TOR VERGATA
UNIVERSITY OF ROME

SMA LOG

Co-funded by the Erasmus+ Programme of the European Union

KA2 - Cooperation for innovation and the exchange of good practices
Capacity Building in Higher Education
Joint project

Master in Smart Transport and Logistics for Cities / SmaLog

The role of emerging information and communication technologies (e-ICTs) in improving travel experiences

Final conference, Kharkiv

Antonio Comi, University of Rome Tor Vergata (coordinator)

Overview

- Introduction
- The emerging technologies in the transport sector
- Examples of innovations
  - in transit systems: operations control & travel info
  - in urban freight: smart urban routing

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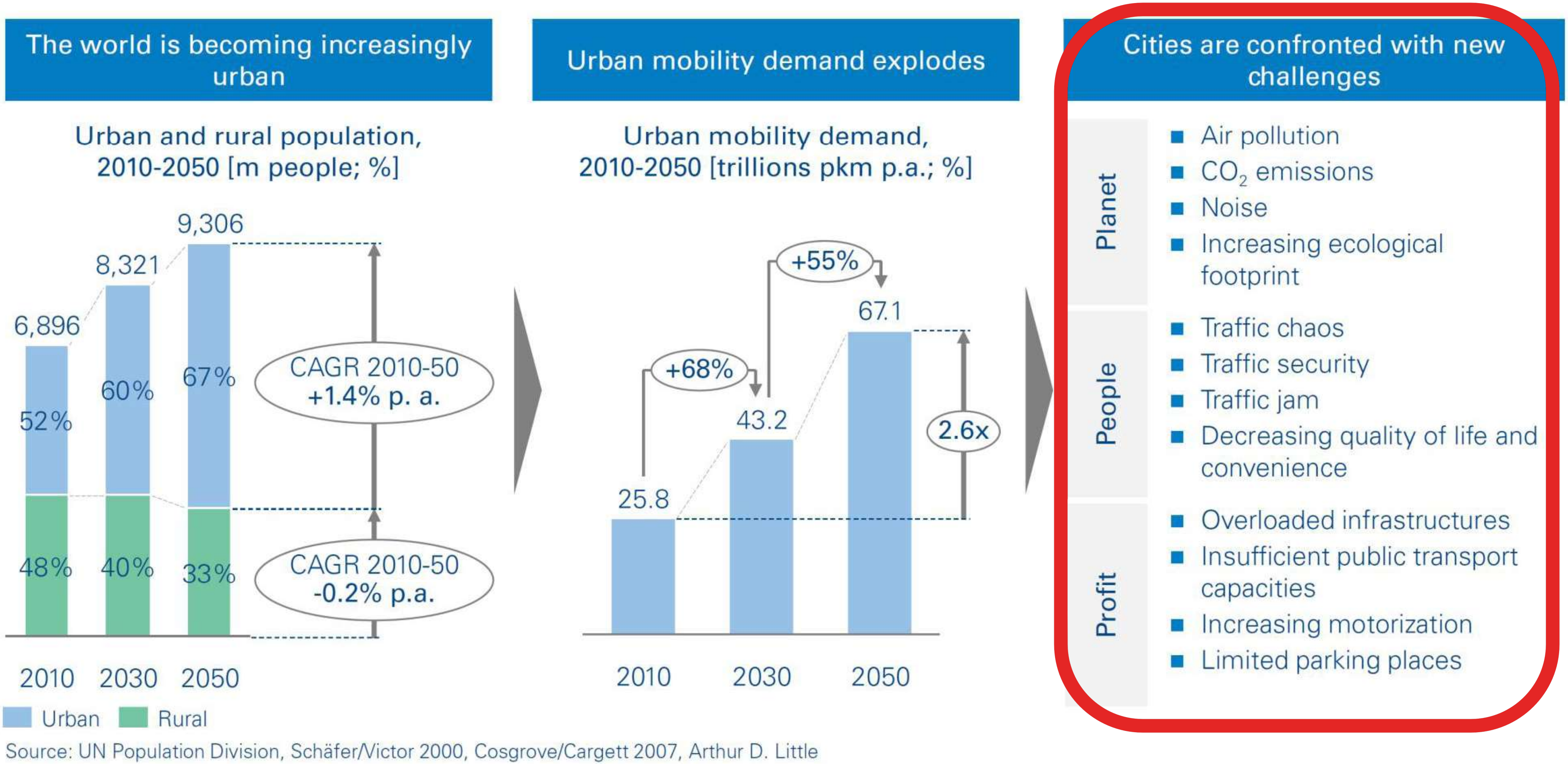
Introduction (1)

- The future of earth will be urban ….



