Sep. 14, 2020
The 19th Behavior Modeling in Transportation Networks

Mechanism Design & Behavior Modelling

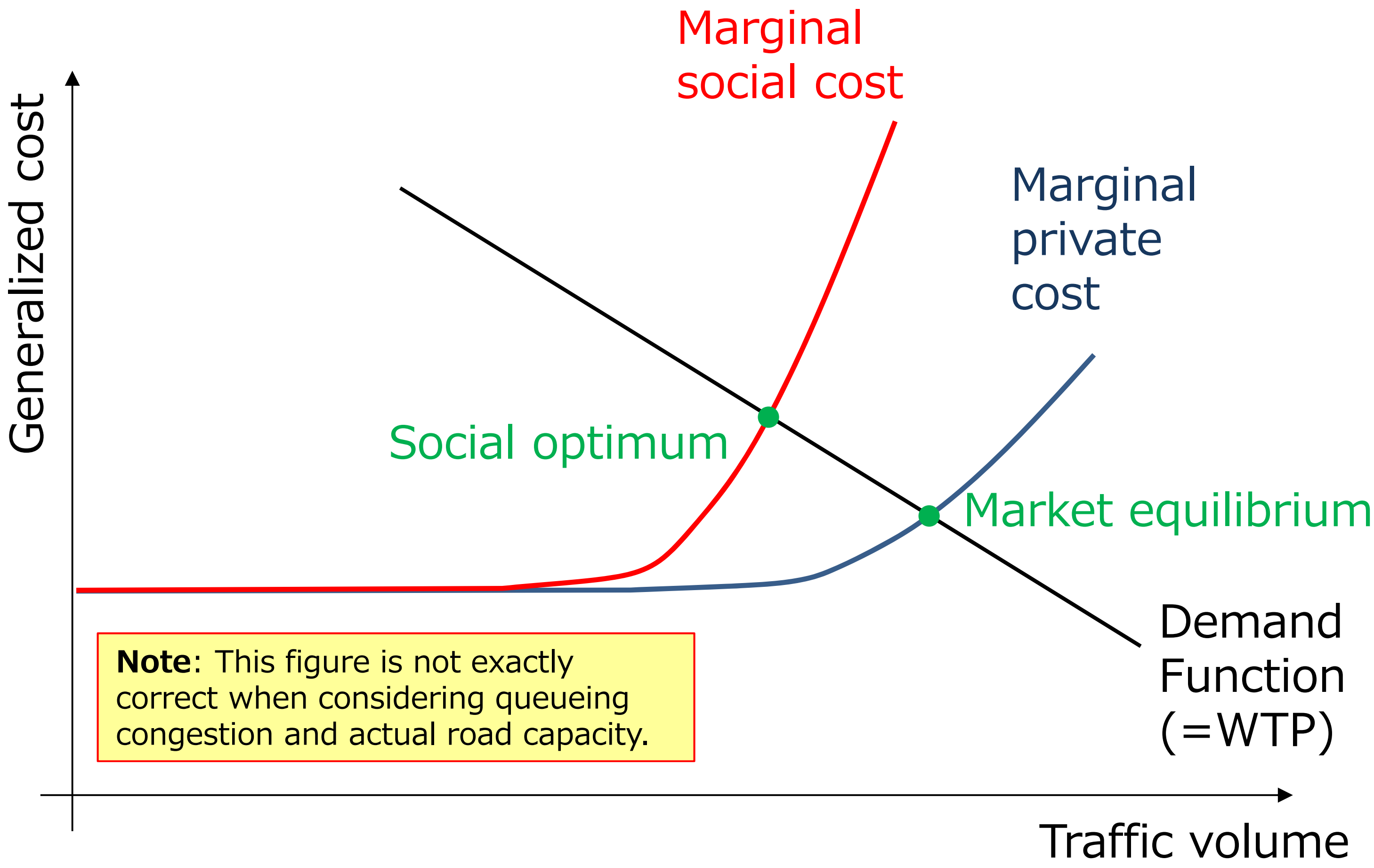
Hiroshima University
Makoto Chikaraishi

A class of problems we address

- There are a lot of examples that your decision, or allocating some limited resources to you, would bring negative benefits to others.

- **Some examples**
  - School choice:
    - Your successful enrollment would prevent others’ enrollment.
  - Land use:
    - Parking lots in CBD prevent others to utilize the land in different ways.
  - Car use:
    - Your car use would worsen traffic congestion.
  - Public transit use:
    - Your public transit use would worsen crowding in public transit.
  - Taxi/Ride hailing:
    - Your taxi/ride-hailing use may increase others’ waiting time.

