People and Parcels sharing taxis
A new Transportation Service Model for Hanoi

Pham Quang Dung, Do Phan Thuan, Nguyen Xuan Hoai

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Outline

Context

- People and freight transportation operations are handled separately
- Vehicles travel a lot without load, e.g, taxis
- Impacts
  - For society: pollution, traffic jams, high traveling cost (itinerary price)
  - For transportation companies: high operations cost
- Literature: share-a-ride models have been proposed
  - People and People sharing mini buses: e.g., [Cordeau & Laporte, 2003]
  - People and Parcels sharing taxis [Li et al., 2014]

Objectives

- Propose a new hybrid transportation model for Hanoi city extending the model of [Li et al., 2014]: combine people and freight transportations into a unique system
  - Add, modify the model of [Li et al., 2014] taking into account specific features of Hanoi city
  - Add stochastic components into the proposed model
- Propose new prediction-based algorithms for computing the route plan of vehicles real-time

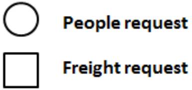
New dynamic version

- Locations (depots) of taxis are different
- Waiting time at each stops (pickup, delivery) is limited
- There are capacitated parkings for taxis (waiting is unlimited)
- Travel time on each street is associated with a lower bound and a upper bound
- Some segments of the road network may be forbidden in some time period, for example, taxis cannot travel on Thai Thinh street from 6am to 9am and from 4pm to 7pm.
- A passenger can accept or refuse traveling with parcels

New version - example

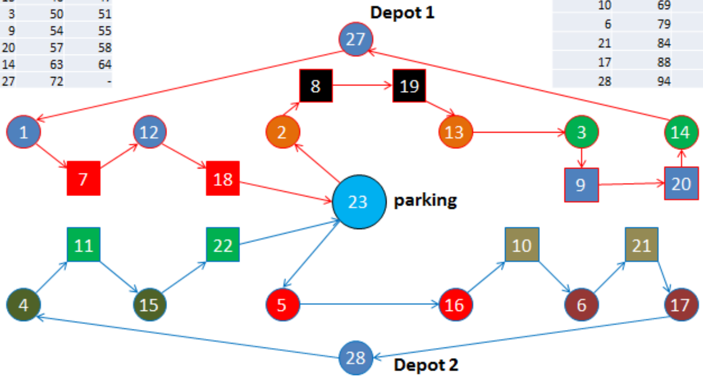
Taxi 1

Point	arrive	depart
27	-	1
1	9	10
7	15	16
12	20	21
18	23	24
23	25	35
2	36	37
8	38	39
19	42	43
13	46	47
3	50	51
9	54	55
20	57	58
14	63	64
27	72	-



Taxi 2

Point	arrive	depart
28	-	5
4	9	10
11	18	19
15	27	28
22	33	34
23	40	50
5	55	56
16	61	62
10	69	70
6	79	80
21	84	85
17	88	89
28	94	-

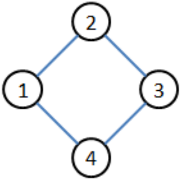


Outline

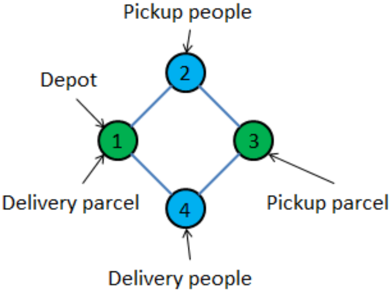
Input

- A physical road network
- A set of taxis
    - Depot
    - Maximum duration
    - Capacity
- Parkings
- Passenger and parcels requests
    - Origin and destination locations
    - Time windows
    - Maximum delivery distance and time (passenger request)
    - Maximum number of stops (origins or destinations of parcel requests) between one passenger service

Transformed road networks

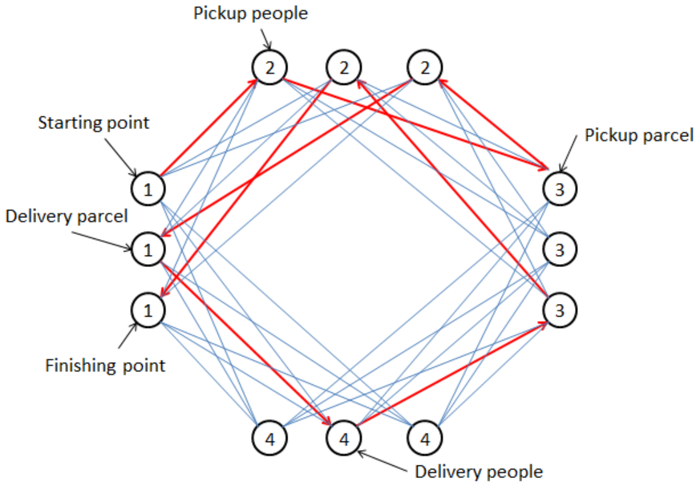


a. Physical road network



b. Position of passenger and parcel requests on the physical road network

Transformed road networks



An itinerary on the transformed network
(each point of the network appears at most 3 times in any itinerary)

