Game-theoretic Randomization for Security Patrolling with Dynamic Excution Uncertainty

Albert Xin Jiang[†], Zhengyu Yin[†], Chao Zhang[†], Sarit Kraus[*], Milind Tambe[†]

[†]University of Southern California, [*]Bar-Ilan University

CREATE HOMELAND SECURITY CENTER National Center for Risk and Economic Analysis of Terrorism Events

TEAMCORE USC

Motivation

Time-critical security patrolling domains


Fare inspection in LA Metro Rail (*TRUSTS*)

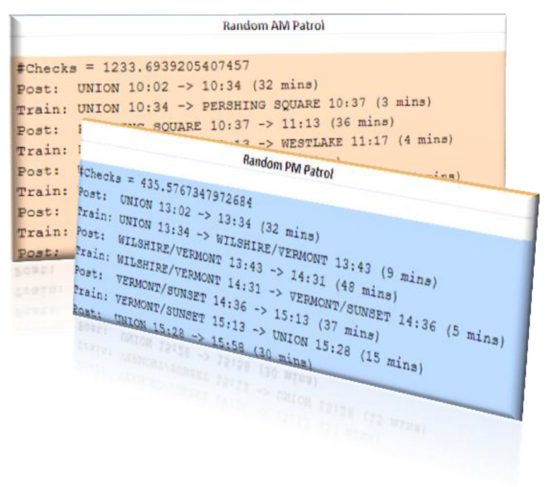

Ferry escort in New York

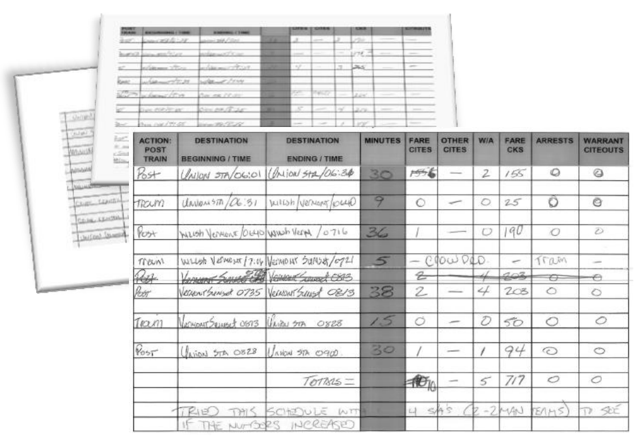

Patrolling Port of Boston (PROTECT)

Game-theoretic Model for Security: Stackelberg Equilibrium
- Defender commits to a randomized patrol schedule
- Attacker plays best response

Fare Evasion Problem in LA Metro
- In 2007 alone, estimated revenue loss of $5.6 million
- Los Angeles Sheriff's Department (LASD) periodically patrols the Metro system
- TRUSTS system for randomized fare inspection (2012)

Problem Statement





Field Tests for TRUSTS v.1 (2012): officer often deviate from schedule (missing a train, making an arrest, etc.)

Execution uncertainty at earlier time steps can affect the defender units' ability to carry out their planned schedules in later time steps

Desired patrol schedules should
- be robust against execution uncertainty
- contain contingency plans

Contributions

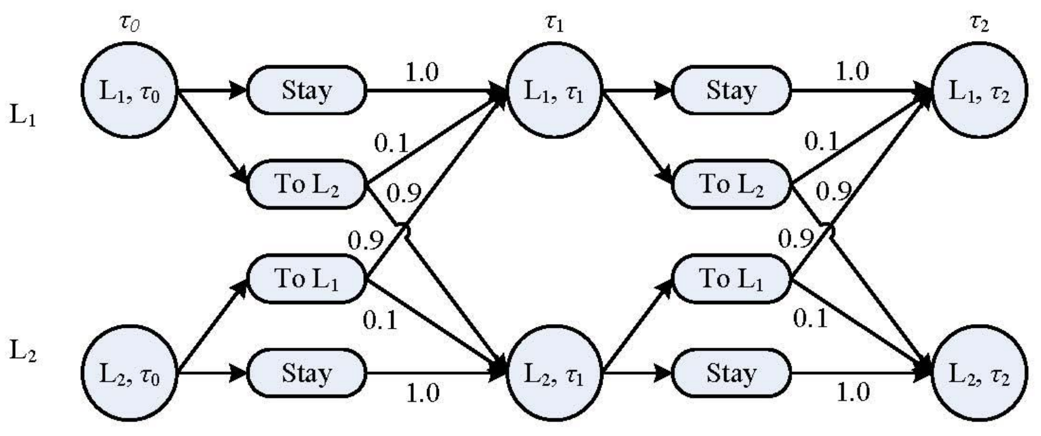
General Stackelberg game model for patrolling with execution uncertainty
- Using Markov Decision Processes to model probabilistic transitions in defender's execution of patrols
- Combines game theory and planning under uncertainty

Efficient algorithm when utility functions are separable

Outputs robust patrol schedules with contingency plans
- Applied to TRUSTS system for LA Metro
- Smart-phone app under evaluation (See Our Demo!)

