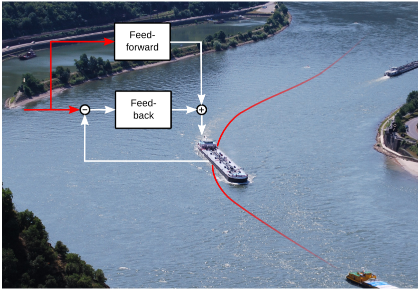
Reduction of Fuel Consumption by Using Automatic Path-Following Systems



A. Lutz, Prof. Dr.-Ing. E.D. Gilles
Institute for System Dynamics, University of Stuttgart, Germany

CCNR Workshop on Inland Navigation CO_2 emissions, 12th April 2011

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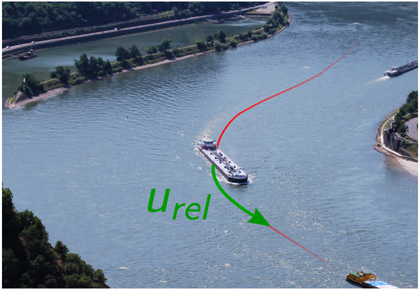

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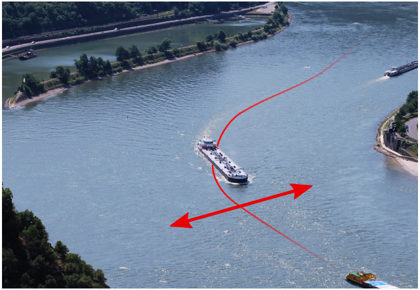

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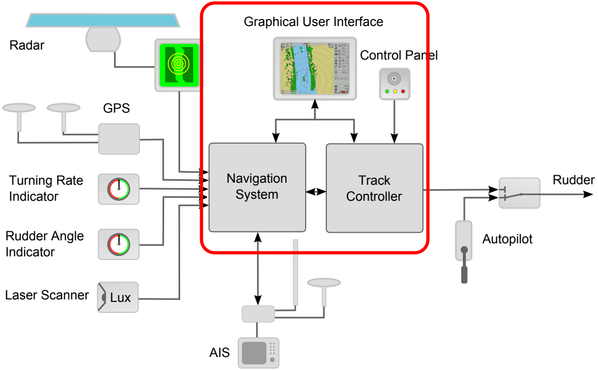
Hardware



Hardware:

- Navigation computer
- Sensors to measure the dynamic state
- Sensors to capture information about the environment
- Access to the rudder

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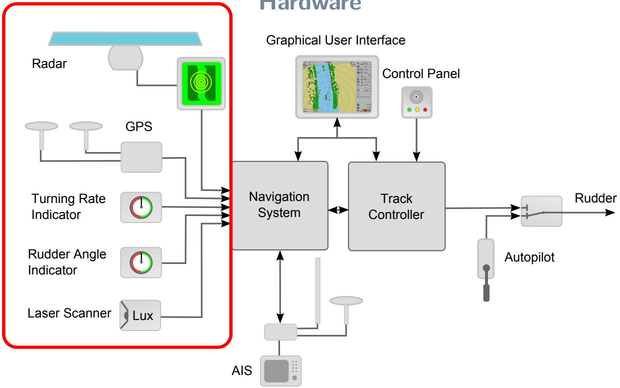

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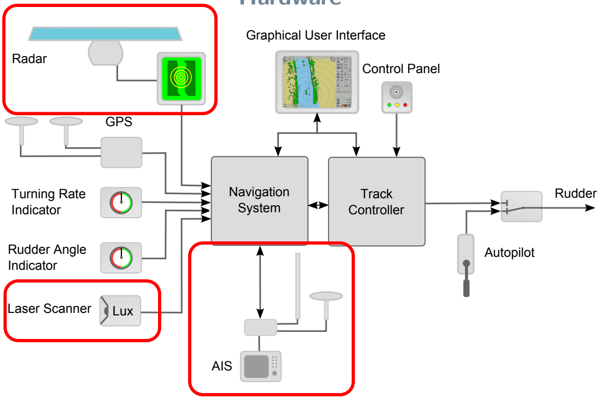

