A sustainable dynamic allocation of patrolling tug vessels to oil ships along the northern Norwegian coast

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Project members

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- Norwegian Coastal Administration (NCA)

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Research project

- Operations in offshore industry are usually run dynamically with high uncertainty
- The Norwegian Coastal Administration (NCA) monitors all ship traffic along the Northen coast from the Vessel Traffic Service Centre in Vardø.
- The NCA commands a fleet of patrolling tug vessels able to save drifting oil tankers from grounding

Automatic Identification System (AIS)

- Required for every ship of a certain size
- Every ship broadcasts real-time data such as

Identification	Heading
Position	Destination
Speed	Cargo

- Real-time and historical AIS data is made available for this project through the cooperation with the NCA

Main Challenge

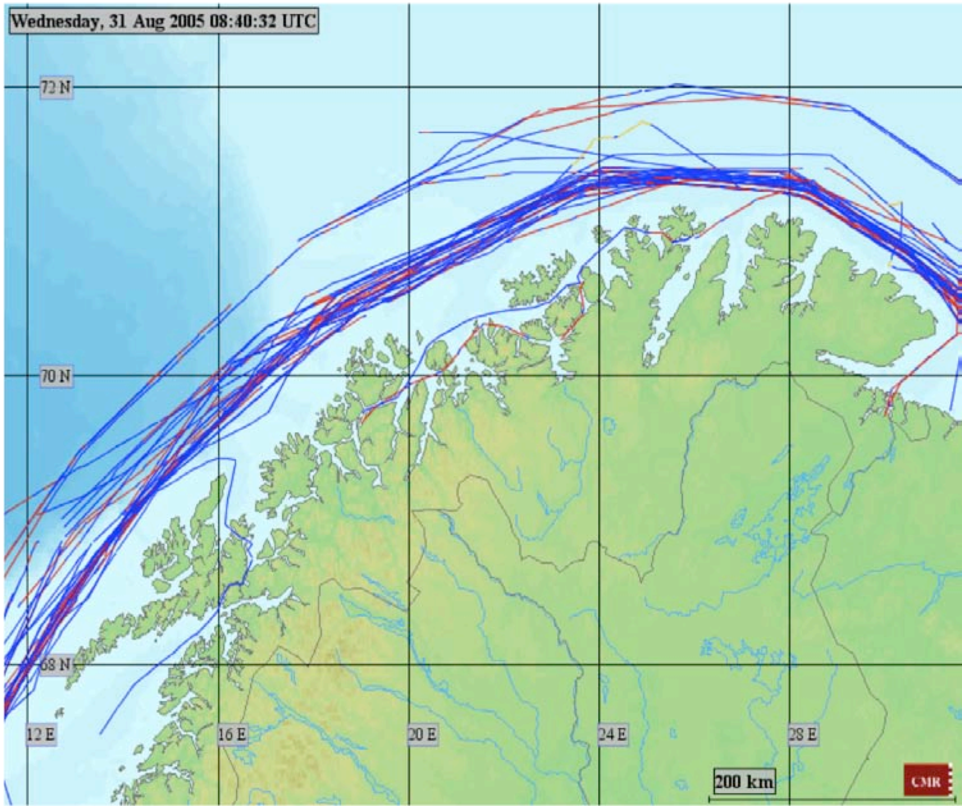
- Tug vessels are managed manually
- Development of large oil and gas fields near the Northern Norwegian coast (increase traffic in years to come)

Previous work

- Bye, R. T., van Albada, S. B. and Yndestad, H. (2010). *A receding horizon genetic algorithm for dynamic multi-target assignment and tracking: A case study on the optimal positioning of tug vessels along the Northern Norwegian coast.* Proceedings of ICEC 2010 - International Conference on Evolutionary Computation, 2010.
- Robin T. Bye. *A receding horizon genetic algorithm for dynamic resource allocation: A case study on optimal positioning of tugs.* Series: Studies in Computational Intelligence, vol. 399, pp. 131--147, 2012. Springer-Verlag: Berlin Heidelberg.

