Trends in Transportation and Logistics and the Role of Optimization

M. Grazia Speranza

University of Brescia

IN4PL 2022

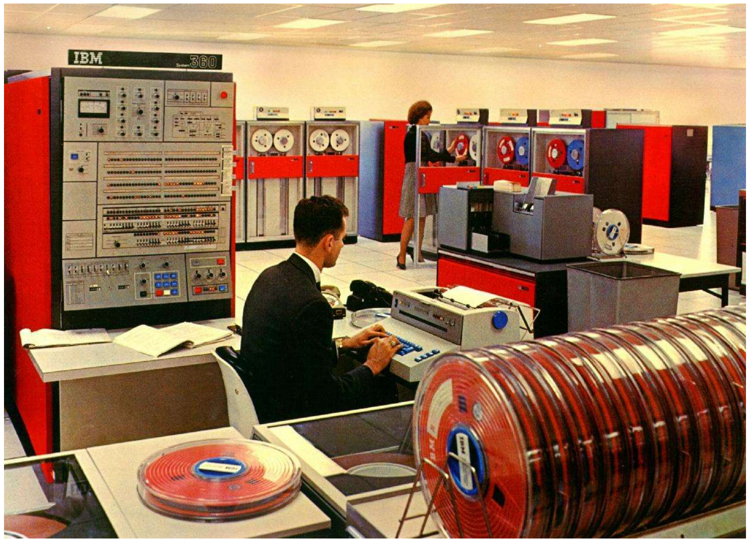
Optimization in transportation and logistics

1960's and 70's

"Transportation science" emerged

"Transportation" meant traffic and public transportation

"Logistics" referred to physical distribution and inventory management



The contributions

Vehicle routing

Facility location

Warehouse management

Optimization:

trains and aircrafts

Traffic assignment

Network design

Crew management

Supply chain management

Bus scheduling

Inventory management

Production planning and scheduling

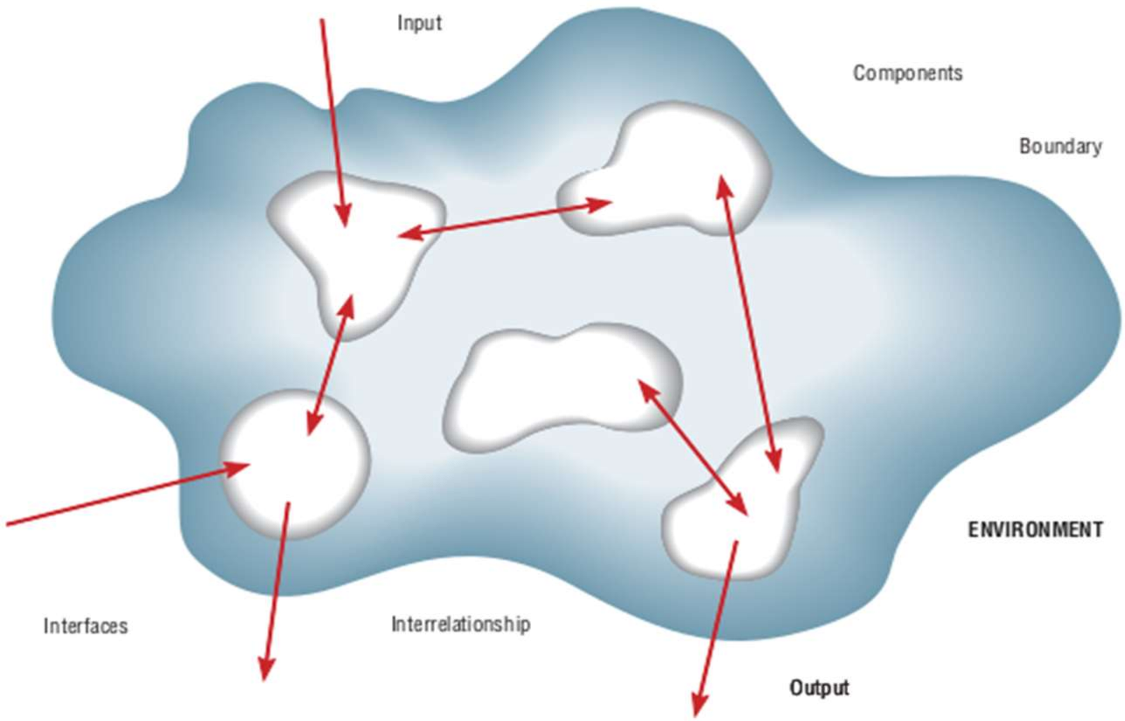
The contributions: efficiency

Efficient use of scarce resources

Scarcity is a fact of life.

While people's desire for goods is unlimited, the resources to produce them are limited

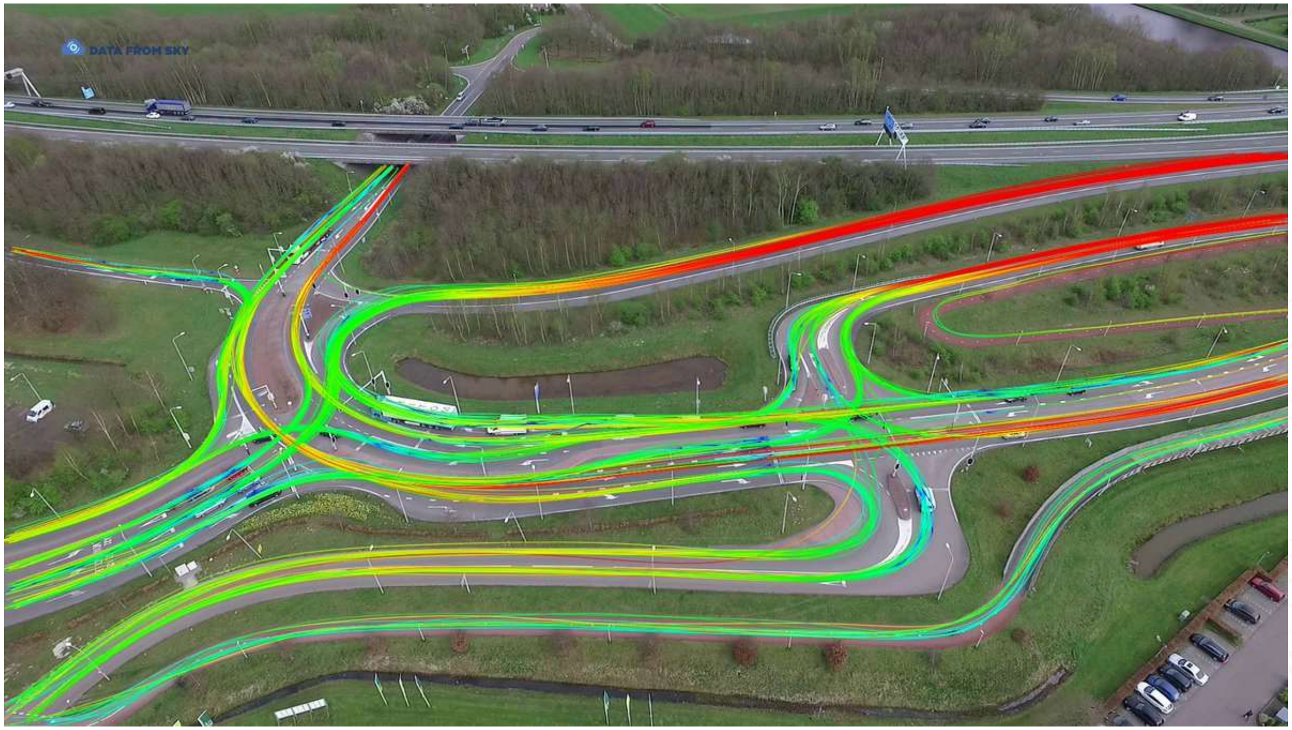
The contributions: systemic approach



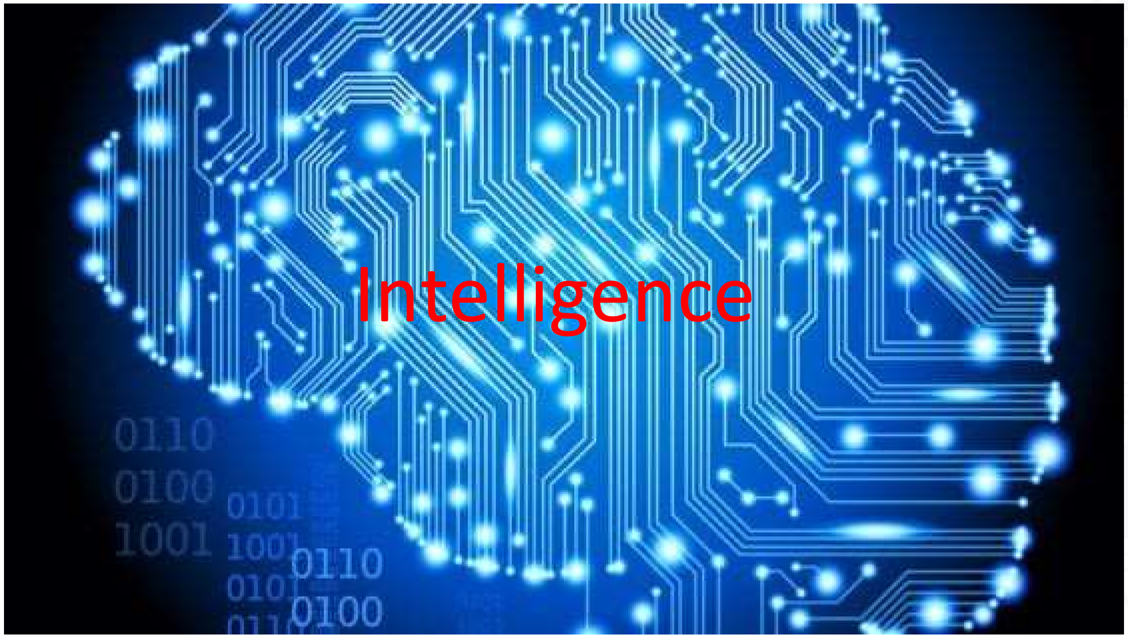
UNIVERSITY OF BRESCIA

The contributions: looking ahead

Anticipation of consequences

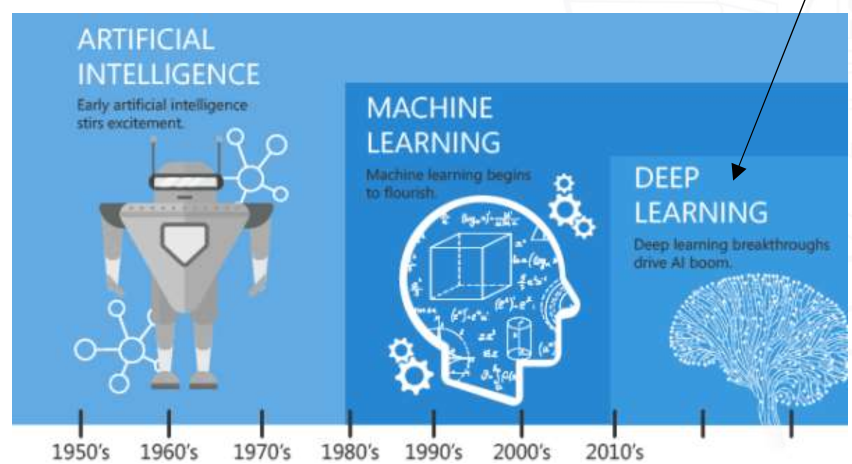


The contributions: in one word



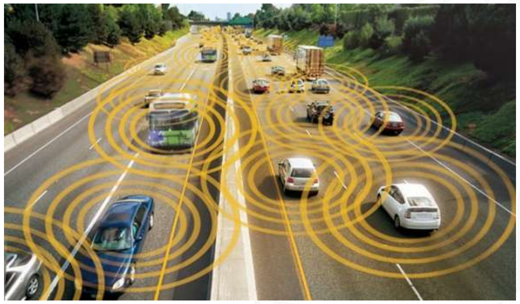
Technology

optimization



UNIVERSITY OF BRESCIA

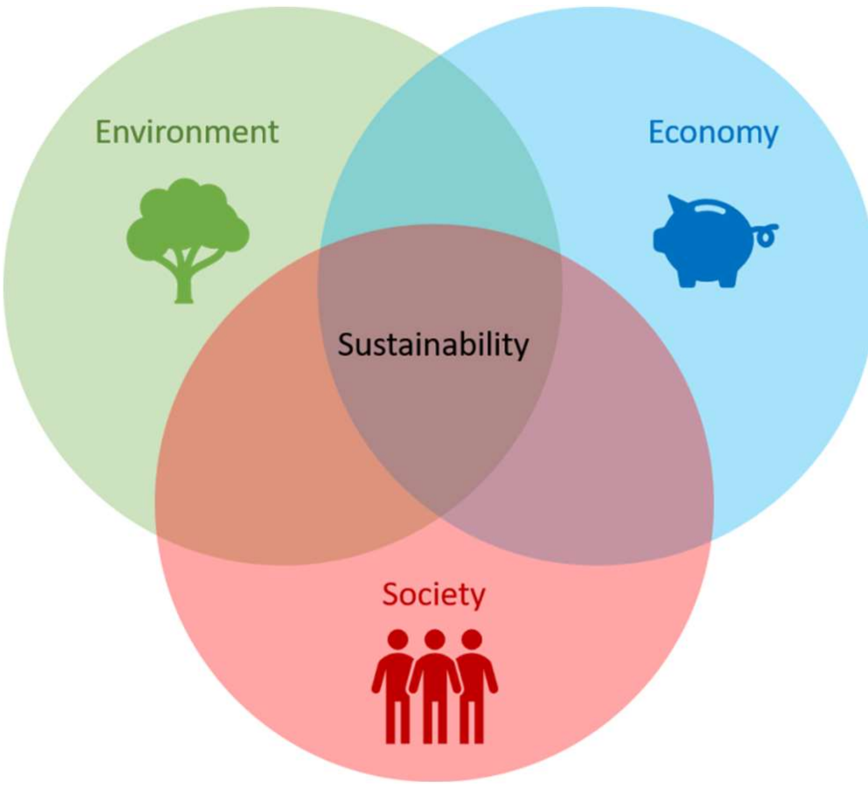
Trends in transportation



Trends in logistics

UNIVERSITY OF BRESCIA

Moreover…



Meeting the needs of the present without compromising the ability of future generations to meet their needs

