Automated Planning for Liner Shipping Fleet Repositioning

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Maersk Line

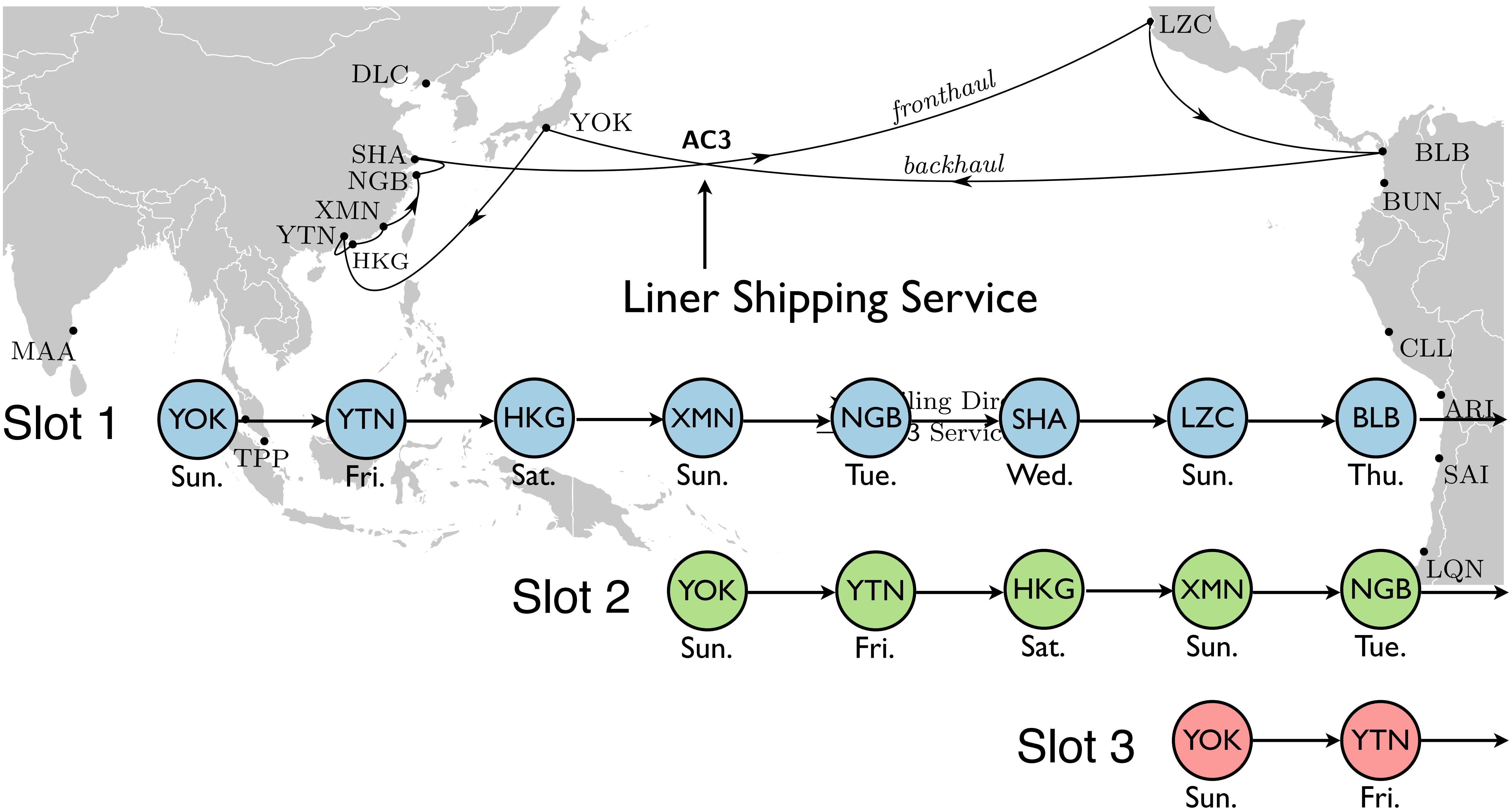
Motivation

- Globally: ~100 repositionings monthly
- Cost: From $200K - $1 million per vessel
- Maersk Line saved $100 million last year repositioning by hand.