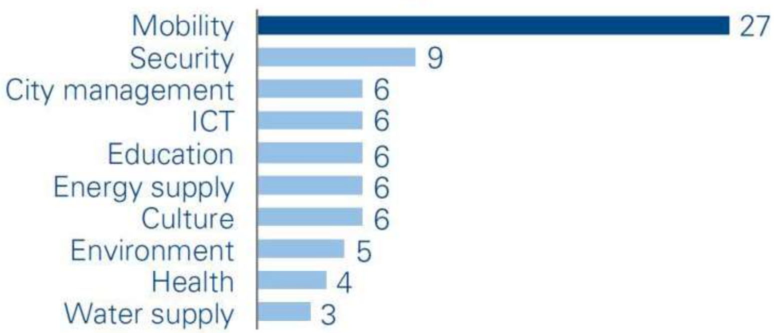
Arthur D. Little Lab and International Association of Public Transport (UITP), The Future of Urban Mobility 2.0, 2014

Introduction (2)

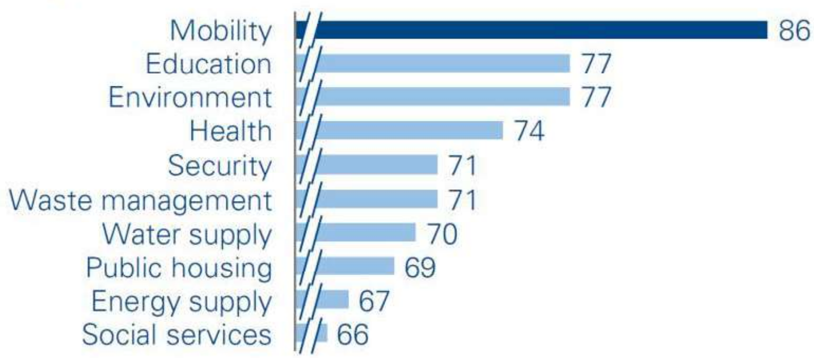
Mobility is the n°1 priority for cities and will require significant investment

Mobility: Priority n°1 for cities

Urban mobility infrastructure is the n°1 priority area for cities in attracting investors 1) 3)



Highest needs for investment in cities 2007-2017 1) 2)



Constant growth of investments in urban mobility

Global urban mobility investment volume in bn EUR

- In 1990 investment amount in global urban mobility equaled **185 bn EUR**
- For 2050 the need of **829 bn EUR** is being forecasted (growth by the factor 4.5)

Source: Siemens, Bureau of Transport Statistics, Arthur D. Little
1) Siemens "Megacity Challenges Study" 2) % saying high need for investment 3) Percentage of respondents

Arthur D. Little Lab and International Association of Public Transport (UITP), The Future of Urban Mobility 2.0, 2014

Introduction (3)

Mobility is the n°1 priority for cities and will require significant investment

The **local expectations** and global calls for rapid transitioning **towards more sustainable urbanization** models take place at a time when health and stress levels in cities are increasingly being regarded as **a global problem**.

Arthur D. Little Lab and International Association of Public Transport (UITP), The Future of Urban Mobility 2.0, 2014

How to stop city life from stressing us out?

- Accessibility and development *versus* congestion

A city living on total automotive dependence becomes dysfunctional, inefficient and inconvenient for life. The goal of the transport system is to move people, not vehicles.

- Transport *versus* the environment?

New data from the World Health Organization (WHO) show that, at the global level, nine out of ten people breathe air containing pollutants exceeding WHO air quality guidelines and inconvenient for life.

- Mobility *versus* health and well-being?

Mobility *versus* health and well-being?