Oil tanker traffic

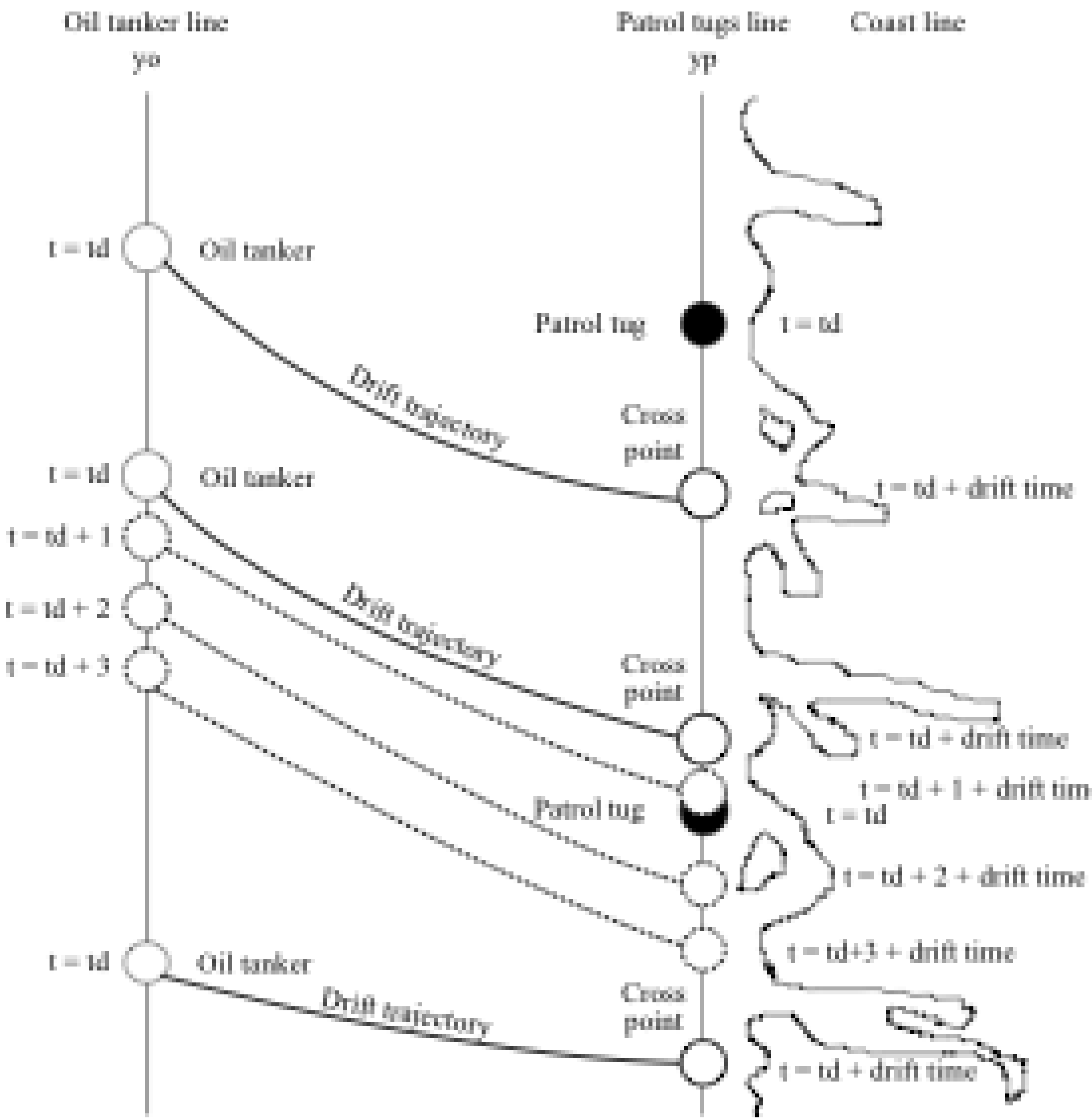
- Tankers sail in corridors off the coast
- Tug vessels stay near shore
- Approximated as parallell lines



Courtesy NCA

Research Questions

- Which agents shall track which targets ?
- How can the agents collectivelly move so that the net tracking performance is maximised ?
- How to defined the performance (cost measure)?
- How can the agents incorporate future changes in the state space?



Courtesy Bye

Method

- Examine a finite number of potential patrol trajectories and evaluate a cost function for each
- Use a genetic algorithm (GA) to find good solutions in reasonable time
- Use receding horizon control (RHC)to incorporate a dynamic environment and update trajectories
- Plan trajectories 24 hours ahead but only execute first hour, then replan and repeat

Courtesy Bye

Cost Function

$$f\left(t, C_i\right) = \sum_{t=t_d}^{t_d+T_h} \sum_{c=1}^{N_o} \min_{p \in P} \left| y_t^c - y_t^p \right|$$