Model

Patrolling game with execution uncertainty
- Two-player Bayesian Stackelberg game
- Leader (defender) has multiple units
- Defender's strategy space: an MDP for each unit
- Defender commits to mixed patrol schedule, attacker respond (Strong Stackelberg Equilibrium)
- Multiple types of attacker



- State s: (location, time)
- Action a
- Transition function T(s,a,s')
- Utility depends on:
  joint trajectory of defender units
  attacker type and action

Computation

Challenge: exponential # of defender pure strategies

If utility function has separable structure
- Utility decomposed into sum over individual transitions
- Expected utility only depend on the marginal coverage x(s,a,s')
- Compactly represent defender strategies using marginal coverage
- Standard SSE formulation: efficient practical algorithms (e.g., Yin & Tambe 2012)
- For zero-sum games: linear program

$$\max_{\mathbf{w},\mathbf{x},\mathbf{u}} \sum_{\lambda\in\Lambda} p_\lambda u_\lambda + \sum_i \sum_{s_i,a_i,s_i'} x_i(s_i,a_i,s_i')R_i(s_i,a_i,s_i')$$

$$x_i(s_i,a_i,s_i') = w_i(s_i,a_i)T_i(s_i,a_i,s_i'), \forall s_i,a_i,s_i'$$

$$\sum_{s_i',a_i'} x_i(s_i',a_i',s_i) = \sum_{a_i} w_i(s_i,a_i), \forall s_i$$

$$\sum_{a_i} w_i(s_i^+,a_i) = \sum_{s_i',a_i'} x_i(s_i',a_i',s_i^-) = 1,$$

$$w_i(s_i,a_i) \geq 0, \forall s_i,a_i$$

$$u_\lambda \leq \mathbf{x}^T U_\lambda^d \mathbf{e}_\alpha, \forall \lambda\in\Lambda,\ \alpha\in\mathcal{A},$$