Formulation - Input

- A transformed road network $G = (V, E)$
- A set of time points of the planning horizon $T = \{tb, tb + 1, \ldots, te\}$
- $\delta^+(i) = \{j \mid (i, j) \in E\}, \forall i \in V$
- $\delta^-(i) = \{j \mid (j, i) \in E\}, \forall i \in V$
- n, m: respectively number of passengers and parcels, $\sigma = n + m$
- K: set of taxis $K = \{1, \ldots, |K|\}$
- $V^{po} = \{1, \ldots, n\}$: set of passenger origins
- $V^{fo} = \{n + 1, \ldots, n + m\}$: set of parcel origins
- $V^{pd} = \{\sigma + 1, \ldots, \sigma + n\}$: set of passenger destinations
- $V^{fd} = \{\sigma + n + 1, \ldots, 2\sigma\}$: set of parcel destinations
- p: number of intermediate parkings (where taxis can rest for a long time)
- $VP = \{2\sigma + 1, \ldots, 2\sigma + p\}$: set of parkings, each parking $i \in VP$ is associated with a capacity c_i which is the maximum number of taxis that are at i at the same time
- VP is partitioned into $VP^1 \cup VP^2 \cup \cdots \cup VP^q$, points of each VP^i are associated with a real parking, $\forall i \in \{1, \ldots, q\}$

Formulation - Input

- $2\sigma + p + i$ and $2\sigma + p + i + |K|$ are respectively the starting and terminating depots of taxi $k, \forall k \in K$
- $D^o = \{2\sigma + p + 1, \ldots, 2\sigma + p + |K|\}$
- $D^d = \{2\sigma + p + |K| + 1, \ldots, 2\sigma + p + 2|K|\}$
- $S = V^{po} \cup V^{pd} \cup V^{fo} \cup V^{fd} \cup D \cup VP$: set of all stops
- $V = S \cup V^i$: all points (V^i is the set of intermediate points of the network)
- each arc $(u, v) \in E$ is associated with
  - $d_{u,v}$: distance from point u to point v
  - $\bar{t}_{u,v}$: maximum travel time from point u to point v
  - $\underline{t}_{u,v}$: minimum travel time from point u to point v
  - A set $F(u, v)$ of time points at which taxis are forbidden
- For each $i \in V^{po} \cup V^{fo}$
  - P_i: shortest path on G from i to $i + \sigma$: by default, if no sharing is realized, passenger/parcel at stop i will be traveled to $i + \sigma$ a long path P_i
  - D_i: length of P_i
  - T_i: minimum traveling time on P_i

Formulation - Input

- $\overline{w_s}$: maximum waiting time allowed at stop $s, \forall s \in S$ (by convention $\overline{w_s} = \infty, \forall s \in VP$)
- q_i: weight of request i
- $[e_i, l_i]$: time window of request i
- d_k: depot of taxi $k, d_k \in D, \forall k \in K$
- Q_k: capacity of taxi k
- $\overline{T}_k$: maximum duration for taxi $k, \forall k \in K$
- η_i: maximum number of stops between passenger service i ($\eta_i = 0$ means that passenger i requests a direct ride)
- $\overline{T}_i$: maximum delivery time for passenger request $i, \forall i \in V^{po}$
- $\overline{D}_i$: maximum delivery distance for passenger request $i, \forall i \in V^{po}$

Formulation - Input

- α: initial fare charged for delivering one passenger
- β: initial fare charged for delivering one parcel
- γ_1: fare charged for delivering one passenger per kilometer
- γ_2: fare charged for delivering one parcel per kilometer
- γ_3: average cost (e.g., fuel) per kilometer for delivering requests
- γ_4: discount factor for exceeding the direct delivery time of passengers