T_h = time horizon

N_o = number of oil tankers

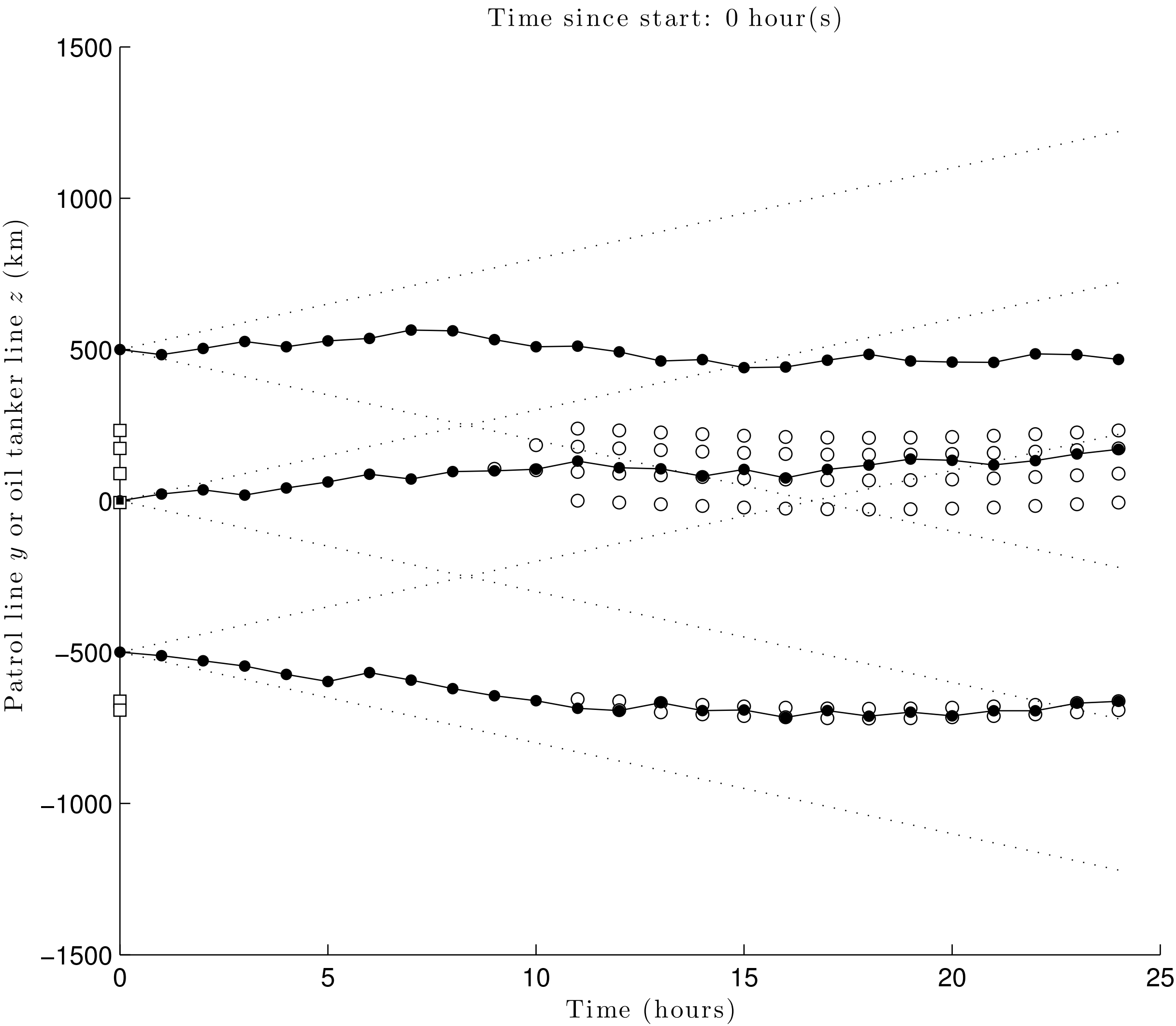
N_p = number of oil tankers

y_t^p = patrol point on the pth tug's patrol trajectory at time t

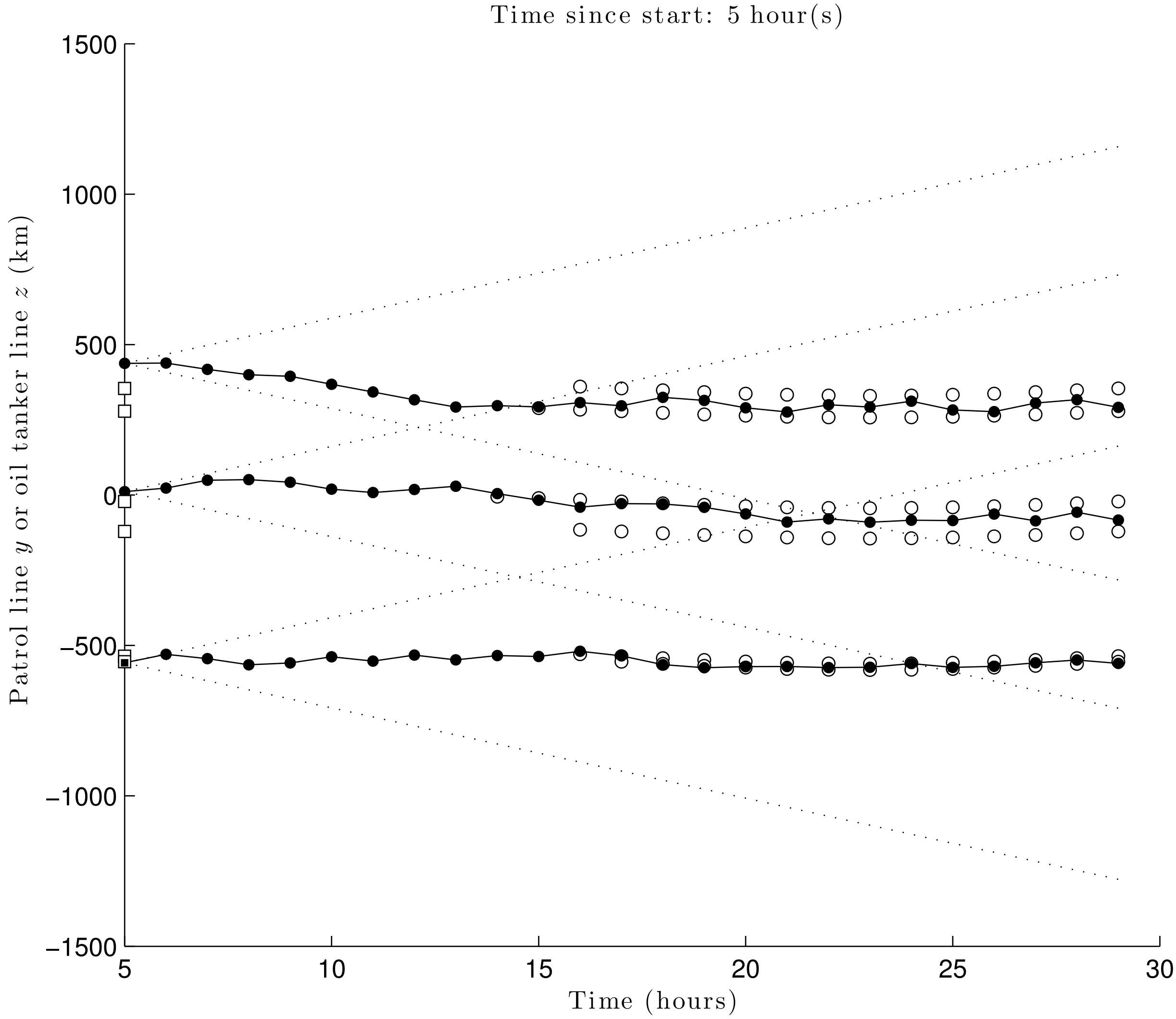
y_t^c = a cross point on the cth oil tanker's drift trajectory at time t