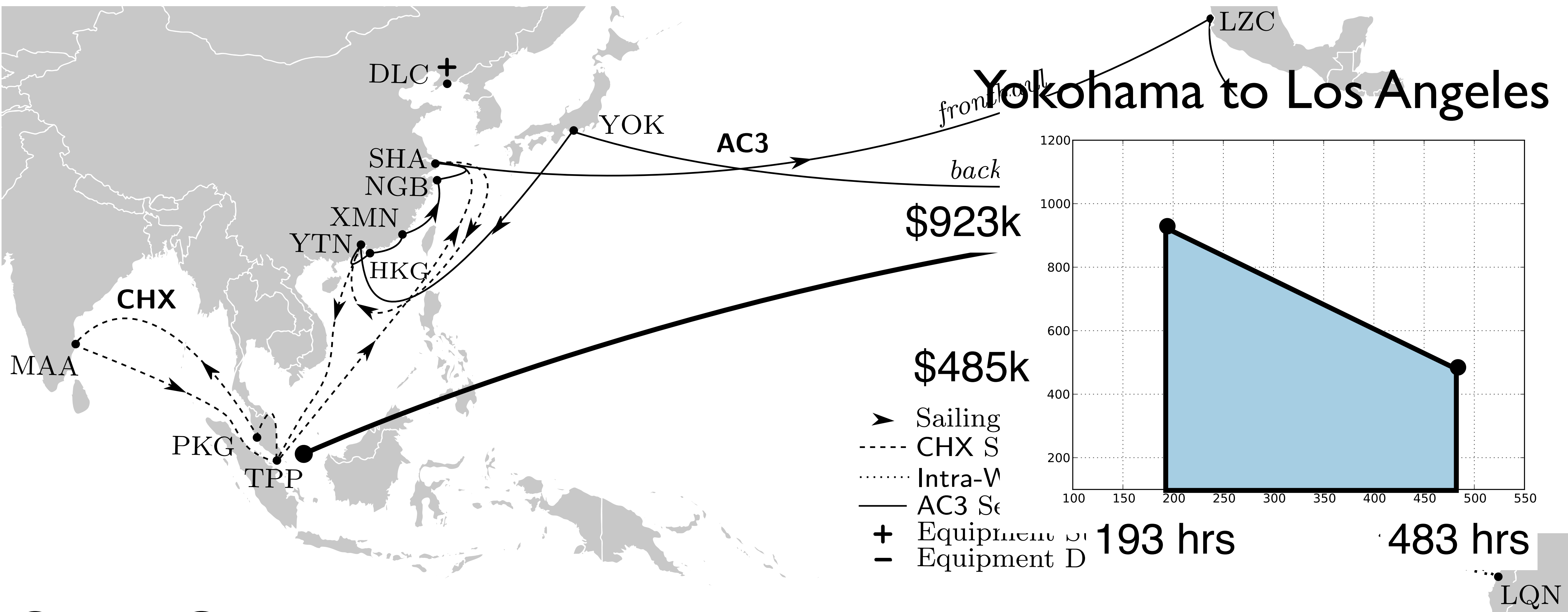
Outline

1. Liner Shipping Fleet Repositioning
2. PDDL Domain
3. Solution methods
   a. Linear Temporal Optimization Planning
   b. POPF
   c. MIP
4. Computational Results
5. Conclusion & Future Work