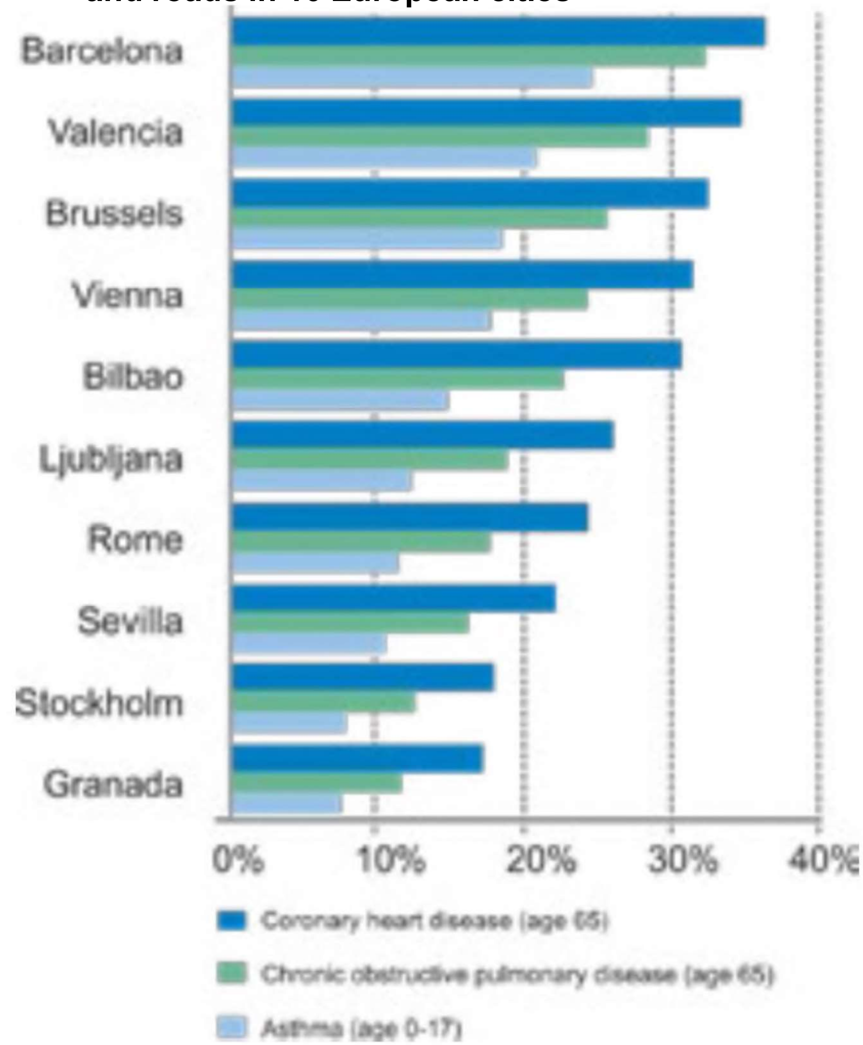
- The negative effects of transport activities relate mainly to the impact of transport on:
  - the lives and health of the population and
  - the resultant decline in the quality of life.

- The life and health of the population are affected by
  - road safety,
  - the impact of transport on the environment and
  - reduced physical activity

  due to the **excessive use of private cars**.