UNIVERSITY OF BRESCIA

Technology and optimization

Intelligence is needed

Transportation (freight and people)

Freight-empty returns:
31% for companies
23% for logistic companies

People-use of personal cars:
70-75%

Waste of capacity

Unnecessary emissions

UNIVERSITY OF BRESCIA

Directions in research

Collaborative

Systemic

Dynamic

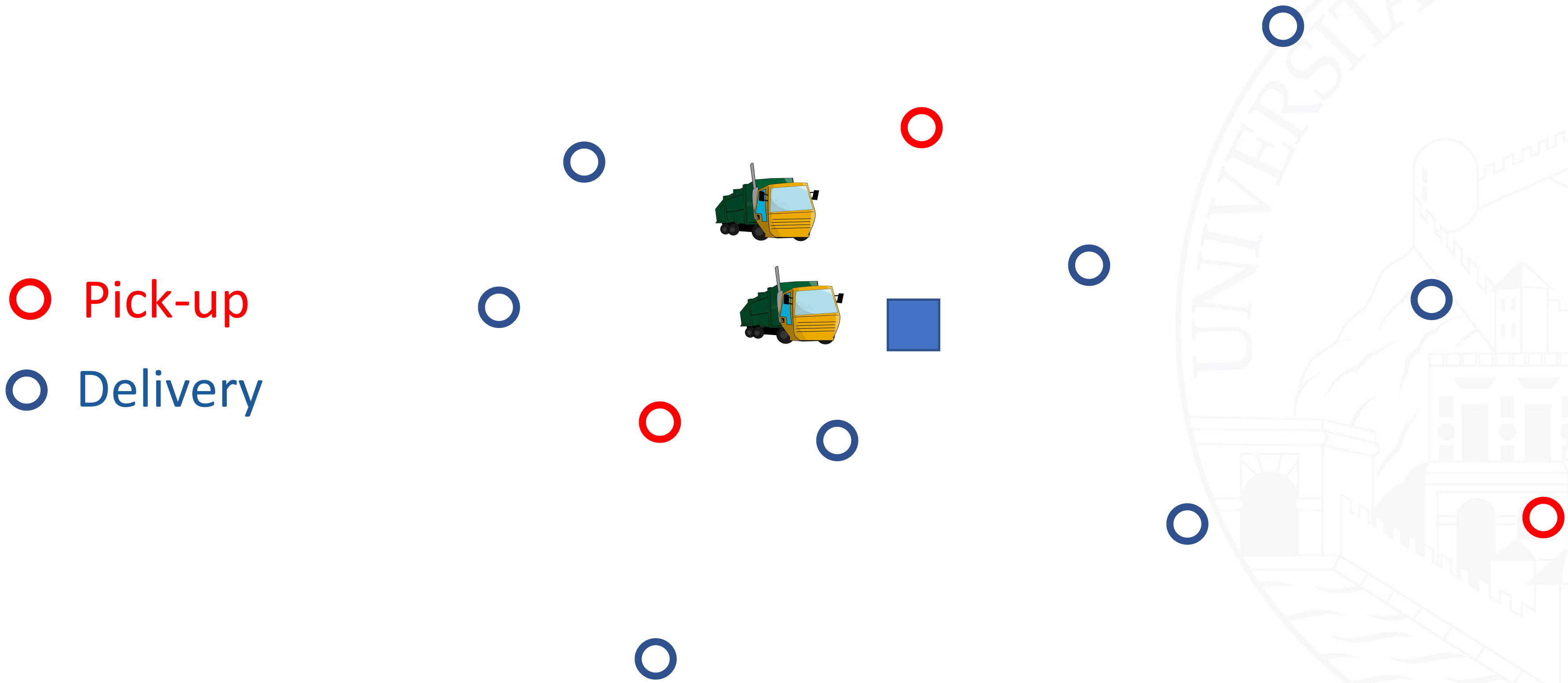
Data-driven

Technology-driven

UNIVERSITY OF BRESCIA

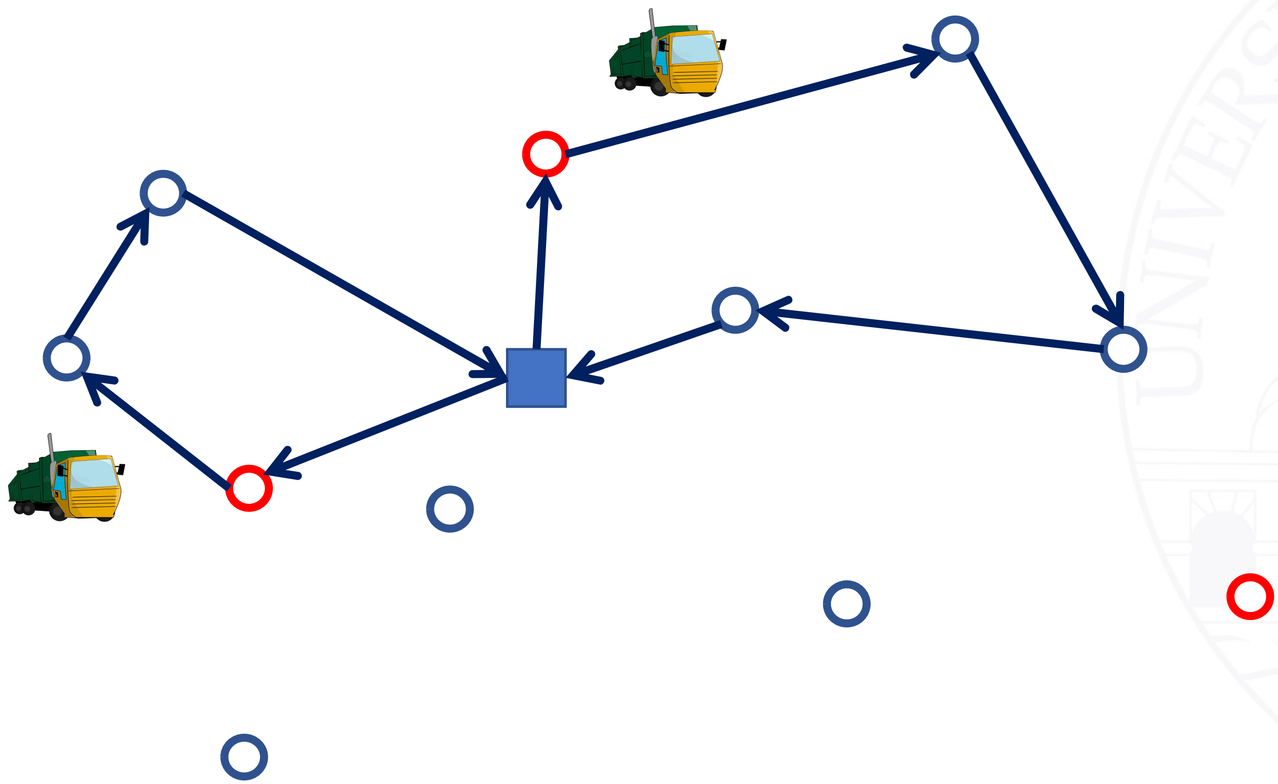
Freight

Coordination of pick-up and delivery over time

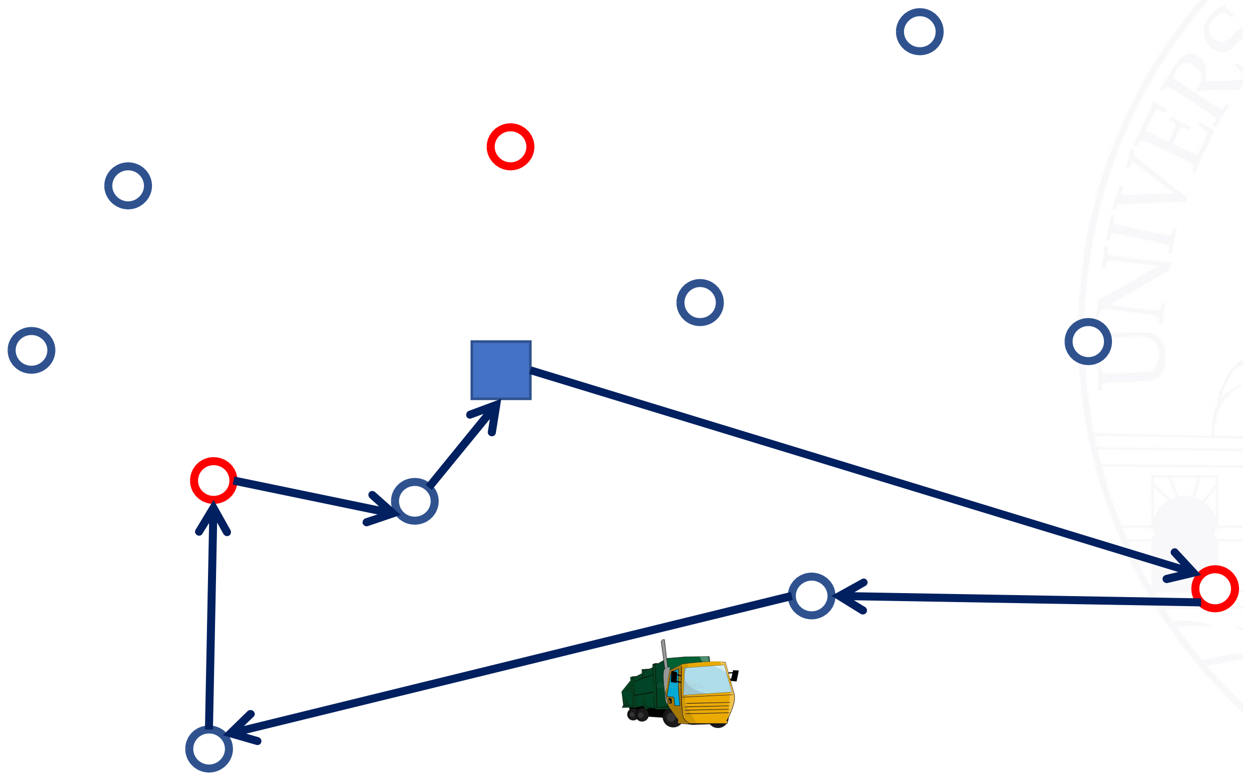


Archetti, Christiansen, Speranza, EJOR, 2018

Coordination of pick-up and delivery over time