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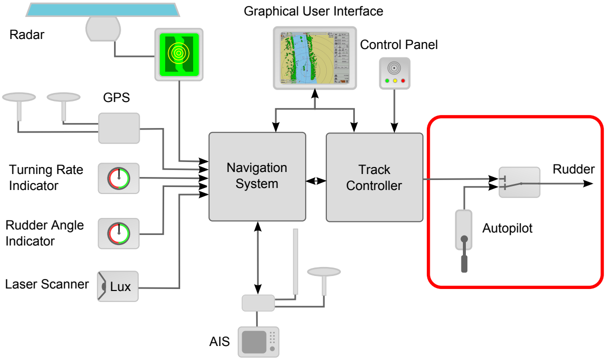

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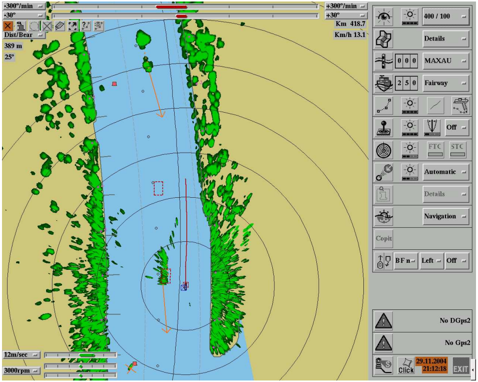
Software

Software: (based on Radarpilot 720°)

- ECDIS chart
- Radar object tracking (fusion with AIS)
- Map matching: ECDIS chart with radar image
- Ranges of encounter for collision avoidance
- Guiding lines

Software



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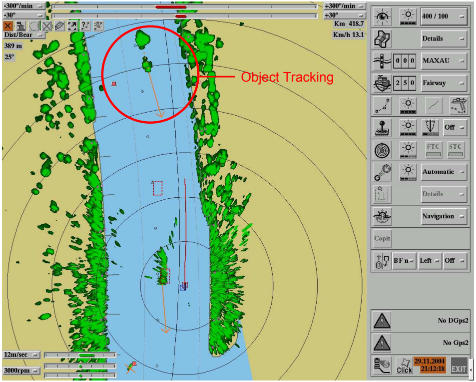

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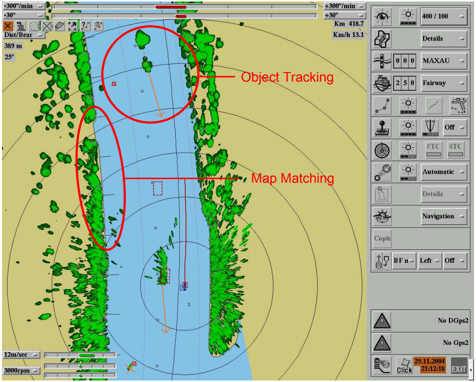

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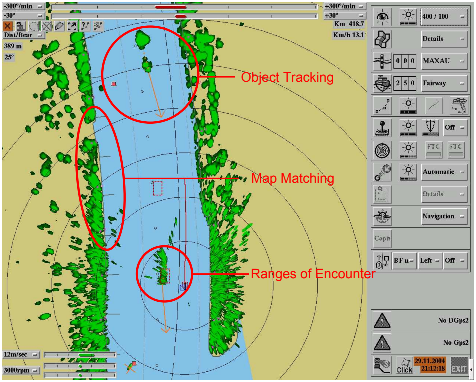

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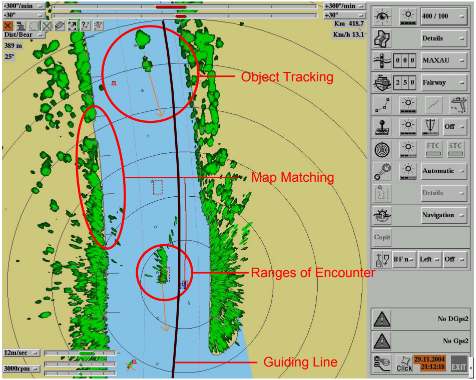

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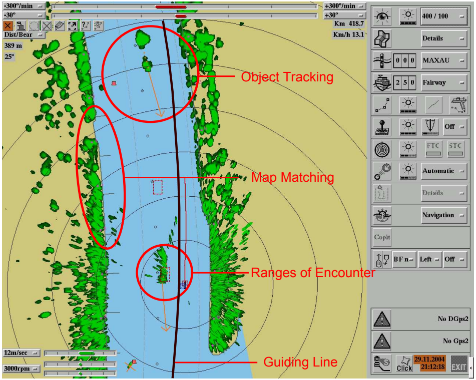