No intervention,
No social welfare maximization

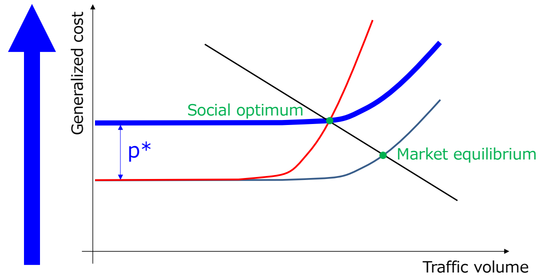


<u>Market equilibrium ≠ Social optimum</u>

Three types of interventions

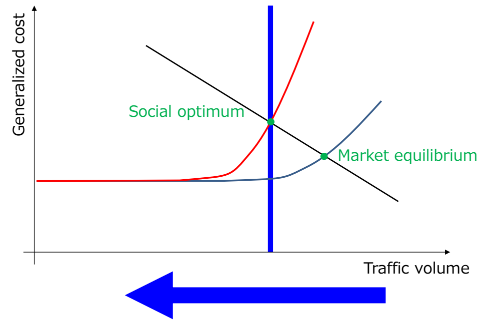
1. Price-based regulations

- ✓ Static/dynamic road pricing
- ✓ Evolutionary road pricing



2. Quantity-based regulations

- ✓ Tradable bottleneck permits
- ✓ Tradable mobility/travel credits



3. Other regulations/incentives

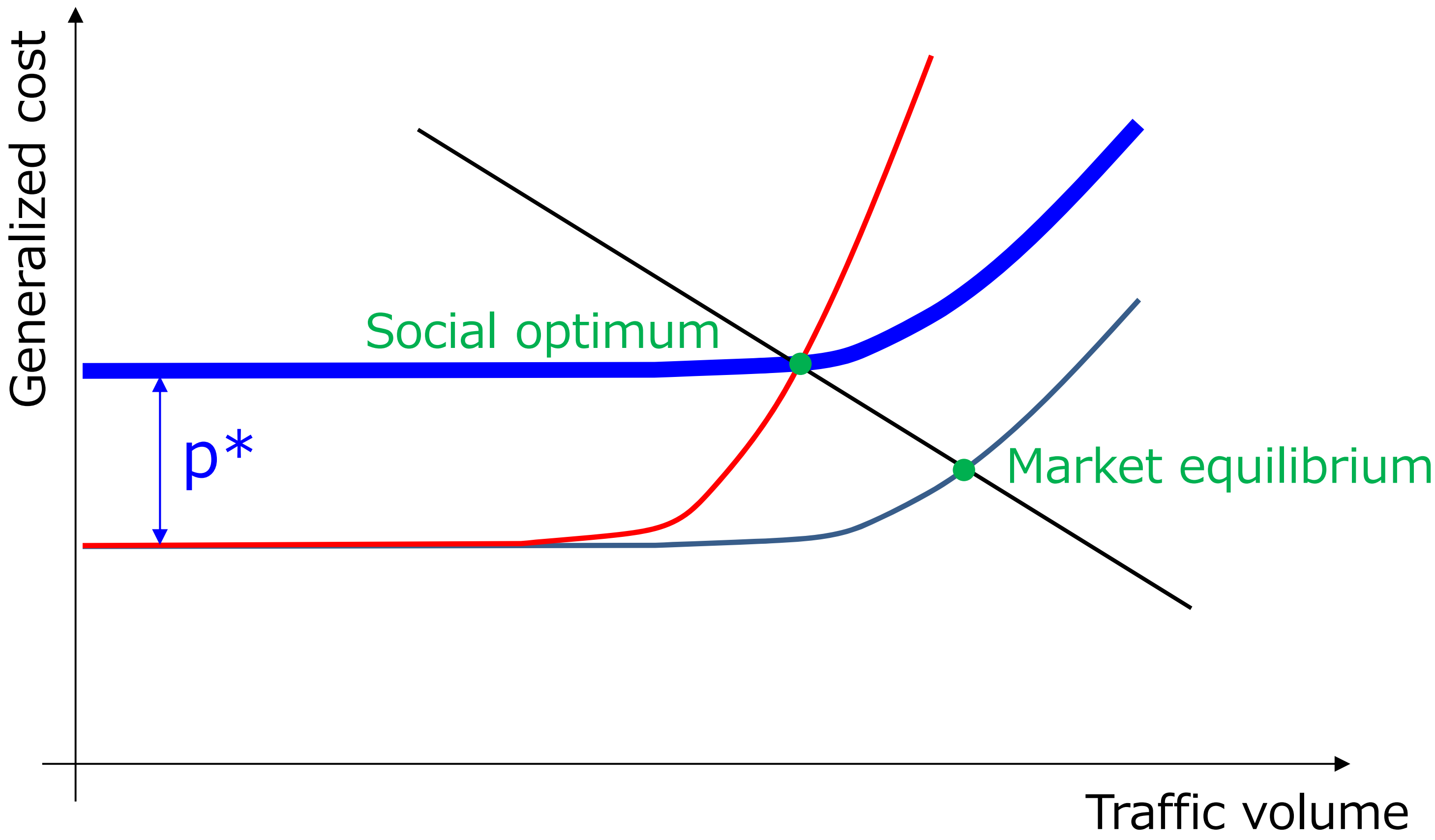
- ✓ Two-sided market
- ✓ Personalized incentives

In particular, the 3rd type demands further behavioral studies.

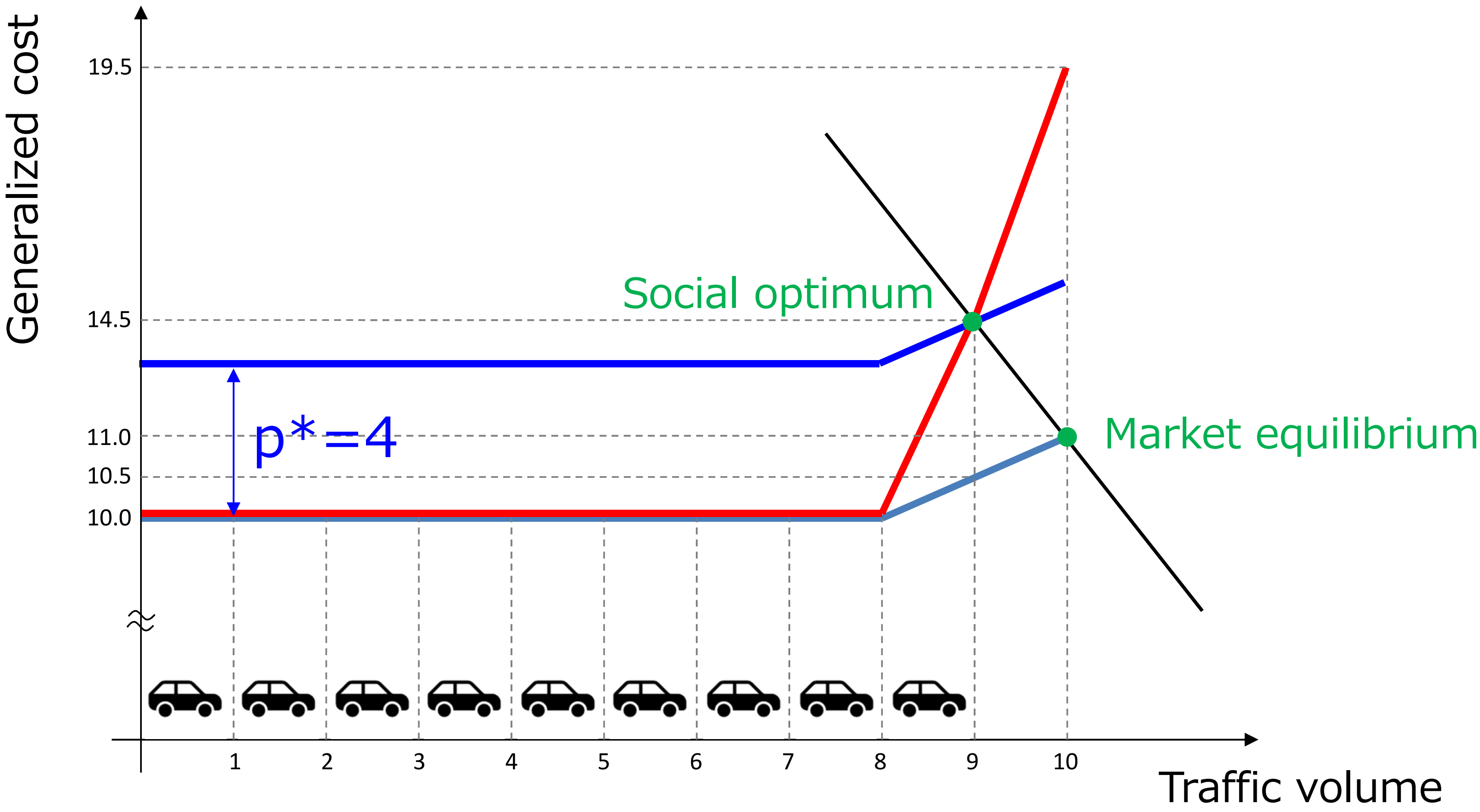
1. PRICE-BASED REGULATIONS

Price-based regulations: Idea

Road pricing: Ask all road users to pay p*



A simple example



Problems:

1. Spatio-temporal generalization

- [**Spatial**] Not one single road section, but network.
- [**Temporal**] Demand is not fixed, but varying across time of day, day of week, etc.