Coordination of pick-up and delivery over time



Coordination of pick-up and delivery over time

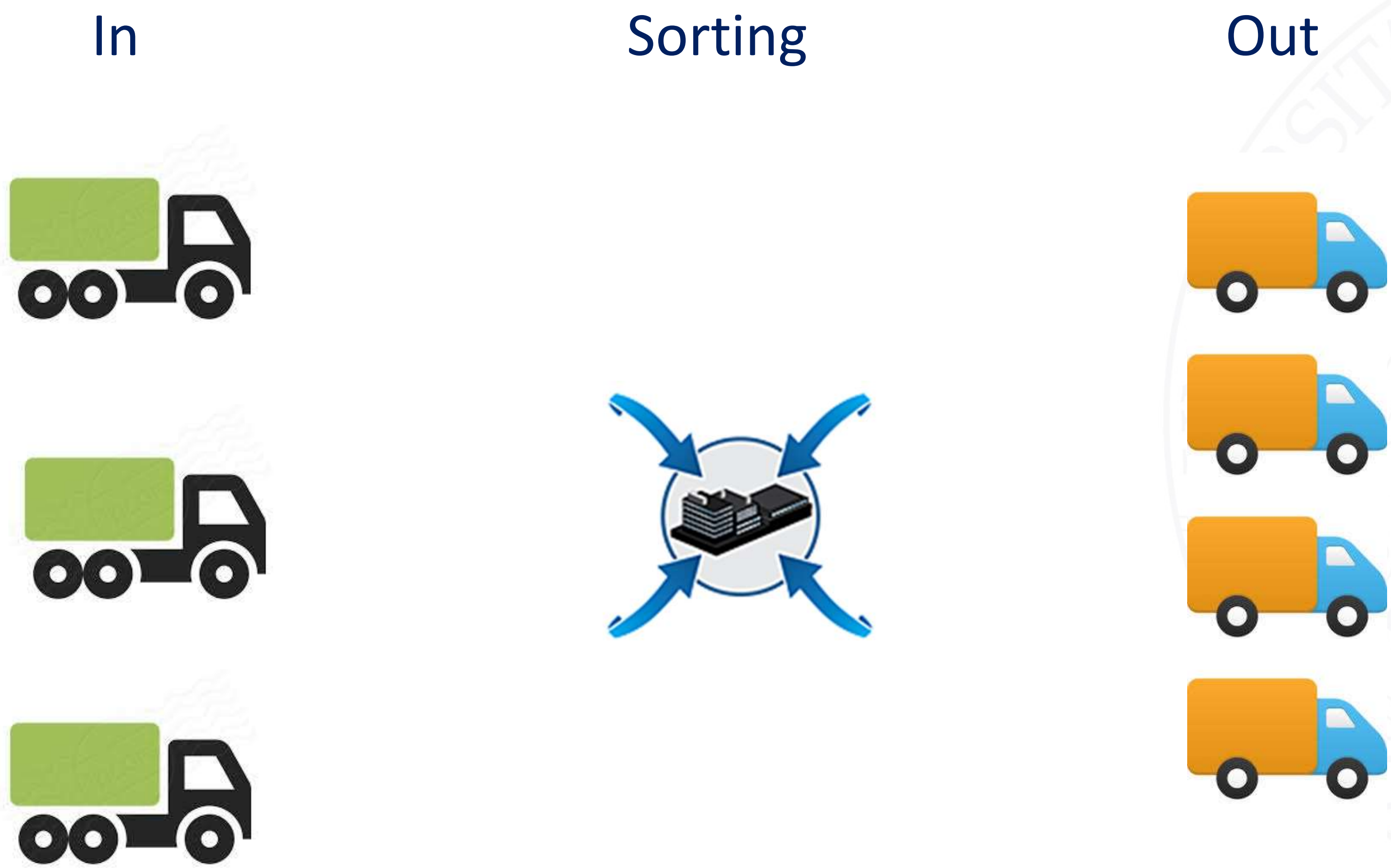
- Sequential policy: each customer independent
- Coordinated policy

	% total cost (average)	% total cost (max)
T=3	40.47	63.19
T=6	27.66	40.28
Low inventory cost	36.36	52.97
High inventory cost	34.67	63.19
All	35.54	63.19

UNIVERSITY OF BRESCIA

Reduction of emissions: 35.54%

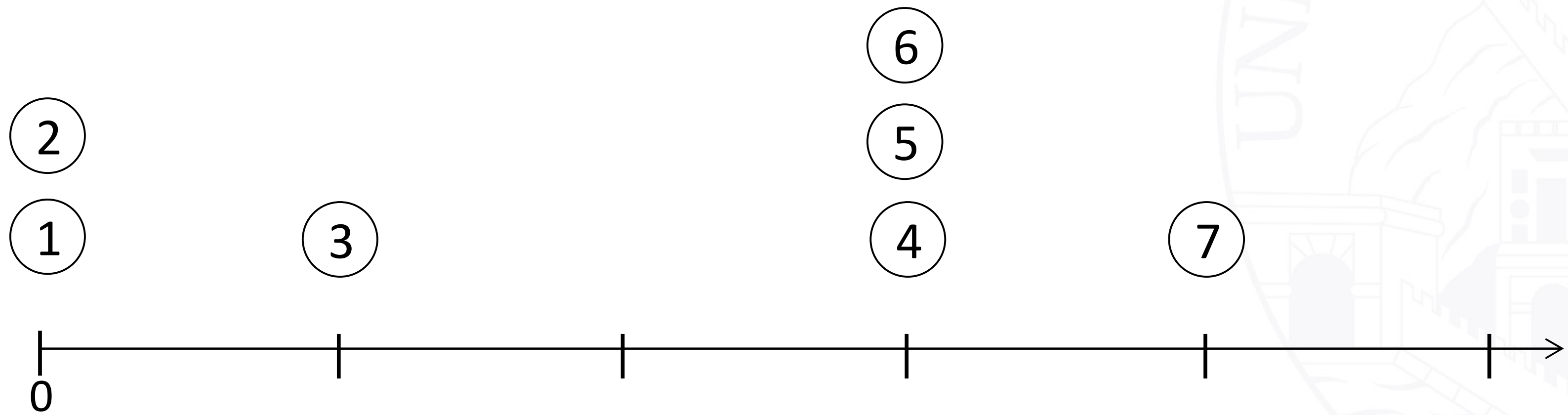
Coordination of operations over time



Coordination of operations over time

Arrival times

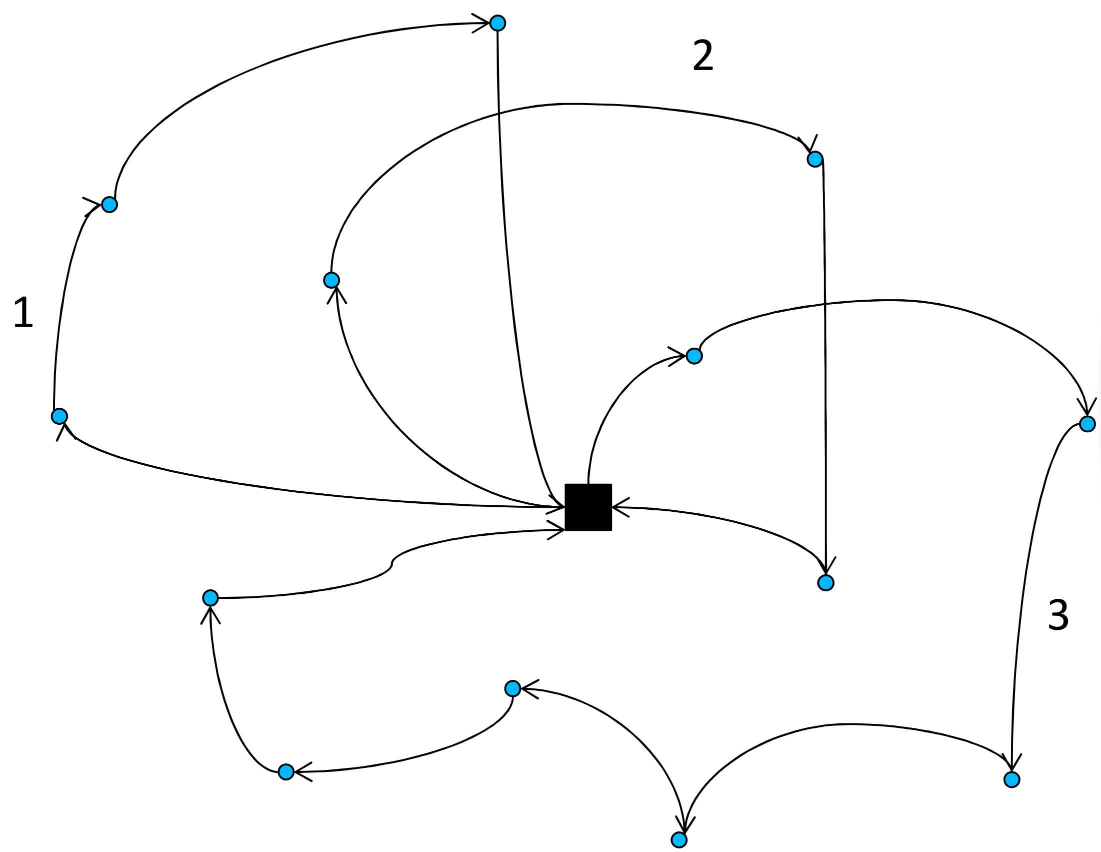
Release dates



Archetti, Feillet, Mor, Speranza, EJOR, 2020
Archetti, Feillet, Mor, Speranza, COR, 2018

