Network reliability-based optimal toll design

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Overview

- Policy objectives of road authorities
- Research framework
- Definition of reliability-based optimal toll design problem
- Mathematical formulation
- Experimental results
- Reliability paradox
- Conclusions
- Further research

Policy objectives of road authorities

- Manage demand
- Optimize congestion
- Maximize social welfare gains
- Reduce environmental impacts
- Raise revenues to recoup maintenance cost and construction cost
- Improve network reliability

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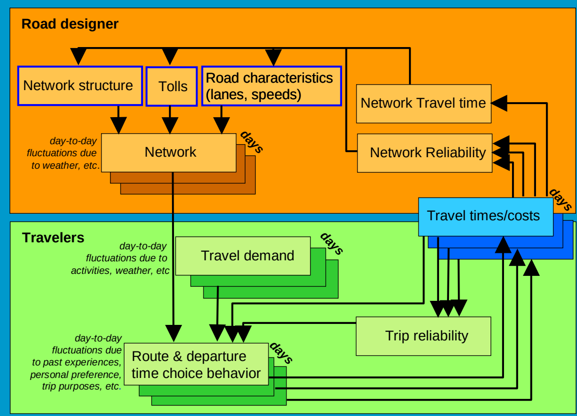
Research framework



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Definition of reliability-based optimal toll design problem

Upper level

- Road authority set tolls in a network, based on the prediction of travelers' reactions to tolls
- Minimize network cost, composed of network travel time and network reliability

Lower level

- Make trip and route choice decisions based on the toll levels
- Minimize their perceived travel cost, composed of travel times and tolls

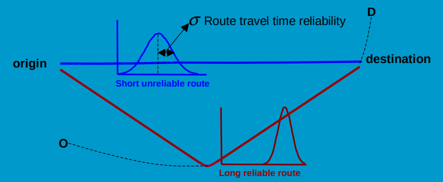
Definition of reliability-based optimal toll design problem

Reliability on network level

- Capacity reliability
- Travel time reliability
  - Total travel time
  - Total utilities including travel time and variability
  - Standard deviation of total network travel time

Definition of reliability-based optimal toll design problem

Definition of Network reliability

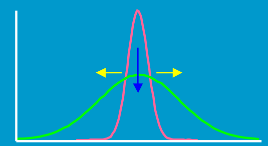


- Day-to-day capacity variations and demand fluctuations lead to travel time variability
- Reliability is defined by a series of day-to-to travel times of a particular period of the day

Definition of reliability-based optimal toll design problem

Expected impacts of road pricing

- Destination choice
- Trip choice → Vertical demand drop
- Mode choice
- Departure time choice
- Route choice



Mathematical formulation

Formulation of bi-level optimization problem

$$\min_{\theta} Z = \hat{\tau} + \frac{\gamma}{\alpha}\hat{\rho}$$

Subject to:

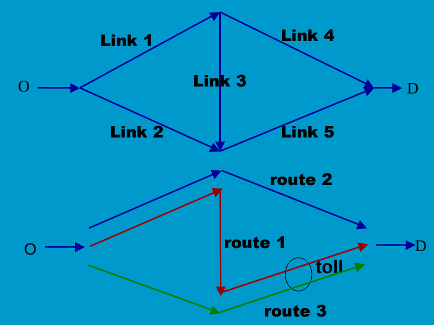
$$\theta_a(t) \geq 0, \quad \forall a \in A, \forall t \in T,$$

$$\sum_{(r,s)} \sum_{p \in P^{rs}} \sum_{k} \tilde{F}_p^{rs}(k)\left(q_p^{rs}(k) - \tilde{q}_p^{rs}(k)\right) \geq 0, \quad \forall q_p^{rs}(k) \in \Omega.$$

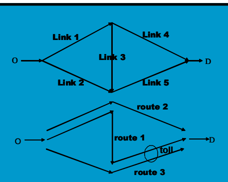
Solution approach: Quasi-Monte Carlo approach is applied to model simultaneous day-to-day capacity & demand variations

