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OPERATIONAL PLANNING AND COMBINATORIAL OPTIMIZATION IN SIMULATION MODELS OF MARINE TRANSPORTATION SYSTEMS

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LLC «Bureau Hyperborea»

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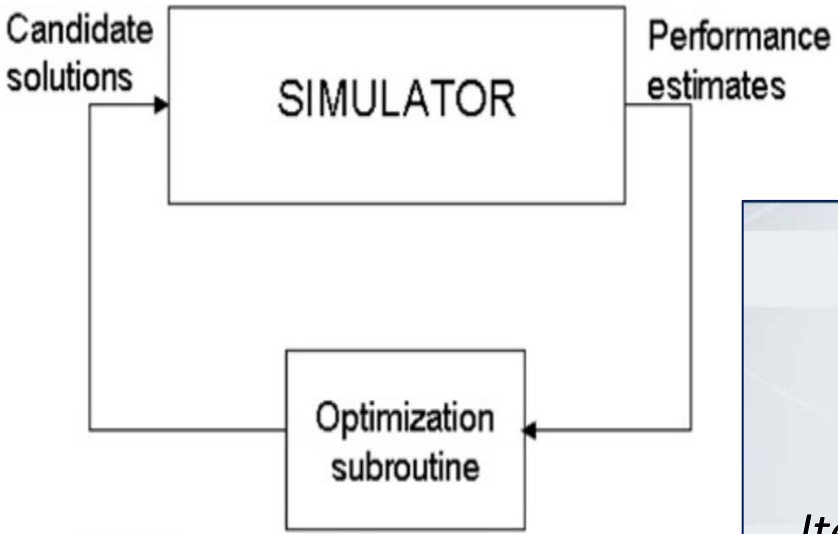
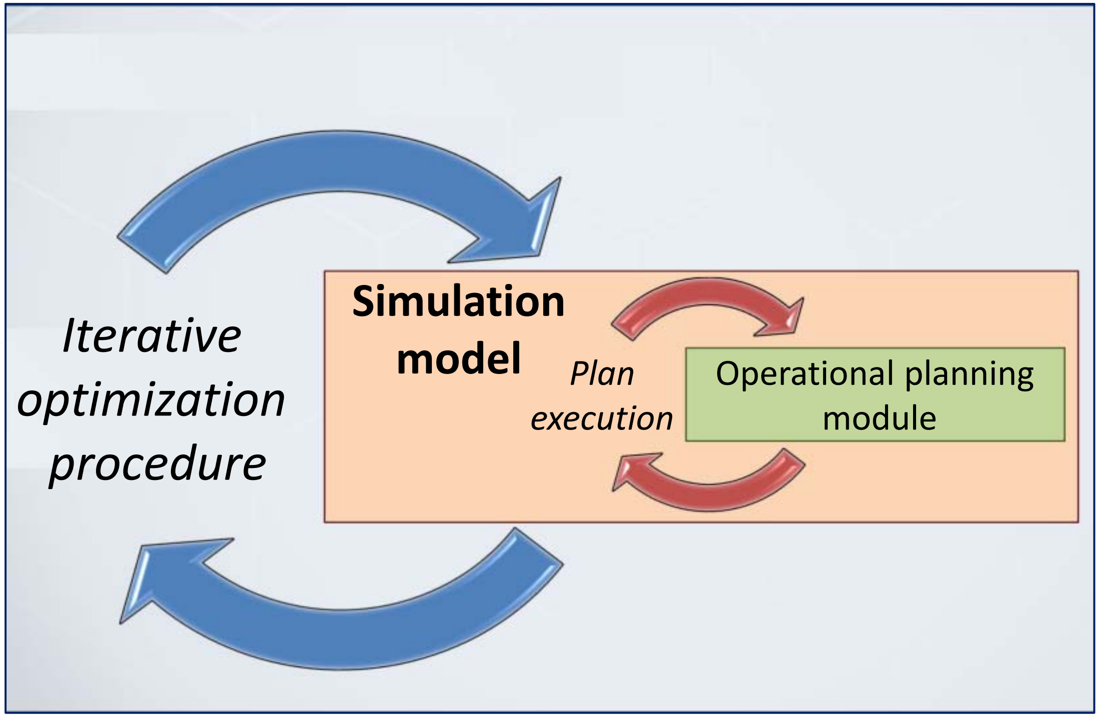
Simulation–Optimization interaction in MTS models