Liner Shipping Services



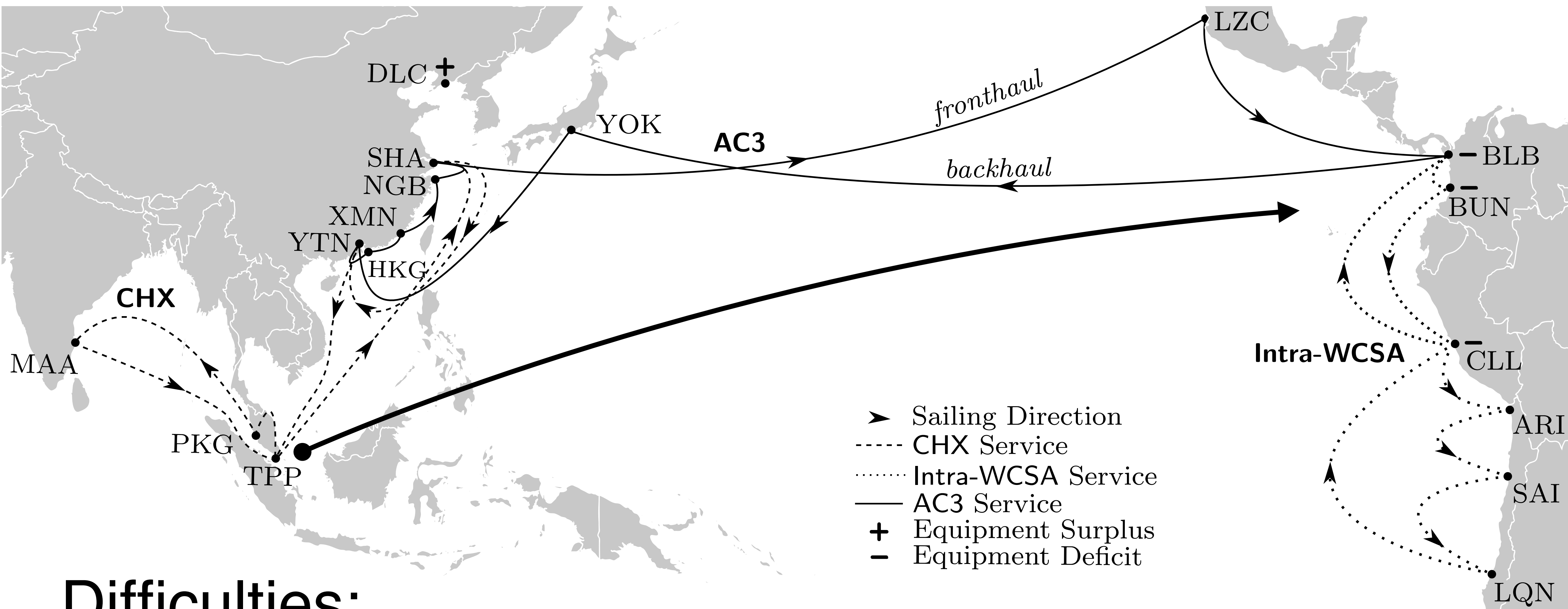
Repositioning



Goal: Optimize cost!

- Sail on service
- Sail with equipment
- Slow steam
- Respect cargo flows

Repositioning



Difficulties:

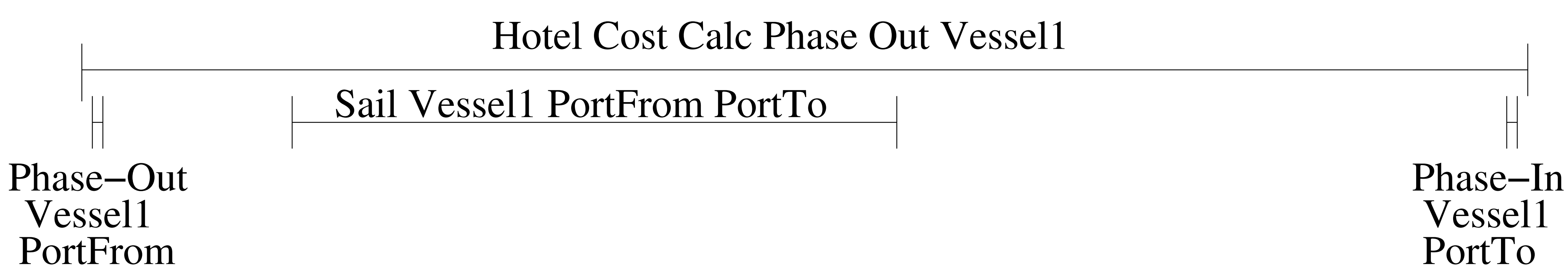
- Vessel interactions (SOS & Phase-in)
- Action duration linked costs
- Hotel cost

PDDL 2.1 Domain

- High level actions: `phase-out`, `phase-in`, `sail`, `sail-on-service`, `sail-equipment`
- Model aspects:
  - TILs: Between 146 and 266

```
(at 16    (vessel-may-phase-out vessel0 pMYTPP))
(at 16.1  (not (vessel-may-phase-out vessel0 pMYTPP)))
(at 504   (vessel-may-phase-in pPABLB))
(at 504.1 (not (vessel-may-phase-in pPABLB)))
```

