Robust Design of CAV-Dedicated Lanes Considering CAV Demand Uncertainty and Lane Reallocation Policy

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Study background

- Traffic congestion is a major issue in metropolitan areas.
  - ➢ Travelers experience 34 hours of extra delay in 2019 compared to 1982.
- Connected and autonomous vehicles (CAVs) and associated infrastructure can reduce congestion by increasing the quantity or quality of travel supply
  - ➢ Transition era with mixed CAVs and human-driven vehicles (HDVs).
- The connectivity feature of CAVs enables the exchange of information to/from other CAVs through V2V and intelligent roadside units.
- CAV-dedicated lanes can improve mobility during the transition era.
- Due to the little or zero lateral wander of CAVs (19), CAV-dedicated lanes may have smaller lane widths from an HDV-only scenario to a mixed stream scenario.

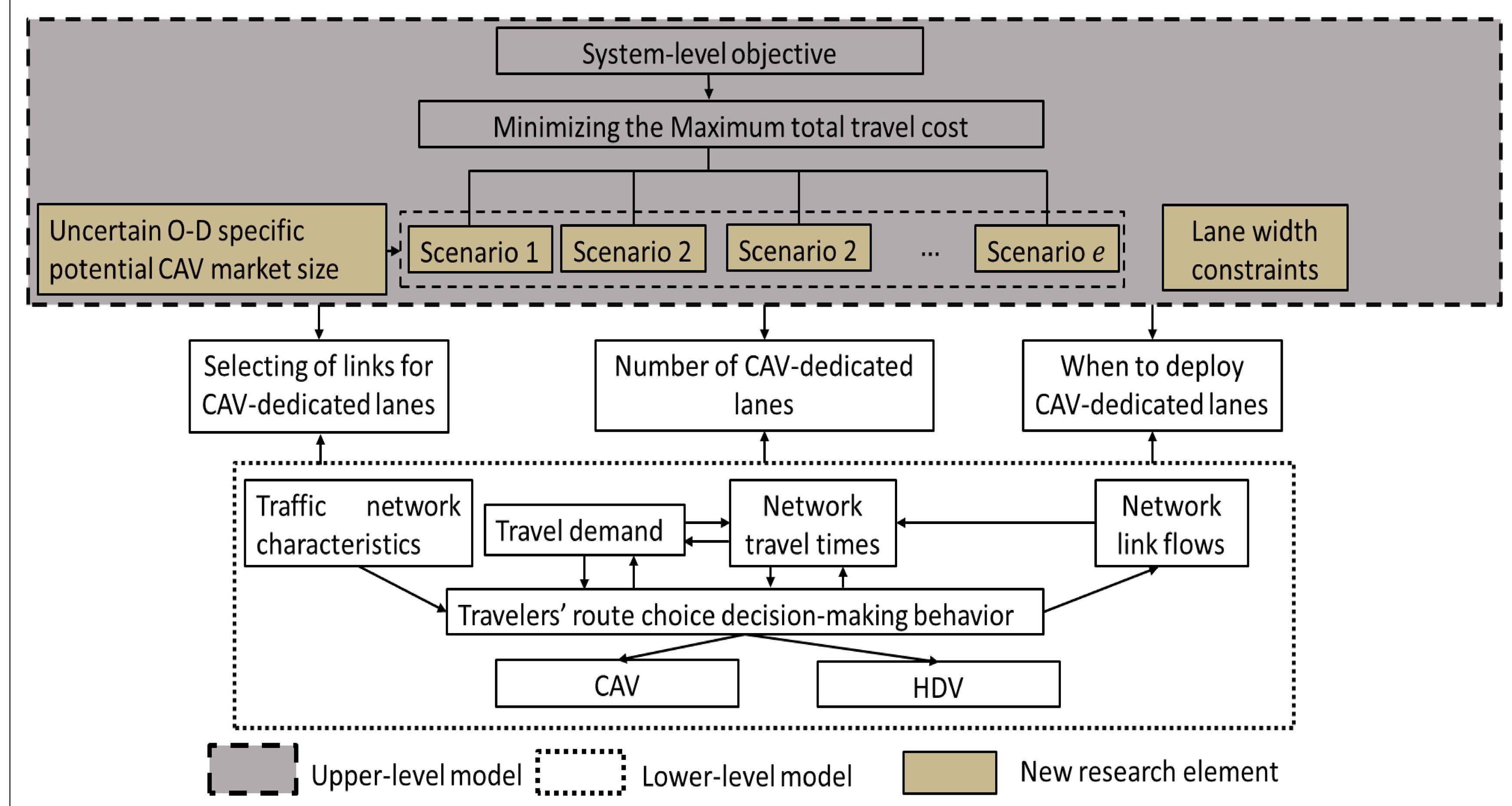
Research objectives and contributions

- The objective of this research is to identify the optimal locations of CAV-dedicated lanes in urban highway network to minimize total travel time.
- CAV market size is uncertain due to the unknown consumers' willingness to purchase CAVs over planning horizon with duration of several years
  - ➢ Potential CAV market size uncertainty
- Lane reallocation strategy
  - ➢ Due to the little or zero lateral wander of CAVs, CAV-dedicated lanes may have smaller lane widths, from an HDV-only scenario to a mixed stream, to increase the number of lanes in a wide highway corridor.
  - ➢ The CAV-dedicated lane width could be close to the maximum vehicle width to accommodate for more lanes