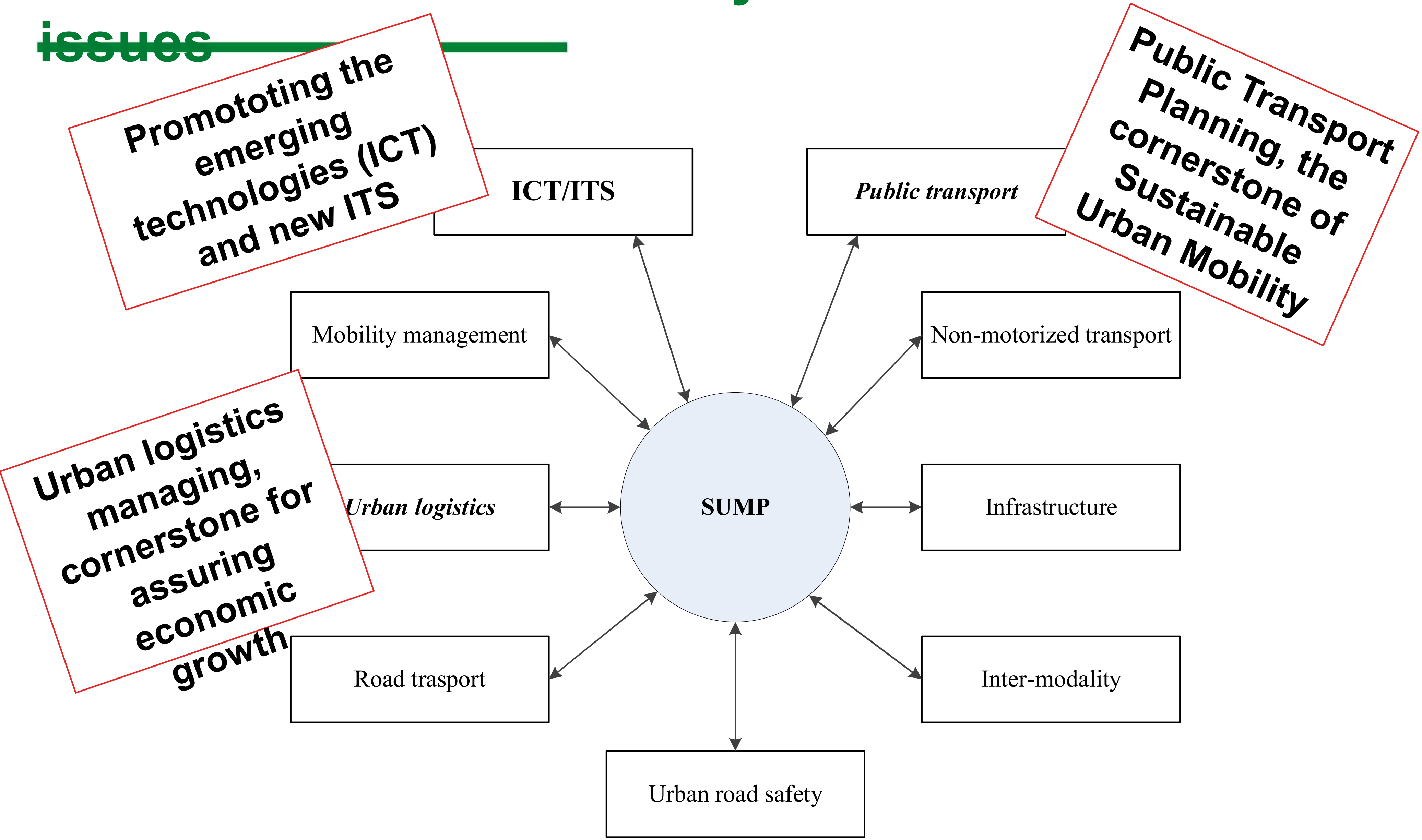
- Air pollution is ranked fourth in the list of global health risk factors

Proportion of the population suffering from chronic diseases whose incidence may be associated with living near the busiest streets and roads in 10 European cities



Sustainable Development Goals

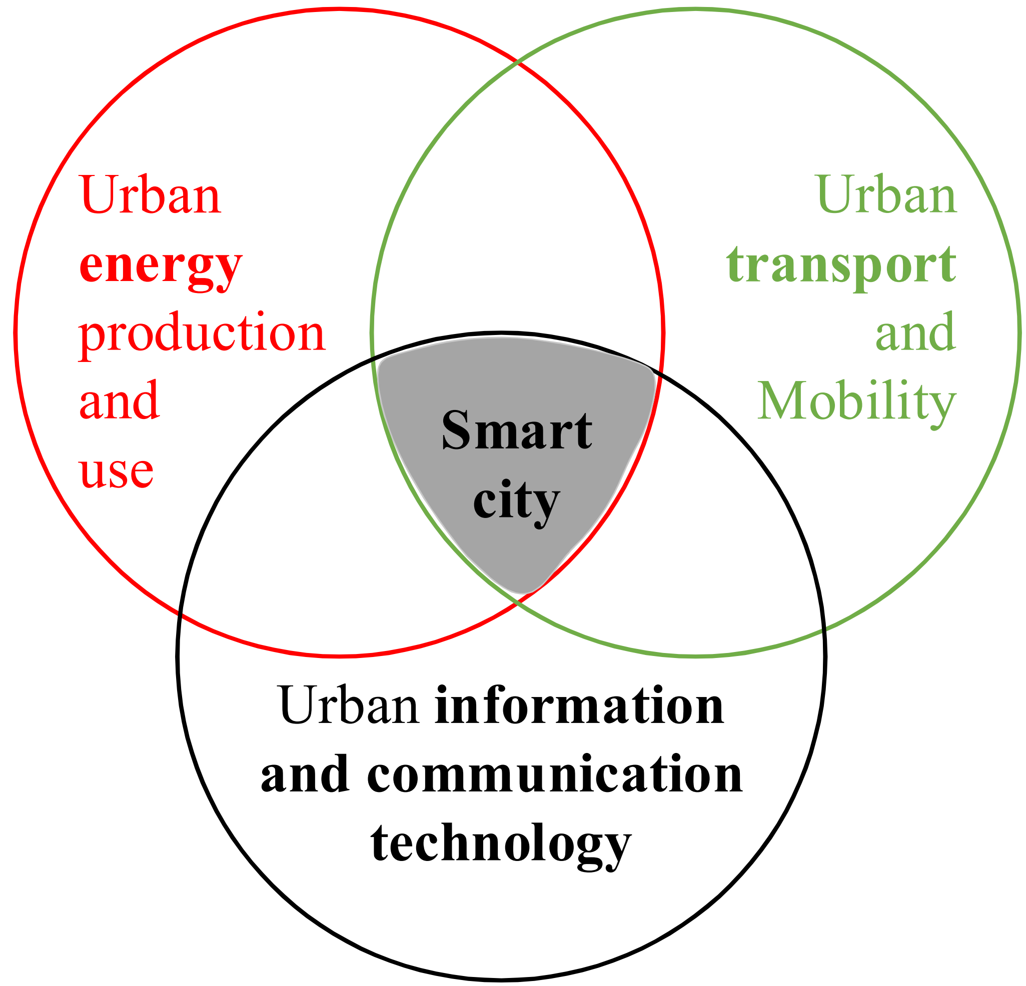
Sustainable Urban Mobility Plan *versus* urban ~~issues~~