Traditional 2-level interaction scheme

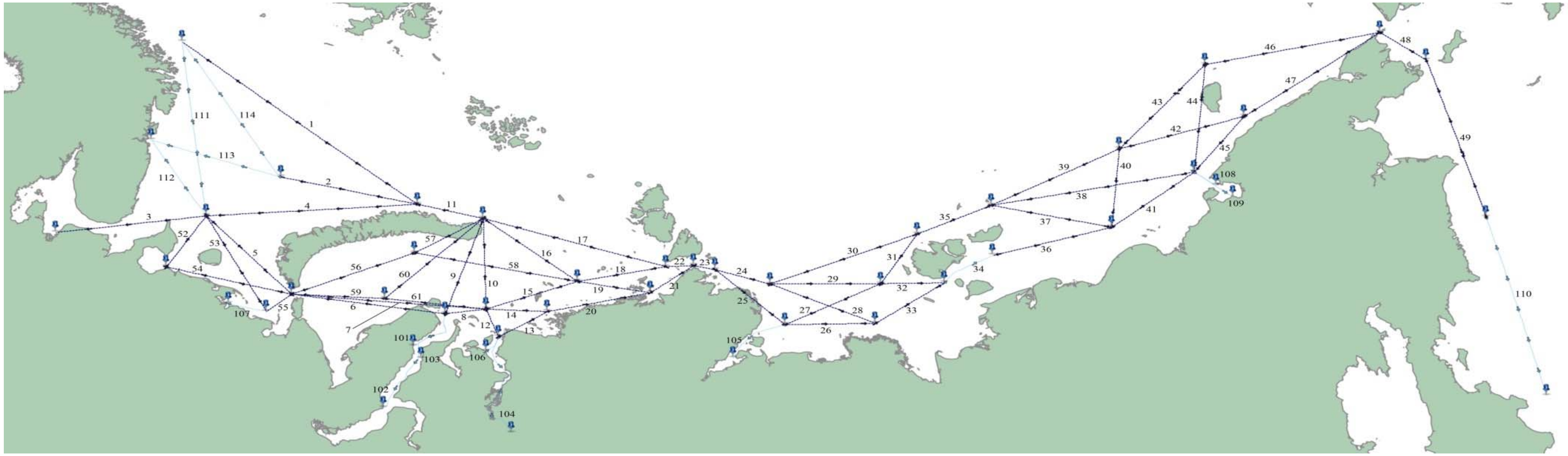
Enhanced 3-level interaction scheme



Fu, M.C. 2002. Optimization for simulation: theory vs. practice.
INFORMS Journal in Computing 14(3)



Icebreaker fleet management. Problem statement



Questions

- What is the optimal order of vessel voyages to be escorted by an icebreaker?
- Which vessels should join each icebreaker-leaded caravan?
- Where should the points of caravan forming and disbanding be located?
- Which vessels are able to pass the whole route or its part independently?

