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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

Routing strategies minimizing travel times...

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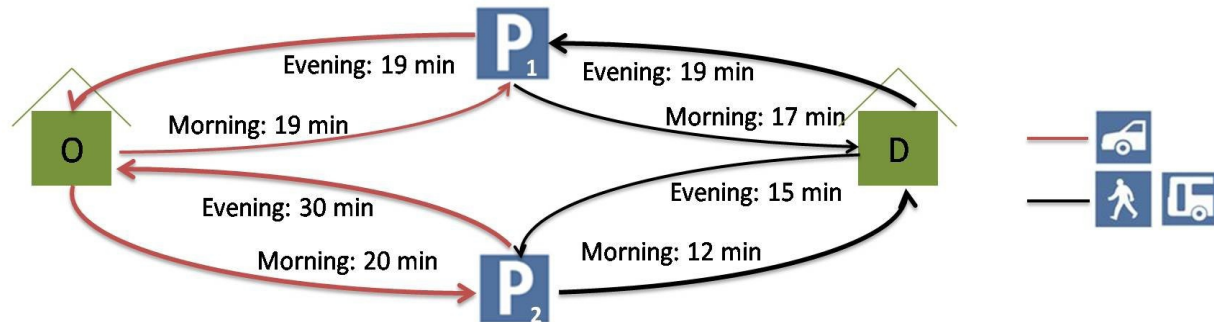


Motivations and objectives

- **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.

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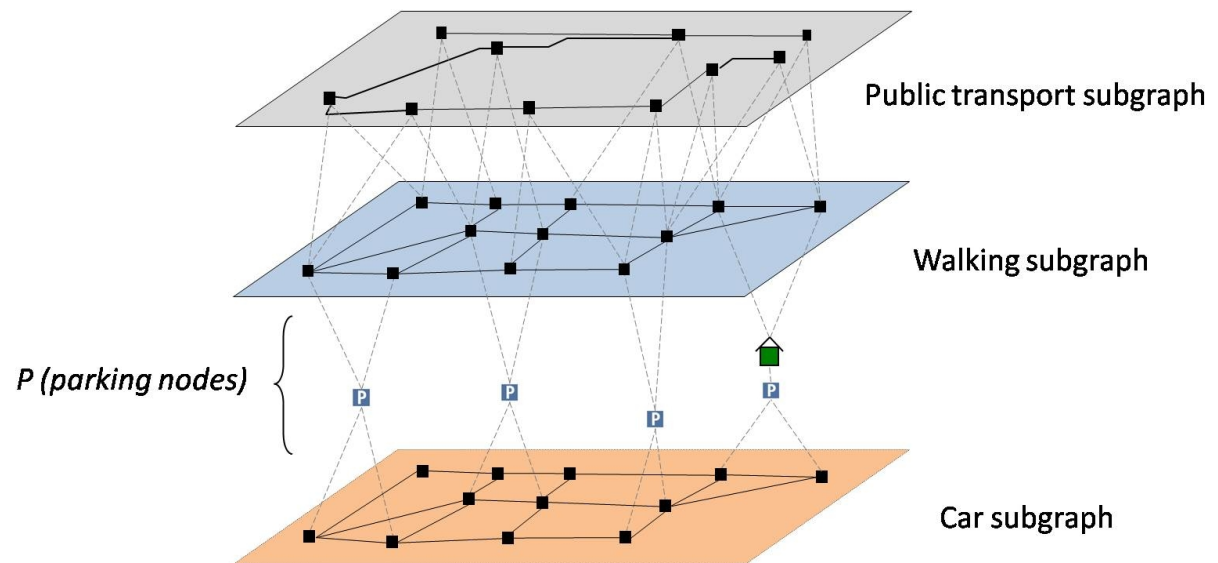
Multimodal trip chains minimizing travel times

- **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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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.



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Multimodal trip chains minimizing travel times