(c.f.,松井寛(編)：交通ネットワークの均衡分析ー最新の理論と解法ー,土木学会, 1998)

2. Considering queues of vehicles on roads

- Flow congestion → Queuing congestion

(c.f., 桑原雅夫: 交通流理論―流れの時空間変化をひも解く―, 交通工学研究会, 2020)

3. Difficulty in observing demand function

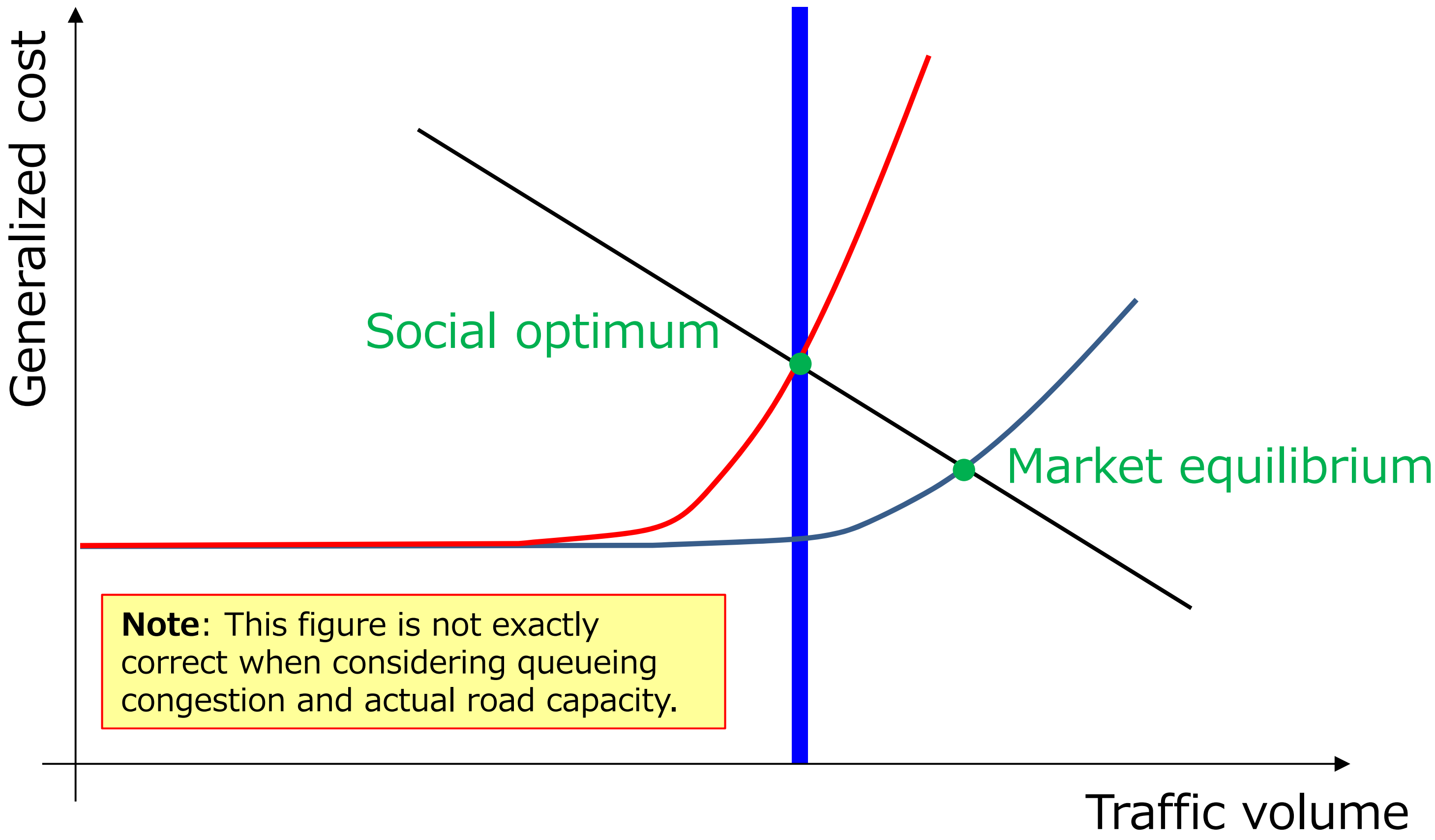
- **Achieving social optimum without demand information**
  - **Quantity-based regulations with a proper mechanism design**

(e.g., Akamatsu et al., 2006; Akamatsu and Wada, 2017)

2. QUANTITY-BASED REGULATIONS

Quantity-based regulations: Idea

Limited number of permits will be issued



Note: This figure is not exactly correct when considering queueing congestion and actual road capacity.

How should we allocate permits to road users?
→ Mechanism design

What is Mechanism Design?

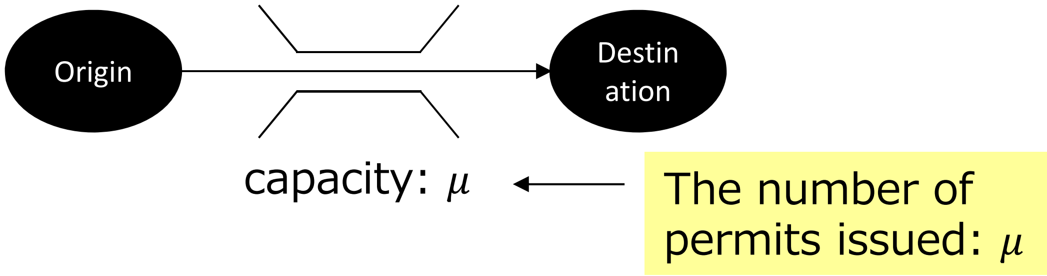
- **Mechanism Design**
  - Find a mechanism that maximizes some objective function (e.g., social welfare) to a problem that involves multiple self-interested agents.
    - Examples of objective functions
      - Maximizing social welfare, maximizing revenue, etc.
  - **Applications**
    - Emission trading scheme
    - Fishing quotas
    - Government bond auction
    - Allocating transportation resources/services

- **Two key ideas in designing the mechanism**
  - <u>Strategy-proof</u>: nobody has an incentive to tell a lie (incentive compatible)
  - <u>Efficient resource allocation</u>: maximizing social welfare

Tradable bottleneck permits (TBP)

Akamatsu et al. (2006); Akamatsu (2007)

- **Tradable bottleneck permits (TBP)**



- **Applications to transportation systems**
  - Airport slot allocations (Schummer and Vohra, 2013)
  - Car Sharing (Hara and Hato, 2018)
  - Tradable mobility credits (Yang and Wang, 2011)
  - Tradable bottleneck permits (Akamatsu et al., 2006; Akamatsu, 2007)
- **Common features**
  - Transport managers/operators do not need to observe users' demand preferences.
  - The strategy-proof and efficient mechanism.

Basic settings

- $i = \{1,2,\ldots,n\}$: Individual (bidder)
- v_i : Individual i's private value (equal to his bid) [strategy-proof]
- $x \in A$: option (A : a set of possible outcomes)
- t_i: Actual payment
- Utility function: quasi-linear function

$$U(a, t_i; v_i) = v_i(x) + t_i \quad \forall (a, t_i)$$

Private value Payment

Our goal:

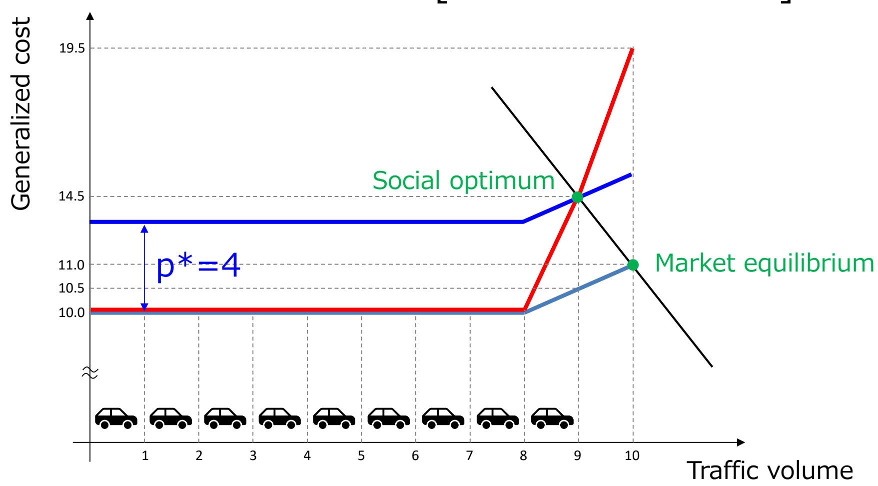
$$x^*(v) = \arg\max_{x \in A} \sum_{i=1}^{n} v_i(x)$$