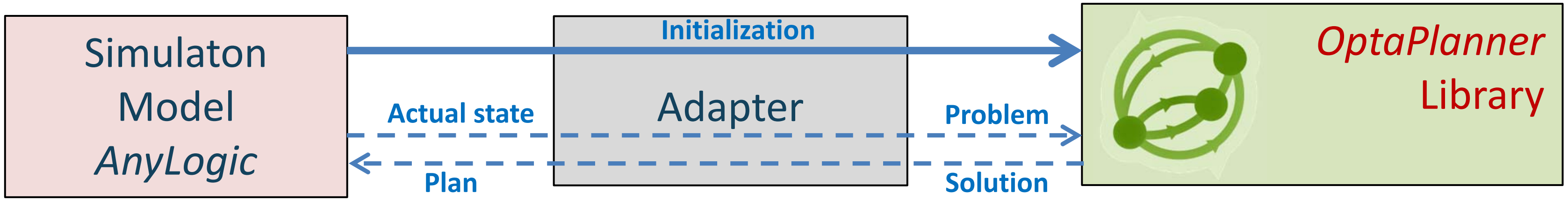
Possible Solutions

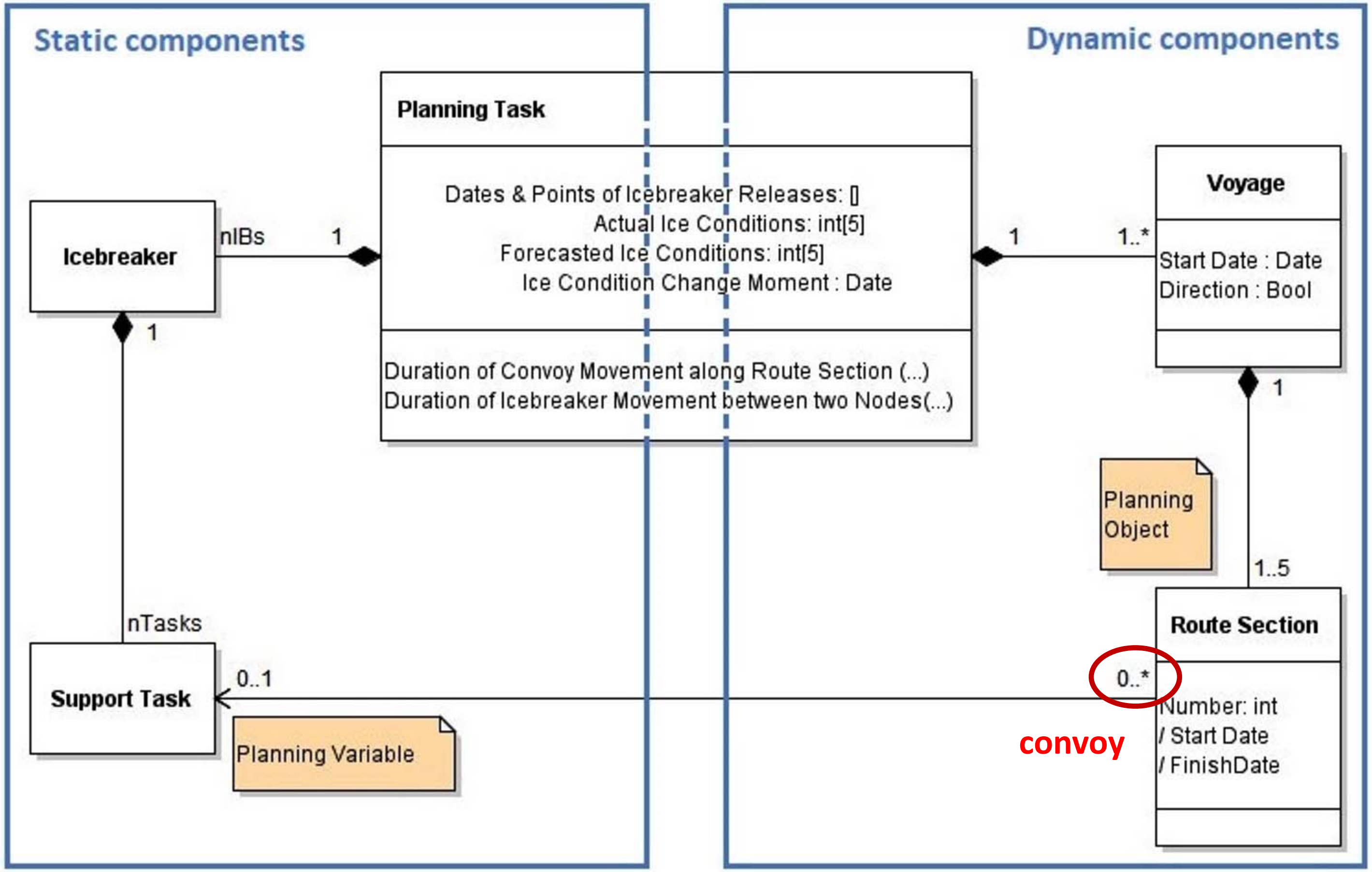
1. Heuristic methods
   - *Situational "greedy" algorithms*
   - *Algorithm for identifying geographical areas of icebreaker involvement*
2. **Combinatorial Optimization on a graph**
   - ***External Solver (Opta Planner)***
   - *Biult-in Solver (Amalgama Platform)*
3. Joint optimization of ship trajectory and icebreaker assistance in a continuous geographical space

