Routing strategies minimizing travel times within multimodal transport networks
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Motivations and objectives

• Routing applications mostly consider only one transport mode and one-way trips.

• In France, transport users make in average 4 trips per day.

• Multimodality appears as a solution in front of the saturation of transport infrastructures.

⇒ Necessary to adapt classical shortest path algorithms to the multimodal routing problem, taking into account chained trips.

  • **One-way trips**: multimodal fastest path algorithm
Motivations and objectives

- **Two-way trips**: algorithmic strategy based on the one-way algorithm

Morning optimal path via $P_2$: 32 min

Optimal viable two-way path via $P_1$: 74 min

- **Trip chain**: extension of the two-way strategy to the case of 3 or more chained trips.

Routing strategies minimizing travel times...

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Multimodal trip chains minimizing travel times

- Network model
  - **Multi-layered graph**: one level associated to each mode
    \[ \forall (i, j) \in E, m_{ij} \in M = \{C, W, PT\} \]
  - Nodes \( i \in P \) represent parking areas for modes with a parking constraint (C)

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• Network model

  ➢ Multimodal path: a set of interconnected monomodal paths of modes \( \{c_k\}_{k=1}^K \), with \( c_k \in M \)

  ➢ For each mode \( m \) having parking constraints:
    • \( V_m \) = set of nodes where a vehicle is available,
    • \( P_m \) = set of nodes where a parking space is available.

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• **Travel time function**
  
  ➢ **FIFO travel time functions** allow a decreased complexity for the shortest path problem.
    • Classical methods to find a shortest path: *labelling algorithms*.
  
  ➢ **Travel time function for each mode**
    • *Walking*
      ➢ Static travel time
    
    • *Public transports*
      ➢ Based on theoretical timetables
      ➢ Naturally FIFO
Multimodal trip chains minimizing travel times

- Travel time function
  - Travel time function for each mode
    - Car
      - Flow speed estimations built from operational data...
        - Individual travel time measures
        - Traffic data: flow rate, occupancy, individual speeds
      - … with different methods depending on the type of network
        - Urban signalized / unsignalized network
        - Urban freeways
    - Method to build a FIFO travel time function from piecewise constant flow speeds, proposed by Sung et al, 2000.
      - Inserted in the shortest path algorithm
      - Slight increase in the complexity of the algorithm
Multimodal trip chains minimizing travel times

• **Fastest multimodal one-way path**
  
  - **Objective**: find a shortest path between \( o \) and \( d \) for a departure at time \( t \).

  - **Method**:
    - Label-setting algorithm, automaton representing the viable mode combinations
    - Implicit expansion of the graph on the different states
    - A path from \( o \) to \( j \in V \) can be represented by a pair \((j, s)\), where \( s \in S \) is the state giving the modes that can be used to continue the path.

  - A path \((j, s)\) has three labels associated:
    - Potential: \( \pi^s_j \)
    - Predecessor node: \( \text{pred}^s_j \)
    - State of the predecessor node: \( \text{pred}S^s_j \)
Multimodal trip chains minimizing travel times

- Fastest multimodal one-way path

  - Automaton defining the viable mode combinations

Routing strategies minimizing travel times...

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- Fastest multimodal one-way path

  - Specific features of the proposed labelling algorithm:
    - Vehicles parked anywhere in the network can be taken into account in the routing process
    - It is possible to require that a vehicle is available at destination
Multimodal trip chains minimizing travel times

- **Fastest multimodal two-way path**
  - **Objective**: find a two-way path between o and d
    - Leave o at time $t_1$
    - Leave d at time $t_2$
  - **Constraint**: A private vehicle used during the first trip has to brought back to its initial parking place at the end of the second trip.
  - **Method**: the proposed strategy is based on several applications of the one-way algorithm.
Multimodal trip chains minimizing travel times

- Fastest multimodal two-way path

\[ P^* \leftarrow P_{\text{car}} \cup \{o\} \]

<table>
<thead>
<tr>
<th>Step</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Origin(s)</td>
<td>({o} \rightarrow P^*)</td>
<td>(P^* \rightarrow {d})</td>
<td>({d} \rightarrow P^*)</td>
<td>(P^* \rightarrow {d})</td>
</tr>
<tr>
<td>Destination(s)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Departure-time(s)</td>
<td>(t)</td>
<td>For each request from (i \in P^* \rightarrow d), (A_i)</td>
<td>(t')</td>
<td>For each request from (i \in P^* \rightarrow d), (A_i)</td>
</tr>
<tr>
<td>Car required at destination?</td>
<td>yes</td>
<td>no</td>
<td>no</td>
<td>no</td>
</tr>
<tr>
<td>(V_{\text{car}})</td>
<td>({P_0})</td>
<td>(\emptyset)</td>
<td>(\emptyset)</td>
<td>({i})</td>
</tr>
<tr>
<td>(P_{\text{car}})</td>
<td>No modification</td>
<td>No modification</td>
<td>No modification</td>
<td>(P_{\text{car}} = {P_0})</td>
</tr>
<tr>
<td>Initial state</td>
<td>(NA)</td>
<td>(NA)</td>
<td>(NA)</td>
<td>(UC)</td>
</tr>
<tr>
<td># iterations of the one-way algorithm</td>
<td>1</td>
<td>(M)</td>
<td>1</td>
<td>(M)</td>
</tr>
<tr>
<td>Outputs (arrival time(s))</td>
<td>For each path from (o \rightarrow i \in P^*) (A_i)</td>
<td>For each path from (i \in P^* \rightarrow d) (A_i)</td>
<td>For each path from (d \rightarrow i \in P^*) (A_i)</td>
<td>For each path from (i \in P^* \rightarrow d) (A_i)</td>
</tr>
</tbody>
</table>

Routing strategies minimizing travel times...