- **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

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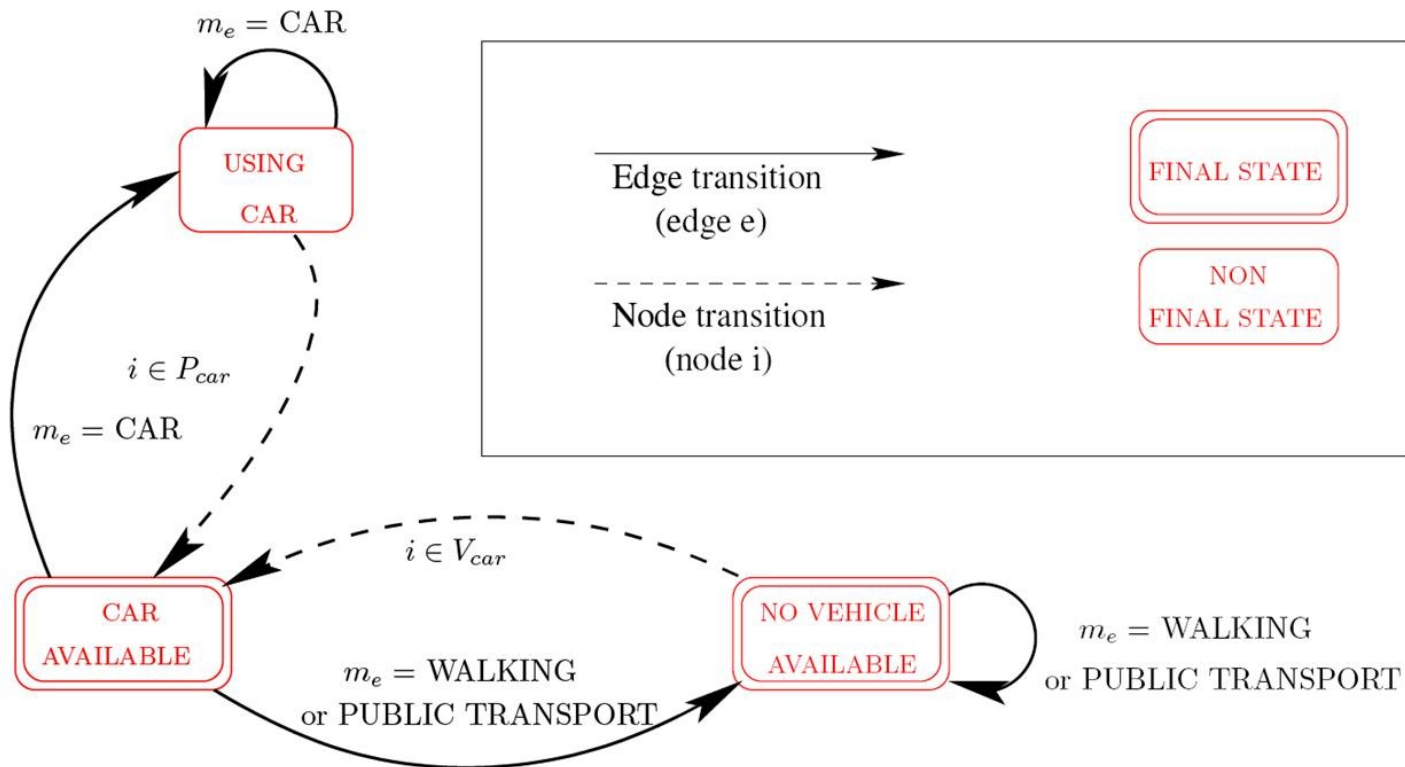
Multimodal trip chains minimizing travel times

- **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**



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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

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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 be 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_2^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

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Multimodal trip chains minimizing travel times

- **Fastest multimodal two-way path**

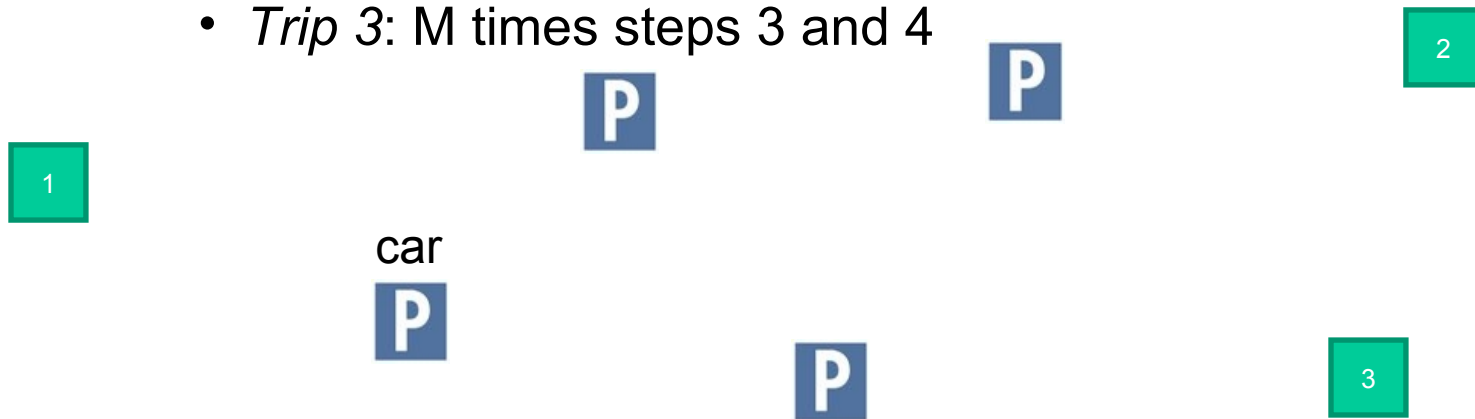
- The node $i^* = \operatorname{argmin}_{i \in P^*} (A_2^i + A_4^i)$ gives the parking node used in the shortest two-way path.
- $2M + 2$ iterations of the one-way algorithm, where M is the cardinality of P^* .

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



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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

Optimal one-way trip		Optimal one-way trip Travel time = 00:23:48 Departure time = 07:30 Arrival time = 07:54	Return trip with car parked in P ₁ Travel time = 00:29:00 Departure time = 17:00 Arrival time =17:29
Walking from O to P ₀	00:02:50		
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



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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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