Flexible many-to-few + few-to-many = an almost personalized transit system

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"Personalized" transit systems

Motivations

- Offer a competitive transportation w.r.t. the private one:
  - capture additional demand
  - better serve population needs
  - cover larger areas
- Sustainability
  - reduce the operational costs
  - increase the resource utilization
- Integration with traditional transportation systems
  - from the users point of view
  - from the management point of view

Dial a Ride systems

Users ask for personalized rides (door-to-door service)

similar to a taxi service

They are served collectively

similar to a bus service

Initially devised to meet needs of users with reduced mobility

Extended to deal with "low demand" areas or periods

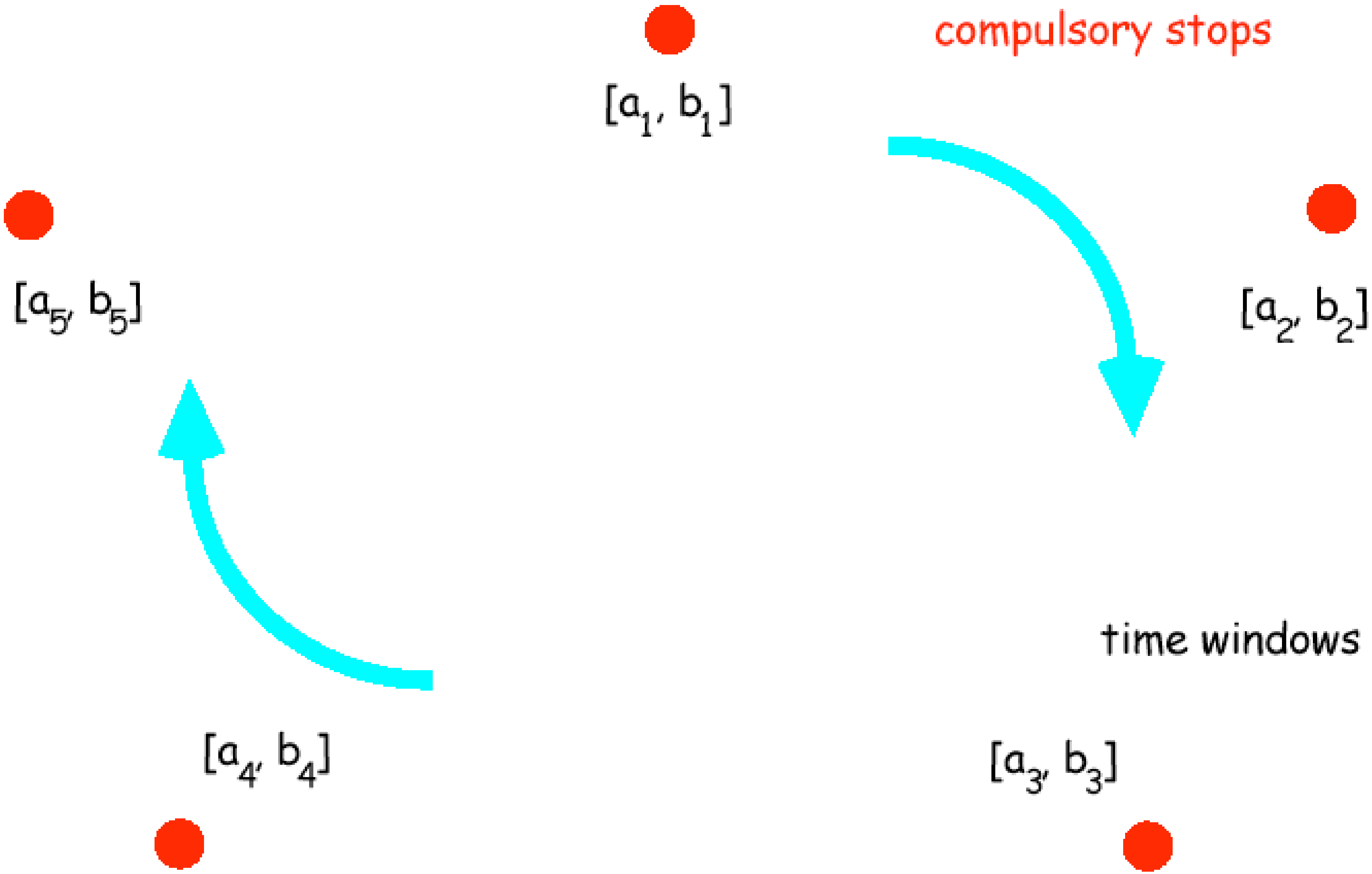
residential outskirts, night service ...

Fixed Line	vs.	DAR
known itinerary and timetable		variable itinerary and timetable
no reservation is needed		accessed only through reservation
one vehicle covers a small area		one vehicle covers a large area
low service quality		good service quality
no decision problems during service		difficult decision problems for pick-up and delivery
network design phase		no network design
		no integration with the fixed lines
		competition with taxi operators
		localization devices are needed