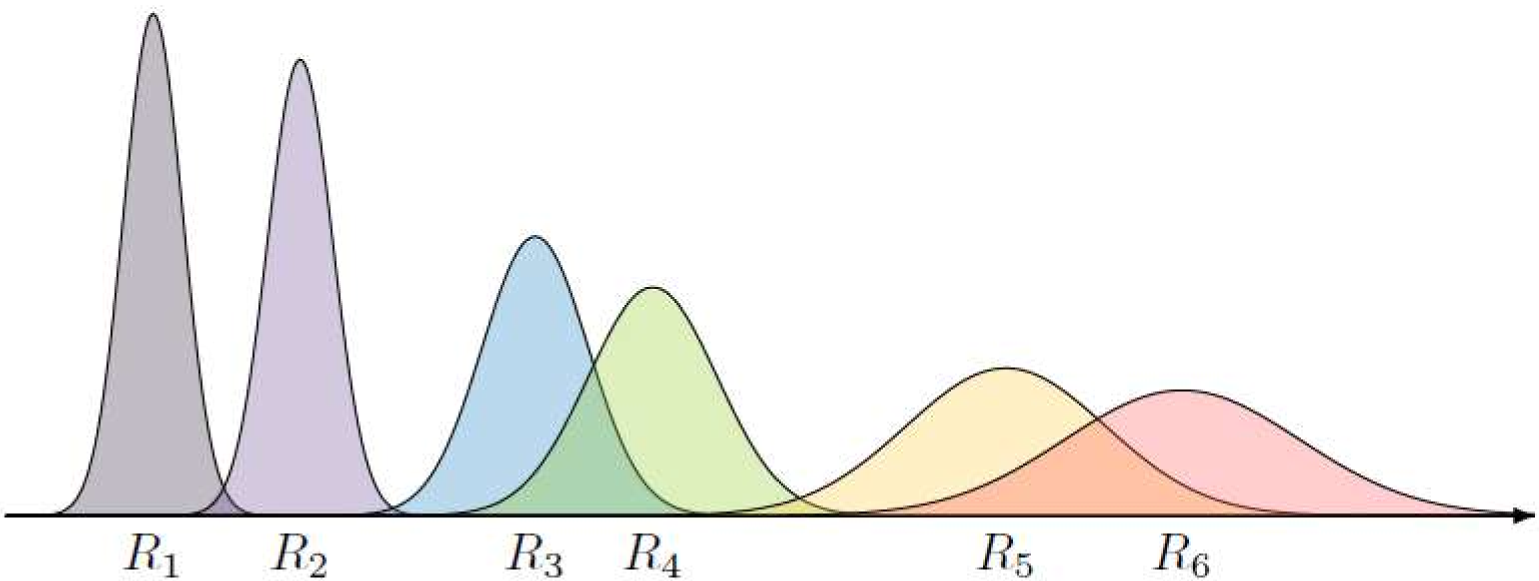
UNIVERSITY OF BRESCIA

Coordination of operations over time



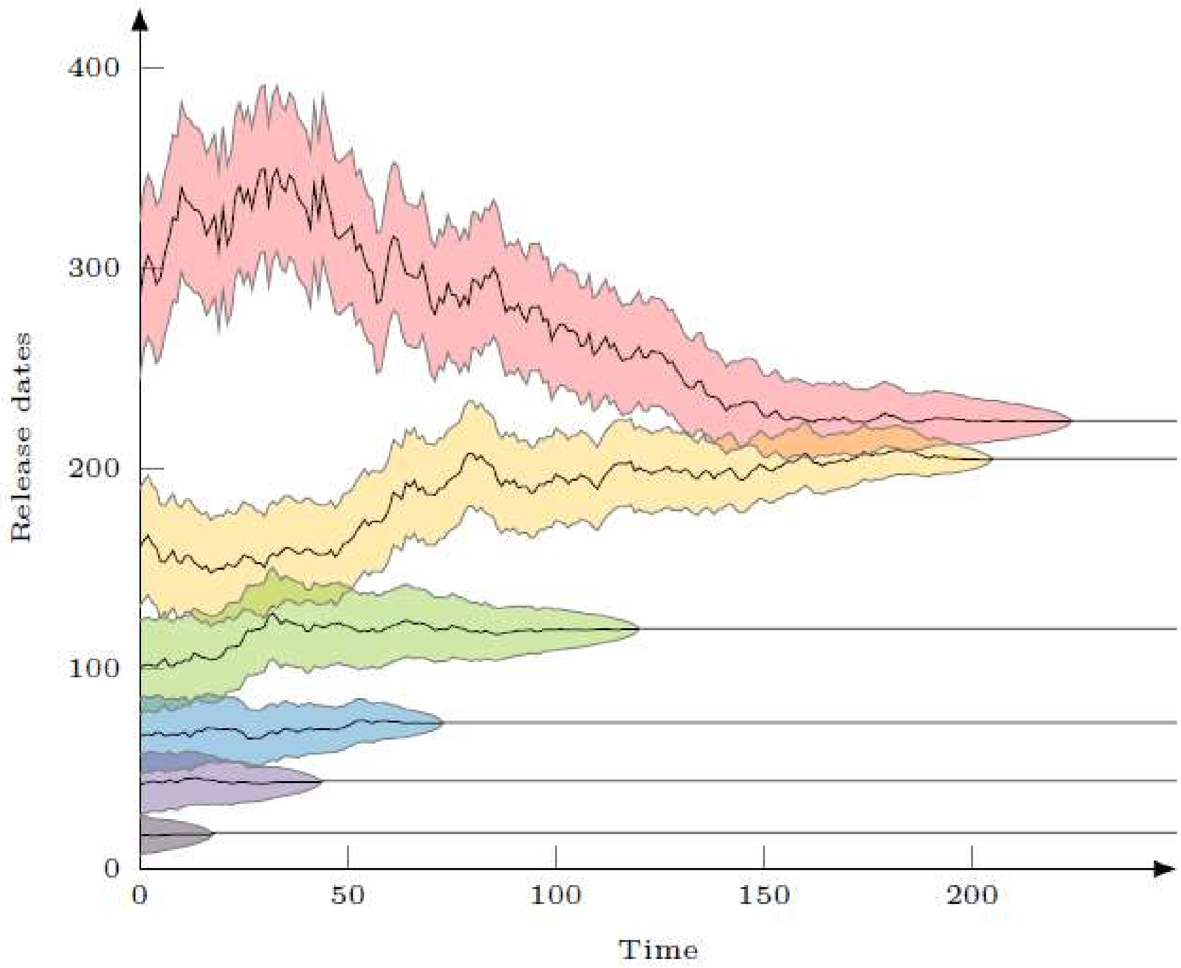
UNIVERSITY OF BRESCIA

Coordination of operations over time



UNIVERSITY OF BRESCIA

Coordination of operations over time



Coordination of operations over time

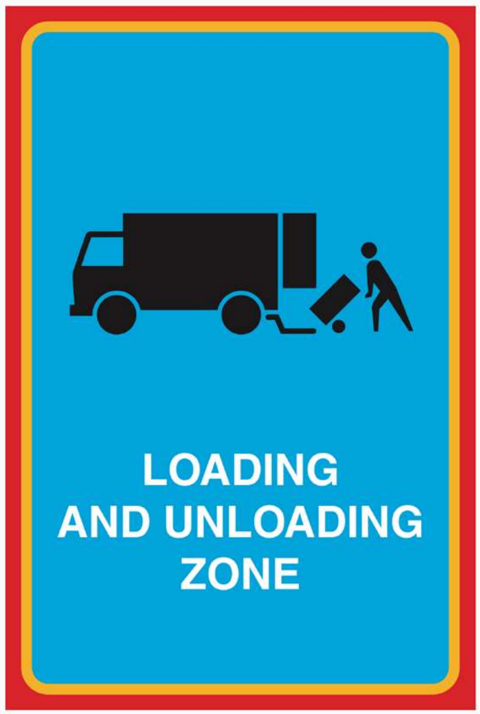
Iterated local search

	Avg. Deterministic	Avg. Stochastic	Avg. R	Avg. RD	Avg. RDW	Avg. "myopic"
$\delta = 0$	2.69	0.72	1.77	1.68	1.67	11.96
$\delta = 0.5$	2.96	1.40	2.35	2.17	2.02	14.74
$\delta = 1$	3.10	1.34	3.03	2.39	2.25	10.85
$\beta = 0.5$	1.91	1.28	1.67	1.61	1.51	24.22
$\beta = 1$	3.79	0.90	2.37	2.56	2.11	11.10
$\beta = 1.5$	3.05	1.29	2.40	2.09	2.02	2.23
Avg.	2.92	1.16	2.14	2.09	1.88	12.52

Reduction of emissions: 13%

UNIVERSITY OF BRESCIA

Loading/unloading areas



Loading/unloading areas

University of Brescia

Loading/unloading areas

Causes of double parking:

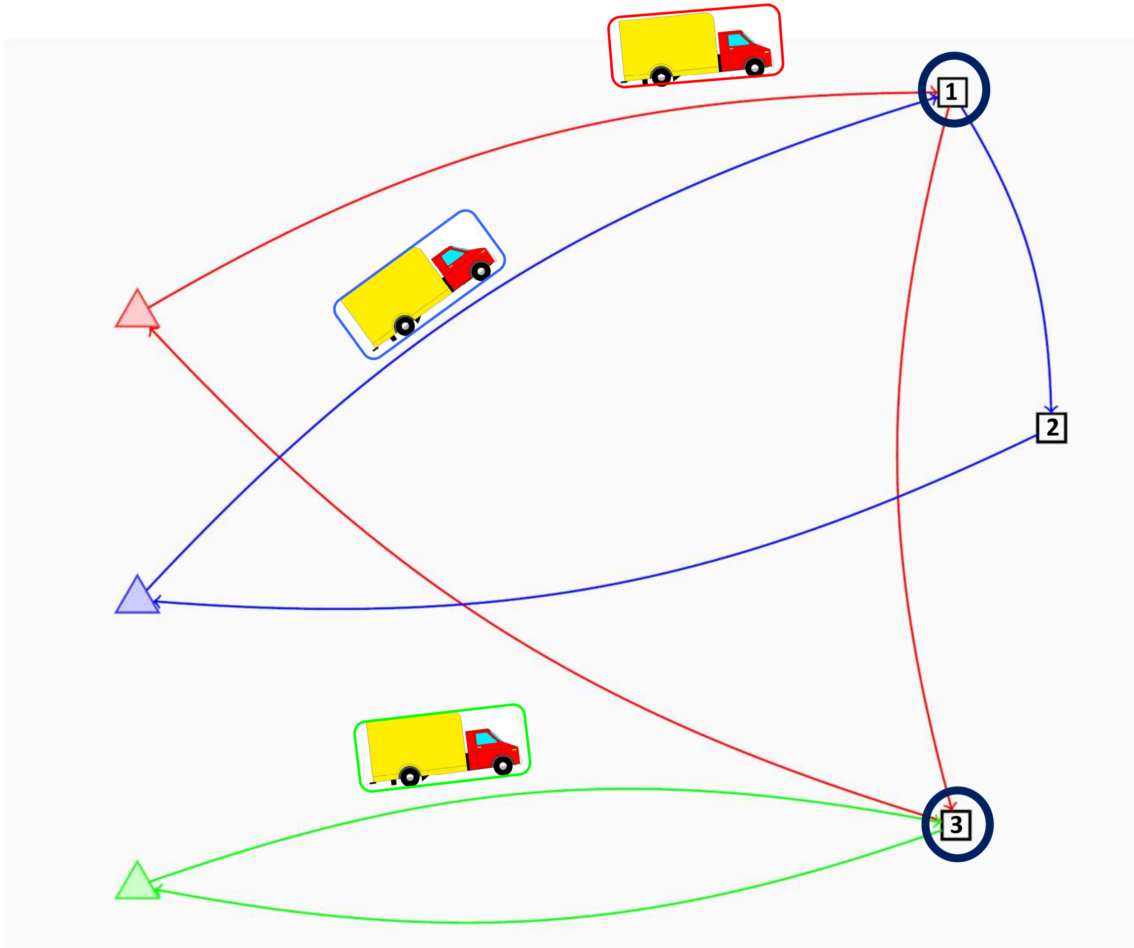
- Scarcity of L/U areas
- Need to deliver
- Individual routes and schedules

Consequences of double parking:

- One less lane available
- Queues of vehicles
- Emissions

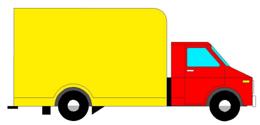
UNIVERSITY OF BRESCIA

Loading/unloading areas



UNIVERSITY OF BRESCIA

Loading/unloading areas

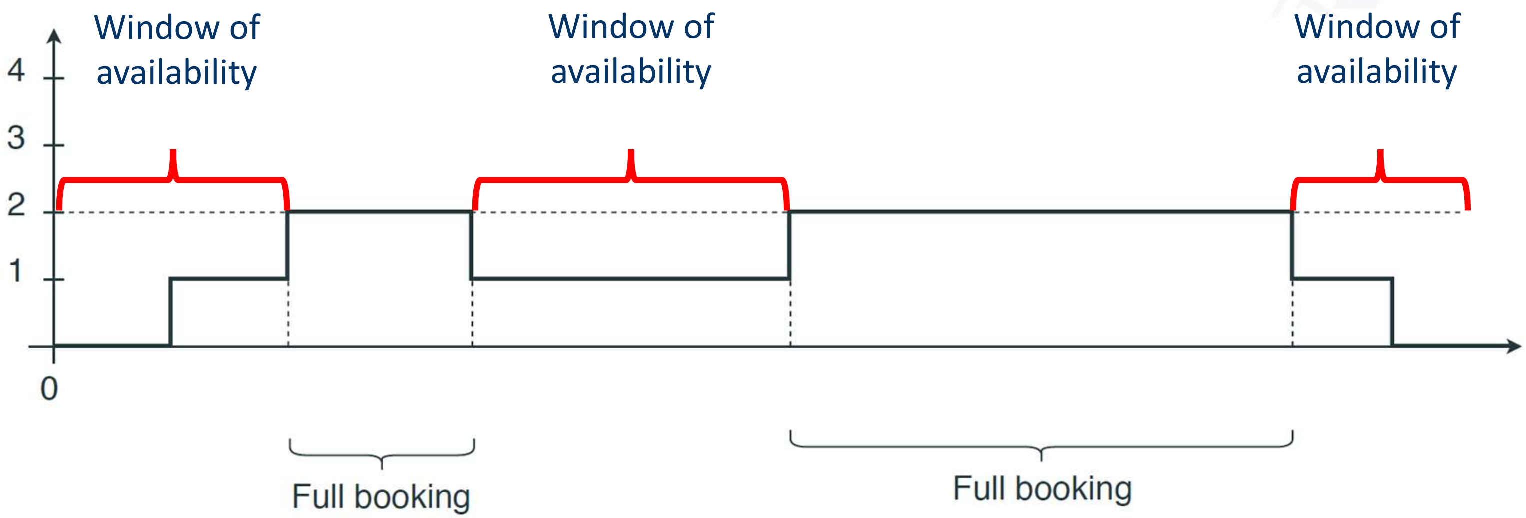


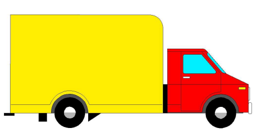
A vehicle makes a booking of the L/U areas