$P = \left\{1, \ldots, N_p\right\}$

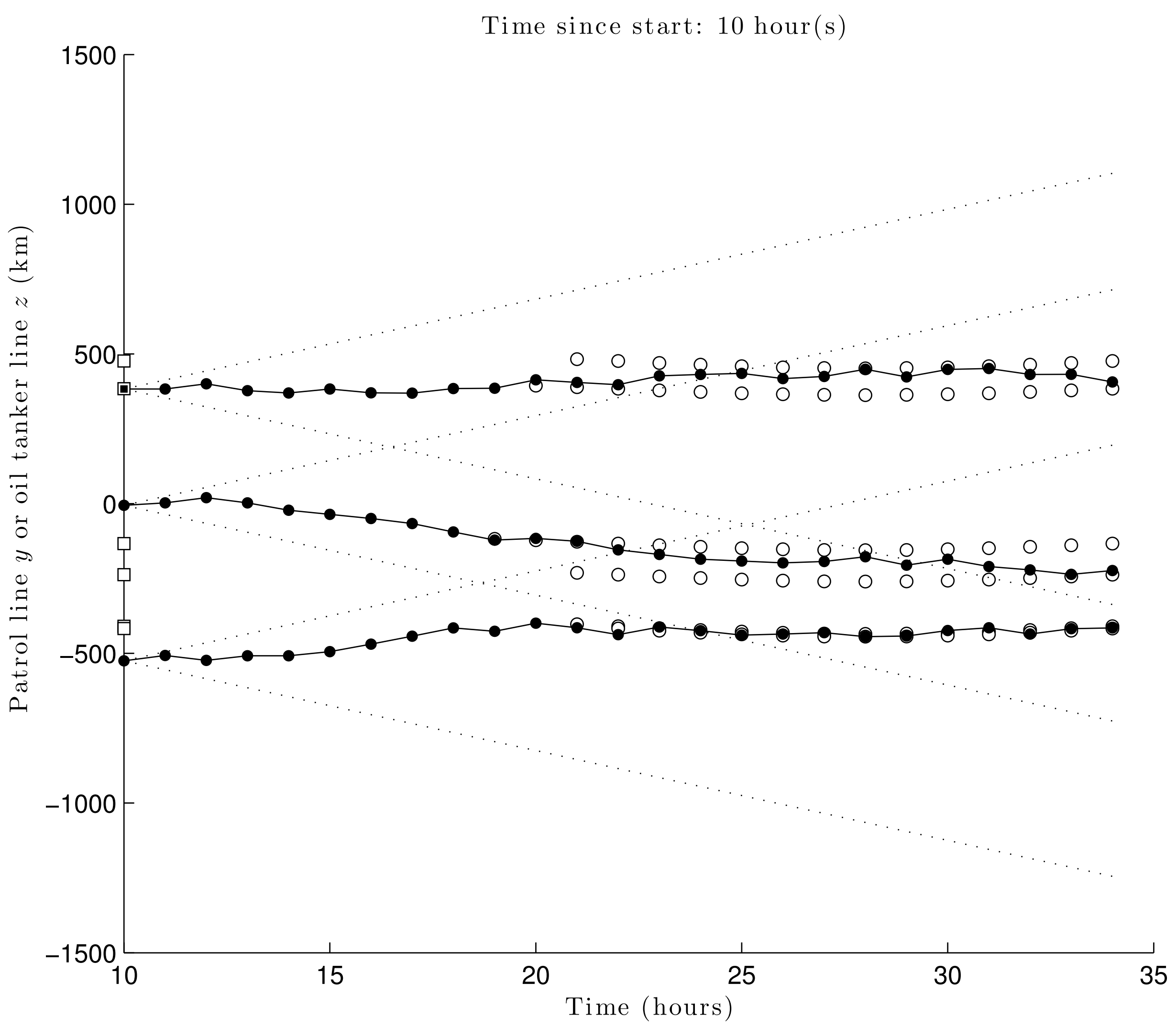
C_i = chromosomes



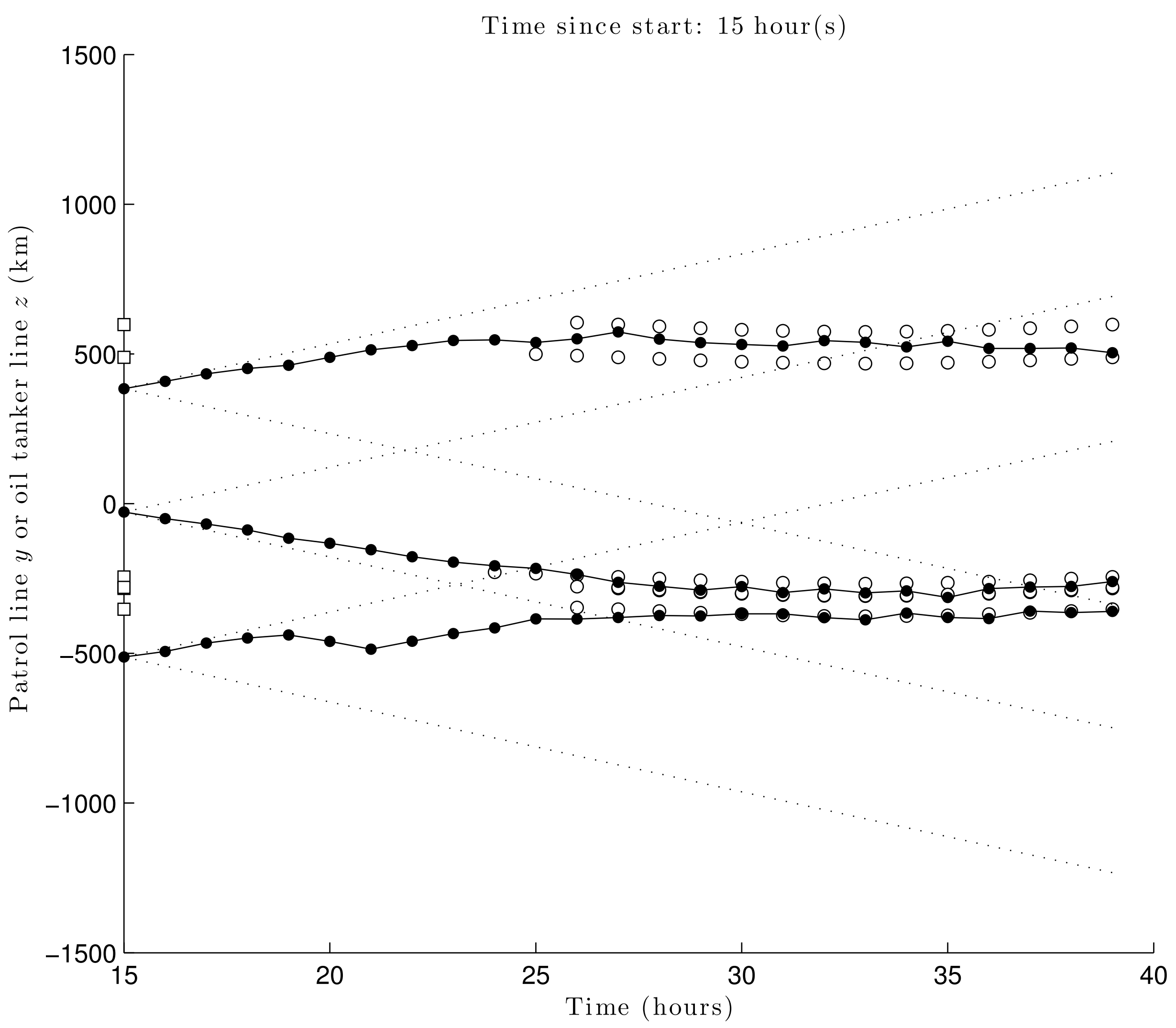
Time since start: 0 hour(s)
Patrol line y or oil tanker line z (km)
Time (hours)
1500
1000
500
0
−500
−1000
−1500
0
5
10
15
20
25