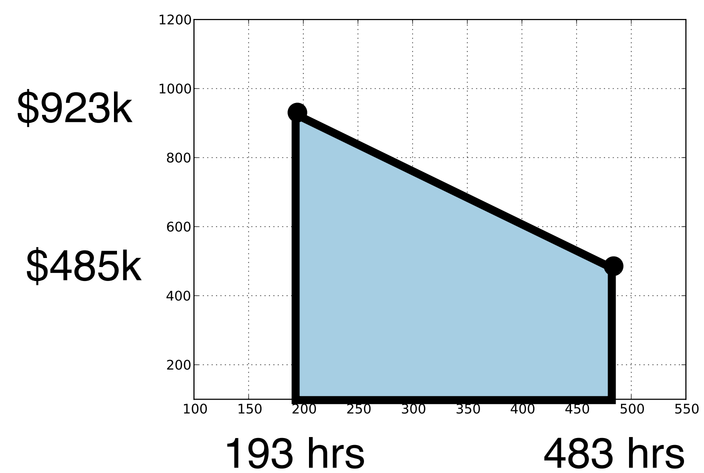
  - Hotel cost envelope actions



PDDL 2.1 Domain

- Model aspects:
  - Action costs that decline with duration

Yokohama to Los Angeles



  - Required concurrency

Related Work

Sapa (Do and Kambhampati 2003) LPG (Gerevini, Saetti, and Serina 2003 & Gerevini and Saetti 2010) Net-benefit planners (HSP*, MIPS-XXL, Gamer) (Helmert, Do, and Refanidis 2008)	Can’t model duration-dependent effects.
Kongming (Li and Williams 2008)	Does not allow multiple updates to a single variable.
TM-LPSAT (Shin and Davis 2005)	Does not optimize a plan metric.

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Linear Temporal Optimization Planning

Partial-Order Planning + Linear Programming

Example: Sail Action

`sail(vessel, from, to)`

Pre:	`at(vessel) = from`
	`state(vessel) = T`
Eff:	`at(vessel) = to`

State variables

Objective:

$$\min \alpha_v (x_v^e - x_v^s)$$

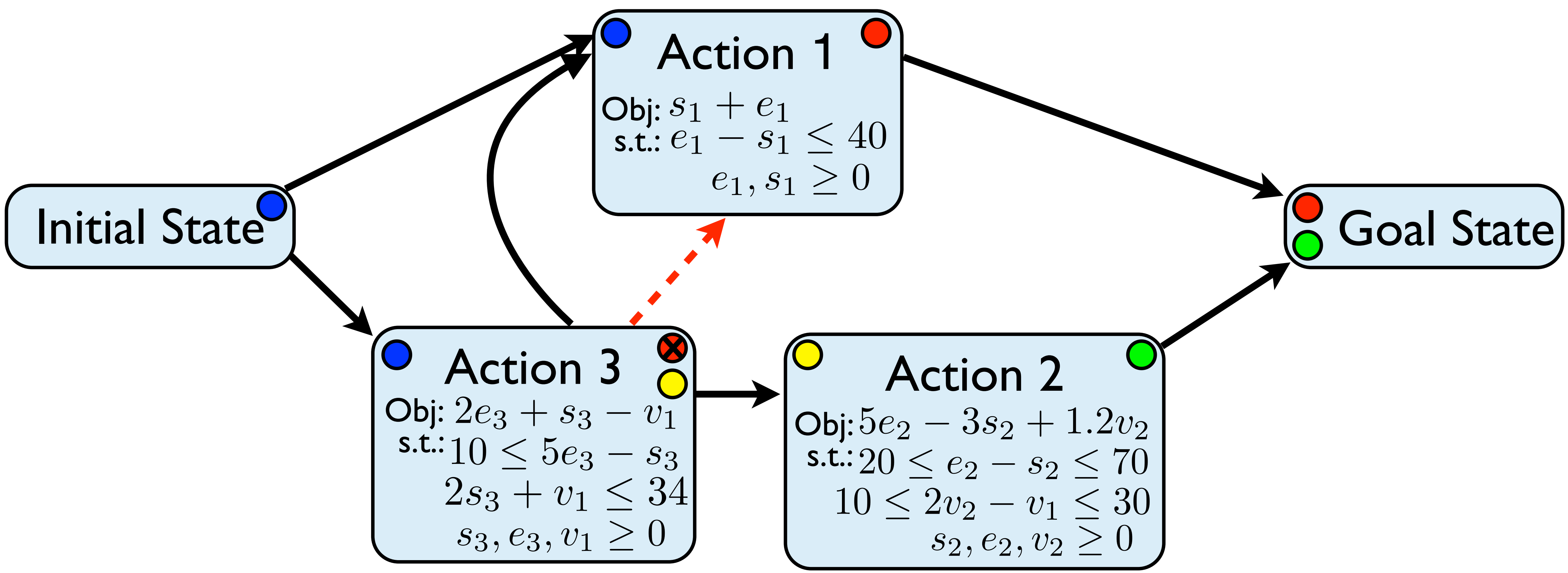
Constraints:

$$10 \leq x_v^e - x_v^s \leq 100$$

$$h_v^s \leq x_v^s$$

Optimization variables

LTOP Plans


Initial State
Action 1
Obj: $s_1 + e_1$
s.t.: $e_1 - s_1 \leq 40$
$e_1, s_1 \geq 0$
Action 3
Obj: $2e_3 + s_3 - v_1$
s.t.: $10 \leq 5e_3 - s_3$
$2s_3 + v_1 \leq 34$
$s_3, e_3, v_1 \geq 0$
Action 2
Obj: $5e_2 - 3s_2 + 1.2v_2$
s.t.: $20 \leq e_2 - s_2 \leq 70$
$10 \leq 2v_2 - v_1 \leq 30$
$s_2, e_2, v_2 \geq 0$
Goal State

LTOP Plans

Initial State

Optimization Model

Obj: $s_1 + e_1 + 5e_2 - 3s_2 + 1.2v_2 + 2e_3 + s_3 - v_1$

s.t.:

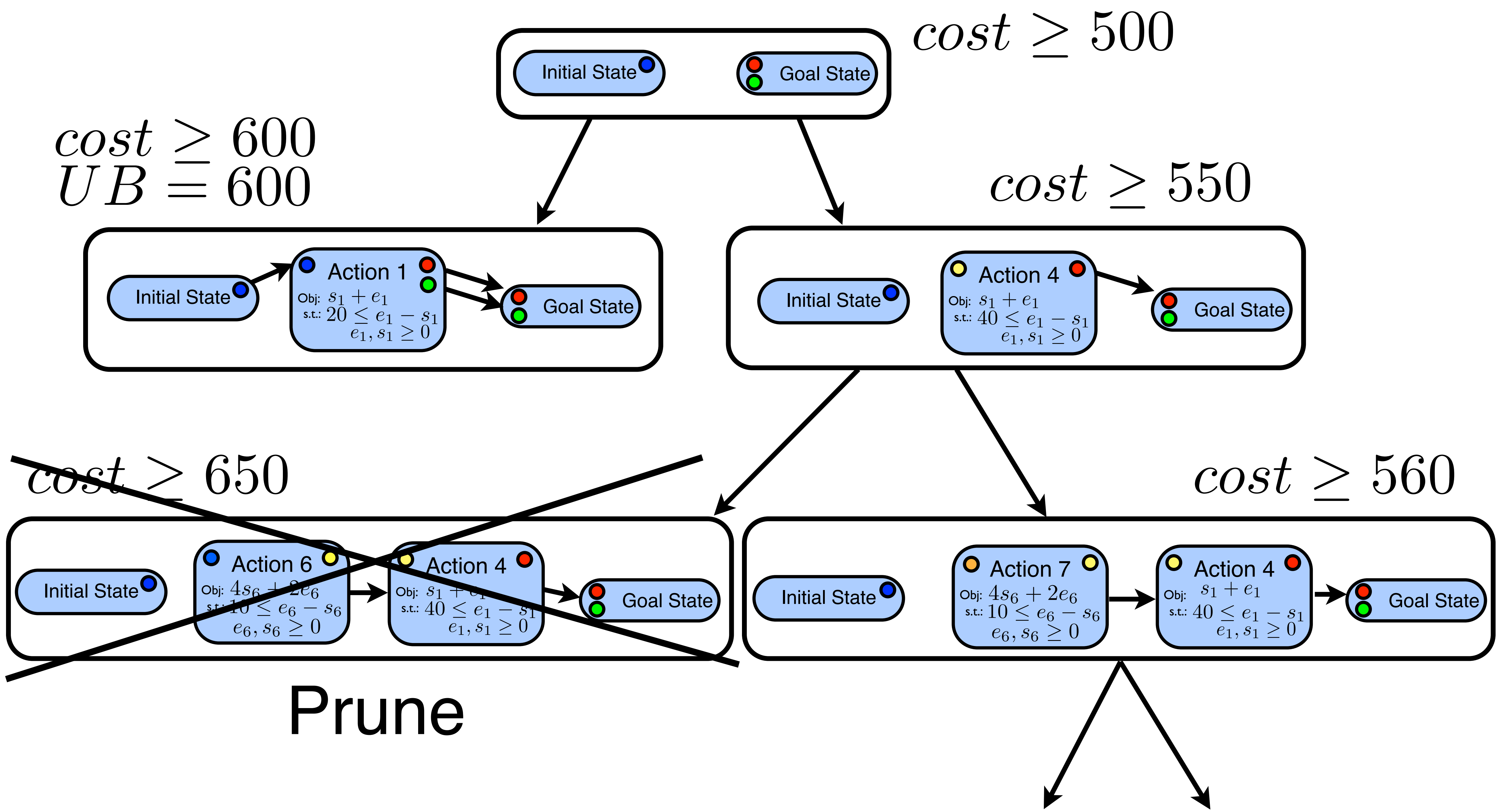
$$e_1 - s_1 \leq 40$$
$$20 \leq e_2 - s_2 \leq 70$$
$$10 \leq 2v_2 - v_1 \leq 30$$
$$10 \leq 5e_3 - s_3$$
$$2s_3 + v_1 \leq 34$$
$$e_3 - s_1 \leq 0$$

