Routing strategies minimizing travel times within multimodal transport networks

Aurélie Bousquet

ECTRI
European Conference of Transport Research Institutes

FEHRL

FERSI

Contents

Motivations and objectives

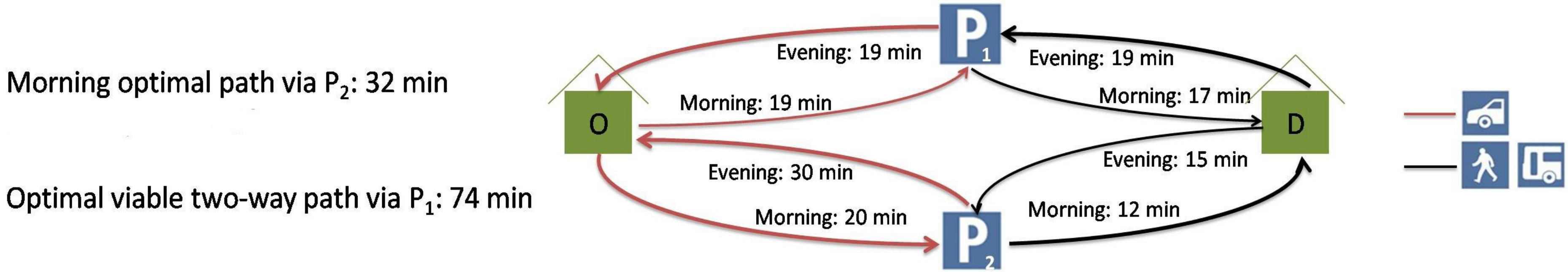
- Routing applications mostly consider only one transport mode and one-way trips.
- In France, transport users make in average 4 trips per day.
- Multimodality appears as a solution in front of the saturation of transport infrastructures.

⇒ 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



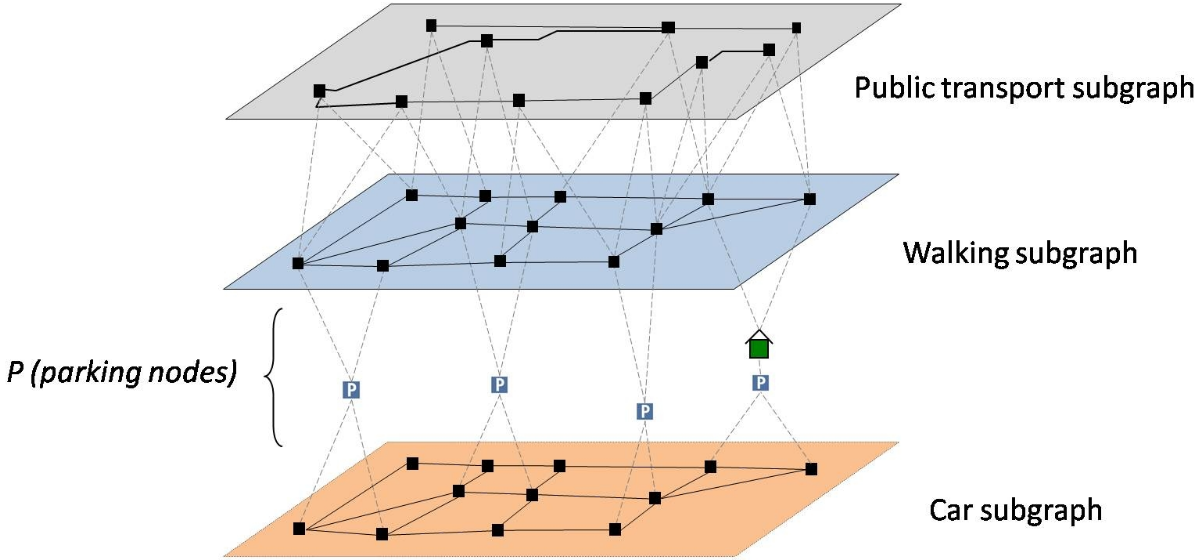
- **Trip chain**: extension of the two-way strategy to the case of 3 or more chained trips.

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)*

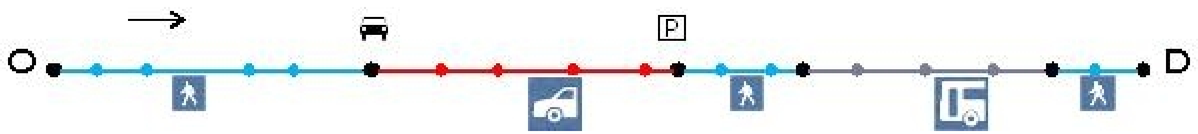


Multimodal trip chains minimizing travel times

- **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.