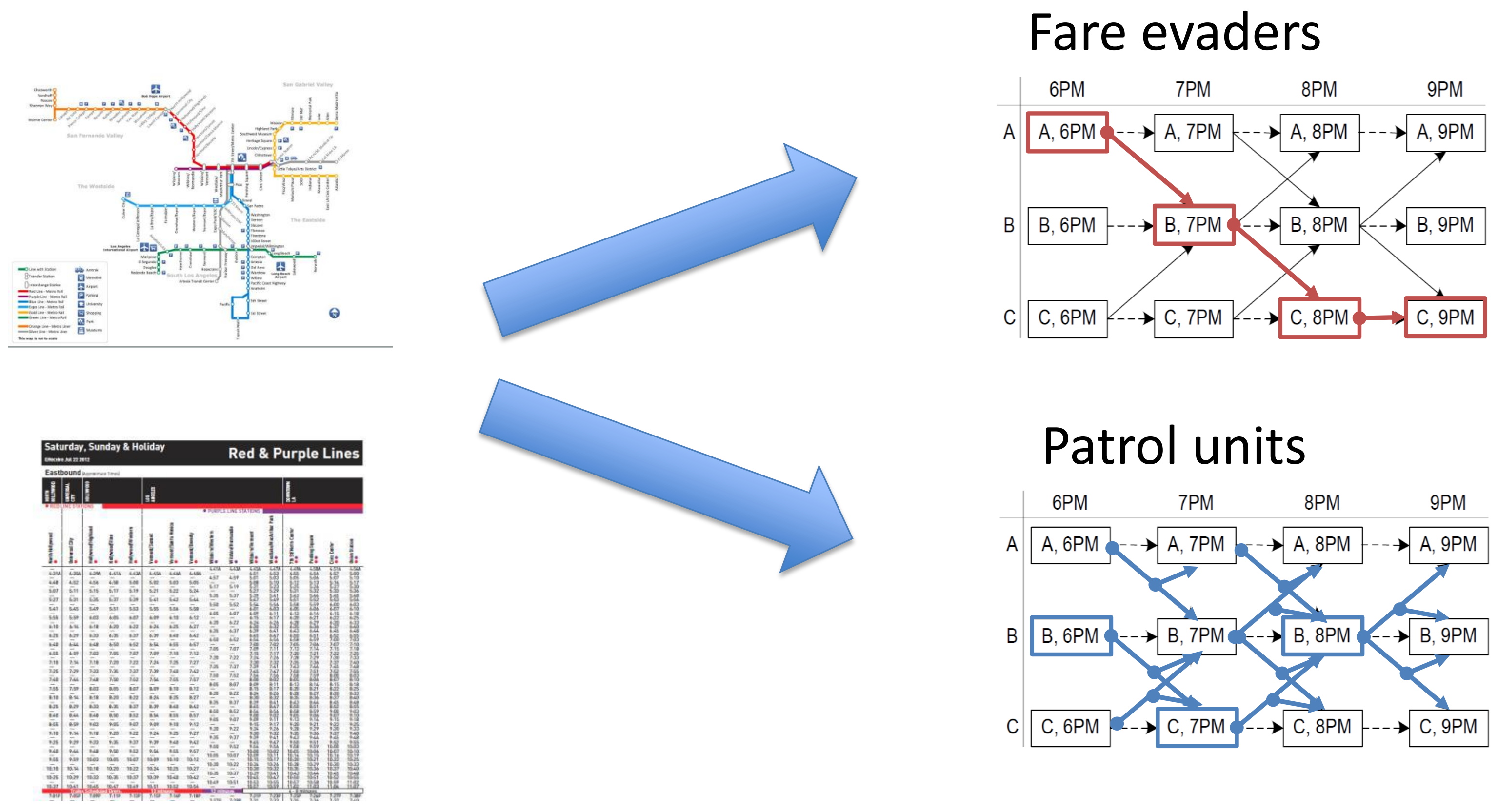
- Calculate decoupled Markovian randomized strategy from the marginals

$$\pi_i(s_i,a_i) = \frac{w_i(s_i,a_i)}{\sum_{a_i'} w_i(s_i,a_i')}$$

- Sample a deterministic strategy by sampling an action at each state
  - Results in an deterministic MDP policy for each unit
  - Prescribes action at every state, i.e., contingency plan for all situations