More action ordering constraints...

$$s_1, e_1, s_2, e_2, s_3, e_3, v_1, v_2 \geq 0$$

Goal State

LTOP Branch & Bound



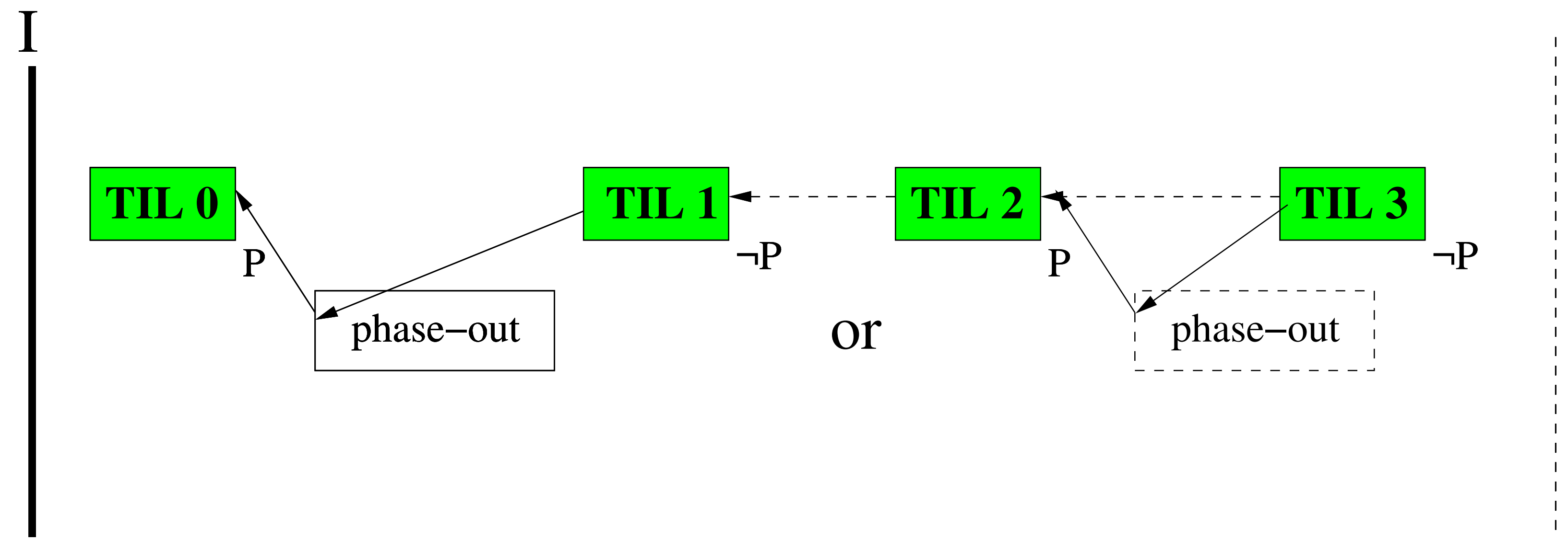
POPF

- Forward-chaining partial-order planner
- Satisficing planner, but can keep searching to improve quality
- Modifications:
  - TIL Handling: Modeled in a MIP (DTP)
  - Cost estimation action pruning

Coles, A. J.; Coles, A. I.; Fox, M.; and Long, D. Forward-chaining partial-order planning. ICAPS-10.