Icebreaker fleet management. Specific features

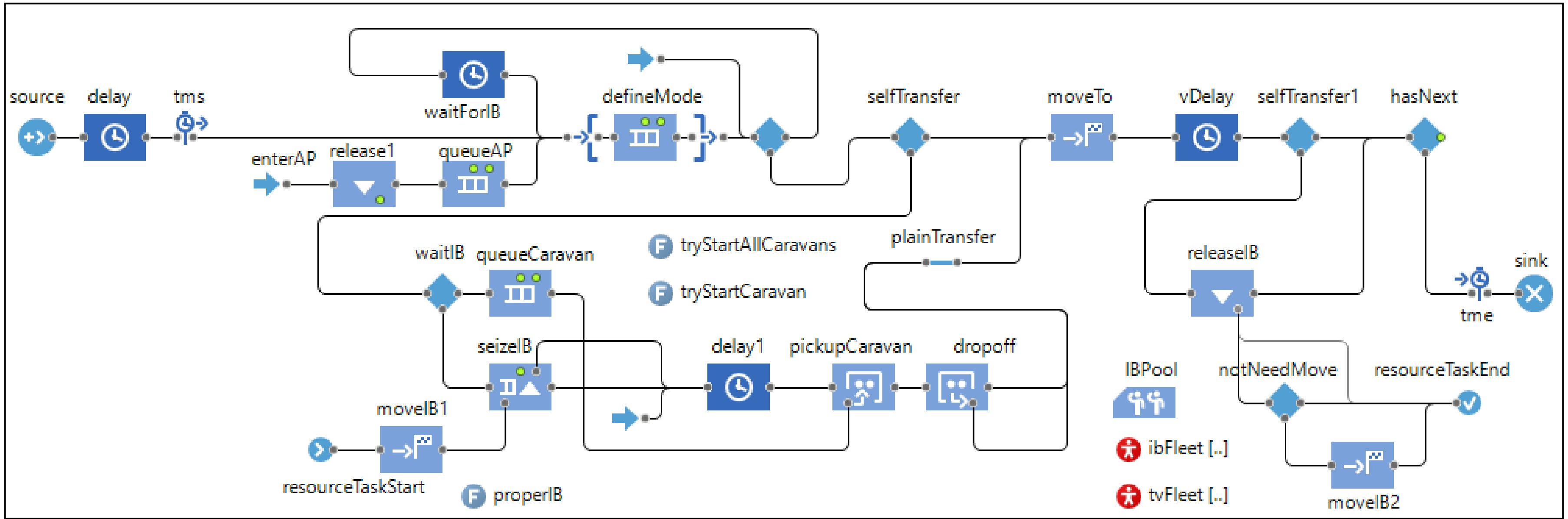
- Icebreaker is a **moving** resource; it can move independently to its place of use according to its own movement pattern.
- Icebreaker is a **shareable** resource; one icebreaker can support the operation of several cargo vessels (caravan) on the same voyage section.
- Icebreaker is an **optional** resource. Most of modern cargo vessels with high ice class are capable of moving independently in a fairly wide range of ice conditions.
- Icebreaker is a **limited and expensive** resource. Icebreaking assistance can significantly increase the speed of passing through heavy ice, but this service is quite expensive. At the same time, the limited number of powerful icebreakers (e.g., in 2025 there should be from 6 to 8 Russian nuclear icebreakers in operation) together with an expected explosive increase in the Arctic cargo traffic will inevitably lead to the escorting of each vessel only on a limited part of the route.

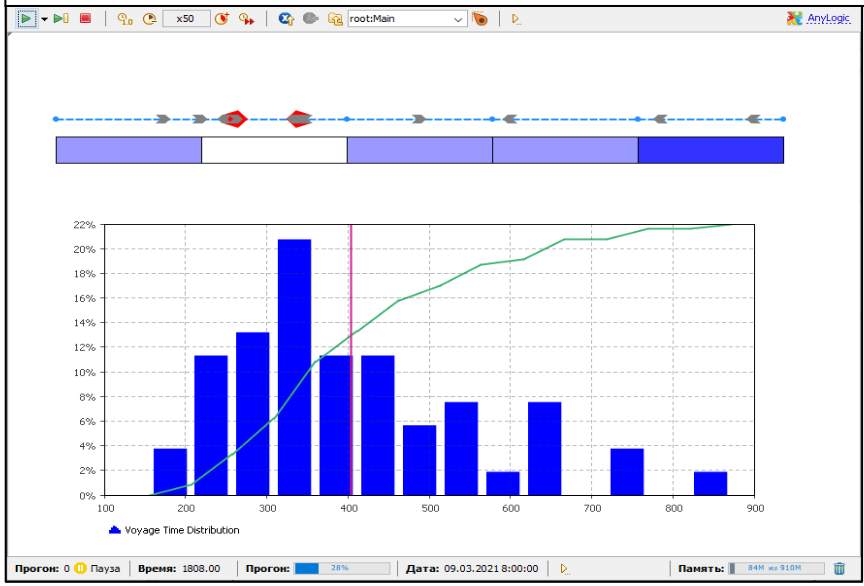
Icebreaker fleet management. Information model





Icebreaker fleet management. Test simulation model





- Voyage route has 5 segments of 300 miles each
- Ice conditions at each segment change every week
- Voyages are from east to west, or from west to east
- Only one type of transport vessel is considered
- The speed of independent ship movement depends on the ice conditions (0.2-10 knots)
- The speed of an icebreaker and a caravan is always 10 knots
- The caravan forms and disbands only at the segment boundaries
- The maximum caravan length is limited