Demand Adaptive System
An attempt to conjugate Fixed Lines with DAR

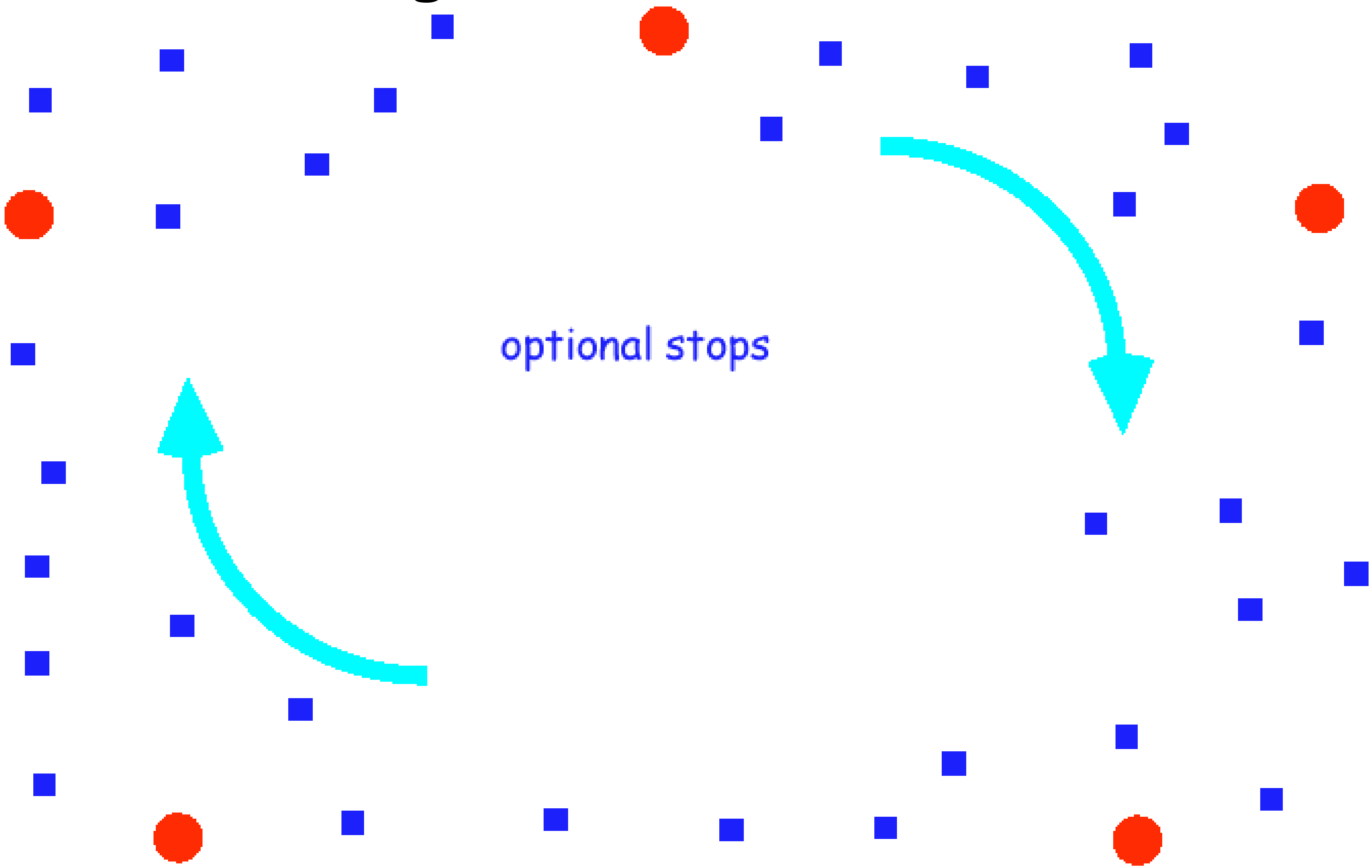
- Lines with compulsory stops and possible deviations upon request
- Flexibility in timetables
- Traditional users can still access the service in compulsory stops (*passive users*)
- Users that make reservations have a better level of service (*active users*)
- Vehicle and driver management can be integrated with traditional services

Building block: 1 flexible line



The bus passes by the compulsory stops within the time windows

Building block: 1 flexible line



The bus passes by an optional stop if a request of transportation is issued

Single line - single tour case: off-line operation decision problem

Given:

- a line (compulsory stops, time windows, optional stops)
- a set of requests *R*
- travel costs and times, "benefits" of serving requests

Select a subset of requests and define the vehicle itinerary

so that

- the time windows constraints are satisfied
- the difference between total benefits and costs is minimized

Notation

request $r \in R$: $r=(s(r),d(r))$ pair of boarding and alighting stops
with benefit $u(r)$:

segment $h = 1,\dots,n$: subgraph between two consecutive
compulsory stops f_{h-1} and f_h

time windows $[a_h,b_h]$ for each compulsory stop f_h

path $p \in P_h$: feasible path from f_{h-1} to f_h
with cost $c(p)$ and travel time $\tau(p)$

Variables

y_r : request selection variable

z_p : path selection variable

t_h : starting time from f_h

$$\max \sum_{r \in R} u(r) y_r - \sum_{h=1}^{n} \sum_{p \in P_h} c(p) z_p$$

$$y_r \leq \sum_{p \in P_h} \delta_{s(r),p} \; z_p \qquad \forall \; r{:}s(r) \text{ is in segment } h, \; h=1,\dots,n$$

$$y_r \leq \sum_{p \in P_h} \delta_{d(r),p} \; z_p \qquad \forall \; r{:}d(r) \text{ is in segment } h, \; h=1,\dots,n$$

$$\sum_{p \in P_h} z_p = 1 \qquad h=1,\dots,n$$

$$t_h + \sum_{p \in P_h} \tau(p) z_p \leq t_{h+1} \qquad h=1,\dots,n-1$$

$$t_n + \sum_{p \in P_n} \tau(p) z_p \leq b_{n+1}$$

$$a_h \leq t_h \leq b_h \qquad h=1,\dots,n$$

$$y_r \in \{0,1\} \qquad \forall \; r \in R$$

$$z_p \in \{0,1\} \qquad \forall \; p \in P_h, \; h=1,\dots,n$$

Solution approaches

Upper bound

- **Lagrangean decomposition of "coupling" constraints**
- **Lagrangean relaxation of "consecutive times" constraints**

Heuristic algorithms

- **basic entities: paths**
- **pool of "promising" paths for each segment updated dynamically**

  approximation of P_h

- **multistart greedy randomized adaptive algorithms**
- **tabu search algorithms**
- **hybrid algorithms**