Coles, A. J.; Coles, A. I.; Clark, A.; and Gilmore, S. T. Cost-sensitive concurrent planning under duration un- certainty for service level agreements. ICAPS-11.

POPF TIL Handling



- POPF TIL handling: dummy actions
- New TIL handling in certain cases:
  - Leave choice of window to a MIP
  - DTP solver insufficient (continuous costs)

POPF TIL Handling

- *f* added/deleted periodically

1. No action adds/deletes *f*

$$\sum_{k=0}^{n} f_k^+ w_k^i \leq step_i \leq \sum_{k=0}^{n} f_k^- w_k^i$$
$$\sum_{k=0}^{n} w_k^i = 1$$

2. No action adds *f*; actions with a precondition on *f* delete *f*

$$\forall_{k=1}^{n} \sum_{i \in F} w_k^i \leq 1$$

MIP

Variables

$y_{a,b} \in \{0,1\}$ – use edge a to b?

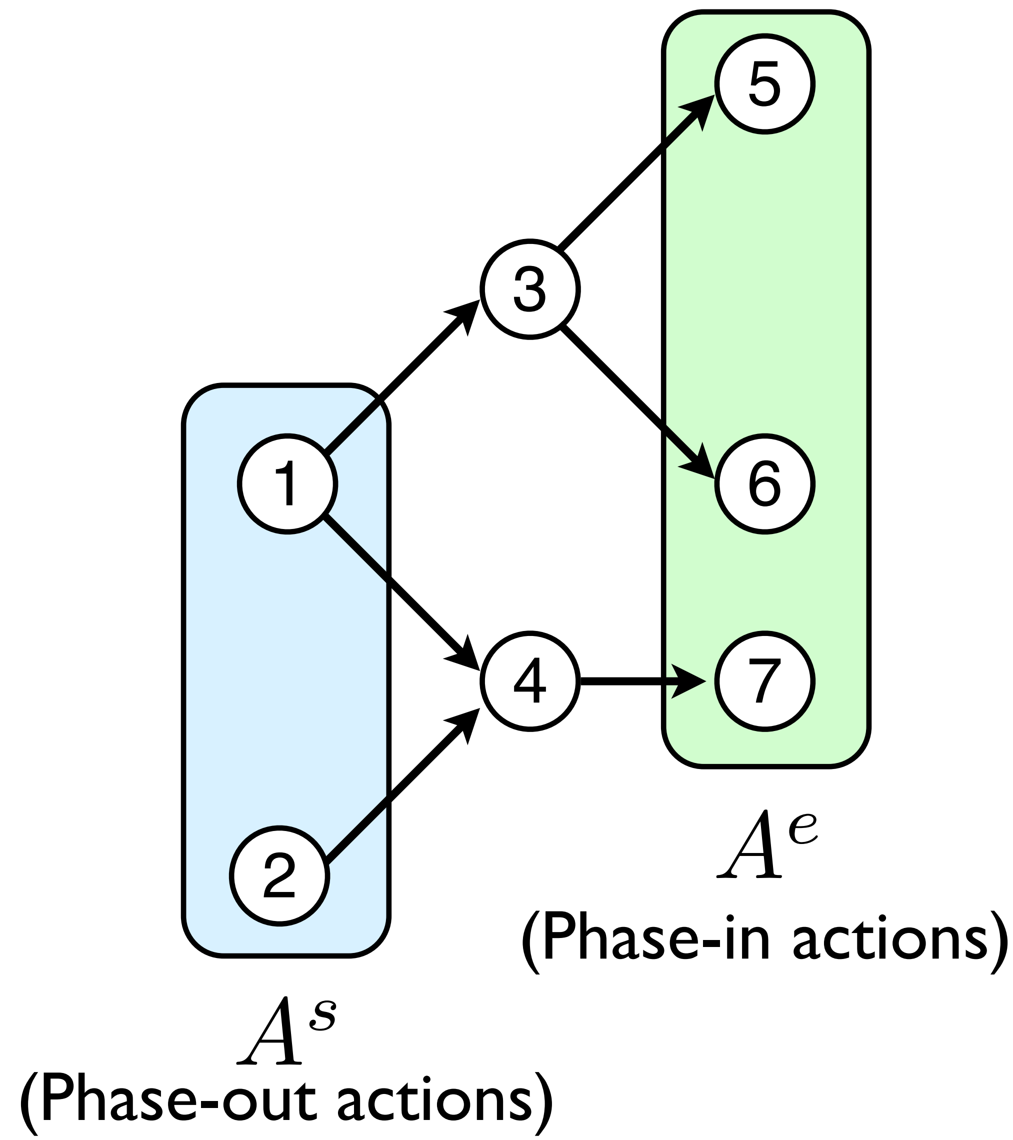
$w_a \in \{0,1\}$ – use action a?