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Multimodal trip chains minimizing travel times

- **Fastest multimodal two-way path**
  
  - The node \( i^* = \arg \min_{i \in P^*} (A_2^i + A_4^i) \) gives the parking node used in the shortest two-way path.
  
  - \( 2M + 2 \) iterations of the one-way algorithm, where \( M \) is the cardinality of \( P^* \).
Fastest multimodal trip chains

- 3CT problem:
  - The two-way strategy can be extended to the case of three or more chained trips
  - Trip 1: Steps 1 and 2
  - Trip 2: M times steps 1 and 2
  - Trip 3: M times steps 3 and 4

Routing strategies minimizing travel times...

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Multimodal trip chains minimizing travel times

• Fastest multimodal trip chains

  ➢ 3-CT problem:

  • 3-CT problem can be solved by $M+1+M(M+1)+M+1 = M^2+3M+2$ iterations of the one-way algorithm

  • This formula can be extended to the k-CT problem

  ➢ k-CT problem:

  • k-CT can be solved by $2M+2 + (k-2) M(M+1)$ iterations of the one-way algorithm.
Application of the two-way strategy on a real-world network

<table>
<thead>
<tr>
<th>Optimal one-way trip</th>
<th>Optimal one-way trip</th>
<th>Return trip with car parked in $P_1$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Walking from $O$ to $P_0$</td>
<td>Travel time = 00:23:48</td>
<td>Travel time = 00:29:00</td>
</tr>
<tr>
<td></td>
<td>Departure time = 07:30</td>
<td>Departure time = 17:00</td>
</tr>
<tr>
<td></td>
<td>Arrival time = 07:54</td>
<td>Arrival time = 17:29</td>
</tr>
<tr>
<td>Driving to the car park $P_1$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Parking the car</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Walking to $D$</td>
<td>00:08:20</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total travel time for the two-way trip : 00:52:48</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Two-way optimisation: total travel time for the two-way trip = 00:50:50

<table>
<thead>
<tr>
<th>First trip : Travel time = 00:25:10</th>
<th>Second trip : Travel time = 00:25:40</th>
</tr>
</thead>
<tbody>
<tr>
<td>Departure time = 07:30 – Arrival time = 07:55</td>
<td>Departure time = 17:00 – Arrival time = 17:26</td>
</tr>
<tr>
<td>Walking from $O$ to $P_0$</td>
<td>Walking from $D$ to a bicycle hiring point</td>
</tr>
<tr>
<td>00:02:50</td>
<td>00:01:00</td>
</tr>
<tr>
<td>Driving to the car park $P_2$</td>
<td>Cycling to another hiring point and giving the bicycle back</td>
</tr>
<tr>
<td>00:06:10</td>
<td>00:02:10</td>
</tr>
<tr>
<td>Parking the car</td>
<td>Walking to an underground station</td>
</tr>
<tr>
<td>00:03:00</td>
<td>00:01:00</td>
</tr>
<tr>
<td>Walking to an underground station</td>
<td>Waiting</td>
</tr>
<tr>
<td>00:02:00</td>
<td>00:01:00</td>
</tr>
<tr>
<td>Waiting</td>
<td>Travelling on the underground</td>
</tr>
<tr>
<td>00:01:00</td>
<td>00:06:00</td>
</tr>
<tr>
<td>Travelling on the underground</td>
<td>Walking to car park $P_2$</td>
</tr>
<tr>
<td>00:06:00</td>
<td>00:02:00</td>
</tr>
<tr>
<td>Walking to a bicycle self-service hiring point</td>
<td>Driving to $P_0$</td>
</tr>
<tr>
<td>00:01:00</td>
<td>00:06:40</td>
</tr>
<tr>
<td>Cycling to another hiring point and giving the bicycle back</td>
<td>Parking the car at $P_0$ (on street)</td>
</tr>
<tr>
<td>00:02:10</td>
<td>00:04:00</td>
</tr>
<tr>
<td>Walking to $D$</td>
<td>Walking to $O$</td>
</tr>
<tr>
<td>00:01:00</td>
<td>00:02:50</td>
</tr>
</tbody>
</table>
Conclusion and perspectives

• Exact methods have been proposed to solve:
  - the one-way problem
  - the two-way problem
  - the multimodal fastest trip chain problem

• To our knowledge, the multimodal trip chain problem has never been studied before.

• Computation times become prohibitive when a large number of parking nodes is considered even for a two-way problem.

• Heuristics need to be developed to reduce computation time.
Thank you!

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