Smart mobility and smart growth

The areas of interest defined starting from the smart growth, through innovation and therefore technological platforms and thematic forums are:

- energy,
- transport and
- information and communication technologies (ICT).



EC, (2012). European Commission, Communication from the commission smart cities and communities European Innovation Partnership, 2012, http://ec.europa.eu/energy/technology/initiatives/doc/2012_4701_smart_cities_en.pdf.

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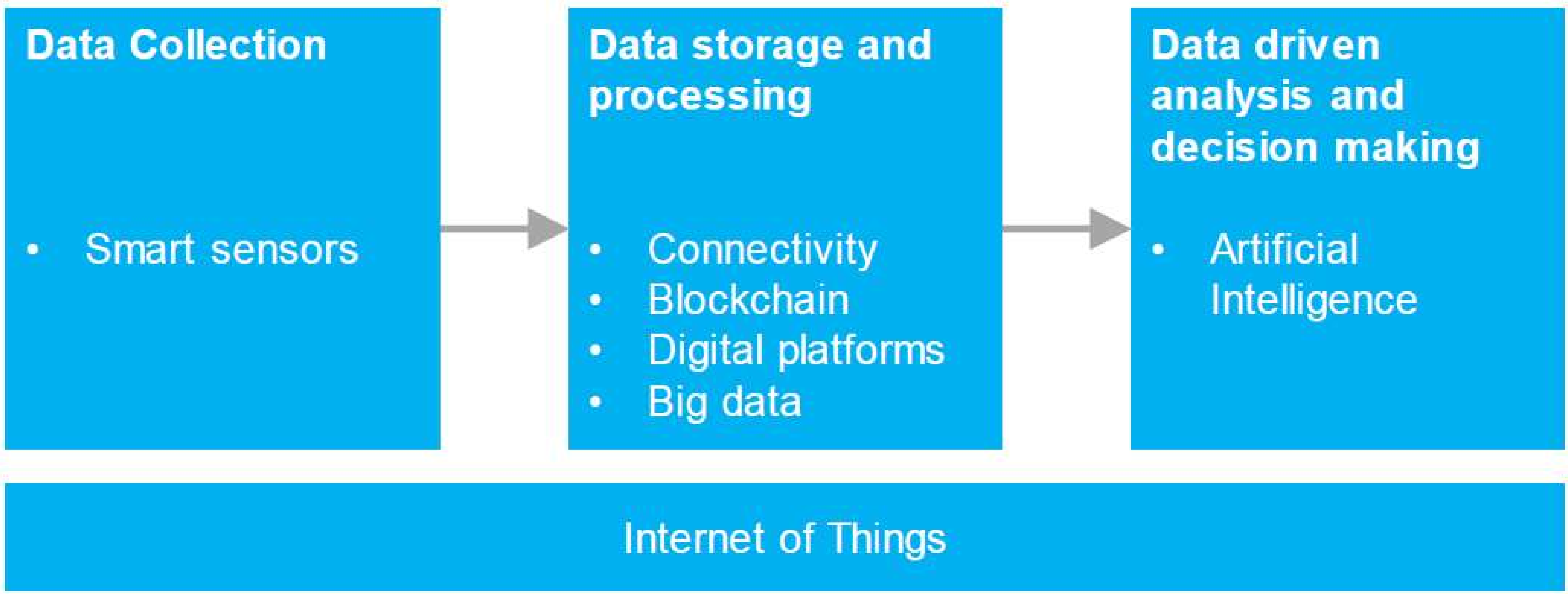
The emerging technologies in the transport sector 1

The emerging information communication technologies (**e-ICT**), and more in general intelligent transport systems (consolidated and advanced), include **opportunity** for each transport and logistics **private** or **public actor** to increase the own utility, as well as to boost innovation in Smart Mobility.