[efficient allocation]

Example

	Private value	Payment
1st vehicle	45 – travel time	p
2nd vehicle	40 – travel time	p
3rd vehicle	38 – travel time	p
4th vehicle	33 – travel time	p
5th vehicle	28 – travel time	p
6th vehicle	25 – travel time	p
7th vehicle	20 – travel time	p
8th vehicle	16 – travel time	p
9th vehicle	14.5 – travel time	p

Willingness to pay (=demand function)



Groves mechanism

- Grove mechanism:

$$t_i = h_i(v_{-i}) + \sum_{j \neq i} v_i(x(v))$$

※ $v_{-i} = (v_j)_{j \neq i}$

Constant for each individual

Total private value of other agents

- Grove mechanism is a truthful mechanism, i.e., a mechanism where bidding the true valuation is a dominant strategy.

Pivotal Mechanism

- In Pivotal Mechanism, we further assume:

$$h_i(v_{-i}) = -\max_{x \in A} \sum_{j \neq i} v_j(x)$$

- And thus the payment will be

$$t_i = \sum_{j \neq i} v_i(x(v)) - \max_{x \in A} \sum_{j \neq i} v_j(x)$$

- When negative externalities exist, obviously

$$\sum_{j \neq i} v_i(x(v)) \leq \max_{x \in A} \sum_{j \neq i} v_j(x) \quad \rightarrow \quad t_i \leq 0$$

- Thus, all agents will not receive any incentive under pivotal mechanism.

VCG Mechanism

- In VCG mechanism, we further assume:

$$x_i = y_i \implies v_i(x) = v_i(y) \quad \forall x, y \in A$$
$$x_i = \emptyset \implies v_i(x) = 0 \quad \forall x \in A$$
$$v_i(x) \geq 0 \quad \forall x \in A$$
$$x_i \subset y_i \implies v_i(x) \leq v_i(y) \quad \forall x, y \in A$$

- Under VCG mechanism,

$$t_i = \sum_{j \neq i} v_j(x^*) - \sum_{j \neq i} v_j(x^*_{-i})$$

Social welfare with agent *i*

Social welfare without agent *i*

where $x^* = \arg\max_{x \in A} \sum_i v_i(x)$: optimal allocation with agent *i*

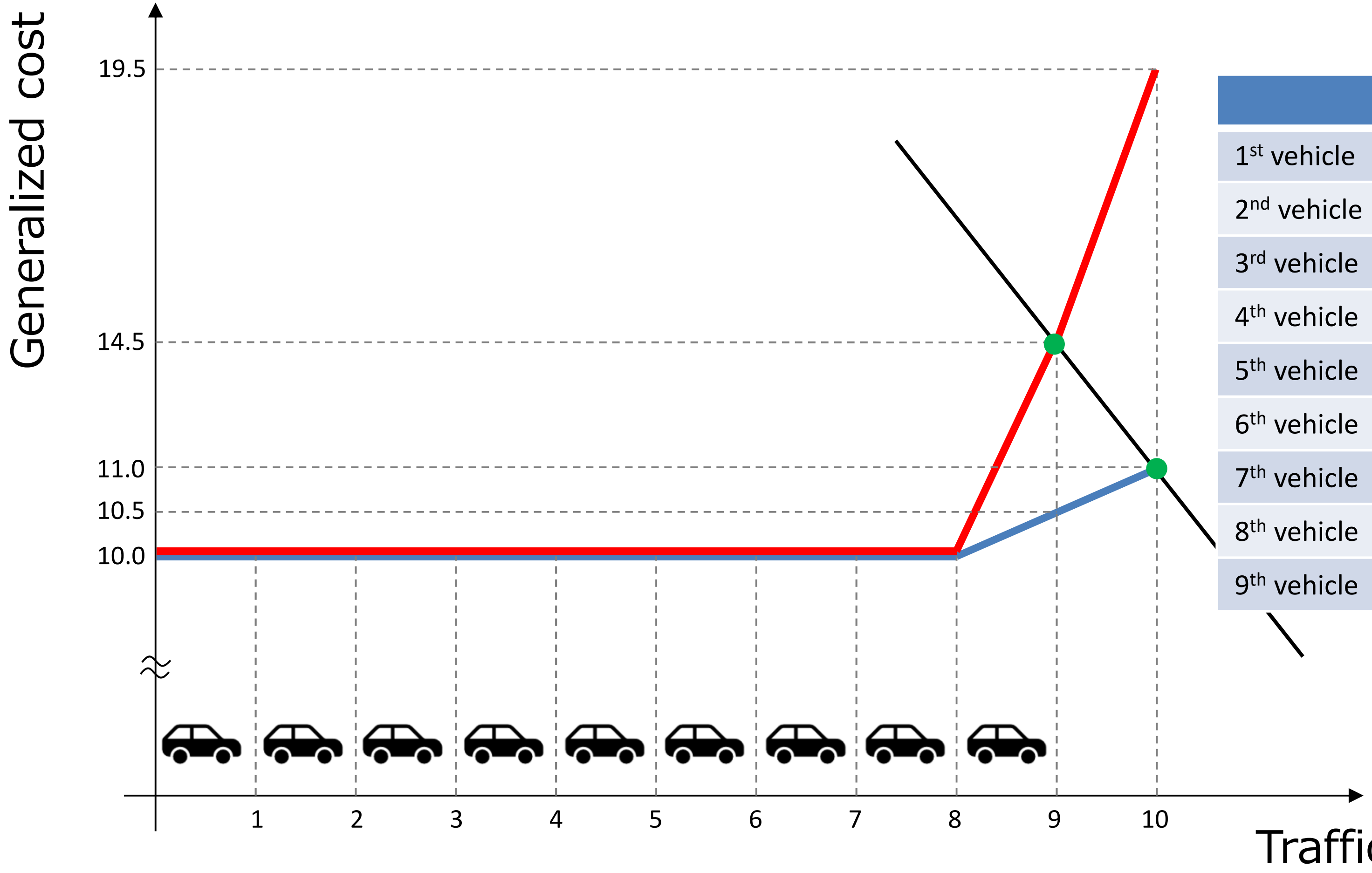
$x^*_{-i} = \arg\max_{x \in A} \sum_{j \neq i} v_j(x)$: : optimal allocation without agent *i*

A simple example

1. Assume that we have 9 permits that will be allocated to road users.
2. For the 1st vehicle,

$$t_1 = \sum_{j \neq i} v_j(x^*) - \sum_{j \neq i} v_j(x^*_{-i}) = 130.5 - 134.5 = -4$$

3. Similarly, for other vehicles, $t_i = -4$.
4. Thus, all road users should pay 4 to get the permit under VCG mechanism, and this is equivalent to the optimum pricing.