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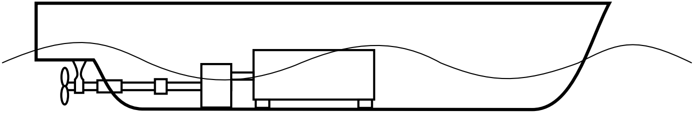
Resistance



Total resistance as in [1], [2], [3]

$$R_{total} = R_F + R_{App} + R_W + R_{Tr} + R_A + R_{Add}$$

R_F . . . frictional resistance
R_{App} . . . resistance of appendages
R_W . . . wave making and wave breaking resistance
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R_{Add} . . . additional resistance, e.g. wind

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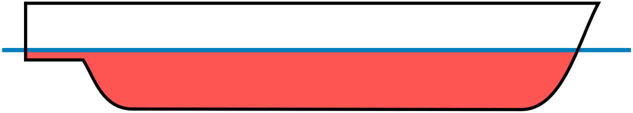

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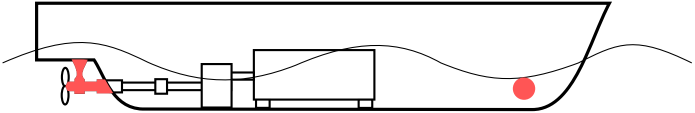

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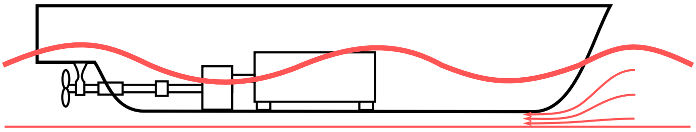

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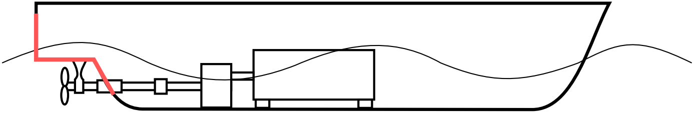

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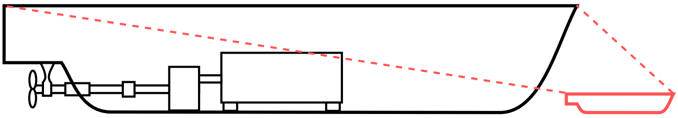

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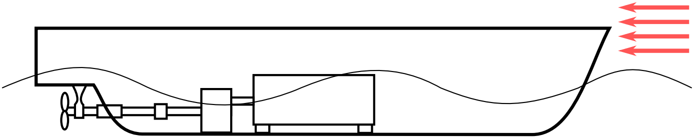

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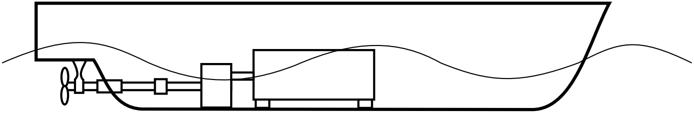

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u_{rel} ... Relative velocity
d ... Depth

Engine and Propulsion System

Required power, efficiency and fuel consumption

$P_{req} = R_{total}\, u_{rel}$ — Required power

$P_{del} = \eta_p\, \eta_s\, \eta_g\, P_e$ — Delivered power

$P_e = B_e / b_e$ with $B_e = \dot{V}\, \rho$ — Engine power

u_{rel} ... Relative velocity

η_p ... Propulsion efficiency

η_s ... Shaft efficiency

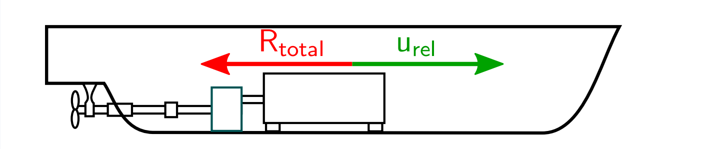
η_g ... Gear efficiency

B_e ... Fuel flow rate

b_e ... Specific fuel consumption

V ... Fuel volume

ρ ... Fuel density



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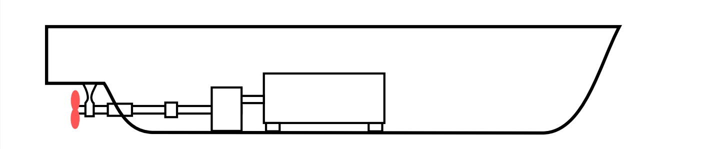