Source: RTC (2020). The impact of emerging technologies on the transport system. Research For Tran Committee, Policy Department for Structural and Cohesion Policies, Directorate-General for Internal Policies, PE 652.226, Brussels

The emerging technologies in the transport sector 2

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The level of maturity of the various emerging technologies varies greatly:

- some are already **widely applied** (e.g. *smart sensors*, connectivity technologies), although further development is expected in the next decade;

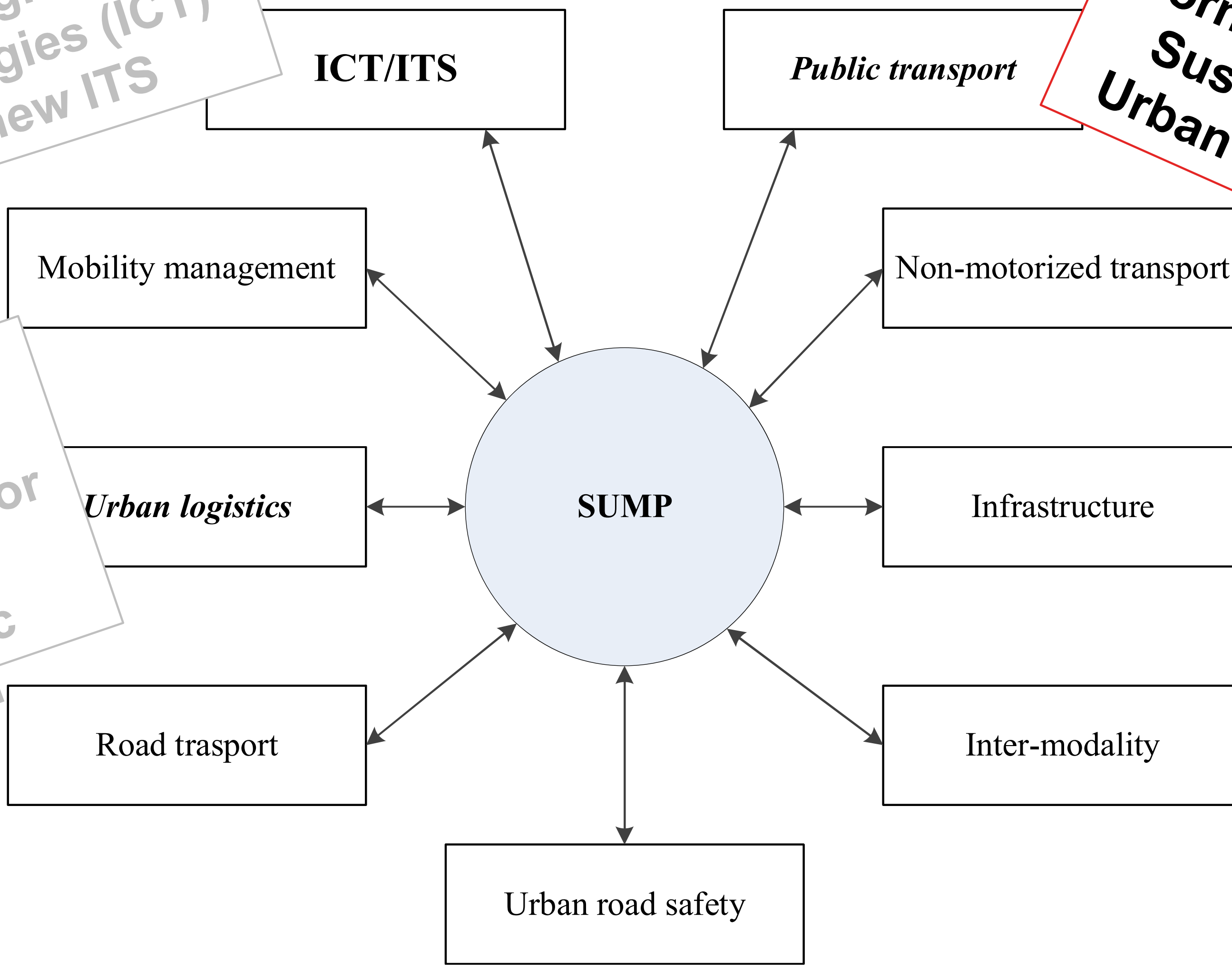
- other technologies (e.g. *artificial intelligence*) are in **potential ground-breaking**, but applications are only just starting to use them, discovering what is already possible and what still needs to be developed.