    - ❑ Tesla Model Y width with unfolded mirrors is approximately 7 ft.
- Our framework develops the robust design of CAV-dedicated lane infrastructure that incorporates:

  (i) uncertainty in the potential CAV market size over several years

  (ii) lane reallocation strategy

Methodology



Bi-level framework for CAV-dedicated lane deployment

Upper-level model

$$\min_{y}\max_{x,\lambda}\sum_{t}\sum_{n}\sum_{a}\sum_{w}\tau_a^t(v_a^t)x_{a,w}^{n,t}$$ Minimizing worst-case total travel time

$$c_{\bar{a}}^t = c_{\bar{a}}^{t-1} + \phi_{\bar{a}}\, y_{\bar{a}}^t$$
$$c_{\underline{a}}^t = c_{\underline{a}}^{t-1} - \phi_{\bar{a}}\, y_{\bar{a}}^t$$
$$c_{\bar{a}}^t \geq \underline{c}_{\bar{a}}$$

Updating capacity of CAV-dedicated lanes and available for HDVs

$$u_{\bar{a}}\cdot\left(l_{\bar{a}}-\sum_{i=1}^{t}y_{\bar{a}}^i\right)+u_{\bar{a}}\cdot\left(l_{\bar{a}}+\sum_{i=1}^{t}y_{\bar{a}}^i\right)\leq U$$ Lane reallocation strategy constraint

$$y_{\bar{a}}^t \in \{0,\dots,J_{\bar{a}}^t\}$$ Transportation agency decision variables

Lower-level model

- The lower-level model seeks to capture the route and vehicle type choices of travelers (CAVs/HDVs).
- Under the equilibrium condition, travelers cannot further reduce their travel times by unilaterally changing the route.
- Demand diffusion model is used to capture the mode choice and adoption rate of CAVs where the CAV adoption rate in each period depends on the adoption rate and the net benefit gained by the CAVs in the previous period.

$$q_w^{2,t} = q_w^{2,t-1}\cdot(1+g(\mu_w^t))\cdot\left(1-\frac{q_w^{2,t}}{\bar{q}_w^t}\right)$$