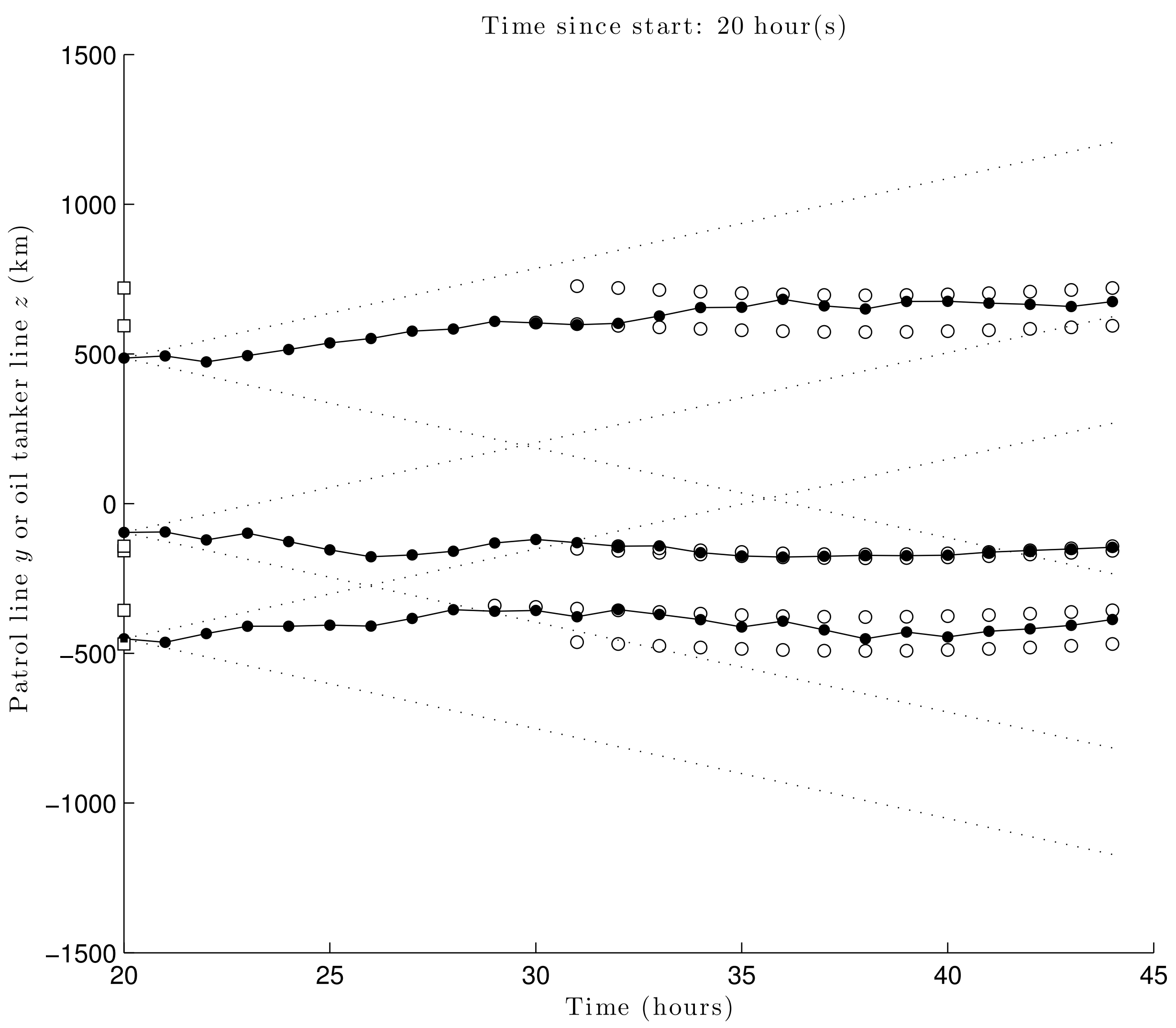
Time since start: 5 hour(s)
1500
1000
500
0
−500
−1000
−1500
5
10
15
20
25
30
Time (hours)
Patrol line y or oil tanker line z (km)