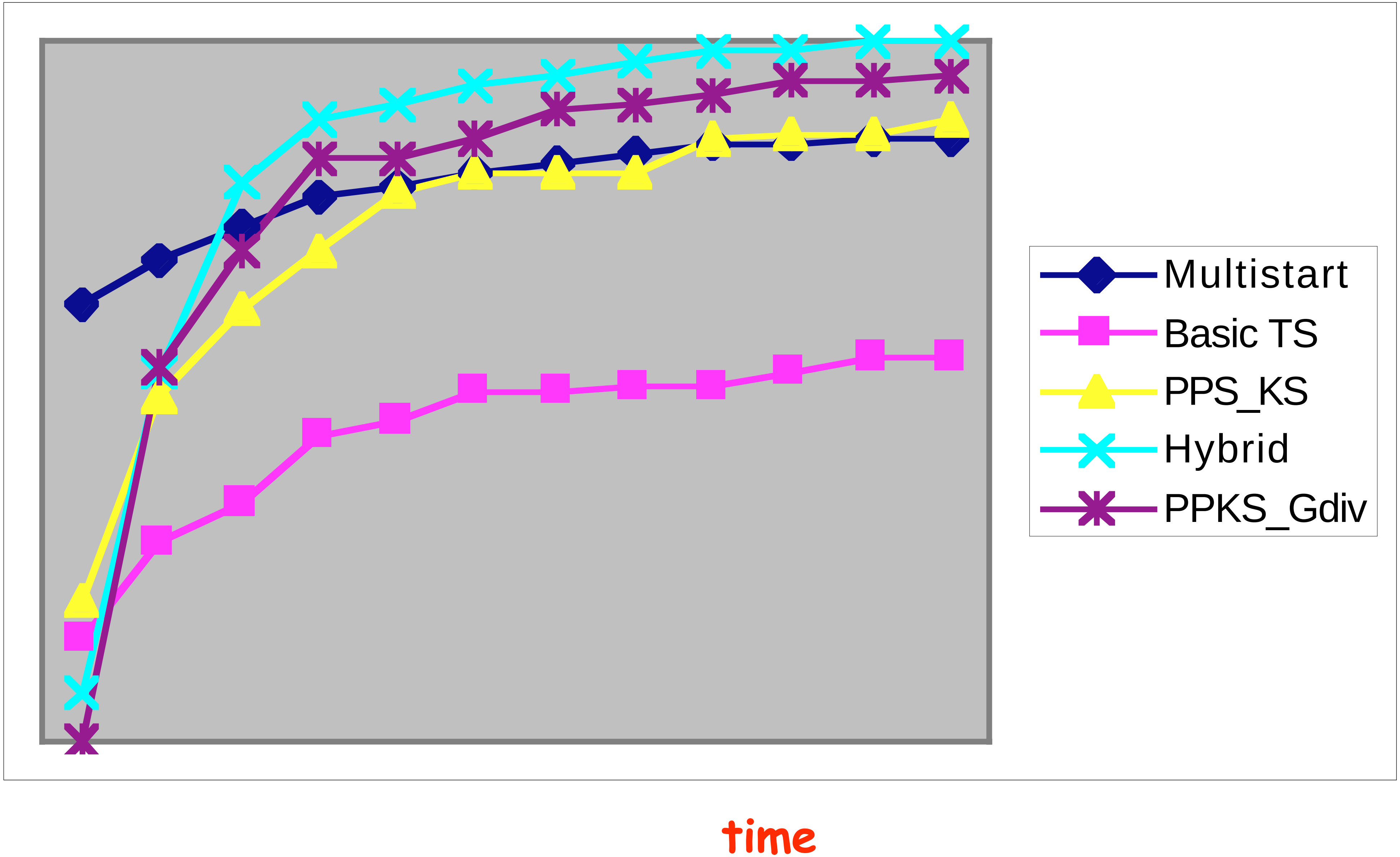
Excerpts of computational results

Winnipeg network
10 segments, 25 optional stops per segment
time windows between 60 to 120 seconds
250 requests
100 seconds runs

	upper bound	multistart	basic TS	hybrid
W1	279	278.61	277.55	278.61
W3	211	207.72	208.83	208.70
W5	227	217.45	213.12	219.39
W7	228	214.03	218.16	216.19

Stockholm network: "easy instances"

Convergence: W5



Designing a flexible line

- Topological level
  - selection of compulsory stops
  - selection of optional stops
  - definition of segments

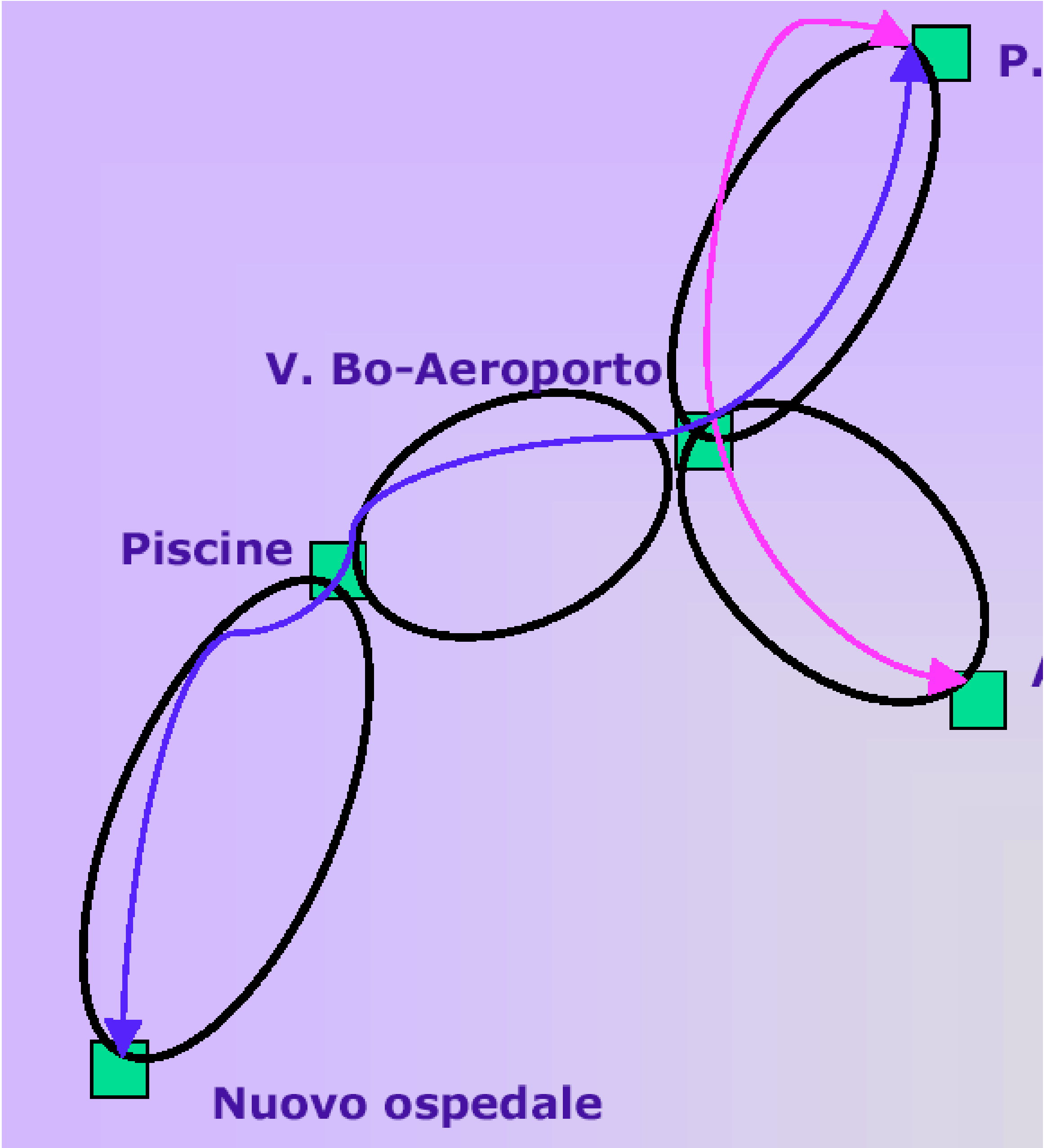
- Temporal level
  - time windows width
  - time difference between consecutive compulsory stops
    - depending on the segment width
    - (i.e., maximum deviation from the direct path)