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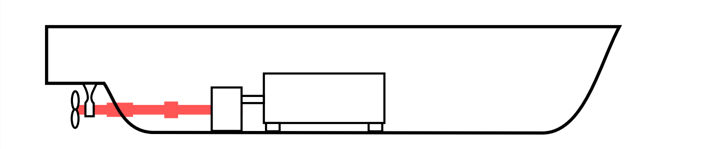

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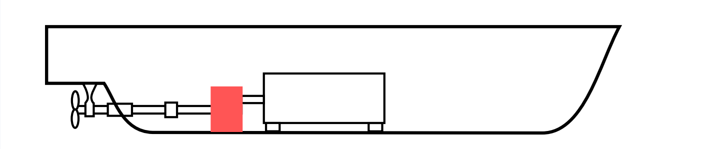

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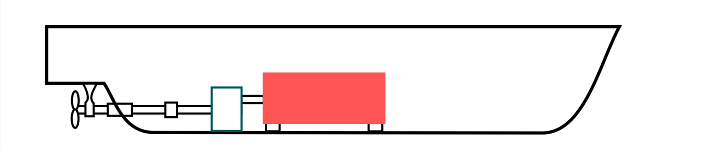

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$\downarrow P_{req} = P_{del}$

$$V = \int_0^t \frac{b_e}{\rho} \frac{R_{total}\, u_{rel}}{\eta_p\, \eta_s\, \eta_g} dt$$

Fuel consumption

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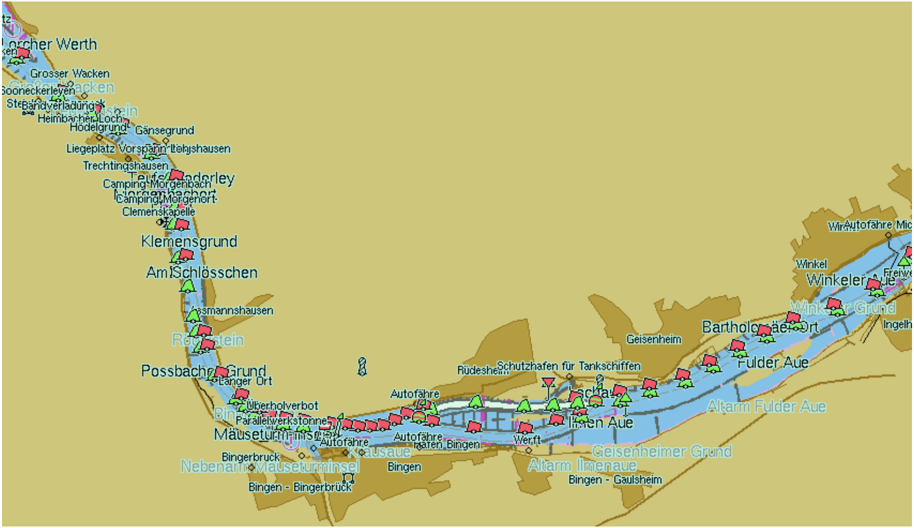
Rhine River, km 520-540



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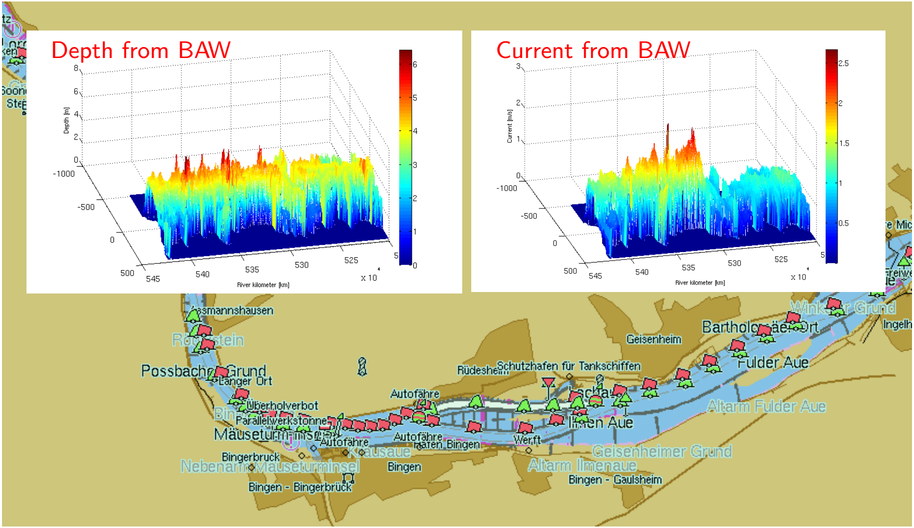