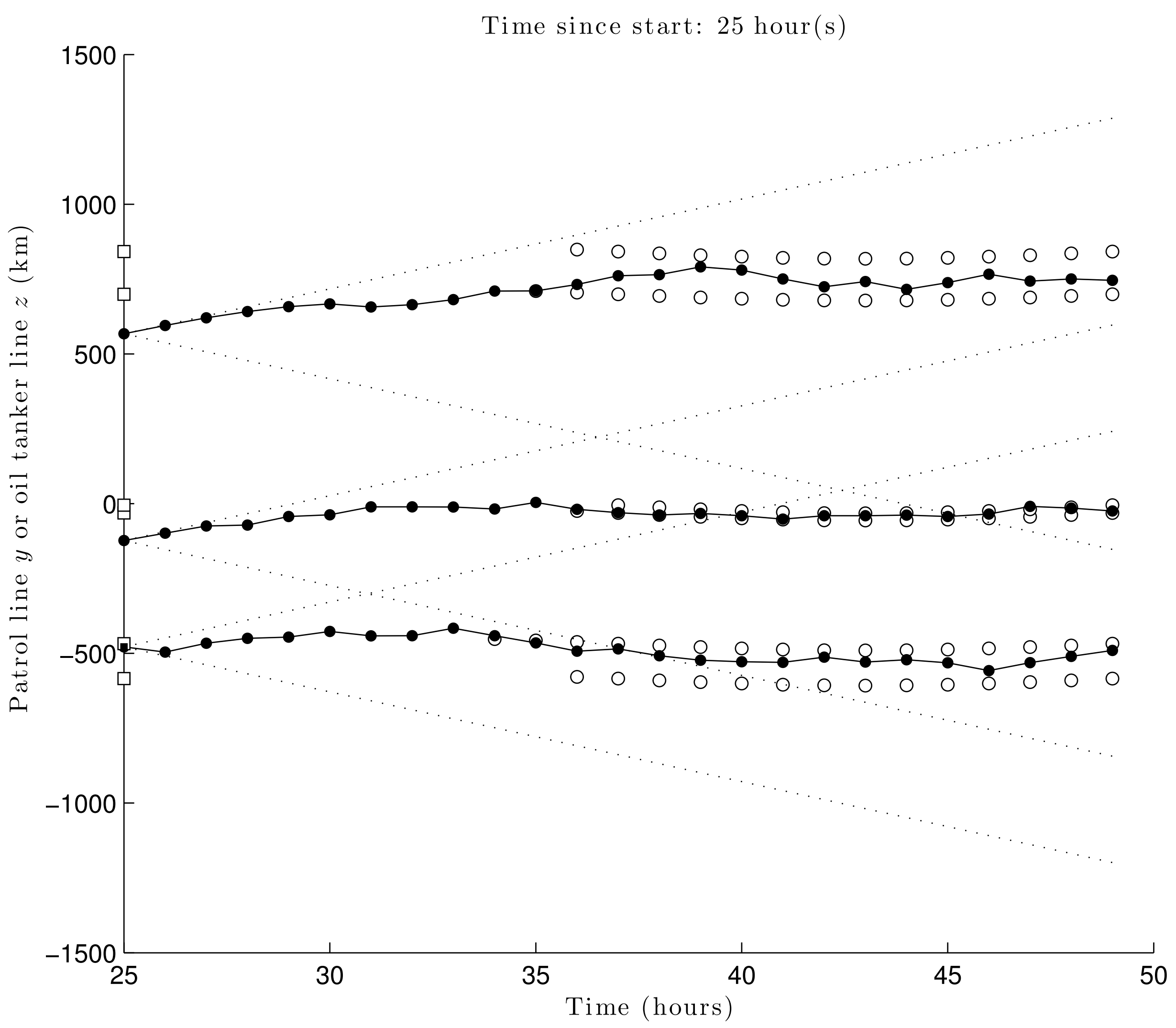
Time since start: 10 hour(s)
1500
1000
500
0
−500
−1000
−1500
10
15
20
25
30
35
Time (hours)
Patrol line y or oil tanker line z (km)