- **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

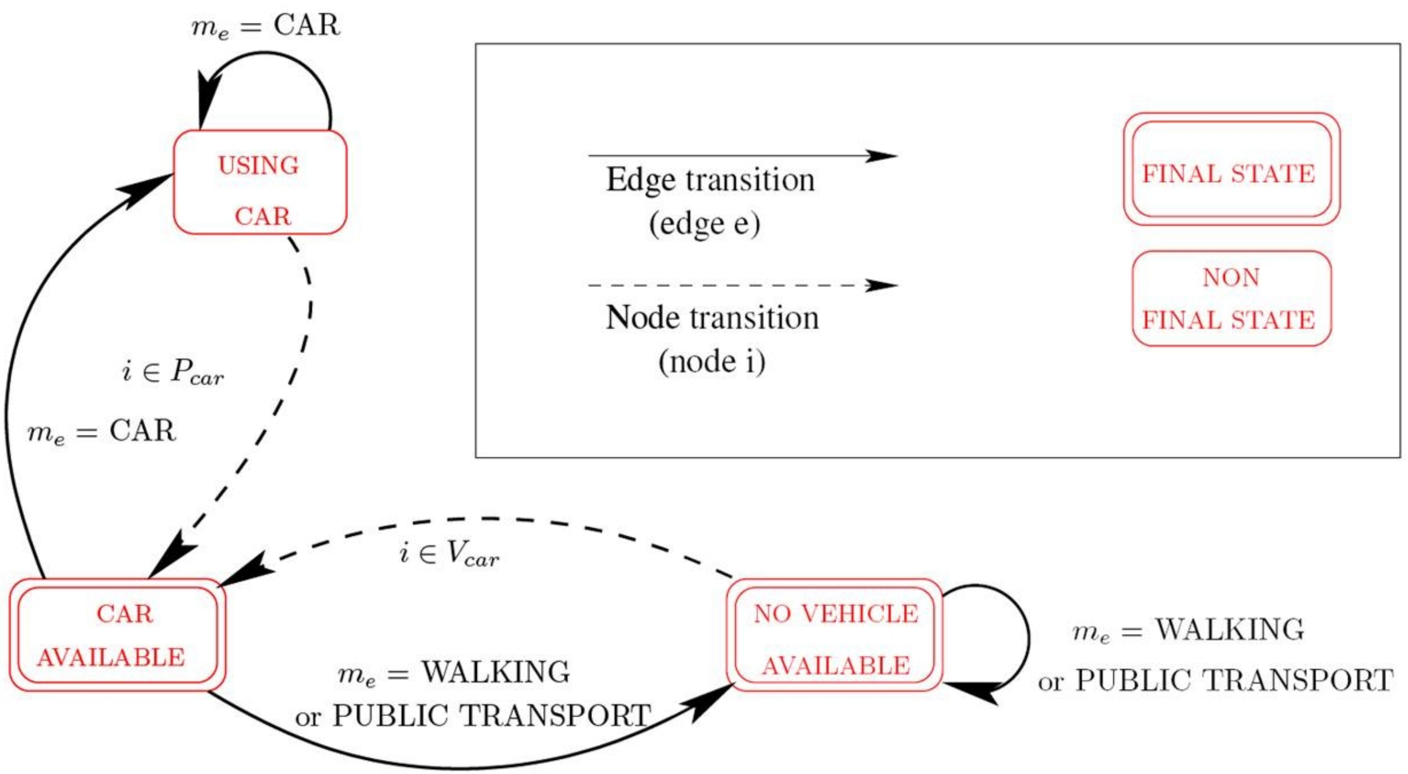
Aurélie Bousquet

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: π_j^s
      - Predecessor node: $pred_j^s$
      - State of the predecessor node: $predS_j^s$

Multimodal trip chains minimizing travel times

- **Fastest multimodal one-way path**
  - **Automaton defining the viable mode combinations**



Multimodal trip chains minimizing travel times

- **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** $P^* \leftarrow P_{car} \cup \{o\}$

Step	1	2	3	4
Origin(s) → Destination(s)	$\{o\} \rightarrow P^*$	$P^* \rightarrow \{d\}$	$\{d\} \rightarrow P^*$	$P^* \rightarrow \{d\}$
Departure time(s)	t	For each request from $i \in P^*$ to d, A_1^i	t'	For each request from $i \in P^*$ to d, A_3^i
Car required at destination?	yes	no	no	no
V_{car}	$\{p_0\}$	$\emptyset$	$\emptyset$	For each request from $i \in P^*$ to d, $\{i\}$
P_{car}	No modification	No modification	No modification	$P_{car} = \{p_0\}$
Initial state	NA	NA	NA	UC
# iterations of the one-way algorithm	1	M	1	M
Outputs (arrival time(s))	For each path from o to $i \in P^*$, A_1^i	For each path from $i \in P^*$ to d, A_2^i	For each path from d to $i \in P^*$, A_3^i	For each path from $i \in P^*$ to d, A_4^i