Different criteria for the urban or extra-urban setting

Example: urban area in Ferrara (Italy)

Compulsory stops and segments

Line structure



Urban line: design parameters

10 segments, 57 optional stops

decided in collaboration with the transportation company

Total travel time: 1 h

imposed by the company

Time window width: from 2 min to 8 min

Urban line: some results

distribution	served req	Q	average LOS
0% comp.	87%	0.97	1.48
30% comp.	89%	0.97	1.49
50% comp.	90%	0.98	1.50

average results on 5 instances of 20 requests

Q: solution profit/upper bound
LOS: actual travel time / "ideal travel time"

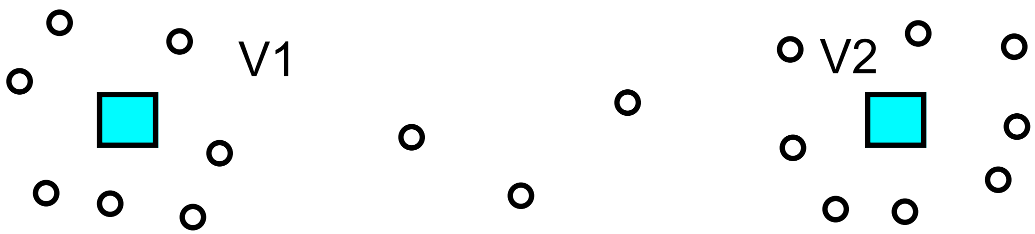
"ideal travel time": minimum travel time from the origin to the destination of the request passing by the compulsory stops satisfying the time windows

Increasing instance sizes

Extra-urban case

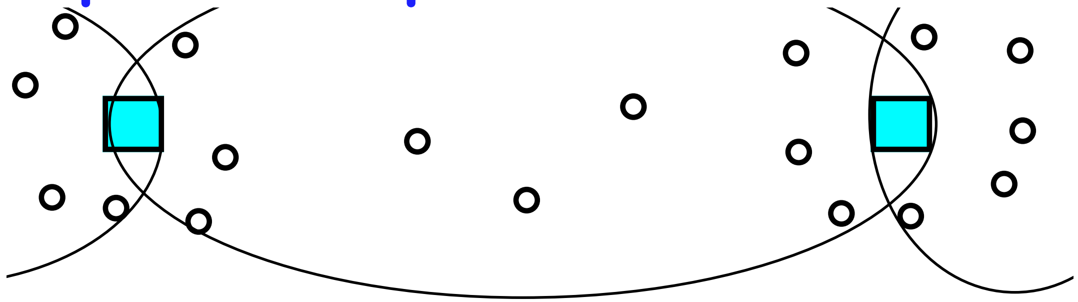
Compulsory stops in the center of villages

The optional stops are not uniformly distributed
(concentrated around the villages)



Question: how to partition the optional stops into segments?

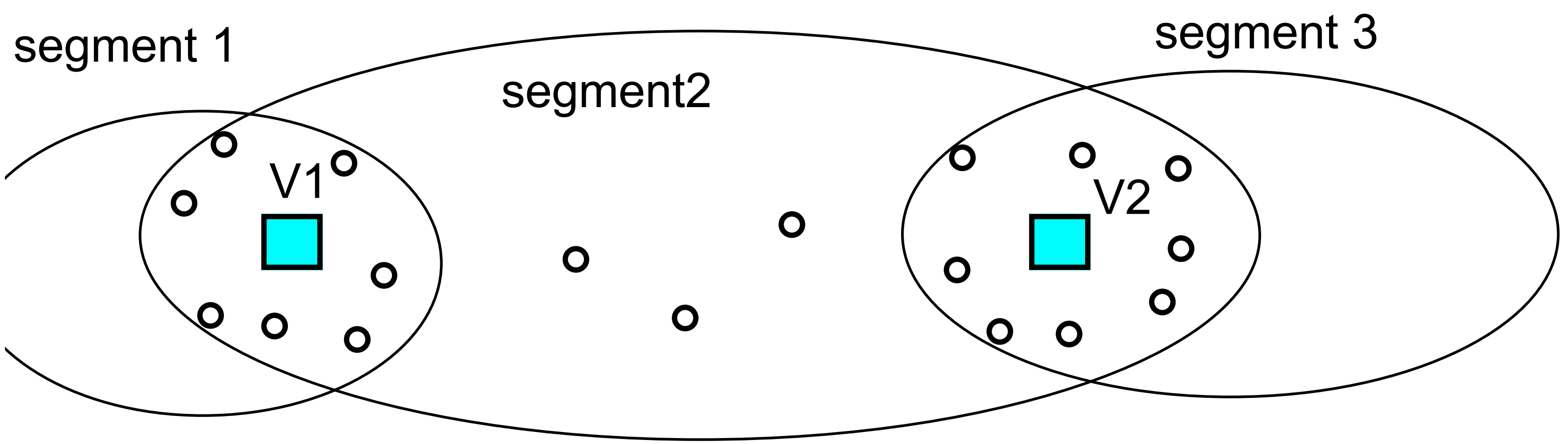
1) Partition the optional stops as in the urban setting



Difficult if there is not a unique way to get in and to get out of the village

2) Duplicate the optional stops of the village:

drop-off stops belong to the incoming segment
pick-up stops belong to the outgoing segment