Icebreaker fleet management. Results

Algorithm	Scenario 1		Scenario 2		Scenario 3	
	T_{ave}	Parameters	T_{ave}	Parameters	T_{ave}	Parameters
Independent movement of cargo vessels	603.4	–	792.0	–	358.5	–
Situational “greedy” algorithm	427.7	V_{cr} = 1.0	717.8	V_{cr} = 1.0	350.5	V_{cr} = 1.0
Icebreaker arranging on duty zones	321.9	k = 0.297 l = 1 V_{cr} = 6	644.3	k = 0.109 l = 1 V_{cr} = 10	306.9	k = 0.193 l = 1 V_{cr} = 10
Combinatorial discrete optimization OptaPlanner	340.3	l_{task}=5	591.5	l_{task}=5	312.5	l_{task}=5
Built-in optimization solver on the base of Amalgama Framework	309.7	different parameters at each planning step	421.1	different parameters at each planning step	259.4	different parameters at each planning step

Operational planning of Transshipment. Problem Statement

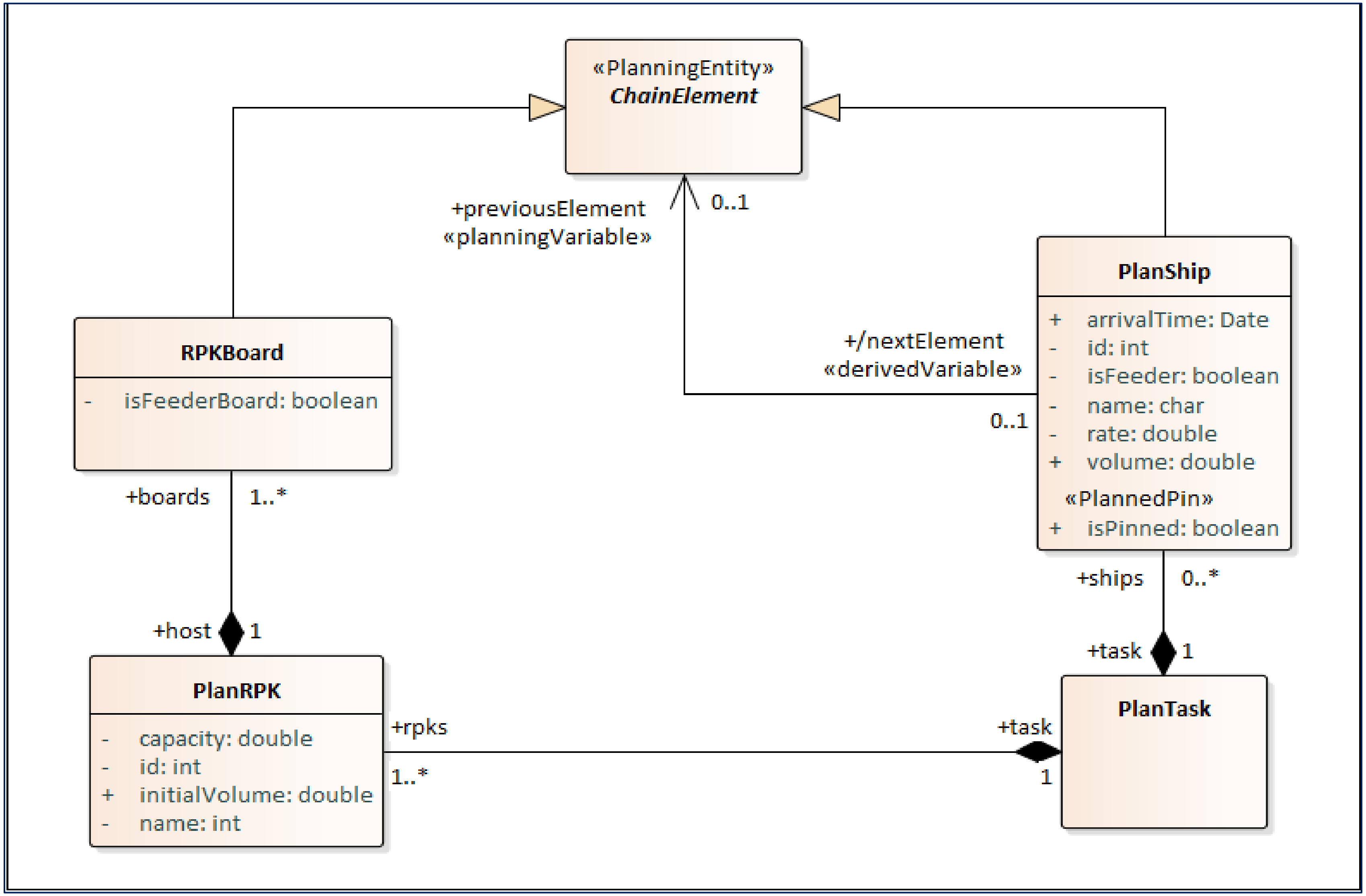
Problems

- Transshipment port contains several Offshore Transshipment Complexes (OTC)
- Each incoming vessel must choose the optimal OTC to perform unloading (for Arctic shuttles) or loading (for Feeders) operations
- The task of choosing the most suitable resource by means of built-in smart dispatching algorithms should be solved on-the-fly when running the simulation model