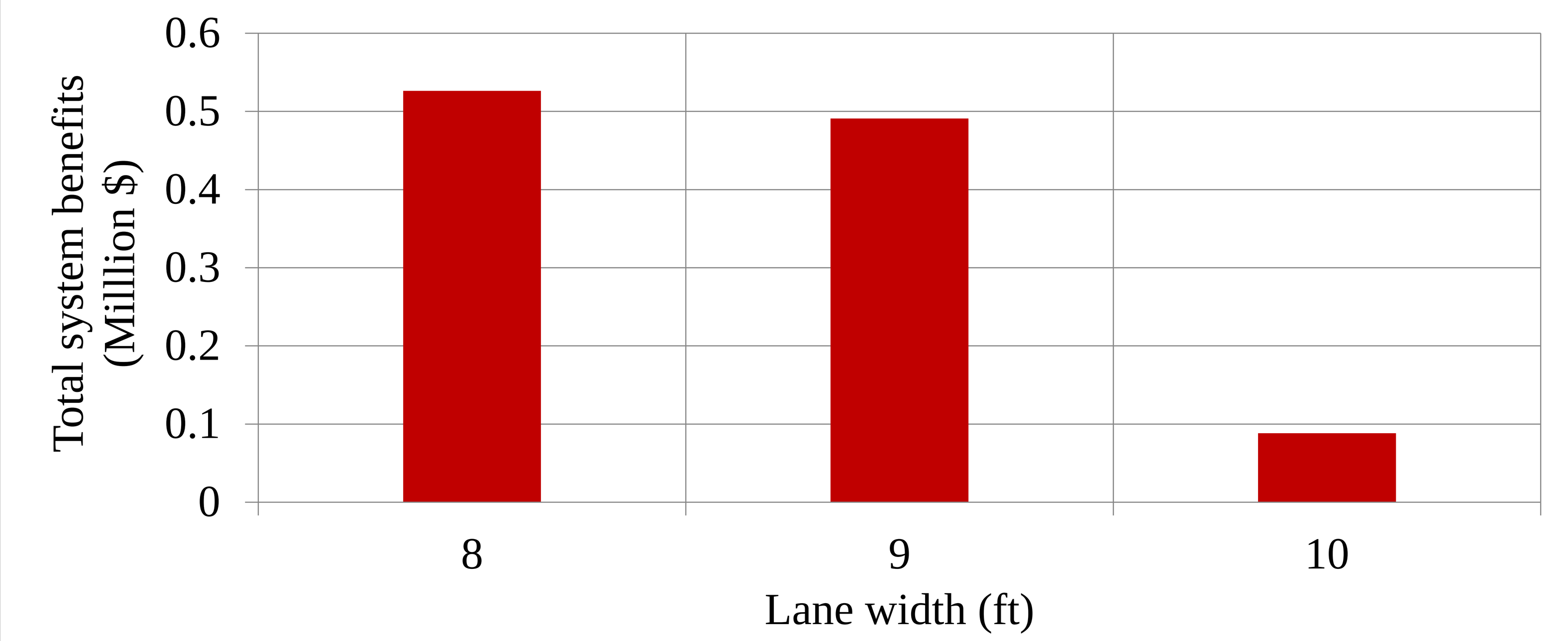
$$g(\mu_w^t) = \kappa\cdot e^{\iota\cdot(\mu_w^t-\bar{\mu}_w^t)}$$

$$\mu_w^t = \chi_w^t\cdot[\alpha_1\cdot c_w^{1,t}-\alpha_2\cdot c_w^{2,t}]-\xi_w^t$$