Experimental results

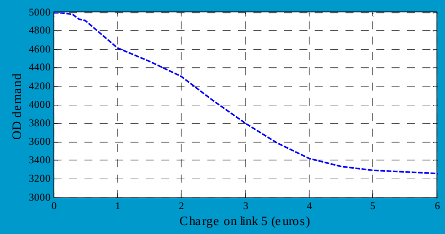
Network



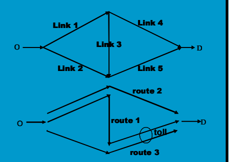
Experimental results



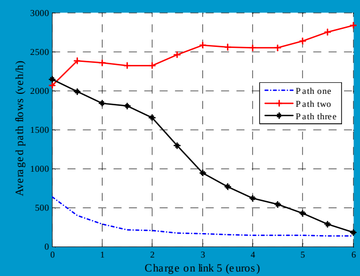
Elastic OD demand



Experimental results

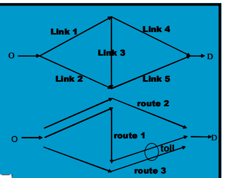


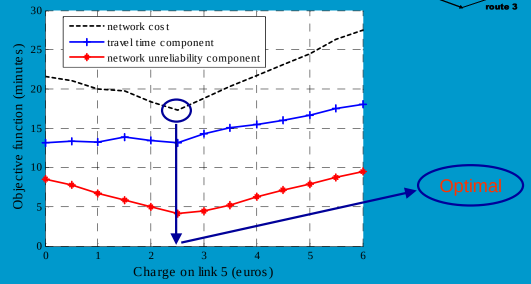
Route flows



Experimental results

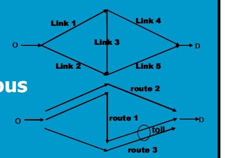
Network performance

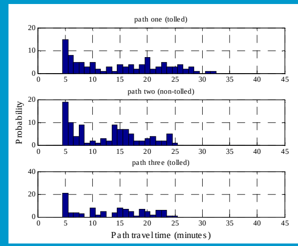




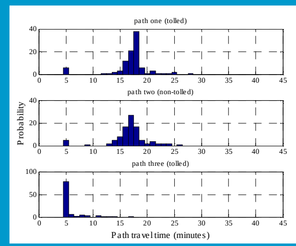
Experimental results

Path travel time distributions with simultaneous fluctuations in both capacities and demand





Without tolls



With optimal tolls

Experimental results

Impacts comparison of different influencing factors

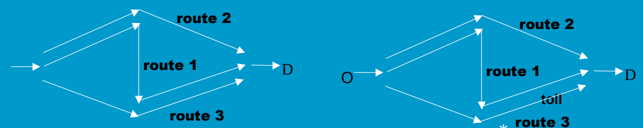
Charge (€)	*Path*	*Affecting factors*	*Route travel time σ (min.)*	*Route travel time μ (min.)*	*CoV*
0	Path 1	capacity variation	3.6	16	23%
		demand fluctuation	7.6	16.9	45%
		simultaneous	8	15	53%
	Path 2	capacity variation	2.4	13	18%
		demand fluctuation	6	13.2	45%
		simultaneous	6.3	12.4	51%
	Path 3	capacity variation	2.15	14	15%
		demand fluctuation	6.2	14.9	42%
		simultaneous	6.4	13.2	48%
2.5	Path 1	capacity variation	0.25	17.6	1%
		demand fluctuation	2.9	17.6	16%
		simultaneous	3.8	17	22%
	Path 2	capacity variation	0.3	17	2%
		demand fluctuation	2.7	17	16%
		simultaneous	3.6	16.8	21%
	Path 3	capacity variation	0.1	5.2	2%
		demand fluctuation	1.8	5.6	32%
		simultaneous	2.1	6	35%

Reliability paradox

Travel cost with optimal charge level

path	affecting factors	route travel costs
path 1	capacity variation	32.6
	demand fluctuation	32.6
path 2	capacity variation	17
	demand fluctuation	17
path 3	capacity variation	20.2
	demand fluctuation	20.6

Unused If DUE



r > $r(\theta^*)$

Conclusions

- Road pricing indeed may improve network reliability
- With the proposed network reliability-based toll design model, optimal tolls for all links, or a set of optimal links can be determined
- With optimal charge, travelers take longer, but more reliable routes
- Trade-offs need to be made between route travel time and travel time reliability
- Only model capacity variations or demand fluctuations will always underestimate the travel time variability
- Adding an additional link into network may lead to a less reliable network

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Further research

- **Model travel time reliability into travel choice behaviors**
- **Model departure time choice**
- **Network structure design**
- **Network characteristic design (lanes)**

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Thank you!

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