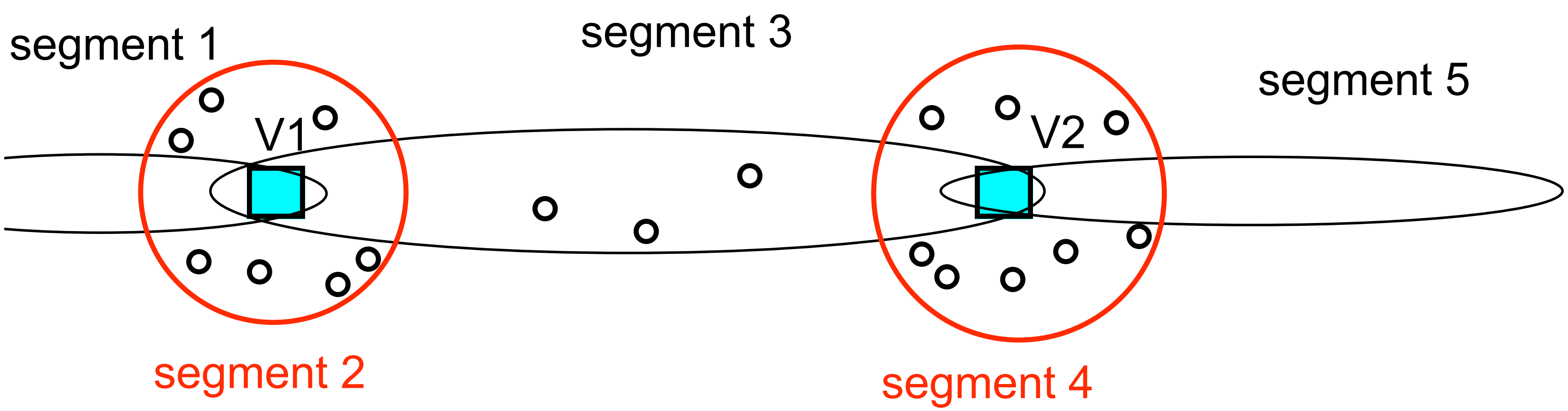


A bus can pass by a compulsory village stop twice (first: drop-off, second pick-up)

s(r) and d(r) may belong to the same segment, though time windows constraints make the paths passing by d(r) before s(r) infeasible

3) Duplicate the compulsory stops of the village center

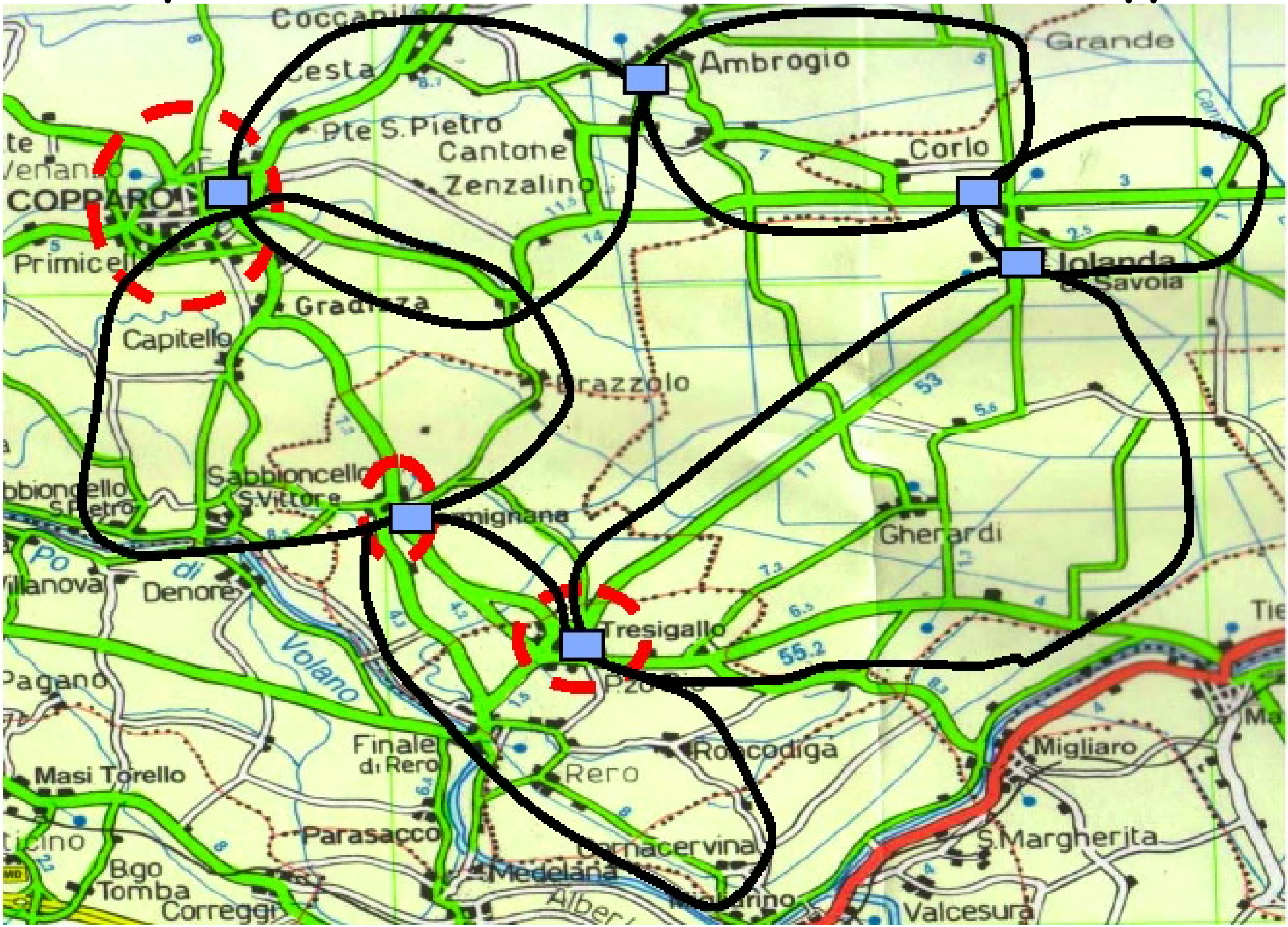
A "village segment" goes from the first copy of the compulsory stop to the second copy and includes all optional stops of the village



A bus passes by a village center compulsory stop twice

- the first time it drops-off passengers (both "passive" and "active")
- the second time it picks-up "passive" passengers

Example: the area "Basso ferrarese" around Copparo



Extra-urban line: design parameters

Optional stops partition method no. 3 in 3 villages

11 segments, 174 optional stops

corresponding to the existing bus stops

Total travel time: 1 h 30 min (very short!)