	Private value
1st vehicle	45 – travel time
2nd vehicle	40 – travel time
3rd vehicle	38 – travel time
4th vehicle	33 – travel time
5th vehicle	28 – travel time
6th vehicle	25 – travel time
7th vehicle	20 – travel time
8th vehicle	16 – travel time
9th vehicle	14.5 – travel time

Major problems

- The mechanisms only take into account externalities to persons who join the system.
  - It would not work for environmental externalities (externalities to persons who are not in the system such as non-car users), health damages (externalities to other life domains), impacts on urban form, etc.
- Transportation may be too fundamental to optimize the system without paying attention to other social systems.
- And some others (will be discussed in later slides)

3. OTHER REGULATIONS/ INCENTIVES

Introduction

The above price-based and quantity-based regulations provide solid theoretical foundations, while further discussions and considerations are needed for practical implementations.

1. **Problems we should further consider**
   - ✓ Mechanism design versus matching (Budish, 2012)
   - ✓ Preference elicitation cost (Nie, 2012; Hara, 2018)
   - ✓ Social acceptability (many references)
2. **Necessary extensions**
   - ✓ Multiple travel modes
   - ✓ Multiple social goals
   - ✓ Flexible transport supply (two-sided market)
3. **New possible directions**
   - ✓ Personalized incentives

Matching vs. mechanism design

Budish, E., 2012. Matching “versus” mechanism design. ACM SIGecom Exchanges, 11(2), 4-15.

- **Matching versus mechanism design**
  - **Mechanism design:** to find a mechanism that maximizes some objective function
  - **Matching:** to find a mechanism that satisfies various good properties

- Applied researchers and practitioners may prefer “**matching**”, because
  1. Difficult to pin down the objective.

     e.g., we often aim for measures of both efficiency and fairness.
  2. Difficult to pin down the true constraints of the problem.

     e.g., the budget could be somewhat flexible.
  3. A lack of tools to “maximize social welfare s.t. constraints”

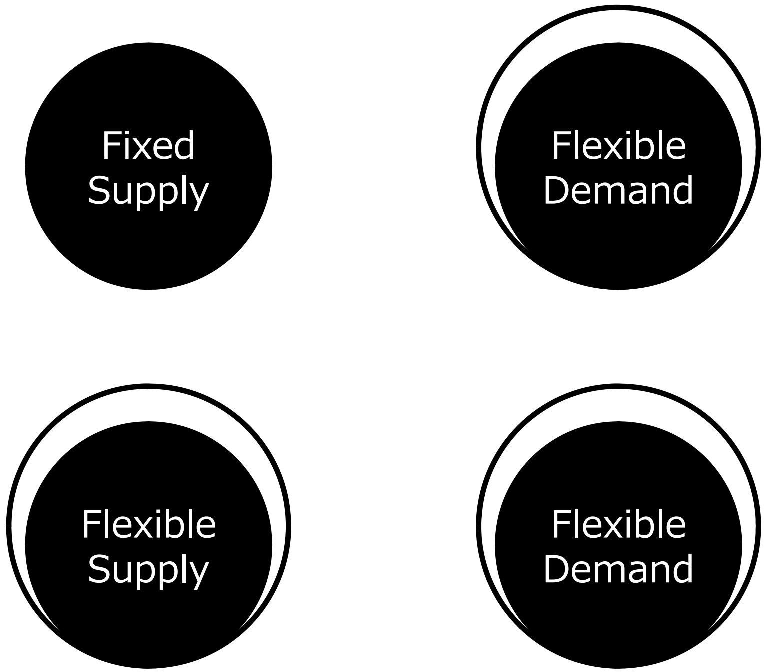
- Applied researchers may prefer to use “good properties” approach rather than “maximize objective” approach.

2. Difficult to pin down the true constraints of the problem.

Flexible transport supply

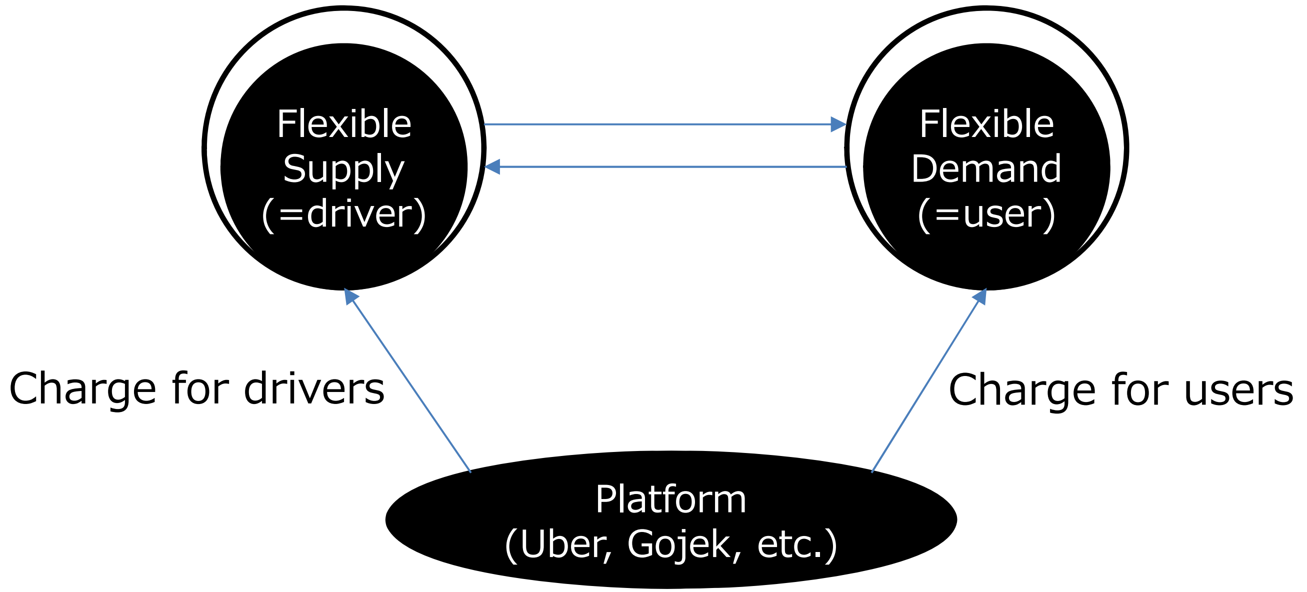
Traditional market:

Emerging market:



Two-sided market

Example: Ride hailing service

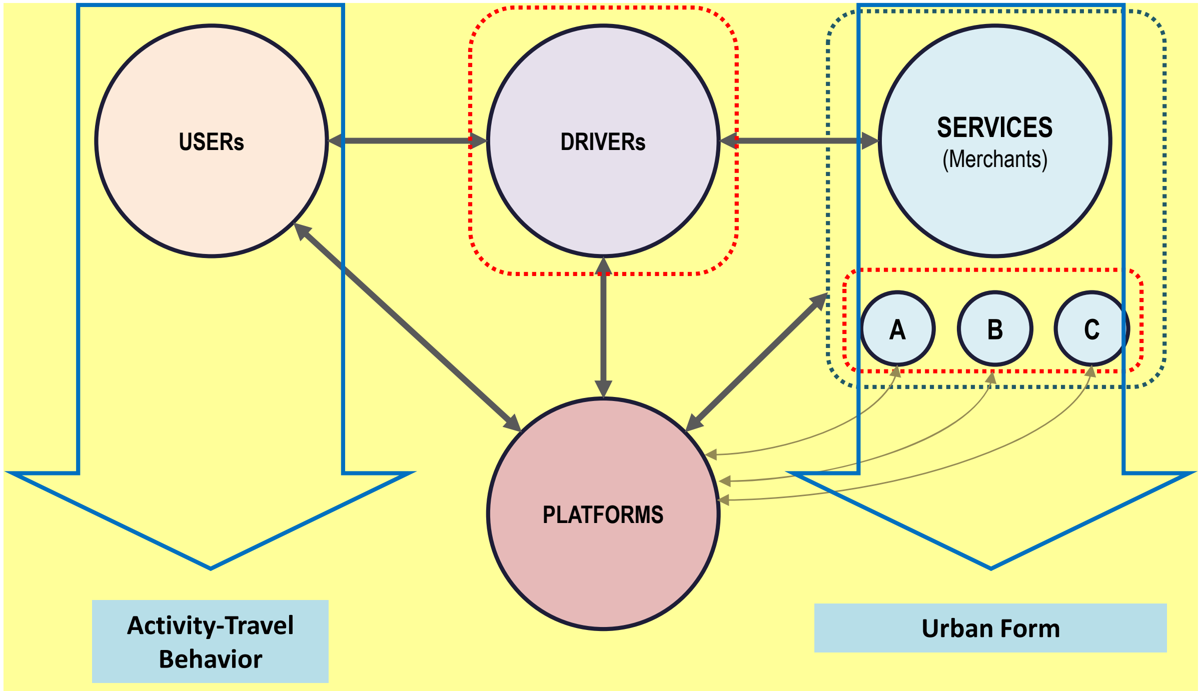


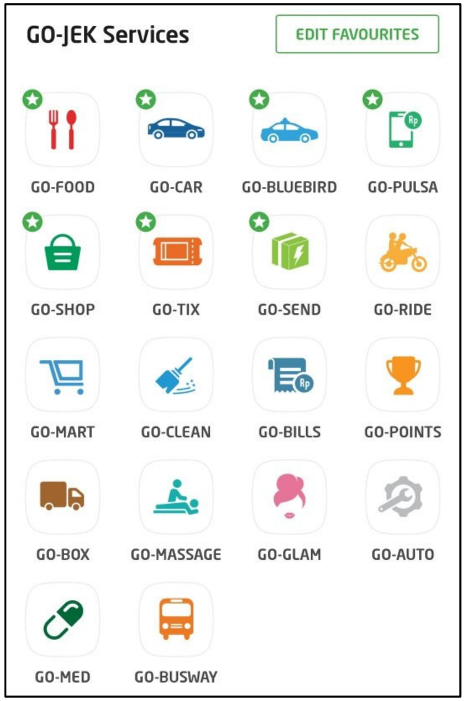
How different are daily fluctuations and weekly rhythms in time-use behavior across urban settings? (Watanabe et al., In press)

- **Hypothesis tested**:
  - High car dependency and compact activity space increase the flexibility in activity-travel decisions, resulting in larger daily fluctuations in discretionary activities (i.e., higher unobserved intra-individual variations). However, long-distance commuting in public transport creates difficulty for the residents to engage in both work at their office and leisure activities in their neighborhoods within a day, forming salient weekly rhythms in discretionary activity engagements (i.e., workday time-use significantly affects non-working day time-use).

In future, transport supply could be flexible enough to meet such fluctuated travel demand, and some modest positive/negative incentives would be good enough to manage the mismatch between transport supply and demand.

Multi-sided market





Online shopping vs. in store shopping

Food delivery service vs. Eating out

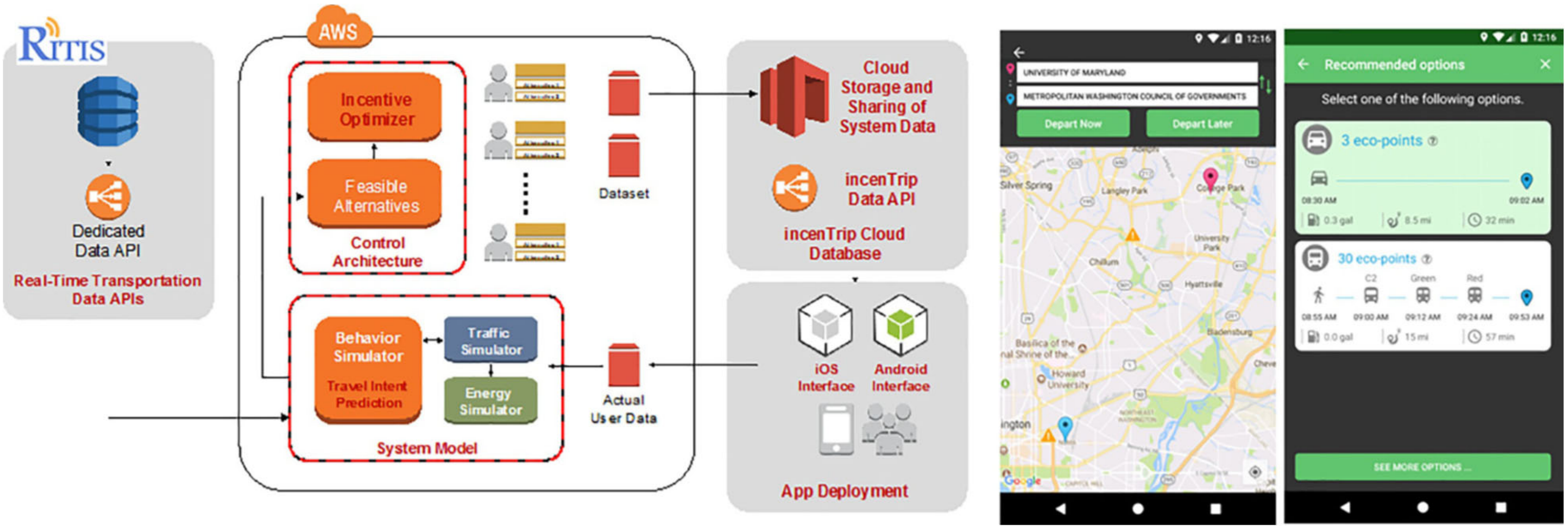
Safira, M., Chikaraishi, M. (2020) Impact of Online-based Food Delivery Service on Individuals' Eating Behavior: A Case study on the Multi-service Transport Platforms (MSTPs) in Indonesia, submitted to TRB annual meeting.