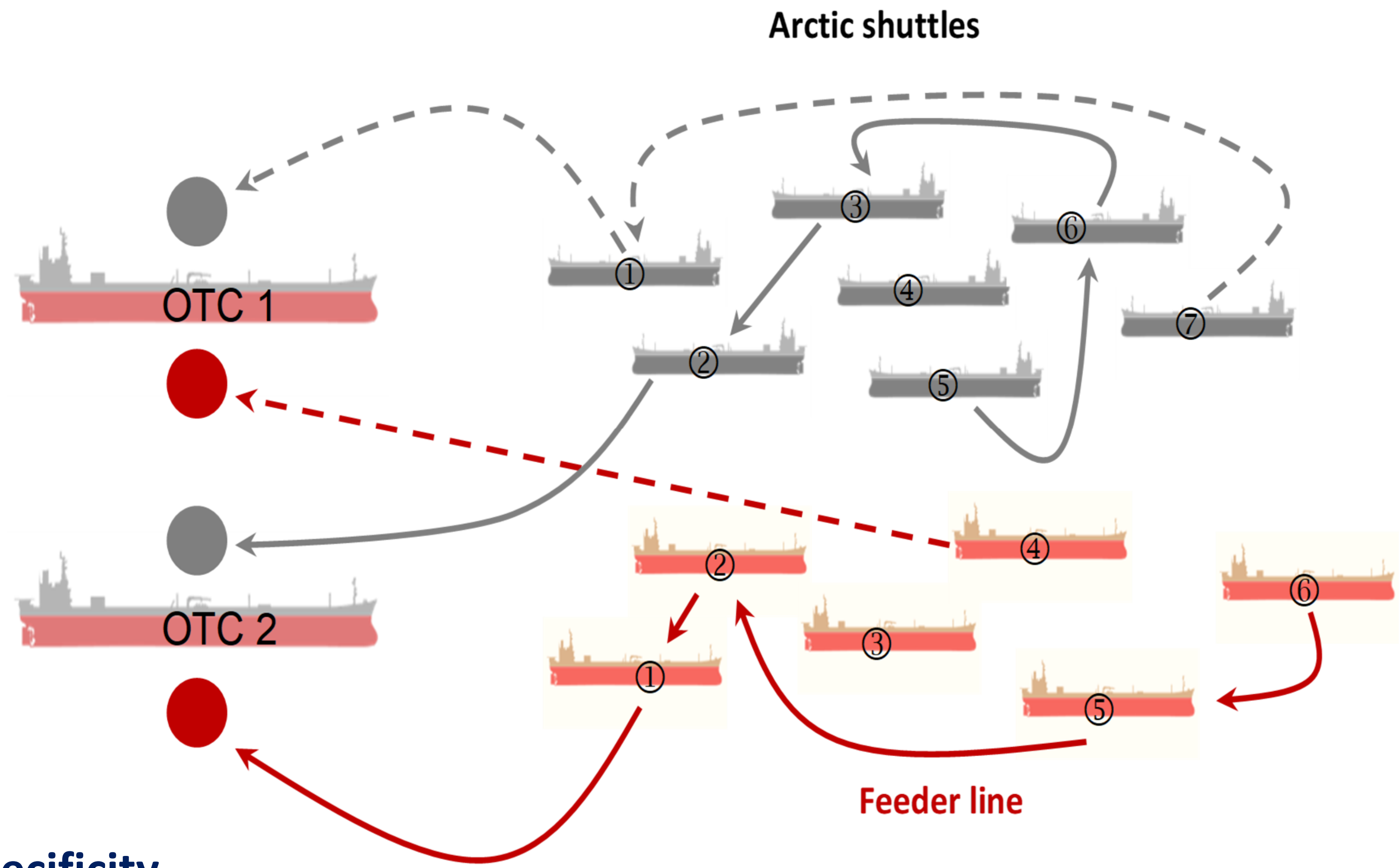
Possible solutions

1. Random choice of OTC (capturing the first suitable resource)
2. Situational “greedy” algorithm of assigning OTC to each incoming vessel
3. Resolving the combinatorial optimization problem for planning all cargo vessels that will arrive within time horizon of the operational planning task. Iterative replanning (rescheduling) during simulation model run