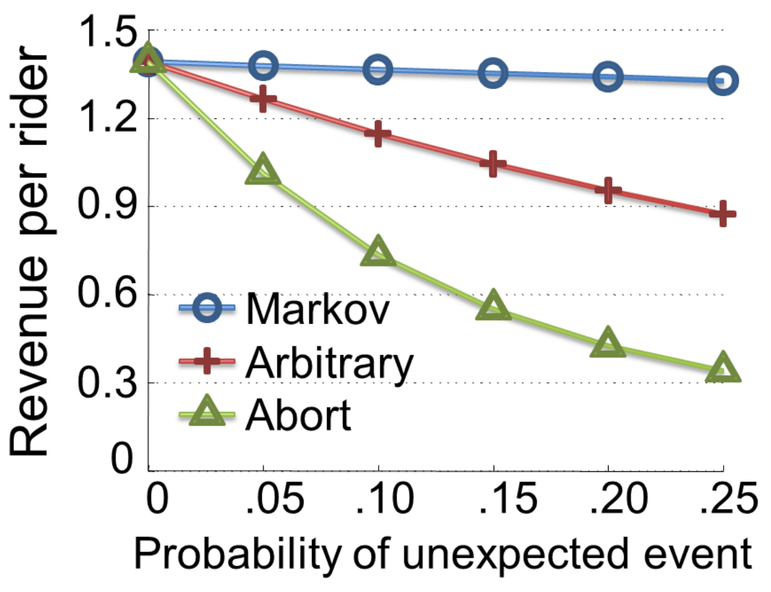
Apply to LA Metro

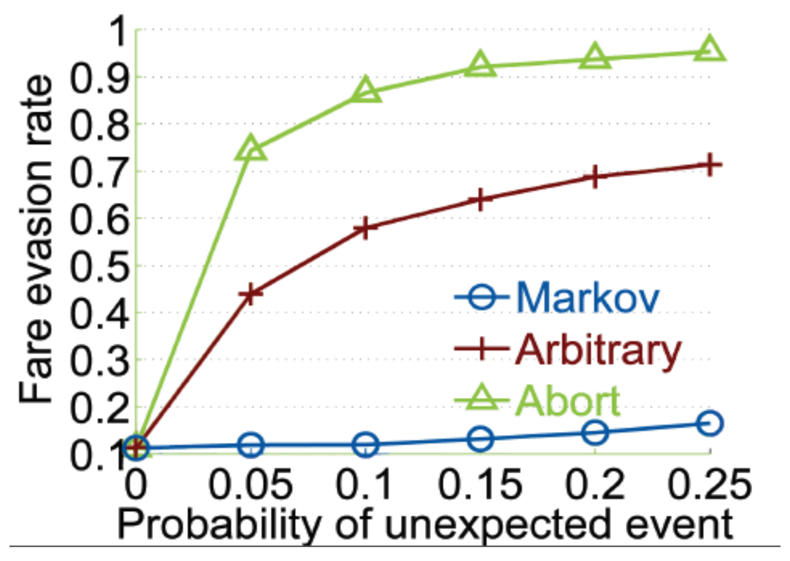
- Zero-sum
- Approximate utility as separable function



Evaluation

Markov strategy (TRUSTSv2) outperforms TRUSTSv1 with simple contingency plans

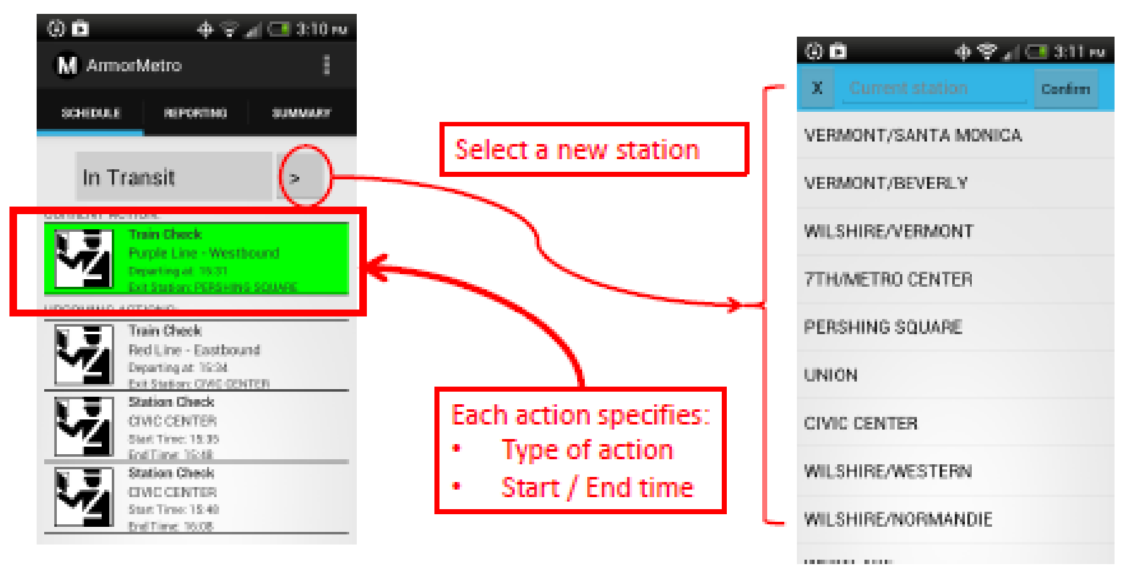




Future Work

- Learning transition probabilities from data
- Non-separable utility: applying techniques from (decentralized) planning under uncertainty / multi-agent coordination, e.g., Dec-MDPs

Mobile Phone Application



Train Check
Purple Line - Westbound

Train Check
Red Line - Eastbound

Station Check
CIVIC CENTER

Station Check
CIVIC CENTER

VERMONT/SANTA MONICA
VERMONT/BEVERLY
WILSHIRE/VERMONT
7TH/METRO CENTER
PERSHING SQUARE
UNION
CIVIC CENTER
WILSHIRE/WESTERN
WILSHIRE/NORMANDIE

Select a new station

Each action specifies:
- Type of action
- Start / End time

- Stores and visualizes sampled schedule with contingency plan
- Collects data
- Under evaluation by LASD
- Check out our demo on Thursday, 10-11am, 3:30-4:30pm
  (Luber, Yin, Delle Fave, Jiang, Tambe & Sullivan)

Our paper: teamcore.usc.edu/people/jiangx/papers/aamas13-execution.pdf

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