Personalized incentives

Trigger the desired behavioral change by providing personalized incentives

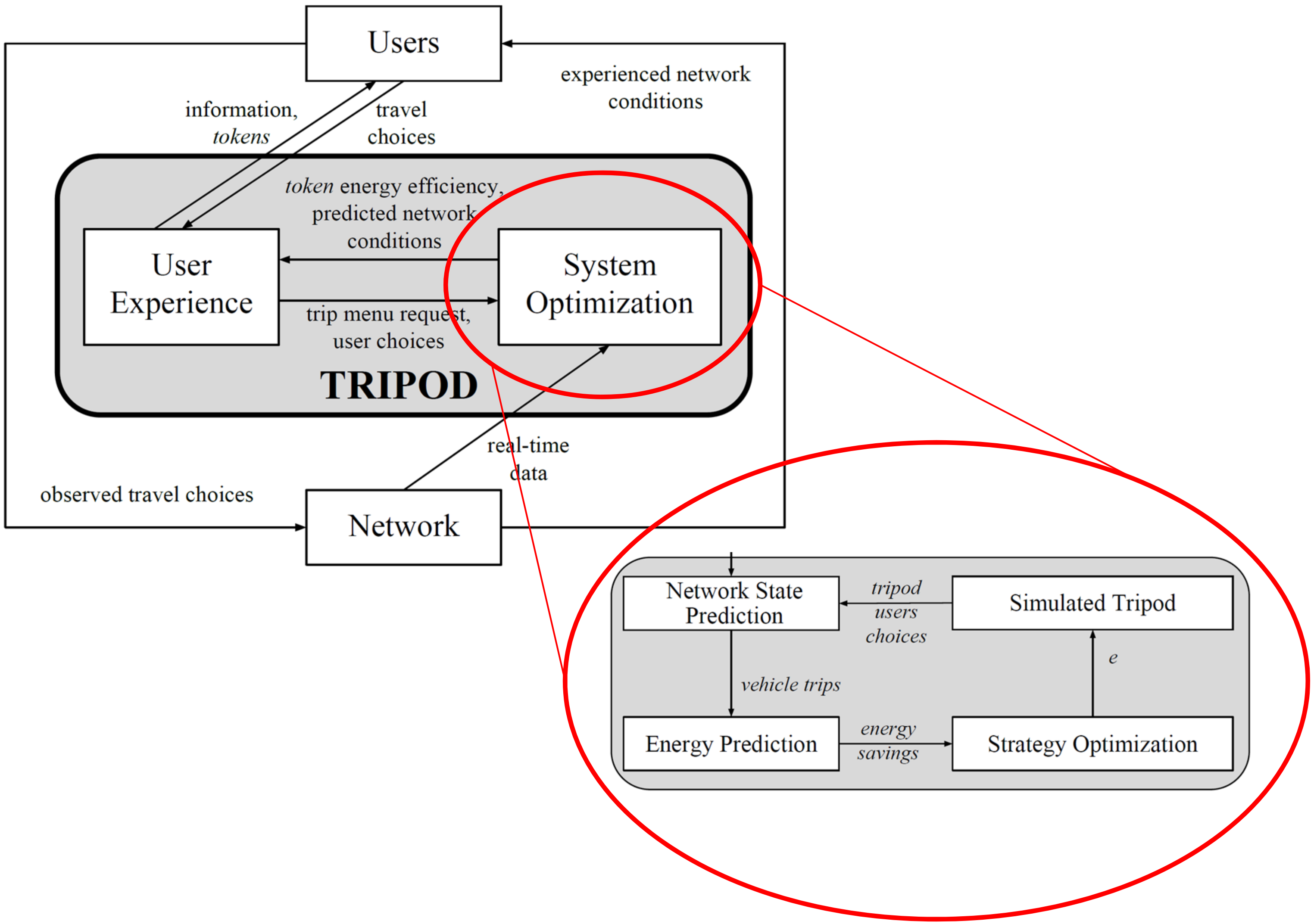
- **Personalized incentives**
  - incenTrip (https://incentrip.org/)
  - TRIPOD (Azevedo et al., 2018)
  - Zhu et al. (2020)

incenTrip



Tang and Hu (2019)

TRIPOD



Users
information,
tokens
travel
choices
experienced network
conditions
token energy efficiency,
predicted network
conditions
User
Experience
System
Optimization
trip menu request,
user choices
TRIPOD
real-time
data
observed travel choices
Network
Network State
Prediction
tripod
users
choices
Simulated Tripod
e
vehicle trips
Energy Prediction
energy
savings
Strategy Optimization

Zhu et al. (2020)

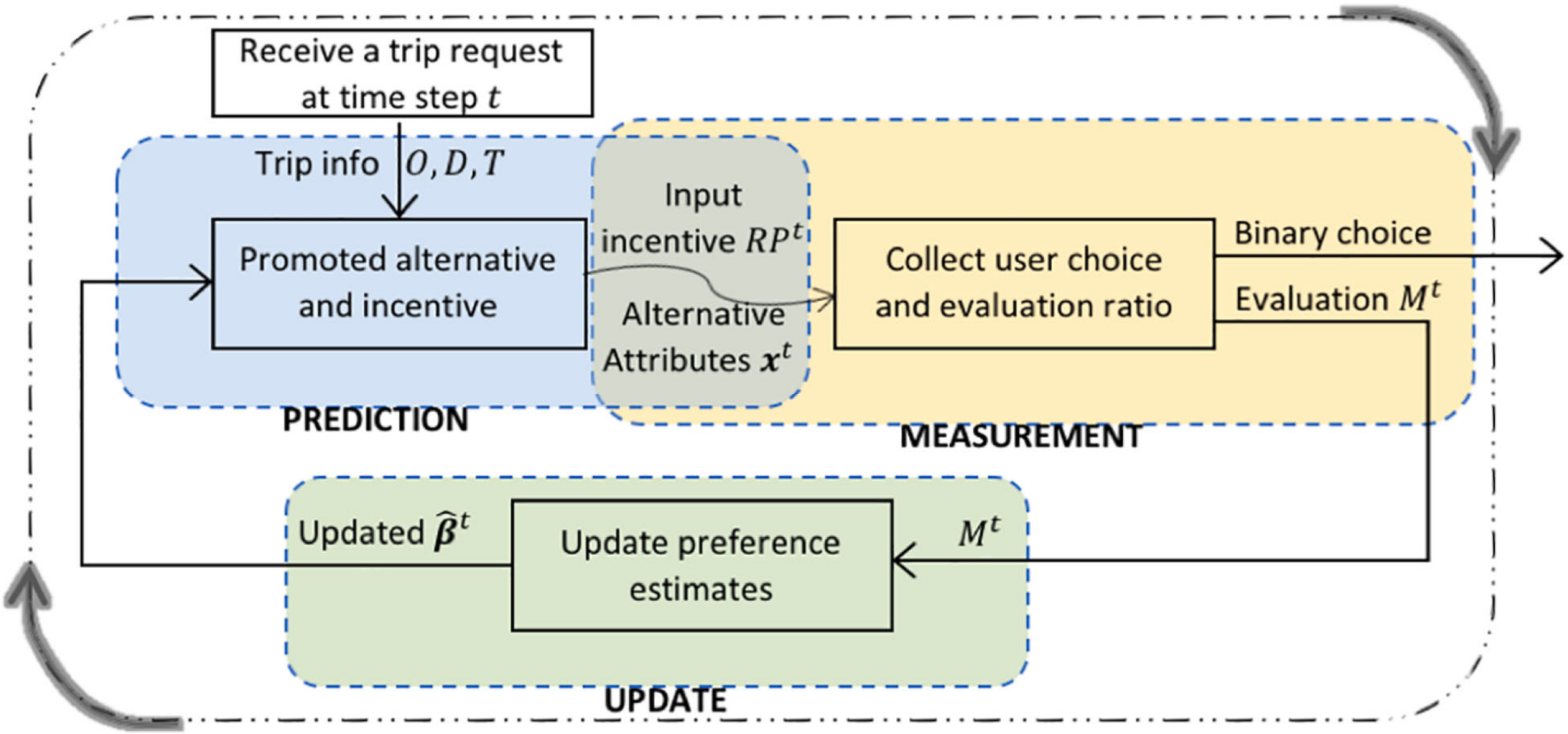


Fig. 1. Flowchart of the personalized system.

Other possible incentivization

Bella Mossa program:
Incentive + gamification
for health benefits

20,000+ people incentivised to travel more sustainably in Bologna

Michael Grimes | Case studies Travel & transport | 29th April 2019 | 0

787,000 journeys on foot

590,000 cycle journeys

508,000 public transport journeys

5,450 car-sharing journeys

1.4 million kg CO2 emissions saved

167 million calories burned

Other possible incentivization

EMPOWER (http://mobility-apps.eu/)

***zwitch**

For free-form initiatives (use eBikes, take the bus, rest your car etc.)