Operational planning of Transshipment. Information model



Operational planning of Transshipment. VRP analogue



Specificity

1. “Customers” are actually moving, while “service vehicles” are static
2. Individual routes of the berthing places of one transportation complex (OTC) cannot be considered independently from each other

Operational planning of Transshipment. Results

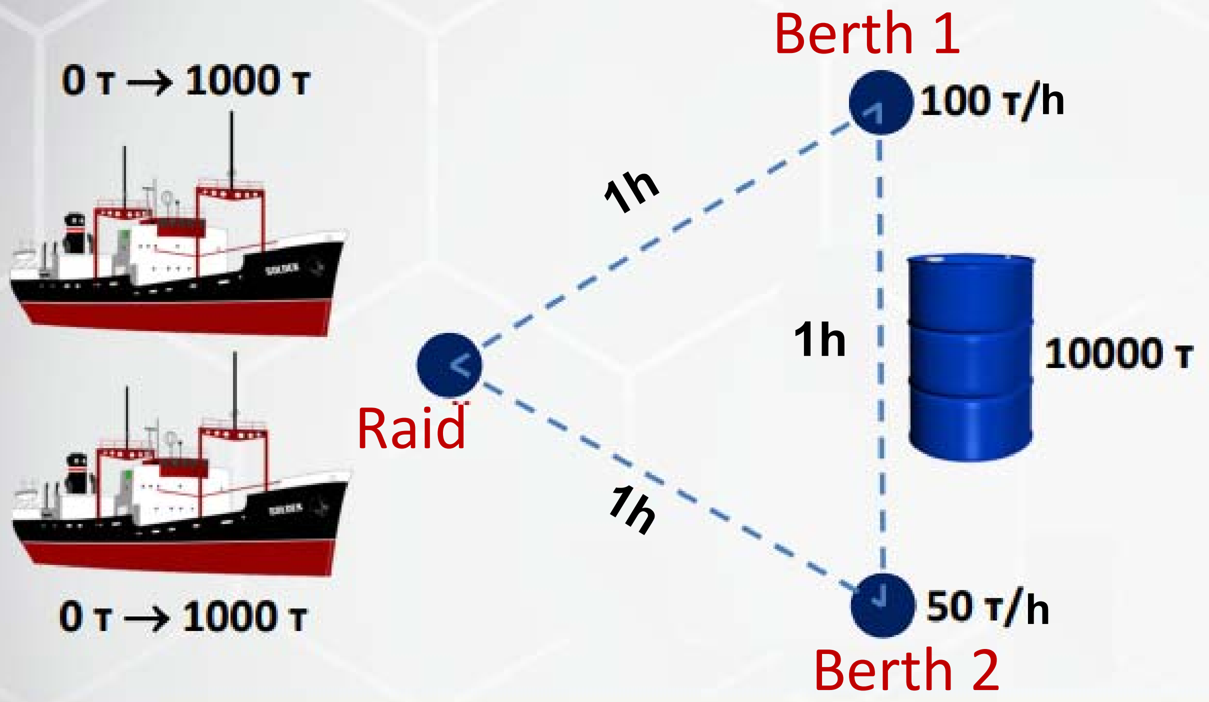
Number of OTCs	Method	Performance indicators					
		LNG cargo flow (ton/year $*10^6$)	Number of port calls	Port time (hours)			
				Ave	Min	Max	St. Dev.
1	Combinatorial	21.8	494	**112.8**	24	450	**69**
	Situational	22.2	501	**109.5**	24	878	84
	Random	21.9	493	**112.2**	24	639	75
5	Combinatorial	29	650	37	24	328	**30**
	Situational	28.7	643	37	24	457	38
	Random	25.2	566	61.7	24	4838	284
10	Combinatorial	30.1	671	**30**	24	244	**15**
	Situational	29.2	654	**31.7**	24	578	41
	Random	23.8	530	75	24	5435	321

- When the intensity of transshipment operations is the highest (small number of OTCs), the situational algorithm gives no worse and sometimes even better results than combinatorial planning.
- An increase in the effectiveness of combinatorial planning is observed with an increase in the number of OTCs (up to 5-10) and a decrease in the overall intensity of their use. In this case, a smart approach for operations planning is required.
- When using CP approach, the stability of the port operations always increases.