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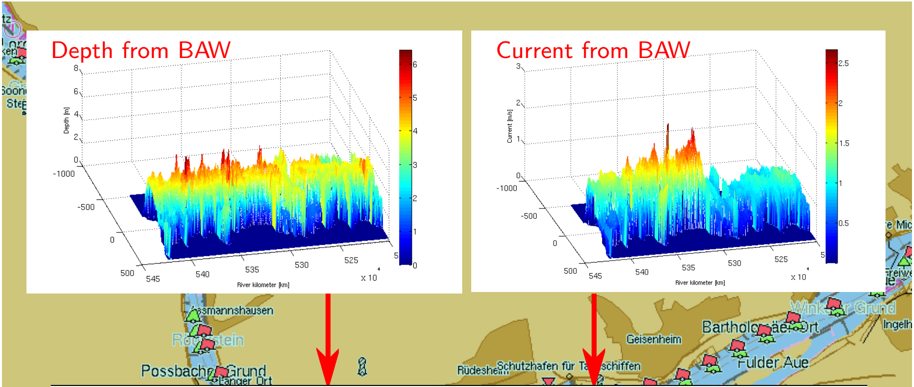
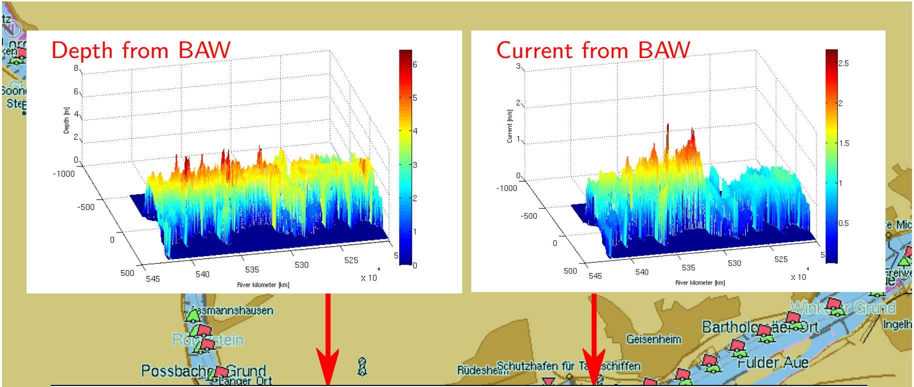


Section		1	2	3	4	5
Location	[km]	520-525	525-530	530-532.5	532.5-539	539-542
Current	[m/s]	1.0	0.8	2.1	1.7	1.4
Depth	[m]	4.1	4.4	4.7	4.9	4.3

Rhine River, km 520-540



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→ Optimization problem: How fast in which section in order to reach destination in time while minimizing fuel?

Velocity Optimization

Simulation specifications

- Ship length: 105 m, width: 9.5 m, draft: 2.7 m
- Engine power: 1000 kW, spec. fuel consumption: 0.18 $\mathrm{kg/kWh}$
- Upstream, Traveling time $3\mathrm{h}$ ($u_{\mathrm{abs}} \approx 7\mathrm{km/h}$)

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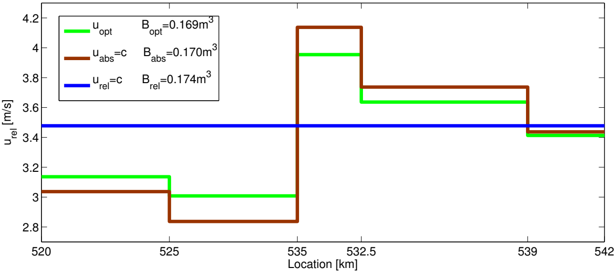
Section		1	2	3	4	5
Location	[km]	520-525	525-530	530-532.5	532.5-539	539-542
Current	[m/s]	1.0	0.8	2.1	1.7	1.4
Depth	[m]	10	10	10	10	10