Easy to set up, no prerequisites

Cities create and manage campaigns themselves

Apps for simple quantitative collection of times, distances, number of trips

CommuteGreener!

Focus on personal awareness & improvements → Awareness-based intervention

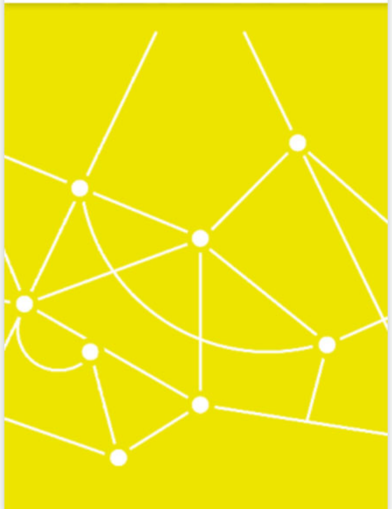
Complemented by campaigns/challenges

Top-lists and gamification (badges) → Nudging active participation

Fully facebook-integrated application → Activating social interactions

Citizens use facebook-web-app or mobile apps

SMART



Always-on tracking of traffic behaviour

Support for 'good' travel decisions

Rewards in individual Rewards-Webshop

City-specific optimization of intelligent tracking

Initial concept and preparation recommended

Or even do we really need an incentive or penalty to internalize externalities?

Hara, Y., Yamaguchi, H.: Behavioral change under COVID-19 state-of-emergency declaration in Japan (unpublished).

– The Japan government did not impose strong restrictions on travel during the COVID-19 pandemic. Just “request”.
– A clear decrease in travel demand after the declaration of the state of emergency without penalty.

People may be a bit cleverer than the model assumes.

各国の外出制限をめぐる措置

	外出制限などの措置	強制力
米国（NY州の場合）	不要不急の外出自粛を要請。原則100%の在宅勤務を義務付け	出勤禁止違反で事業者に罰金
フランス	買い出しや通院などを除き原則外出禁止	違反者に罰金。違反を4回繰り返せば約44万円の罰金と半年の禁錮刑
イタリア	原則禁止。理由を記した証明書の携帯が必要	正当な理由なく外出すれば最大約35万円の罰金
スペイン	食料品購入などを除き原則禁止	違反者には罰金
英国	買い出しや散歩を除き原則禁止	違反者には罰金
ドイツ	一部の州で外出制限。3人以上の集会を禁止	罰則の有無や程度は州により異なる
日本	不要不急の外出自粛を要請	なし

日本経済新聞：
https://www.nikkei.com/article/DGXMZO57774880X00C20A4EA1000/

Other possible considerations

Cooperative Token for Bottlenecks in Disaster Restoration Period (Hara and Chikaraishi, in progress)

1. People often have a will to behave in a cooperative way particularly during disaster without any payment/incentive.
2. In such a case, applying payment/incentive schemes could even worse the outcome (e.g., Gennzy and Rustichini, 2000).
3. Other “softer” interventions which nudge people to behave in a socially better way would be preferable.

Important behavioral aspects

Behavioral effects	Key references	Explanation	Potential effect in TC context
Loss aversion	Kahneman and Tversky (1979)	Losses weigh more than equivalent gains	A higher propensity to reduce credit usage in a situation of credit shortage than of credit surplus
Endowment effect	Thaler (1980) and Kahneman et al. (1991)	People ascribe more value to objects or resources when they are in their possession	Increased reluctance to trade credits
Framing	Tversky and Kahneman (1981) and Levin et al. (1998)	The presentation of an equivalent situation or outcome in a different format leads to a different outcome	Credit-spending patterns depend on the framing of the policy by participants and regulating bodies
Mental accounting	Thaler (1999) and Health and Soll (1996)	Money and resources are psychologically categorized based on different codes and labels	Credits are not equal to the money that they represent; the suggested budget limit may encourage credit conservation
Endowment effect under uncertainty	Kahneman & Tversky (1979)/van Dijk & van Knippenberg (1999)	Endowment effects tend to be stronger in trades that involve uncertainties	Uncertainty over the future credit price and travel may encourage credit conservation
Complexity aversion	Tversky and Kahneman (1974)	People tend to act less rationally and rely more on decision heuristics in complex decision contexts	The more people encounter difficulties in estimating credit costs, the more people will make decisions that satisfy rather than optimize
Regret aversion	Bell (1982) and Loomes and Sugden (1982)	People anticipate the possibility of regret felt if an alternative choice option would result in a better outcome and try to avoid choice options with larger anticipated regret	In TC decision-making contexts with increasing levels of uncertainty, regret aversion might play a more prominent role
Immediacy effect	Keren and Roelofsma (1995) and Green and Myerson (2004)	People tend to attach greater value to immediate rewards than to equivalent rewards that arrive latter	People may overspend their credits at the start of a TC period
Learning effect	Erev and Barron (2005)	People learn from their past decision through feedback	Credit spending may change over time based on how satisfied people are with earlier outcomes

Behavioral effects in tradable credits (TC): Source: Dogteron et al. (2017)

Summary

- **Price-based regulations**
  - Need aggregate demand function
- **Auction-type approach**
  - Demand function is not needed
- **Personalized incentives**
  - Need individual level demand function (or even it would vary depending on time-of-day, day-of-week, etc.)

Increasing needs for "revitalizing" behavioral studies.

References

- Akamatsu, T., Wada, K., 2017. Tradable network permits: A new scheme for the most efficient use of network capacity. Transportation Research Part C: Emerging Technologies 79, 178-195.
- 赤松隆, 佐藤慎太郎, Nguyen, X.L., 2006. 時間帯別ボトルネック通行権取引制度に関する研究. 土木学会論文集Ｄ 62, 605-620.
- Azevedo, C.L., Seshadri, R., Gao, S., Atasoy, B., Akkinepally, A.P., Christofa, E., Zhao, F., Trancik, J., Ben-Akiva, M., 2018. Tripod: sustainable travel incentives with prediction, optimization, and personalization, the 97th Annual Meeting of Transportation Research Board.
- Budish, E., 2012. Matching" versus" mechanism design. ACM SIGecom Exchanges 11, 4-15.
- 原祐輔 (2015) オークション理論とメカニズムデザイン [http://bin.t.u-tokyo.ac.jp/summercamp2015/document/key_hara.pdf]
- Hara, Y., Hato, E., 2018. A car sharing auction with temporal-spatial OD connection conditions. Transportation Research Part B: Methodological 117, 723-739.
- Nie, Y., 2012. Transaction costs and tradable mobility credits. Transportation Research Part B: Methodological 46, 189-203.
- Tang, Q., Hu, X., 2019. Chapter Eight - Triggering behavior changes with information and incentives: An active traffic and demand management-oriented review, in: Ben-Elia, E. (Ed.), Advances in Transport Policy and Planning. Academic Press, pp. 209-250.
- Watanabe, H., Chikaraishi, M., Maruyama, T. (In Press) How different are daily fluctuations and weekly rhythms in time-use behavior across urban settings? A case in two Japanese cities, Travel Behavior and Society (Accepted).
- Yang, H., Wang, X., 2011. Managing network mobility with tradable credits. Transportation Research Part B: Methodological 45, 580-594.
- Zhu, X., Wang, F., Chen, C., Reed, D.D., 2020. Personalized incentives for promoting sustainable travel behaviors. Transportation Research Part C: Emerging Technologies 113, 314-331.