Formulation - Variables

- $X_{i,j}^k$: equal to 1 if taxi k goes directly from point i to point $j, X_{i,j}^k \in \{0,1\}, \forall (i,j) \in E$
- ta_i^k: time point when taxi k arrives at point i, $ta_i^k \in T$
- td_i^k: time point when taxi k departs from point i, $td_i^k \in T$
- $Y_{i,p}^k$: equal to 1 if point i is at position p on the itinerary of taxi $k, \forall k \in K, i \in V, p \in P = \{1, \ldots, |P|\}$, $|P|$ will be determined based on G
- $t_{i,j}^k$: travel time of taxi k from point i to point $j, \forall (i,j) \in E, k \in K$
- r_i^k: time spent by request i in taxi k: $r_i^k = ta_{i+\sigma}^k - td_i^k$
- w_i^k: load of taxi k after visiting stop $i, \forall i \in S$
- $Z_{t,p}^k$: equal to 1 if taxi k is at parking p at time point t
- Y_i^k: equal to 1 if request i is served by taxi k $, \forall i \in V^{po} \cup V^{fo}, k \in K$
- L_i^k: the distance from the depot of taxi k to point i on the itinerary of taxi k

Formulation - Objective function

- Revenue of traveling passengers

$$f_1 = \sum_{k \in K} \sum_{i \in V^{po}} (\alpha + \gamma_1 D_i) Y_i^k$$

- Revenue of traveling parcels

$$f_2 = \sum_{k \in K} \sum_{i \in V^{fo}} (\beta + \gamma_2 D_i) Y_i^k$$

- Transportation cost

$$f_3 = \gamma_3 \sum_{(i,j) \in E} \sum_{k \in K} d_{i,j} X_{i,j}^k$$

- Discount for passengers

$$f_4 = \gamma_4 \sum_{i \in V^{po}} \sum_{k \in K} (\frac{r_i^k}{T_i} - 1) Y_i^k$$

- Objective function (total benefits): $f = f_1 + f_2 - f_3 - f_4 \rightarrow \max$

Formulation - Constraints

- Each point appears at most once on each itinerary of a taxi:

$$\sum_{j \in \delta^+(i)} \sum_{k \in K} X_{i,j}^k \leq 1, \sum_{j \in \delta^-(i)} \sum_{k \in K} X_{j,i}^k \leq 1, \forall i \in V$$

- If a passenger or parcel is picked up, then he must be delivered

$$\sum_{j \in \delta^+(i)} X_{i,j}^k = \sum_{j \in \delta^-(i+\sigma)} X_{j,i+\sigma}^k, \forall i \in V^{po} \cup V^{fo}, k \in K$$

- Flow conservation constraints:

$$\sum_{j \in \delta^+(i)} X_{i,j}^k = \sum_{j \in \delta^-(i)} X_{j,i}^k, \forall i \in V \setminus (D^o \cup D^p), k \in K$$

- Constraints over arrival time, departure time and travel time between two points

$$M(1 - X_{i,j}^k) + ta_j^k \geq td_i^k + t_{i,j}^k$$

$$M(X_{i,j}^k - 1) + ta_j^k \leq td_i^k + t_{i,j}^k$$

Formulation - Constraints

- Constraints over ride time of requests

$$r_i^k = ta_{\sigma+i}^k - td_i^k, \forall i \in V^{p,o} \cup V^{f,o}$$

- Constraints over maximum ride time of taxis

$$\overline{T}_k \geq ta_{d_k}^k - td_{d_k}^k, \forall k \in K$$

- Constraints over time window of requests

$$e_i \leq ta_i^k \leq l_i, \forall i \in V^{p,d}, k \in K$$

$$e_i \leq td_i^k \leq l_i, \forall i \in V^{p,o}, k \in K$$

$$e_i \leq td_i^k \leq l_i \vee e_i \leq ta_i^k \leq l_i, \forall i \in V^{f,o} \cup V^{f,d}, k \in K$$

- Constraints over maximum waiting time at stops

$$td_i^k - ta_i^k \leq \overline{w}_i, \forall i \in S$$

- Constraints over maximum ride time of requests

$$r_i^k \leq \overline{T}_i, \forall i \in V^{p,o}, k \in K$$

Formulation - Constraints

- Bound of direct travel time between two adjacent points of the road network

$$\underline{t}_{i,j} \leq t^k_{i,j} \leq \overline{t}_{i,j}, \forall (i,j) \in E$$