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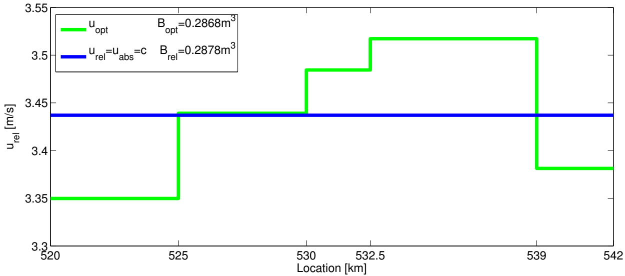
Section		1	2	3	4	5
Location	[km]	520-525	525-530	530-532.5	532.5-539	539-542
Current	[m/s]	1.4	1.4	1.4	1.4	1.4
Depth	[m]	4.1	4.4	4.7	4.9	4.3



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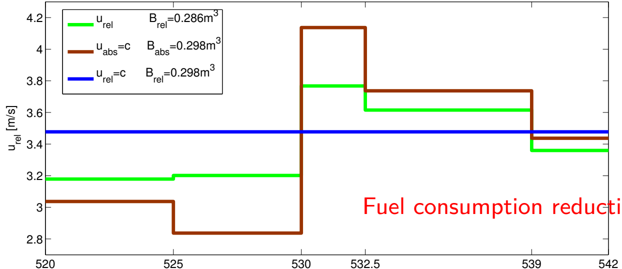

Fuel consumption reduction: 4.0%

Velocity Optimization

Simulation specifications

- Ship length: 105 m, width: 9.5 m, draft: 2.7 m
- Engine power: 1000 kW, spec. fuel consumption: 0.18 $\mathrm{kg/kWh}$
- Upstream, Traveling time 4h ($u_{\mathrm{abs}} \approx 5\mathrm{km/h}$)

Section		1	2	3	4	5
Location	[km]	520-525	525-530	530-532.5	532.5-539	539-542
Current	[m/s]	1.0	0.8	2.1	1.7	1.4
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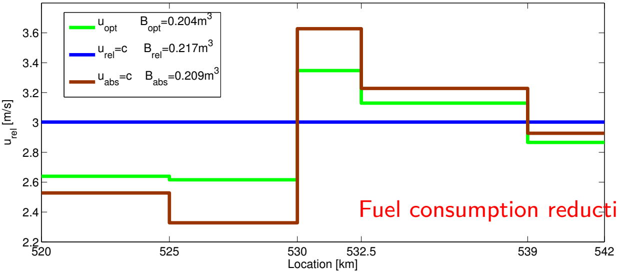

Fuel consumption reduction: 6.0%

Optimization of Lateral Position

Optimization problem: Where to navigate in lateral direction in order to realize and even increase the expected fuel consumption reduction?

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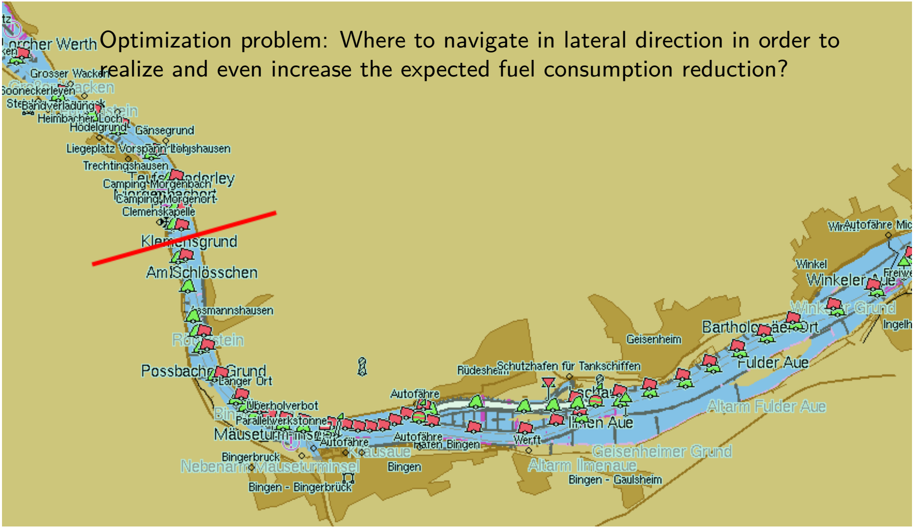