imposed by the company

Time window width: from 2 min to 10 min

Extra-Urban line: some results

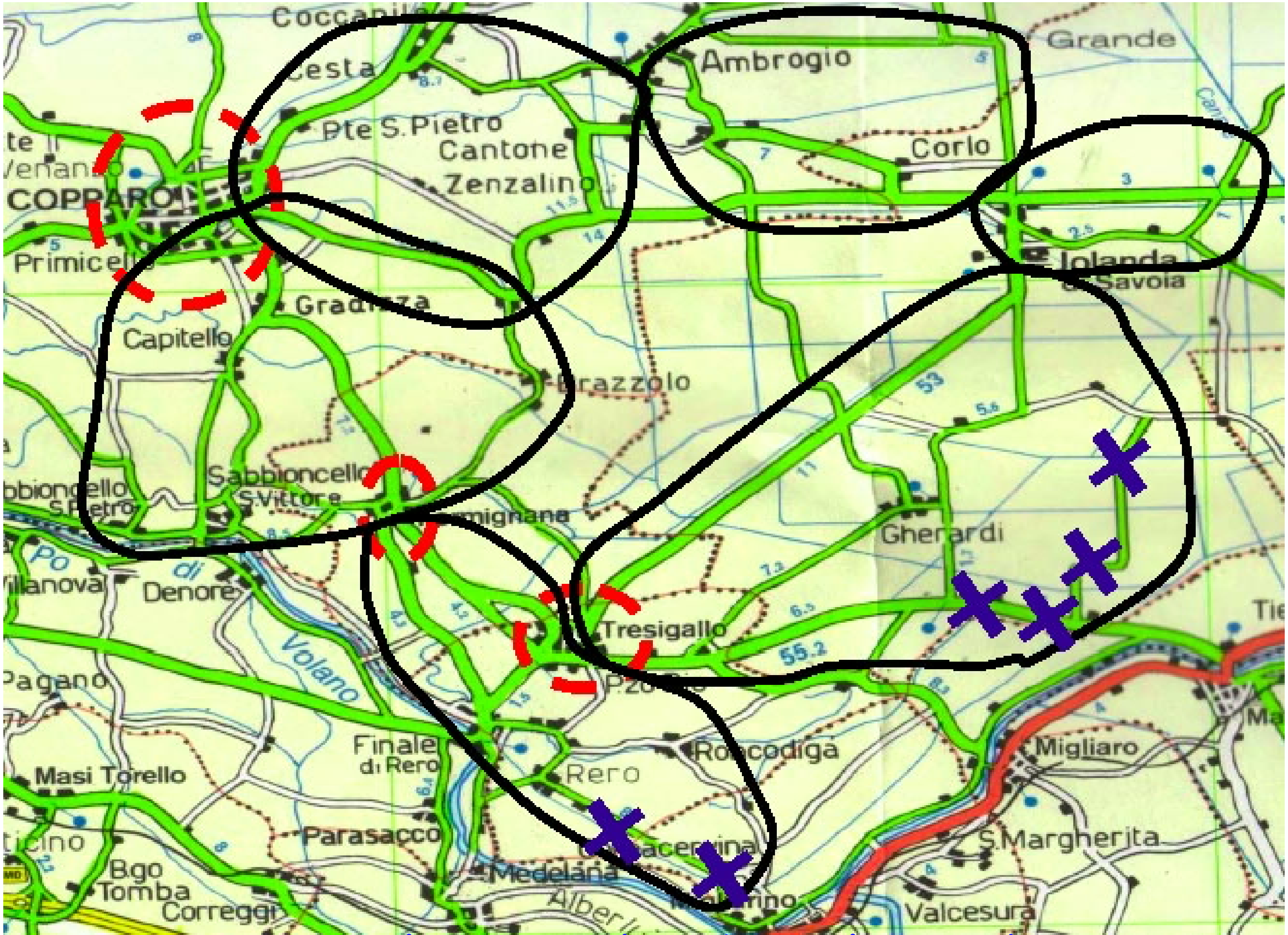
distribution	served req	Q	average LOS
0% comp.	68%	0.92	1.92
30% comp.	84%	0.94	1.95
50% comp.	86%	0.95	1.99

average results on 5 instances of 20 requests

Q: solution profit/upper bound
LOS: actual travel time / "ideal travel time"

"ideal travel time": minimum travel time from the origin to the destination of the request passing by the compulsory stops satisfying the time windows