Time since start: 15 hour(s)
Patrol line y or oil tanker line z (km)
Time (hours)
1500
1000
500
0
−500
−1000
−1500
15
20
25
30
35
40



Time since start: 20 hour(s)
1500
1000
500
0
−500
−1000
−1500
20
25
30
35
40
45
Patrol line y or oil tanker line z (km)
Time (hours)



Time since start: 25 hour(s)
1500
1000
500
0
−500
−1000
−1500
25
30
35
40
45
50
Time (hours)
Patrol line y or oil tanker line z (km)

Main objectives

- To reduce the risk of severe grounding accidents
- ✓ Determine the long-term optimal number of tugs vessels
- ✓ Optimally allocate tug vessels to oil tankers
- Reduce CO_2 emission from tugs vessels

Solutions methods

- Exact Methods
  - A deterministic MIP model for 1D
- Stochastic programming
  - A stochastic MIP model for 2D
- Robust optimization
  - Linear decision rule
- Heuristics methods
  - A unified tabu search algorithms (UTS)
- Hybrid methodology: exact and heuristic

  E.g. Column generation with branch-and-price
- Model Predictive Control (MPC) /RHC

Ongoing deterministic MIP model for 1D

Previous function $\rightarrow f(t, C_i) = \sum_{t=t_d}^{t_d+T_h} \sum_{c=1}^{N_o} \min_{p \in P} \left| y_t^c - y_t^p \right|$

$$\min \sum_{t=t_d}^{t_d+T_h} \sum_{c=1}^{N_o} \sum_{p=1}^{N_p} X_t^{c,p} + Z_t^{c,p}$$

st

$$Y_t^p = Y_{t-1}^p + v_m^p t_s \cdot \left(I_t^p - J_t^p \right) \quad \forall t \in T_h \setminus \{t_d\}, p \in P$$

$$I_t^p + J_t^p \leq 1 \quad \forall t \in T_h \setminus \{t_d\}, p \in P$$

$$X_t^{c,p} - Z_t^{c,p} = Y_t^c - Y_t^p \quad \forall t \in T_h, p \in P, c \in \{1, \ldots, N_o\}$$

$$\sum_{p=1}^{N_p} W_t^{c,p} = 1 \quad \forall t \in T_h, c \in \{1, \ldots, N_o\}$$

$$Y_t^c - Y_t^p \leq W_t^{c,p} \cdot v_m^p \cdot n \quad \forall t \in T_h, p \in P, c \in \{1, \ldots, N_o\}$$

Stochastic programming

- An approach for modeling optimization problems that involve uncertainty
- A stochastic MIP model for 2D

✓ Model uncertain parameters with known distribution function

- Linear decision rule

✓ Used if the distribution is unknown or if the decision maker is very risk-averse (minimize the worst case cost)

Heuristics methods

- Derives from the Greek *heuriskein*, meaning to find, to discover.
- Technique which seeks good or near optimal solutions
- Reasonable computational time (cost)
- Not able to guarantee feasibility and optimality.
- E.g. Genetic Algorithm (GA), Unified Tabu Search (UTS), Ant Colony (AC), Column Generation (CG), Simulated Annealing (SA), etc

Potential constraints/priorities

- Include weather data to identify risk zones and to estimate trajectories of drifting ships
- Include risk categories of ships based on factors such as cargo, amount and type of oil carried, engine type, age and history, etc.
- Confidence level on the probability of no oil tanker running ashore
- Environmental and human capital related constraints

Extension to platform supply vessels(PSVs)

- A ship specially designed to supply offshore oil platforms
- Transportation of goods and personnel to and from offshore oil platforms and other offshore structures.

Questions and Suggestions