Windows of (un)availability for the following vehicles

Mor, Speranza, Viegas, TR E, 2020

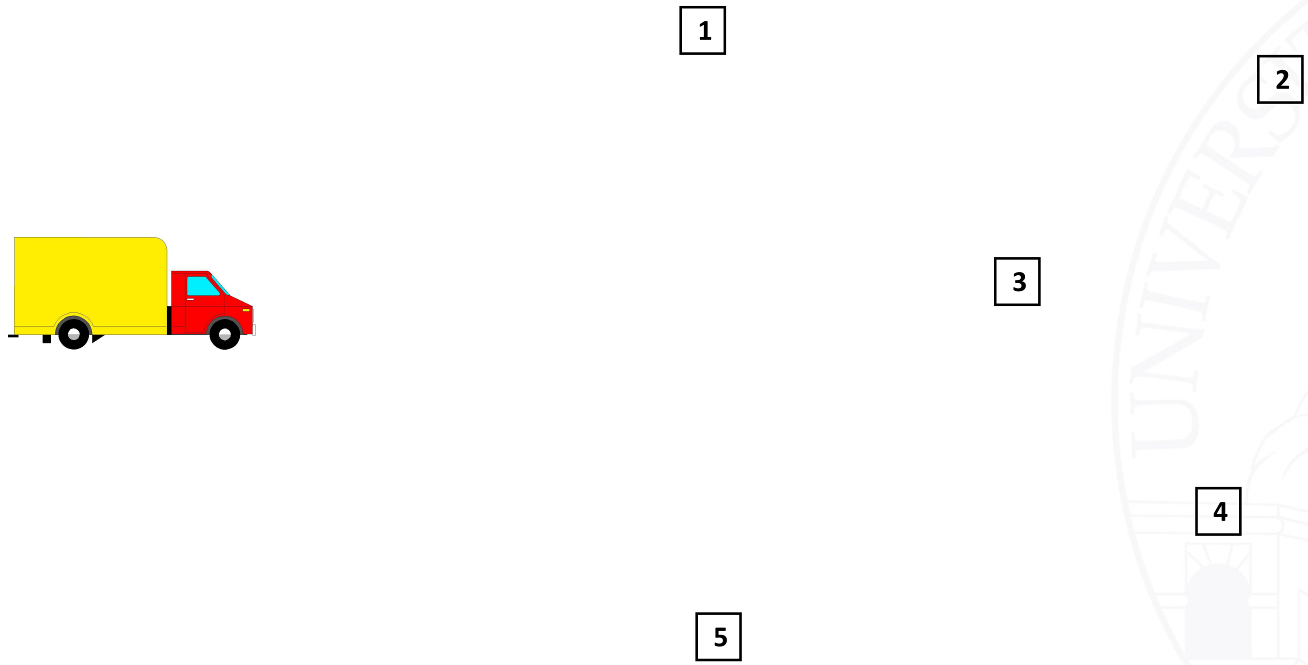
Loading/unloading areas





L/U area with 2 parking spots

Loading/unloading areas



Problem to solve:
A new variant of the TSP (with multiple soft time windows)

Fixed and flexible starting time

Fixed starting time of the route: T_0=q

(the vehicle decides the starting time of the route)

Routing only

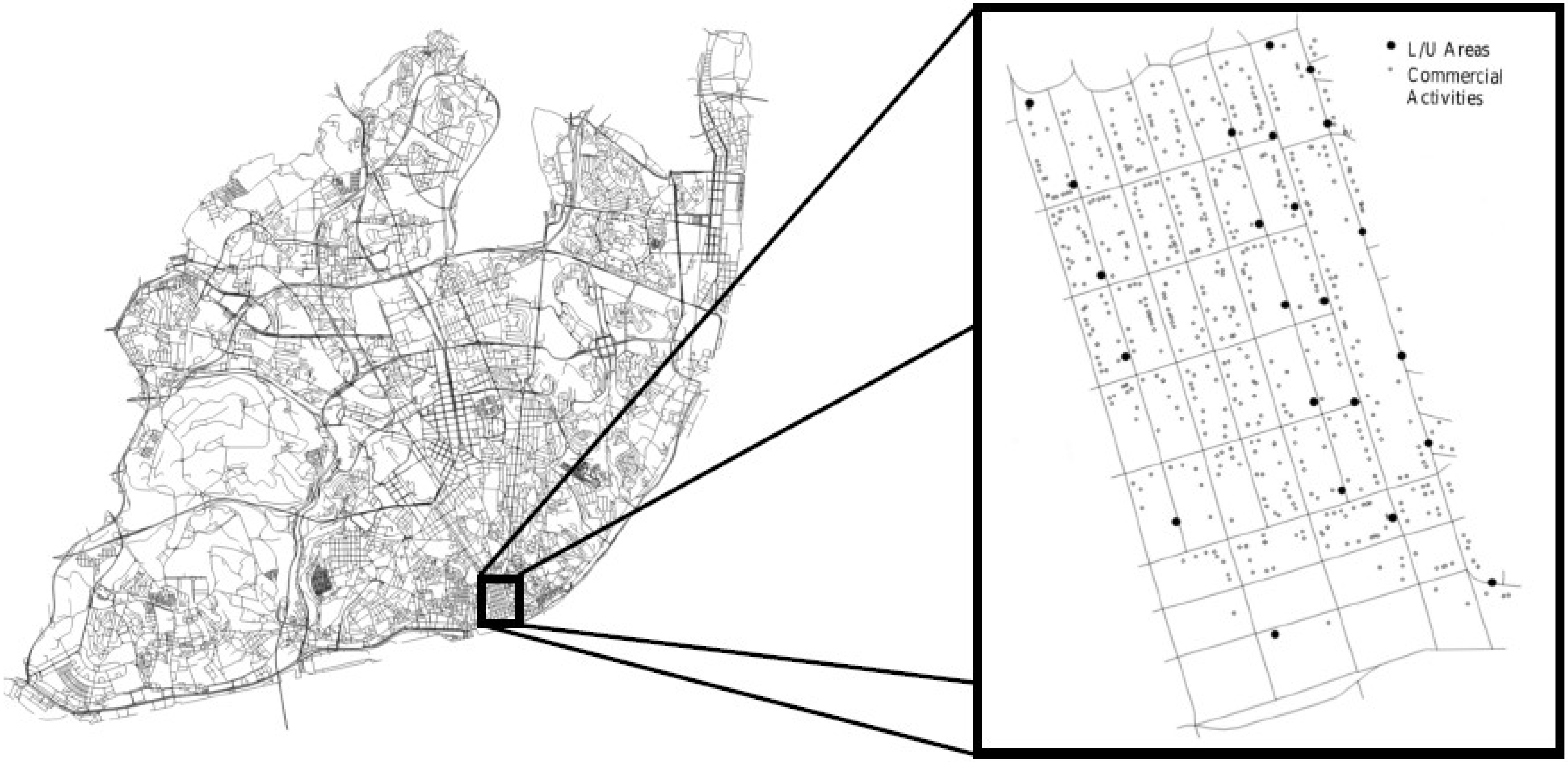
Flexible starting time of the route: $T_0 \geq$q and $T_0 \leq$q+f

(the starting time of the vehicle is between q and q+f)

Routing + Scheduling

UNIVERSITY OF BRESCIA

Computational experiments



Lisbon: 560m x 260m

UNIVERSITY OF BRESCIA

Tests

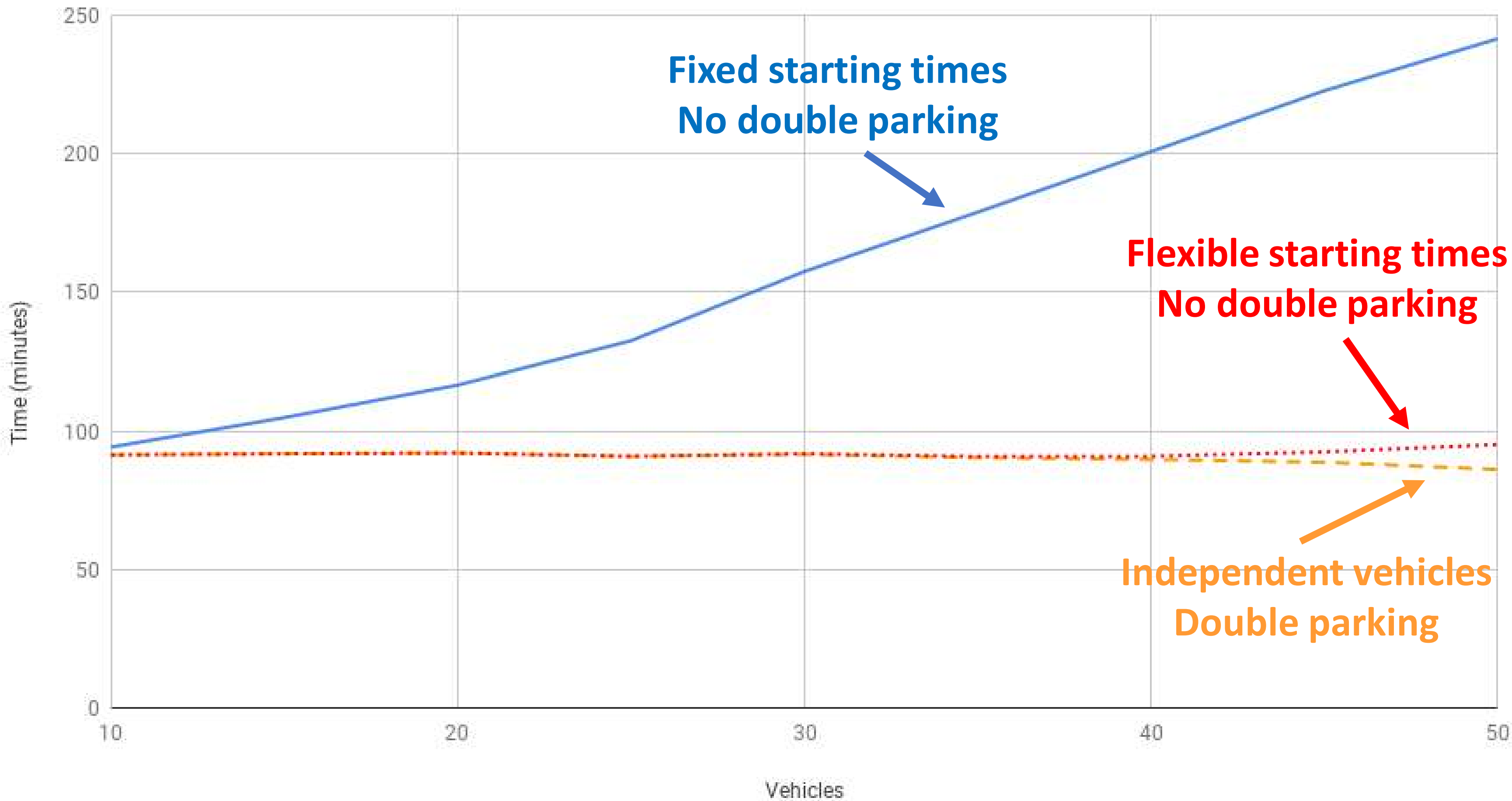
Independent vehicles: TSP for each vehicle (Lin-Kernighan heuristic)

Sequential booking with fixed starting time (formulation solved with CPLEX 12.6)

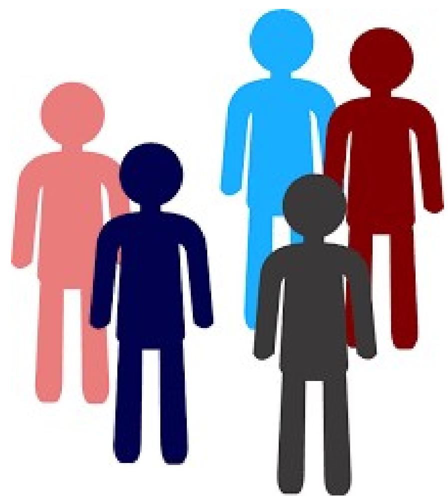
Sequential booking with flexible starting time (formulation solved with CPLEX 12.6)

Trade-off between routing time and number of double parked vehicles

Results (up to 50 vehicles)