Extra-urban case: modified network

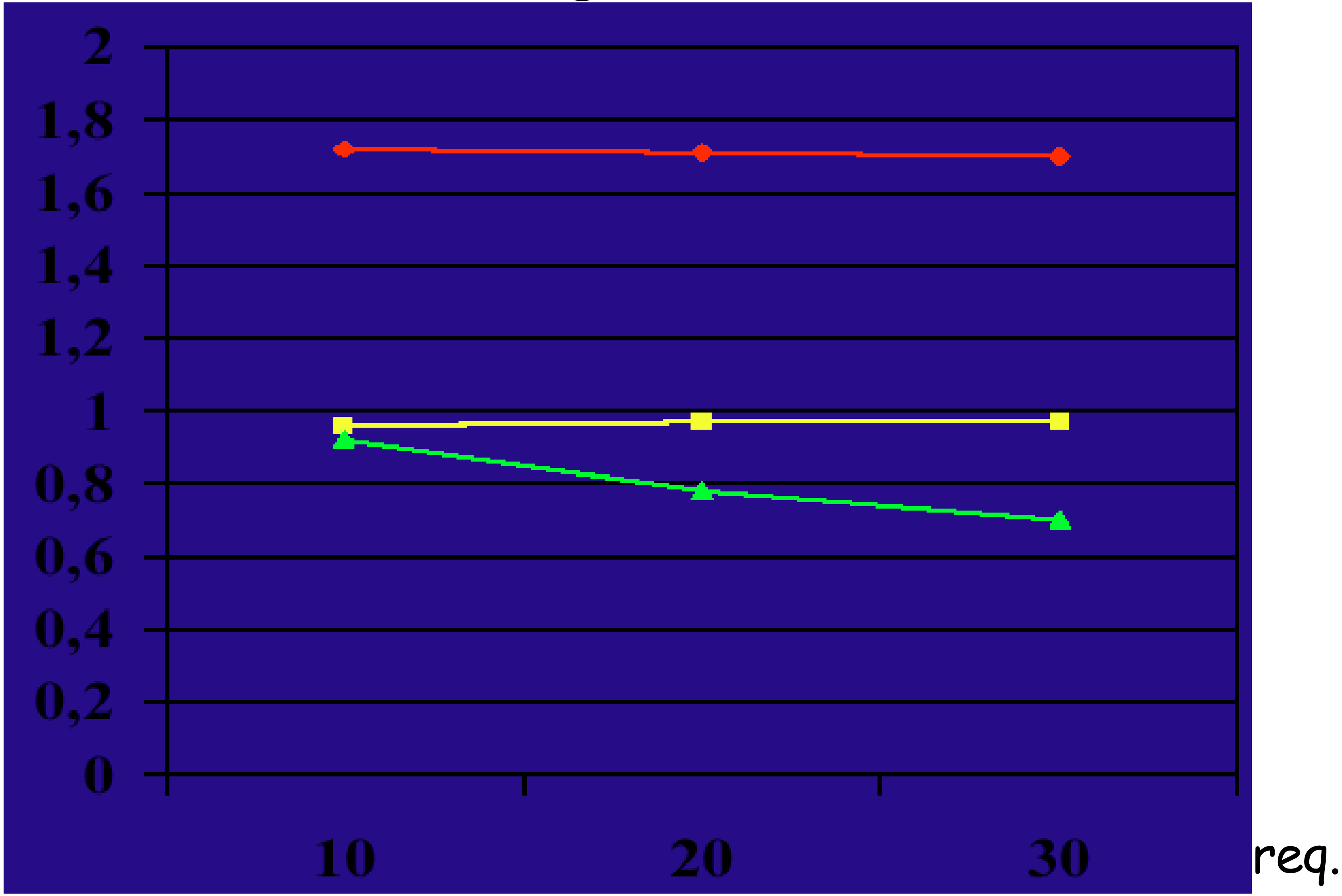


six outlying stops have been eliminated

Extra-Urban line: served requests

distribution	original line	modified line
0% comp.	68%	90%
30% comp.	84%	91%
50% comp.	86%	92%