Source: RTC (2020). The impact of emerging technologies on the transport system. Research For Tran Committee, Policy Department for Structural and Cohesion Policies, Directorate-General for Internal Policies, PE 652.226, Brussels

Sustainable Urban Mobility Plan *versus* urban issues

Promototing the emerging technologies (ICT) and new ITS

Public Transport Planning, the cornerstone of Sustainable Urban Mobility



Urban logistics managing, cornerstone for assuring economic growth

Public transport

The purpose of public transport was transformed from

"transport for the poor" at the end of the 19th century

to

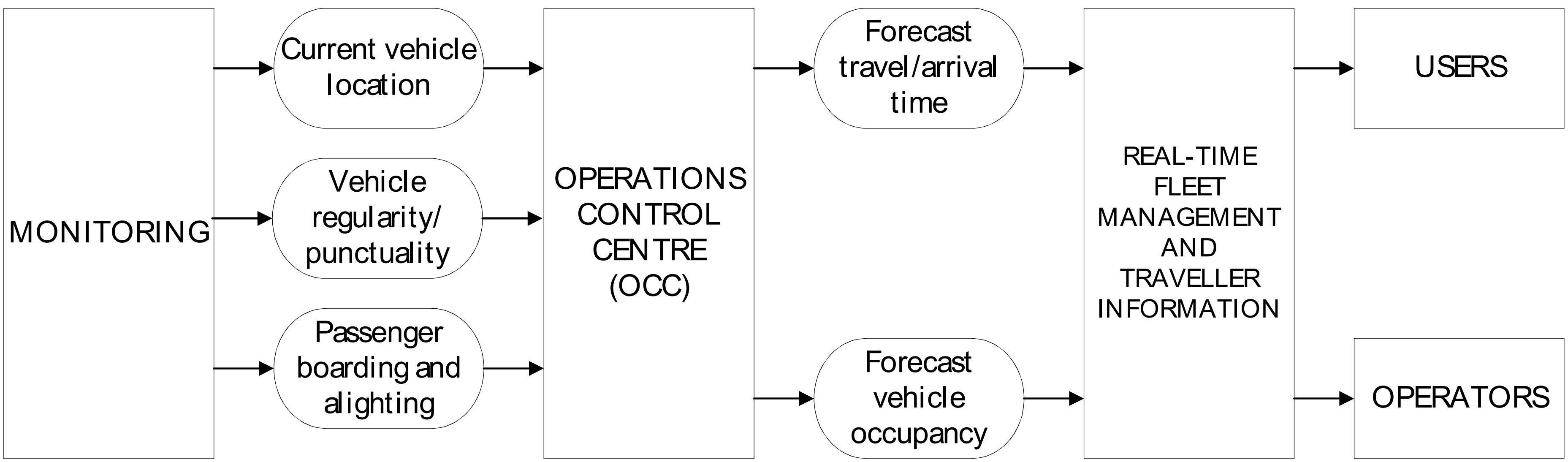
"**transport for sustainable development**" at the turn of the 21st century.

Making **public transit** more attractive is a key role for increasing modal shift from private to public transport and to **reduce the car dependence**.

Transit agencies are called to perform the hard task of more effective planning and managing to satisfy the growing mobility needs of travellers

Advanced TRANSIT operations control and info systems

They apply telematics technologies in order to improve network performances both from users and operators' perspective



- ➢ Real-time transit operations control → Vehicle occupancy forecasting; Vehicle bunching forecasting
- ➢ Real-time information to travellers → Travel advisor

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Example: S.T.O.P.