People



Shared taxi

Emissions

and occupation of space

UNIVERSITY OF BRESCIA

Shared taxi

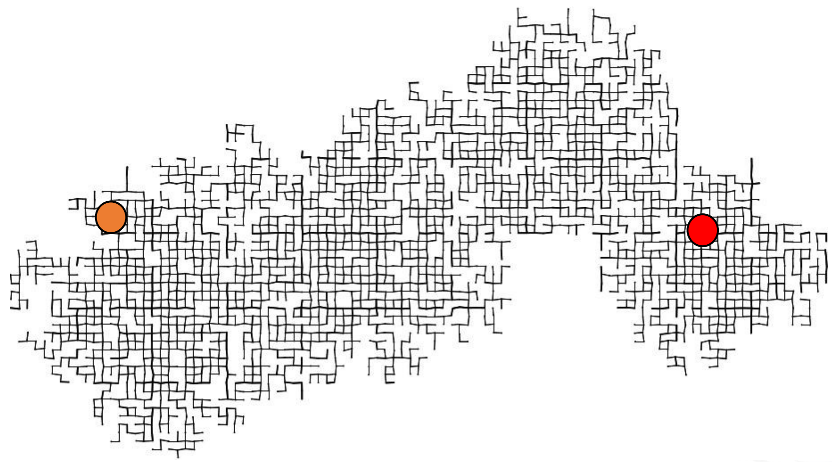
- Public transportation

- Personal car

- Shared taxi

Shared taxi

A simulation/optimization model

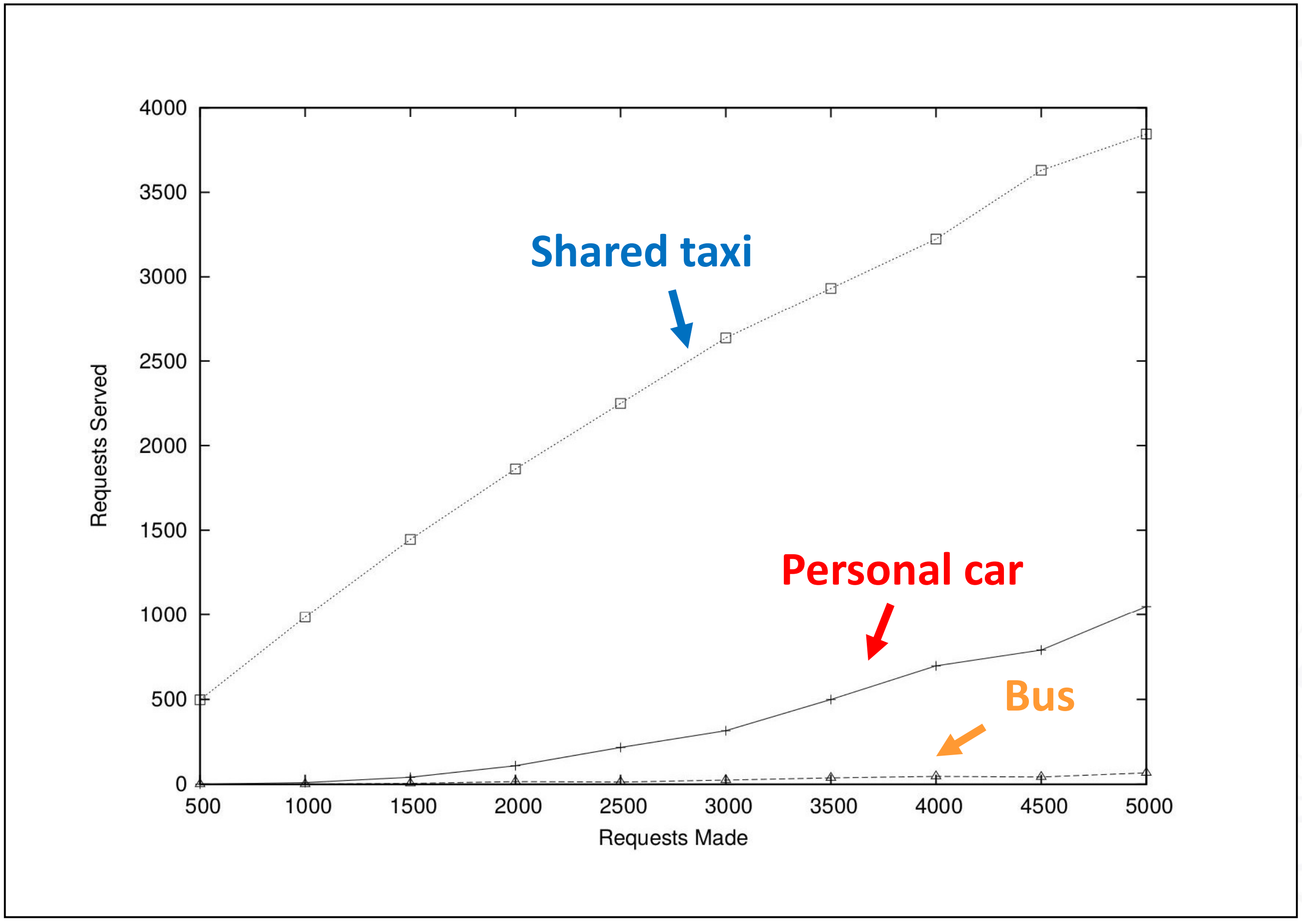


Input:

- Origins
- Destinations
- Request time
- Desired departure time
- Flexibility factor

Archetti, Speranza, Weyland, ITOR, 2018

Shared taxi



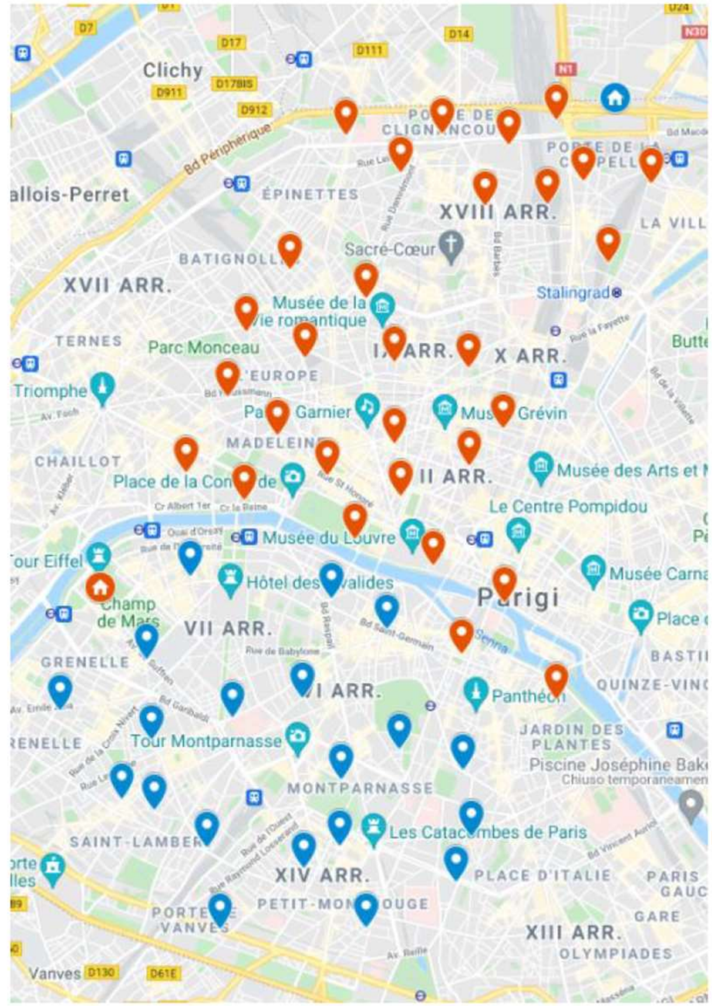
Reduction of emissions: more than 50%

Fair collaboration

Shared taxi service (reservation-based)

Multiple companies

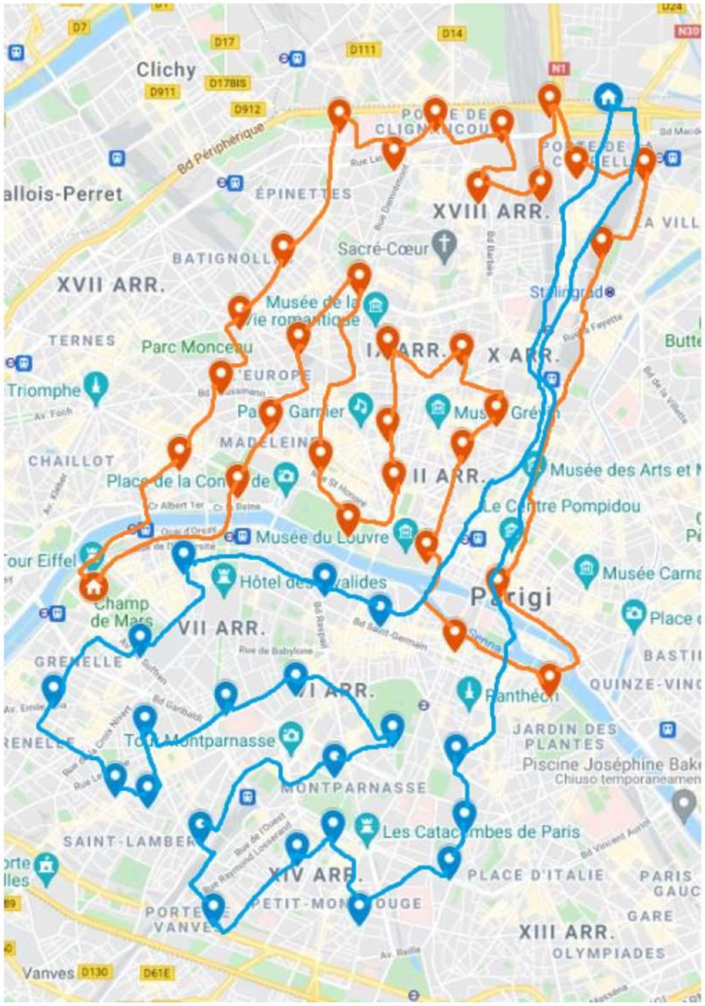
Collaboration initiative



Angelelli, Morandi, Speranza, TR C, 2022

UNIVERSITY OF BRESCIA

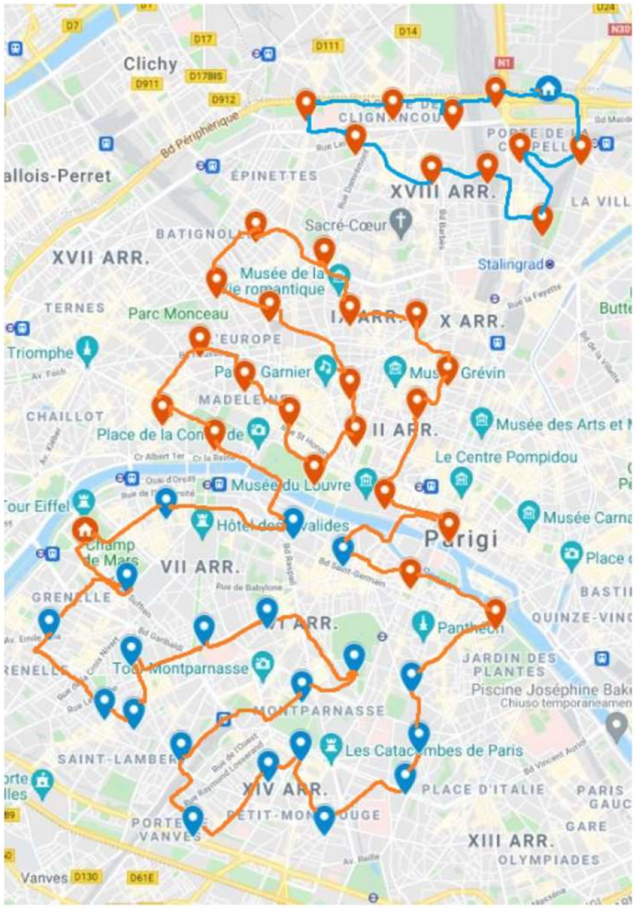
Fair collaboration

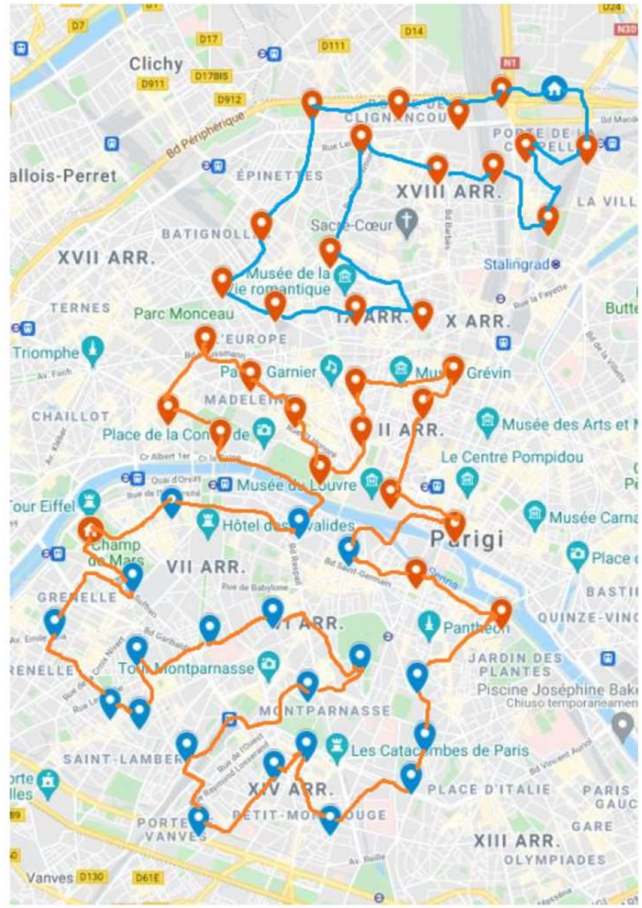


Routes without collaboration

UNIVERSITY OF BRESCIA

Fair collaboration





Routes
with full/ unconstrained
collaboration

Routes
with fair/constrained
collaboration

The problem: basic formulation

$$\min z = \sum_{i\in V}\sum_{j\in V}\sum_{k\in K} c_{ij}x_{ij}^k$$

+ Routing constraints

+ Time windows and maximum time on board constraints

+ Capacity constraints

$$
\begin{array}{llll}
y_c^k \in \{0,1\} & & k \in K & c \in C \\
x_{ij}^k \in \{0,1\} & k \in K & i \in V & j \in V \\
w_i^k \in \mathbb{N} & & k \in K & i \in V \\
u_i^k \geq 0 & & k \in K & i \in V \\
r_c \geq 0 & & & c \in C.
\end{array}
$$