- Constraints over load of taxis

$$M(X^k_{i,j} - 1) + w^k_j \leq w^k_i + q_j$$

$$M(1 - X^k_{i,j}) + w^k_j \geq w^k_i + q_j$$

$$w^k_i \geq \max\{0, q_i\}, \forall i \in V, k \in K$$

$$w^k_i \leq \min\{Q_k, Q_k + q_i\}, \forall i \in V, k \in K$$

- Constraints over capacity of parkings

$$M(Z^k_{t,p} - 1) + t \leq ta^k_p$$

$$M(1 - Z^k_{t,p}) + t \geq ta^k_p$$

$$\sum_{k \in K} \sum_{p \in VP^i} Z^k_{t,p} \leq c_p, \forall t \in T, i \in \{1, \dots, q\}$$

Formulation - Constraints

- Only one passenger request is serviced at a time

$$M(2 - Y^k_{i,p_1} - Y^k_{i+\sigma,p_2}) \geq \sum_{j \in V^{po} \cup V^{pd} \setminus \{i,i+\sigma\}} \sum_{p_1 \leq p \leq p_2} Y^k_{j,p},$$

$$\forall k \in K, p_1 < p_2 \in P, i \in V^{po}$$

- Constraints over maximum number of stops between each request

$$M(Y^k_{i,p_1} + Y^k_{i+\sigma,p_2} - 2) \leq \eta_i - \sum_{j \in V^{fo} \cup V^{fd}} \sum_{p_1 \leq p \leq p_2} Y^k_{j,p},$$

$$\forall k \in K, p_1 < p_2 \in P, i \in V^{po}$$

- Constraints over maximum distance of each request

$$M(X^k_{i,j} - 1) \leq L^k_i + d_{i,j} - L^k_j, \forall (i,j) \in E, k \in K$$

$$M(1 - X^k_{i,j}) \geq L^k_i + d_{i,j} - L^k_j, \forall (i,j) \in E, k \in K$$

$$M(Y^k_i - 1) \leq \overline{D}_i - (L^k_{i+\sigma} - L^k_i), \forall i \in V^{po}, k \in K$$

Formulation - Constraints

- Constraints on forbidden roads

$$td_i^k - t - X_{i,j}^k = 0, \forall (i,j) \in E, t \in F(i,j), k \in K$$

- Channelling constraints

$$\sum_{p \in P, k \in K} Y_{i,p}^k \leq 1, \forall i \in V$$

$$\sum_{j \in V} X_{j,i}^k \geq Y_{i,p}^k, \forall p \in P, i \in V$$

$$\sum_{j \in V} X_{i,j}^k \geq Y_{i,p}^k, \forall p \in P, i \in V$$

Formulation - Constraints

- Channelling constraints

$$\sum_{p \in P} Y^k_{i,p} \geq X^k_{i,j}, \forall (i,j) \in E$$

$$\sum_{p \in P} Y^k_{i,p} \geq X^k_{j,i}, \forall (i,j) \in E$$

$$X^k_{i,j} + 1 \geq Y^k_{i,p} + Y^k_{j,p+1}, \forall k \in K, (i,j) \in E, p \in \{1, \ldots, |P| - 1\}$$

$$Y^k_{i,p} \leq \sum_{q=p+1}^{|P|} Y^k_{i+\sigma,q}, \forall i \in V^{po} \cup V^{fo}, p \in \{1, \ldots, |P| - 1\}$$

Online scenarios

- Passenger request (immediate request):
  - Pickup location
  - Delivery location
- System response
  - NO
  - YES, give some options
    - Direct route (without parcel): time + distance + price
    - Route with parcels: time + distance + reduced price

Online scenarios

- Passenger request (reserved request):
  - Pickup location
  - Pickup time window
  - Delivery location
  - Delivery time window
  - Maximum number of intermediate stops
  - Maximum distance (e.g., 2 times longer than the direct route)
- System response
  - NO
  - YES

Outline

Next steps

- Simulation platform + Hanoi road network (HUST team)
- Different meta-heuristic algorithms for offline and online problems (HUST + UCL)
- Stochastic components and prediction modules (KULeuven + HANU)
- Online anticipatory algorithms for the online problem (KULeuven, UCL, HUST, HANU)

References

- Cordeau, J., & Laporte, G. (2003). The dial-a-ride problem (DARP): Variants, modeling issues and algorithms. 4OR: A Quarterly Journal of Operations Research, 1,pp 89–101
- Baoxiang Li, Dmitry Krushinsky, Hajo A. Reijers, Tom Van Woensel. The share-a-ride problem: people and parcels sharing taxis. European Journal of Operational Research, 2014.