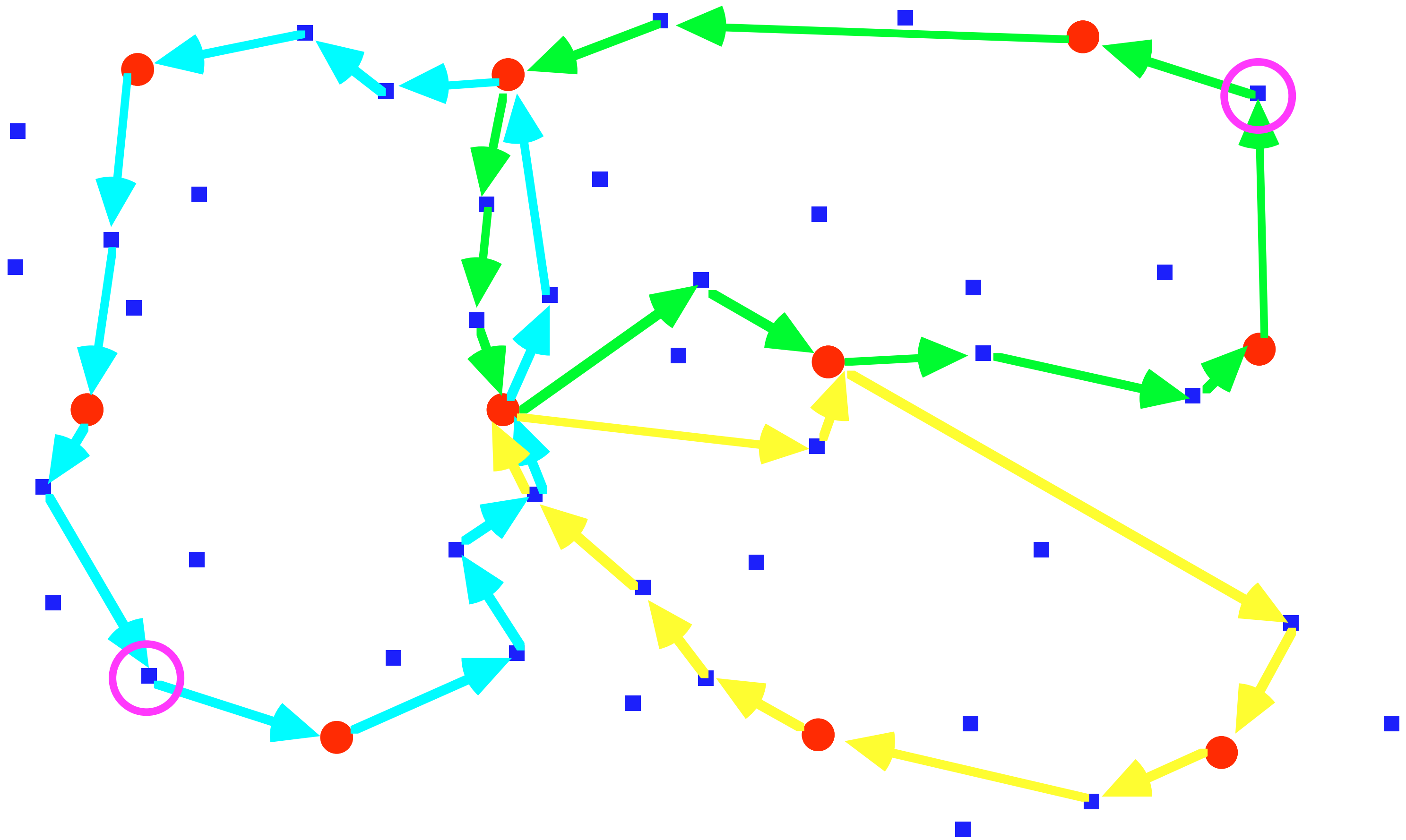
Increasing instance sizes



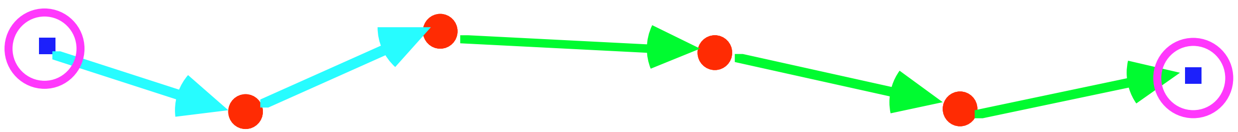
LOS, Q, served req.%

Multiple lines - multiple tours

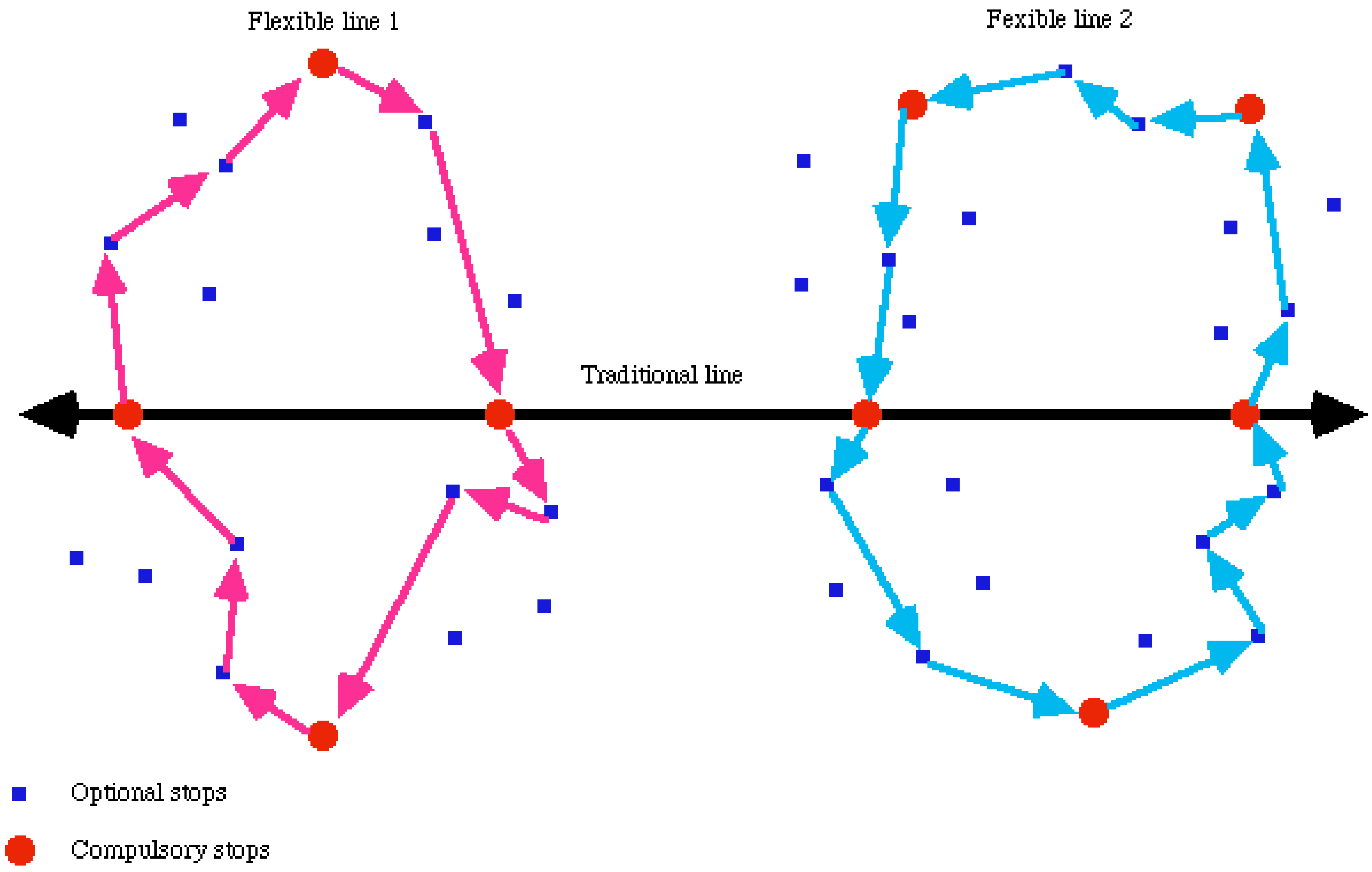
Example



passenger route



Example: integrated system



Assumptions:

- fixed synchronization at compulsory stops
- negotiation for possible displacement in time or space
- taxi rides

The route of a passenger is described by a sequence of vehicle legs

optional - compulsory - … - compulsory - optional

only the first and the last legs must pass by optional stops

the definition of the intermediate legs is not important for the passenger as the synchronization is fixed

Mathematical model

The passenger itinerary can be summarized by the pair of terminal legs that compose it

W_r = set of pairs of boarding and alighting legs corresponding to feasible routes for request r

u_w : benefit related with pair w of request r

σ : index of segment

route selection variables:

$$x_w = \begin{cases} 1 & \text{if request } r \text{ is routed through pair } w \text{ in } W_r \\ 0 & \text{otherwise.} \end{cases}$$

$$y_r = \begin{cases} 1 & \text{if a taxi ride is used for request } r \\ 0 & \text{otherwise.} \end{cases}$$

$$\max \sum_{r \in R} \sum_{w \in W_r} u_w x_w - \sum_{\sigma \text{ segment}} \sum_{p \in P_\sigma} c(p) z_p - \sum_{r \in R} \text{taxi } y_r$$

$$x_w \leq \sum_{\sigma \text{ segment}} \sum_{p \in P_\sigma} \delta_{s(r),p} \, z_p \qquad \forall \, r \in R, \ \forall \, W_r$$

$$x_w \leq \sum_{\sigma \text{ segment}} \sum_{p \in P_\sigma} \delta_{d(r),p} \, z_p \qquad \forall \, r \in R, \ \forall \, W_r$$

$$\sum_{w \in W_r} x_w + y_r = 1 \qquad \forall \, r \in R$$

$$\sum_{p \in P_\sigma} z_p = 1 \qquad \text{for each segment } \sigma$$

$$t_\sigma + \sum_{p \in P_\sigma} \tau(p) z_p \leq t_{\sigma'} \qquad \text{for each consecutive segments } \sigma \text{ and } \sigma'$$

$$a_\sigma \leq t_\sigma \leq b_\sigma \qquad \text{for each segment } \sigma$$

$$x_w, \ y_r, \ z_p \in \{0,1\}$$

Solution approaches

Lagrangean decomposition of coupling constraints (λ)
Lagrangean relaxation of service constraints (μ)

Evaluation of the Lagrangean function $\Phi(\lambda,\mu)$:
solution of many single line problems for each line occurrence
(almost all requests involve only one optional stop)

Parallel approaches

A feasible solution can be generated easily

Conclusions

The proposed system provides a good flexibility maintaining the features of a traditional fixed line system: traditional users and users who ask explicitly for a ride may share the system

Limited technological requirements

Low costs

Integration with traditional transportation systems

Efficient algorithms supporting the managing decisions