$0 \leq x_a^s$ – action begin

$0 \leq x_a^e$ – action end

$0 \leq h_v^s$
$0 \leq h_v^e$ – hotel cost

Activity Graph



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Computational Results

Inst.	MIP	LTOP				POPF (Optimal)	
		DLH	DL	LH	L	Forwards	Reversed
AC3_1_0	**0.4**	1.1	1.1	1.1	1.1	0.7	1.4
AC3_2_0	**9.3**	51.0	51.5	50.4	53.5	-	809.6
AC3_3_0	**23.0**	188.3	196.8	193.3	202.0	-	-
AC3_1_1e	3.8	3.9	3.9	5.2	5.3	**3.3**	4.0
AC3_2_2ce	27.7	**15.2**	25.2	55.2	126.8	-	-
AC3_3_2c	250.5	**203.2**	362.2	2979.7	3715.8	-	-
AC3_3_2e	228.8	**217.1**	263.0	1453.1	2092.8	-	-
AC3_3_2ce1	312.2	**218.2**	260.8	1451.6	2068.4	-	-
AC3_3_2ce2	252.6	**192.4**	216.0	2624.1	3094.3	-	-
AC3_3_2ce3	706.5	**516.9**	685.5	2959.1	-	-	-
AC3_3_3	148.3	**80.0**	102.4	735.0	1140.8	-	-

CPU Time in seconds; 1 hour timeout

Instances all variations on our real-world case study

Computational Results

Inst.	POPF (Satisficing)				
	Standard	Makespan	No MIP relax	No-TIL-Abs	Reversed
AC3_1_0	0.4 (0.0)	0.1 (1.7)	0.7 (0.0)	105.8 (0.0)	0.4 (0.0)
AC3_2_0	32.5 (0.0)	3.2 (1.6)	113.2 (0.0)	13.0 (0.1)	78.1 (0.0)
AC3_3_0	1105.1 (0.0)	117.5 (2.3)	3041.6 (0.0)	88.2 (0.1)	39.2 (0.8)
AC3_1_1e	1.7 (0.0)	0.1 (0.7)	2.3 (0.0)	1079.3 (0.3)	1.2 (1.2)
AC3_2_2ce	1550.6 (0.3)	1.1 (19)	2284.2 (0.0)	31.3 (3.7)	892.5 (1.6)
AC3_3_2c	399.2 (0.2)	9.2 (7.3)	26.3 (1.4)	303.4 (1.3)	602.8 (1.1)
AC3_3_2e	291.5 (1.3)	9.6 (11)	28.4 (2.4)	310.8 (2.3)	688.6 (1.9)
AC3_3_2ce1	303.9 (1.3)	9.7 (11)	28.4 (2.4)	314.5 (2.3)	697.2 (1.9)
AC3_3_2ce2	1464.2 (1.6)	10.0 (12)	204.9 (2.8)	303.4 (2.7)	690.1 (2.3)
AC3_3_2ce3	348.0 (1.1)	10.3 (8.7)	29.4 (1.9)	308.4 (1.7)	603.3 (1.5)
AC3_3_3	1975.5 (2.3)	10.1 (15)	226.0 (3.6)	352.6 (3.4)	699.6 (2.9)

CPU Time in seconds (Optimality gap)

Conclusion

- Question:
  - Should the LSFRP be modeled with a MIP or automated planning?
- Future work:
  - Investigate of planning vs. MIPs on variations of the LSFRP
  - Adding container flows (revenue) to the LSFRP
- Download the LSFRP PDDL Domain:

http://www.decisionoptimizationlab.dk/datasets