Operational planning in simulation models of different subject areas

Subject area	Elements of operational and/or tactical planning	Factors being considered
Exploitation and supply of offshore installations	Looking for a balance between transport vessels and supply vessels competing for berths and weather windows	Cargo flows. Weather forecasts. Voyage schedule
Arctic sea transportation	Optimal routing of ice-class vessel voyages	Significantly dynamical weather and ice conditions
Multimodal container terminals	Optimal placement and stacking of containers in temporary storage areas	Number of operations to move and stacking the containers
Port management	Scheduling of port operations	Limited performance of stationary and mobile elements of port infrastructure (berths, tugs, cranes etc.)
Discrete manufacturing management	Forming an executable plan for the implementation of the production program. Material flow optimization.	Sales, orders, technological routes, work center loading...

Example of port operation planning

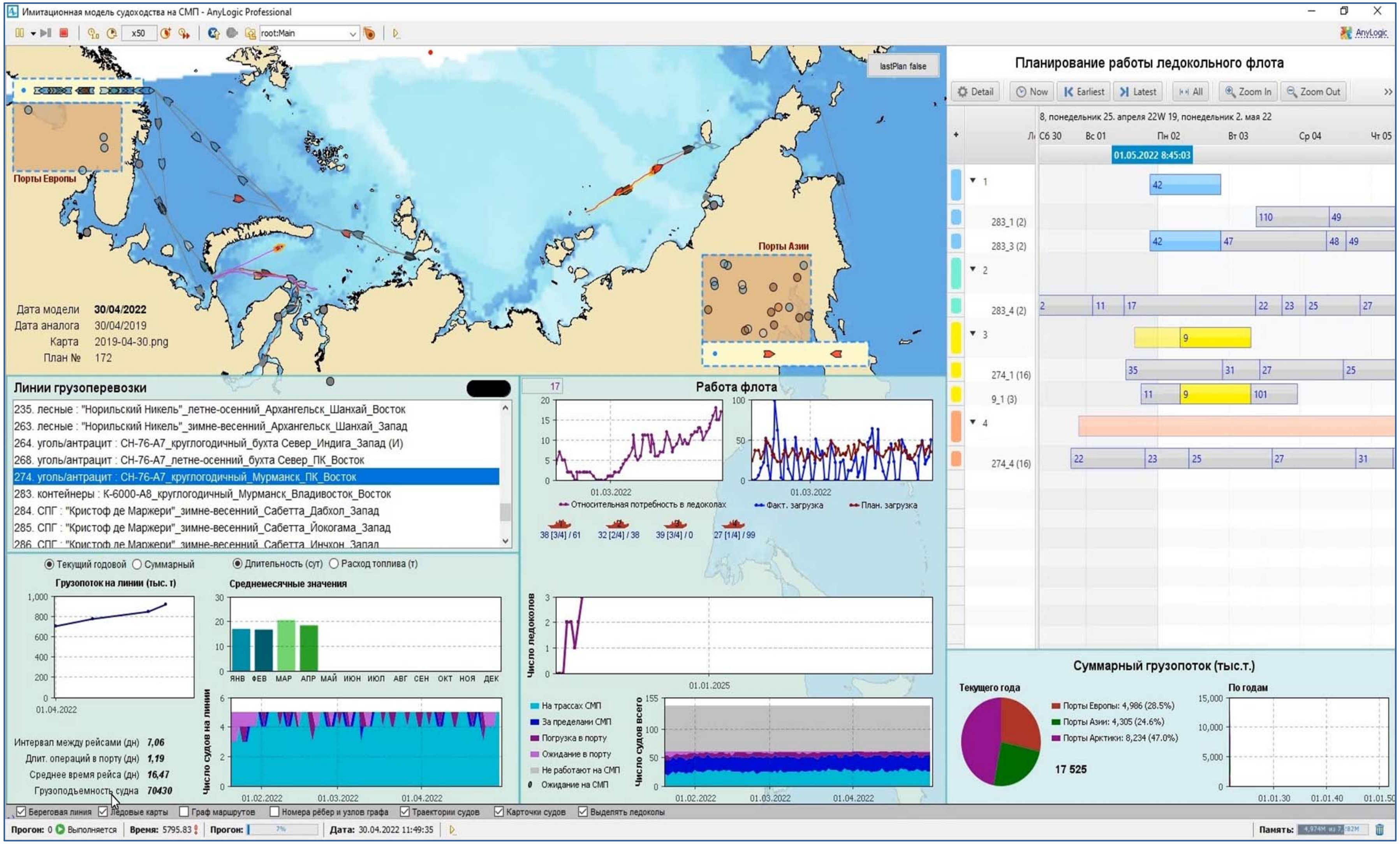


Objective: *Minimize loading time for both vessels*

Method: *Reduction to the problem of constraint satisfaction in logical variables (SAT solvers)*

Solution:

Practical applications



Thank you
for your attention!