Unconstrained optimization

UNIVERSITY OF BRESCIA

The problem: time balance

the difference
between the total travel time (direct transfer)
acquired and conceded by company *m*

$$S_m = \sum_{k \in K_m} \sum_{c \in C \setminus C_m} t_c y_c^k - \sum_{k \in K \setminus K_m} \sum_{c \in C_m} t_c y_c^k$$

$$\boxed{-\tilde{S}_m \leq S_m + S'_m \leq \tilde{S}_m}$$

Time credit (+) or debit (-)

Without memory if =0
With memory if >0

UNIVERSITY OF BRESCIA

The problem: customer balance

the difference
between the number of customers
acquired and conceded by company *m*

$$U_m = \sum_{k\in K_m} \sum_{c\in C\setminus C_m} p_c y_c^k - \sum_{k\in K\setminus K_m} \sum_{c\in C_m} p_c y_c^k$$

$$-\tilde{U}_m \leq U_m + U'_m \leq \tilde{U}_m$$

Customer credit (+) or debit (-)

Without memory if =0
With memory if >0

UNIVERSITY
OF BRESCIA

Adaptive large neighborhood search

while $T_{\max} > 1$ **do**

- $q := resizeNeighborhood(E, w, q, q_{min}, q_{max}, p)$;
- Draw a destroy and a repair operator;
- Destroy the current solution x;
- Repair the destroyed solution and obtain x';
- **if** $cost(x') \geq cost(x^*)$ **then**
  - $w = w + 1$;
- u randomly drawn in $U(0, 1)$;

if $u < e^{\frac{cost(x^*) - cost(x')}{T_{\max}}}$ **then**

- $x = x'$;

if $cost(x') < cost(x^*)$ **then**

- $x^* = x'$;
- **if** $r > R$ **then**
  - $r = 0$;
  - Set destroy and repair operators' scores to initial values;

else

- Update destroy and repair operators' scores;
- $r = r + 1$;
- $T_{\max} = T_{\max} * \gamma$;
- **return** x^*;

A worse solution may be accepted (with decreasing probability)

UNIVERSITY OF BRESCIA

Instances

Map-based 142 instances (real travel time with Graphhopper)

112 instances (2 to 10 companies, 4 to 10 customers)

- 4 cities (Paris, Berlin, London, Rome)
- 4 sizes
- 7 demand scenarios per city

30 instances - Paris only – 5 different demand scenarios for:

- E1: 6 companies, 50 customers
- E2: 3 companies, 100 customers
- E3: 2 companies, 150 customers
- E4: 1 company with 150 customers, 3 with 50
- E5: 1 company with 150 customers, 1 with 100, 1 with 50
- E6: 1 company with 200 customers, 2 with 50

UNIVERSITY OF BRESCIA

Savings on large instances

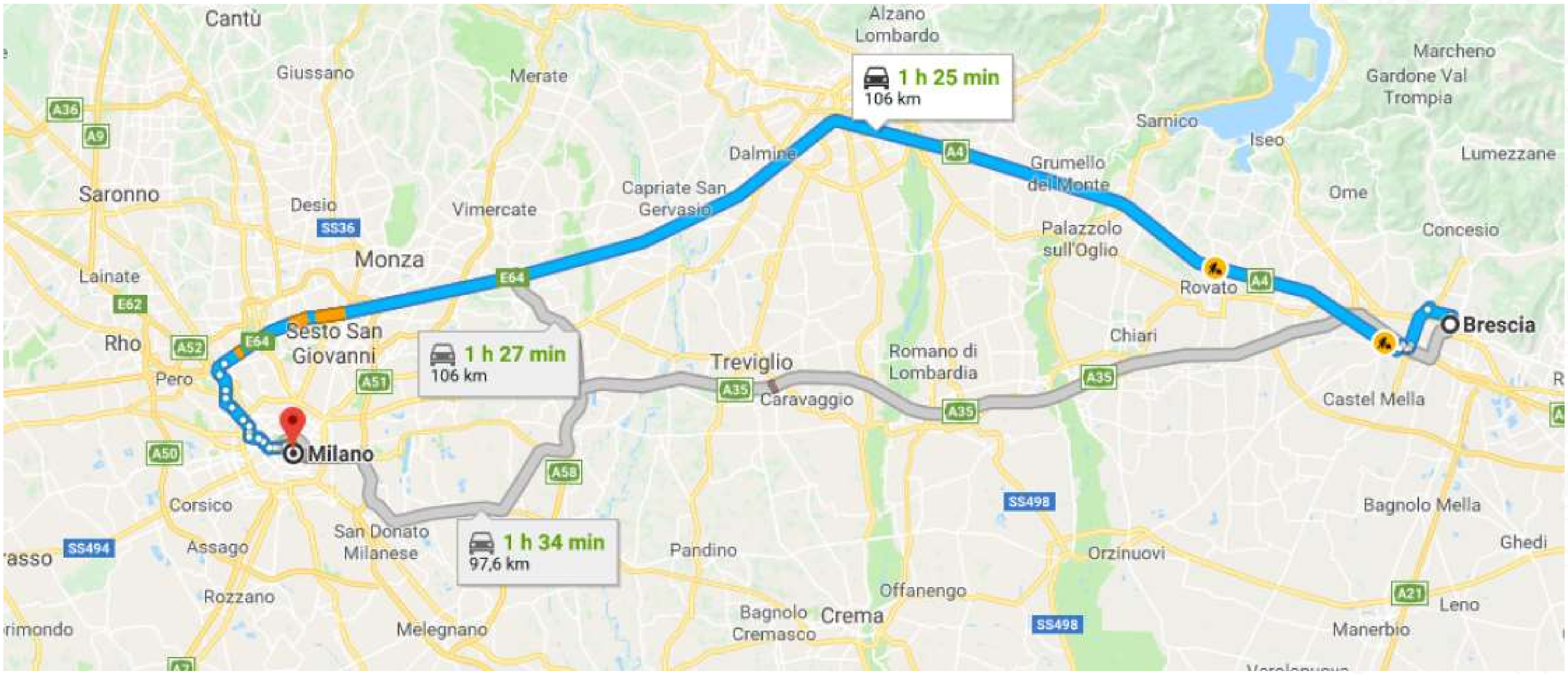
Acceptable % of more or less time or customers

Model	α (%)	Group E		
		Avg.	Max.	Std.
UC	-	18.05	25.30	3.07
T-CDARP	10	17.08	24.56	3.55
	20	17.73	24.79	3.25
	30	18.1	25.14	2.98
C-CDARP	10	15.19	22.32	3.76
	20	16.6	23.16	3.93
	30	17.03	25.21	3.32
TC-CDARP	10	15.01	22.30	3.71
	20	16.57	23.16	2.75
	30	16.97	24.26	3.48