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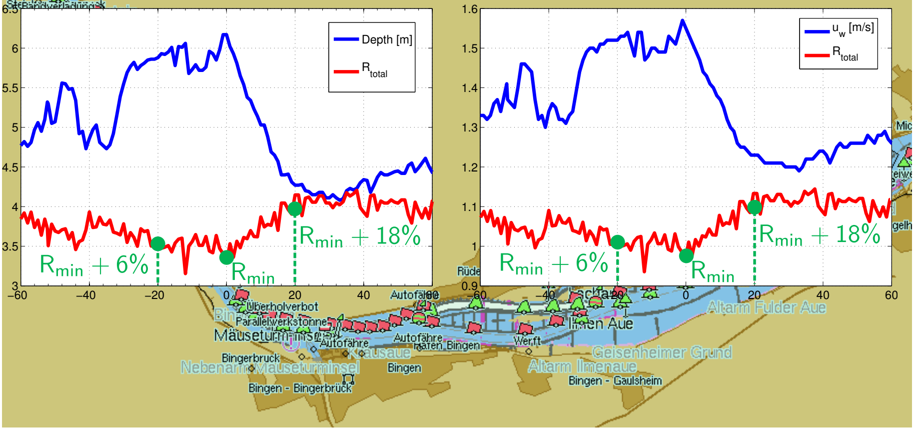
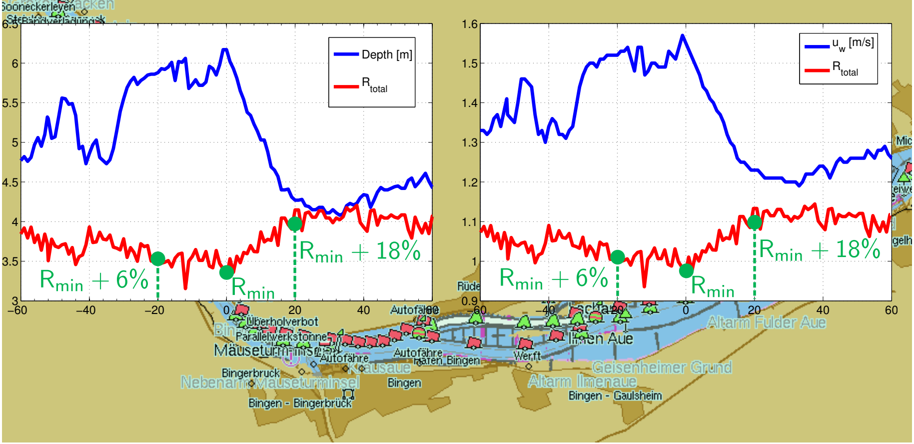


Optimization of Lateral Position

Optimization problem: Where to navigate in lateral direction in order to realize and even increase the expected fuel consumption reduction?



→ Fuel consumption reduction can only be fully realized with automatic path-following systems on optimal guiding lines.

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Summary and Outlook

Summary

- Resistance calculations from literature
- Fuel consumption reduction by adapting the velocity according to depth and current
- Increase of fuel reduction by precisely navigating along an optimal guiding line
- No vessel modifications necessary

Outlook

- Combined optimization along and across the river
  $\rightarrow$ optimal guiding lines
- Investigation at different water levels for different vessels
- Experimental validation

Proposal for validation on the Rhine, ARGO 2

- 20 vessels with navigation system, automatic path-following system and fuel consumption measurement equipment
- River data from Bundesanstalt für Wasserbau (BAW)
- Optimal guiding lines for each vessel and water level
- Comparison between optimal and manual navigation
- Expected fuel consumption reduction: Up to 10%
- Expected cost: $\approx$ 2.0 Mio. €
- Amortization: $\approx$ 8 months

Thank you

for your attention

Reduction of Fuel Consumption by Using Automatic Path-Following Systems

A. Lutz, Prof. Dr.-Ing. E.D. Gilles

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