Aurélie Bousquet

Multimodal trip chains minimizing travel times

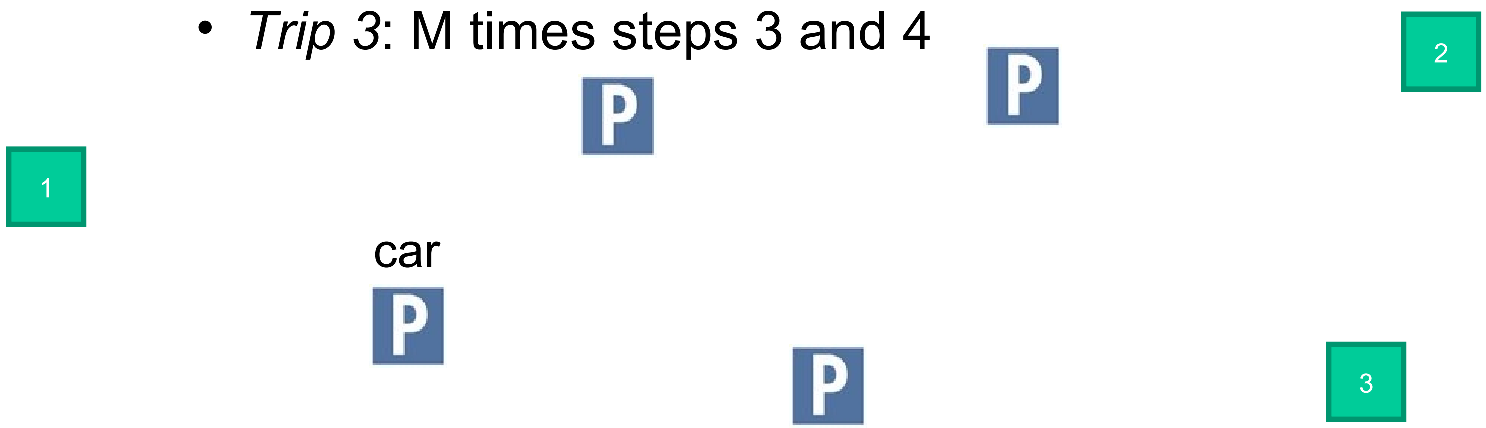
- **Fastest multimodal two-way path**

  - The node $i^* = argmin_{i \in P^*}(A_2^i + A_4^i)$ 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^*.

Multimodal trip chains minimizing travel times

- **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



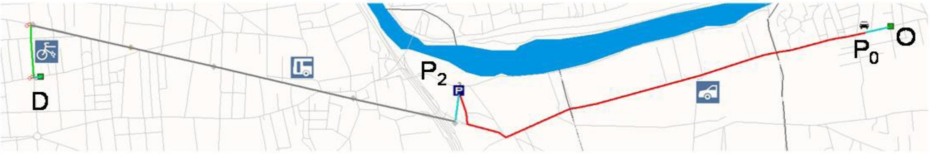
Multimodal trip chains minimizing travel times

- **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

Optimal one-way trip		Optimal one-way trip	Return trip with car parked in P_1
Walking from O to P_0	00:02:50	Travel time = 00:23:48 Departure time = 07:30 Arrival time = 07:54	Travel time = 00:29:00 Departure time = 17:00 Arrival time =17:29
Driving to the car park P_1	00:09:38		
Parking the car	00:03:00		
Walking to D	00:08:20		
Total travel time for the two-way trip : 00:52:48			

Two-way optimisation : total travel time for the two-way trip = 00:50:50			
First trip : Travel time = 00:25:10 Departure time = 07:30 – Arrival time = 07:55		Second trip : Travel time = 00:25:40 Departure time = 17:00 – Arrival time = 17:26	
Walking from O to P_0	00:02:50	Walking from D to a bicycle hiring point	00:01:00
Driving to the car park P_2	00:06:10	Cycling to another hiring point and giving the bicycle back	00:02:10
Parking the car	00:03:00	Walking to an underground station	00:01:00
Walking to an underground station	00:02:00	Waiting	00:01:00
Waiting	00:01:00	Travelling on the underground	00:06:00
Travelling on the underground	00:06:00	Walking to car park P_2	00:02:00
Walking to a bicycle self-service hiring point	00:01:00	Driving to P_0	00:06:40
Cycling to another hiring point and giving the bicycle back	00:02:10	Parking the car at P_0 (on street)	00:04:00
Walking to D	00:01:00	Walking to O	00:02:50



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!

This research is partially supported by the Rhône-Alpes Region. The author would like to thank SYTRAL and Grand Lyon for providing the real-world data used in this work.