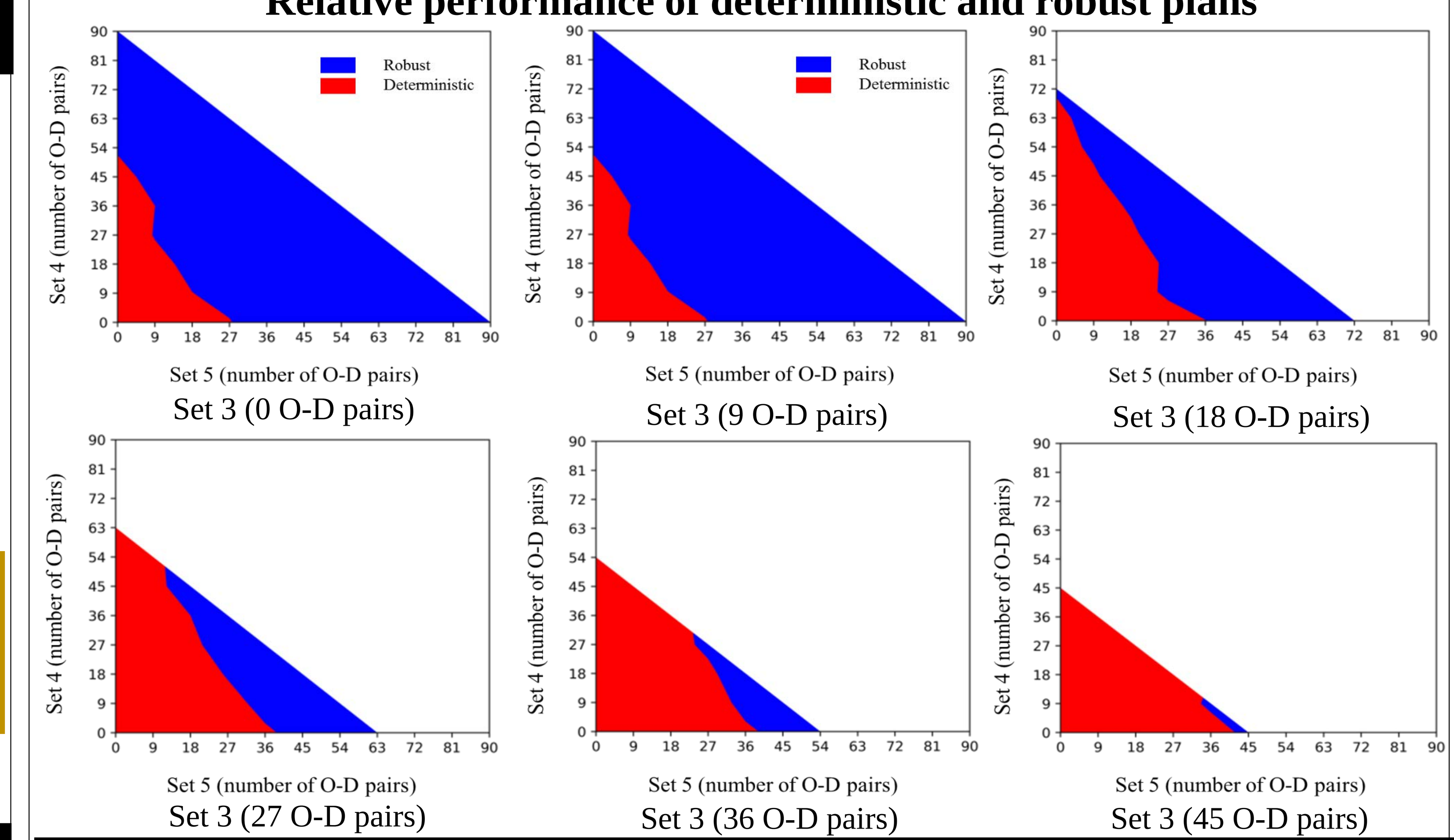
Computational experiments

- The bi-level model is solved using Active-set algorithm.
- The synthetic network consists of 10 nodes, 22 links, and 90 O-D pairs.

Impact of lane reallocation policy on total travel cost



Relative performance of deterministic and robust plans



Concluding remarks

- Propose a robust optimization model to deploy CAV-dedicated lanes in in a highway network for addressing the inherent uncertainty in the forecast of potential CAV market size
- This goal is to minimize worst-case total travel time.
- Lane reallocation policy
- Demonstrate that impact of uncertainty of consumers' willingness to purchase CAVs on total travel cost can be reduced by motivating travelers to purchase CAVs
- Lane reallocation policy can provide a 6% reduction in total travel cost by reducing lane width to 9 ft in this small network.
- Robust strategies can perform better than the deterministic strategies in reducing average and variance of total system travel cost under different possible scenarios for consumers' willingness to purchase CAVs.