Reduction of emissions: 15%

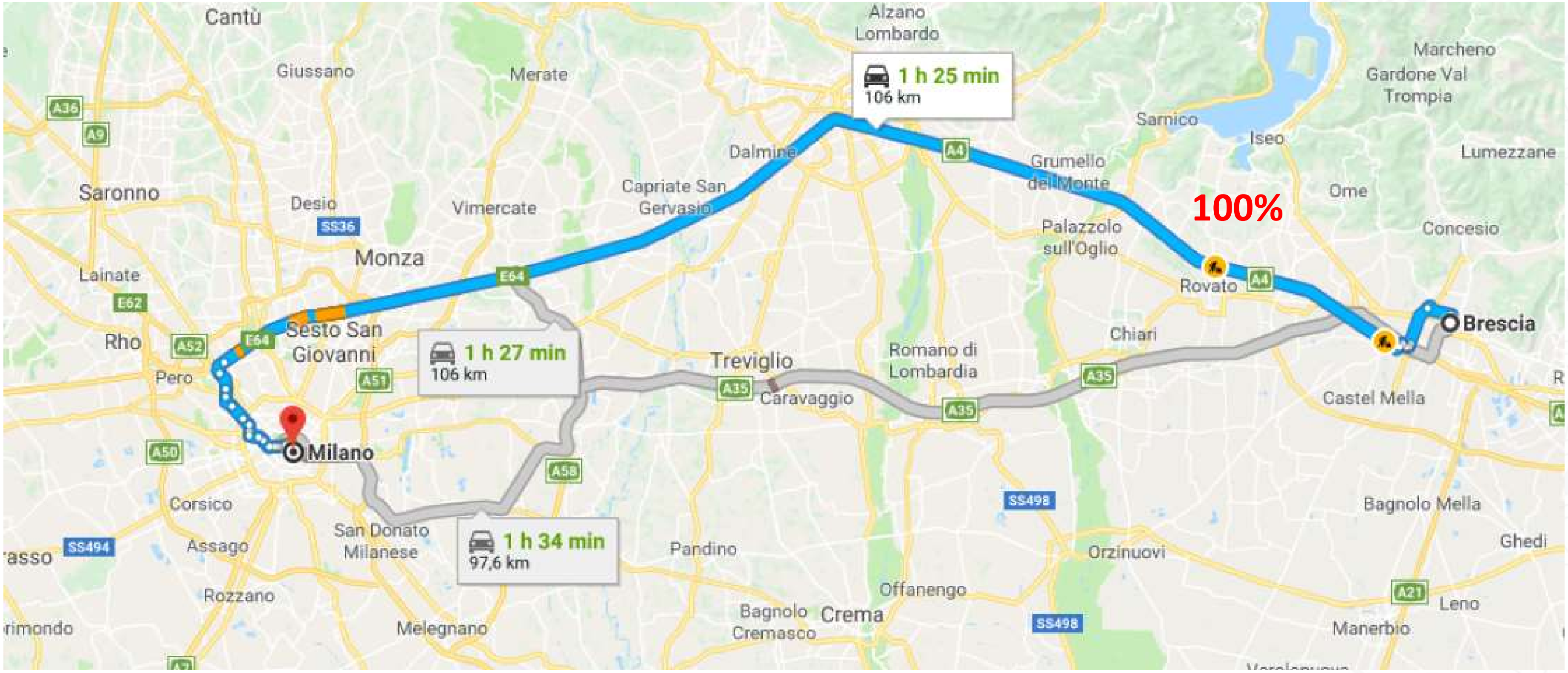
UNIVERSITY OF BRESCIA

Coordination of sat-navs

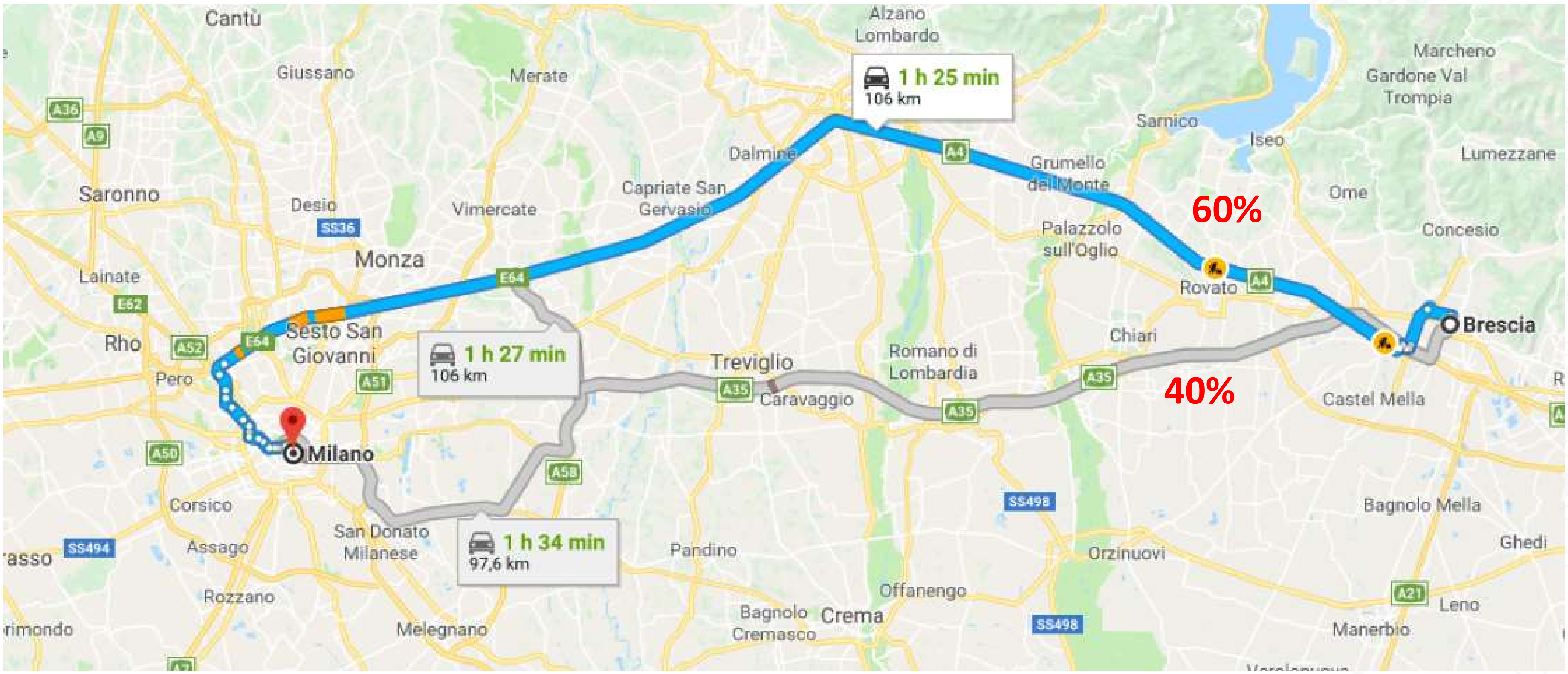


UNIVERSITY OF BRESCIA

Coordination of sat-navs



Coordination of sat-navs



M.Grazia Speranza

Traffic assignment

Long paths for some drivers ← Minimum total travel time

User-equilibrium vs System-optimum

Selfish behaviour

(Nash equilibrium,

no one can switch to a path of smaller cost) → Congestion

UNIVERSITY OF BRESCIA

Coordination of sat-navs

$$t_{ij}^{FF}[1 + 0.15(\frac{x_{ij}}{u_{ij}})^4]$$

Travel time on arc (i,j) with flow x_{ij}

Min Total travel time

on <u>paths of limited length</u>

➡

Non linear optimization problem

on an exponential number of paths

UNIVERSITY OF BRESCIA

Coordination of sat-navs

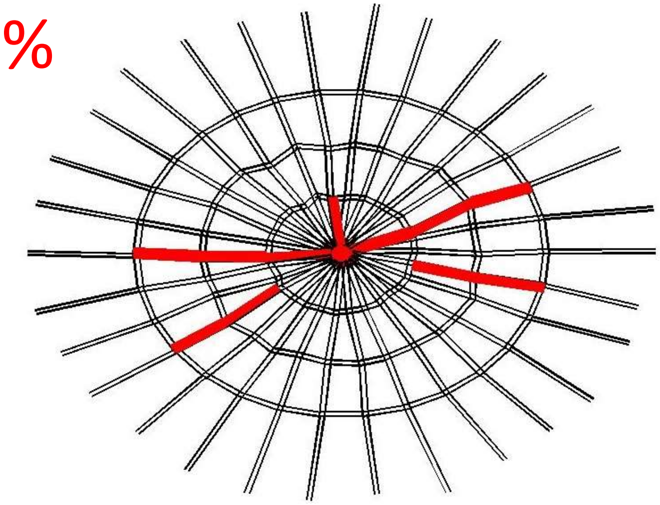
Min Total travel time (piecewise approximation)

LP and MILP with exponential number of binary variables
(FP-UC-SO and L-UC-SO)

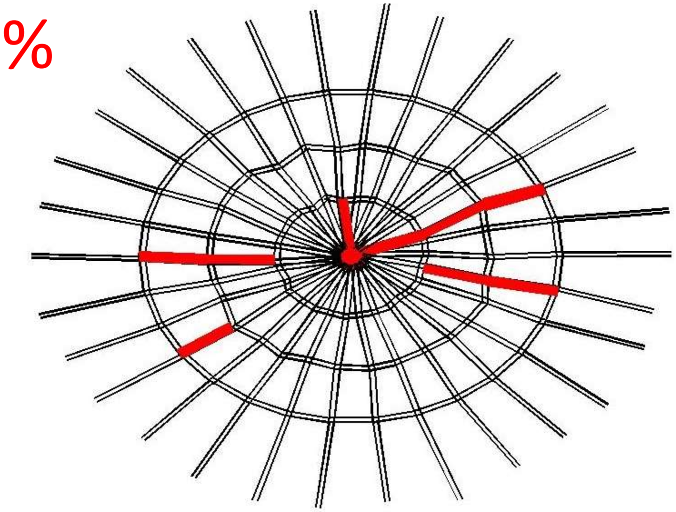
Angelelli, Morandi, Savelsbergh, Speranza, EJOR, 2021
Angelelli, Morandi, Speranza, COR, 2019 and 2020

UNIVERSITY OF BRESCIA

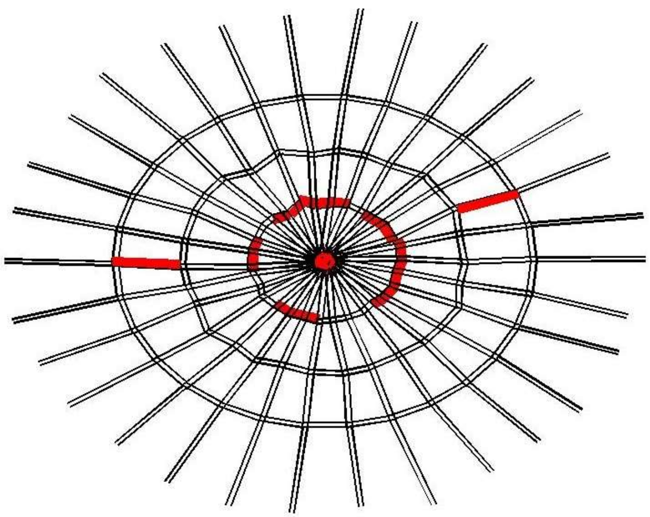
0%



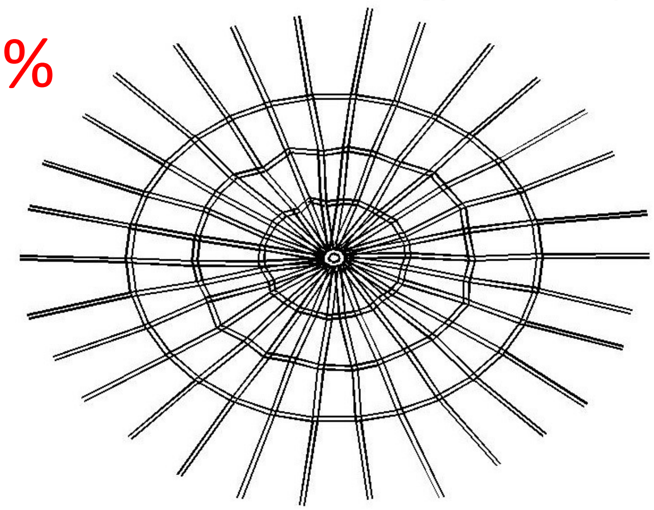
5%



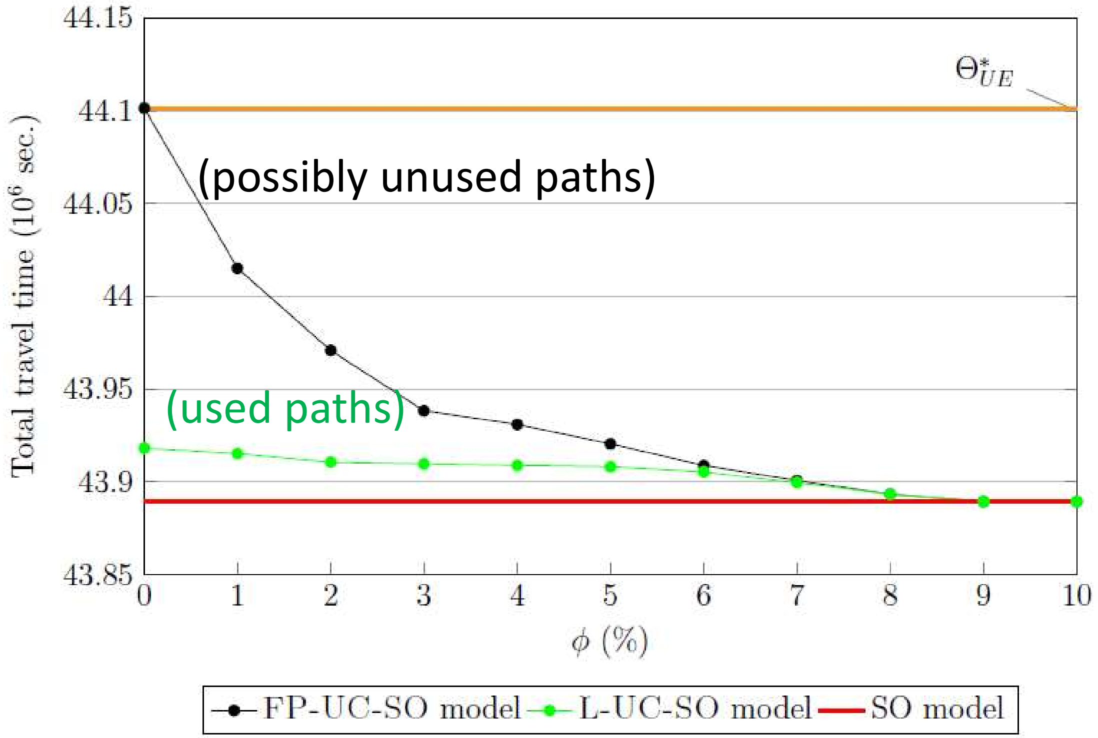
8%



10%



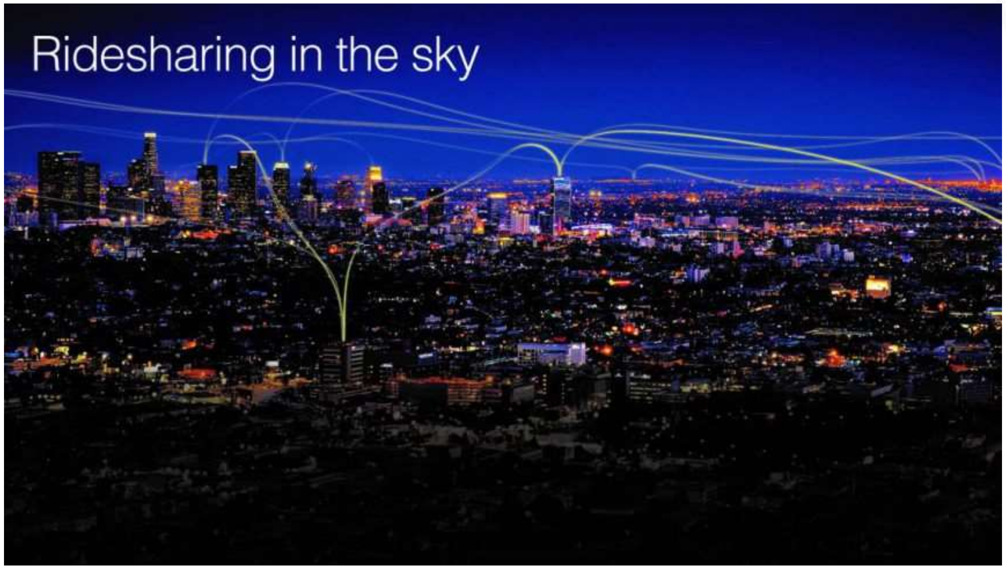
Coordination of sat-navs



Reduction of emissions: 20%

UNIVERSITY OF BRESCIA

The future



UNIVERSITY
OF BRESCIA

The future