Proceedings of the 16th International IEEE Annual Conference on Intelligent Transportation Systems (ITSC 2013), The Hague, The Netherlands, October 6-9, 2013

STOP: a Short term Transit Occupancy Prediction tool for APTIS and real time transit management systems

A. Nuzzolo, U. Crisalli, L. Rosati and A. Ibeas

- Short-term Transit Occupancy Prediction Tool

✓ with Network Modelling Approach

✓ developed at TLRC of Tor Vergata University of Rome using:

- Diachronic Network Model
- Time dependent O/D matrices
- Random utility schedule based dynamic path choice model with sequential run choice
- Count-based updating of time-dependent O/D matrices and path choice model parameters
- Dynamic Within-day assignment model

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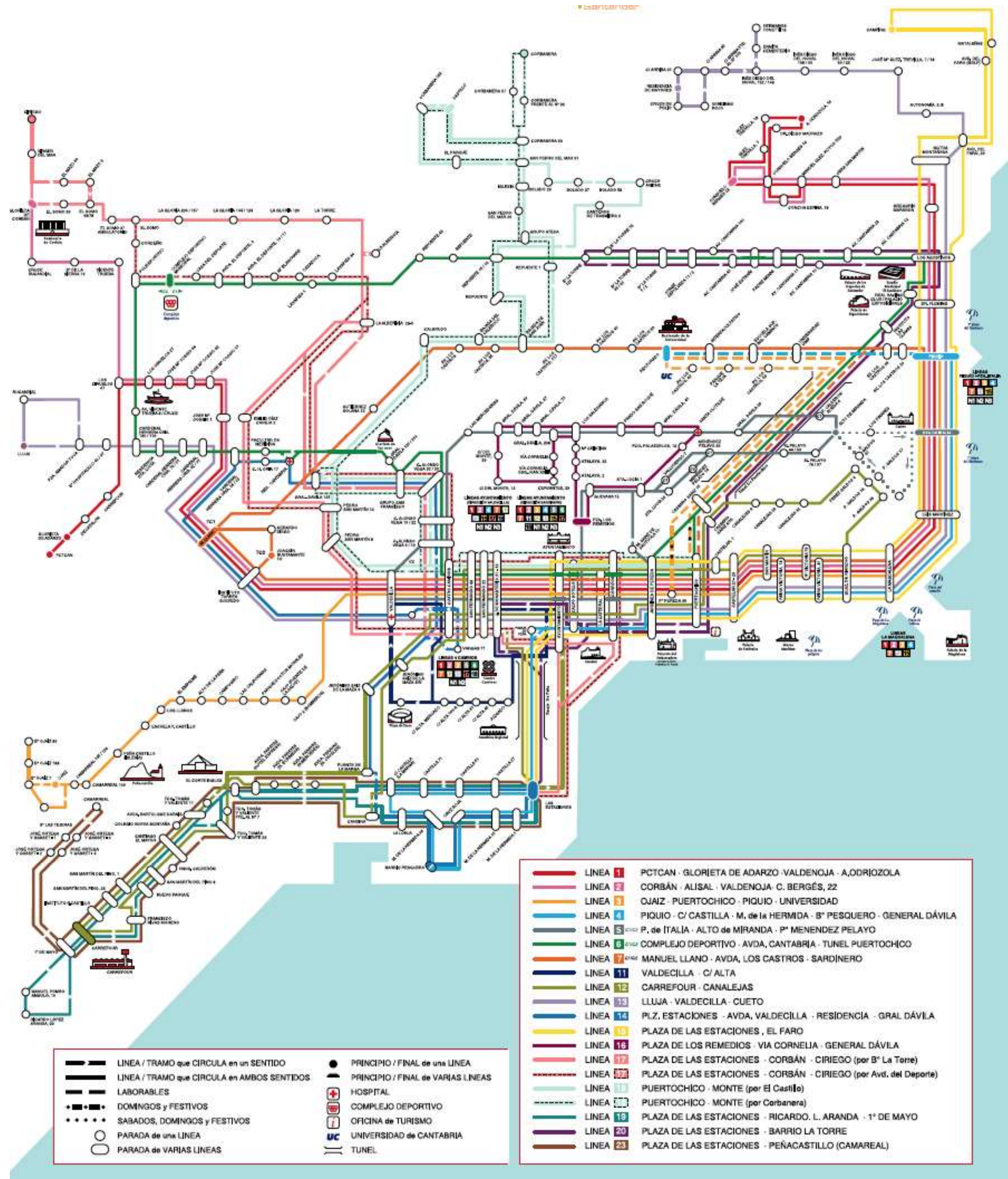
City of Santander (Spain)

STOP Application Test

- ✓ 43 bus lines
- ✓ 430 stops
- ✓ 60 stops with RT information

- ✓ Simulation period: 1:00 - 4:00 pm
  - 264 runs for 43 lines
  - 10.915 trips by PT

- ✓ Every bus of TP is equipped with boarding sensor allowing to count passenger boarded at stops



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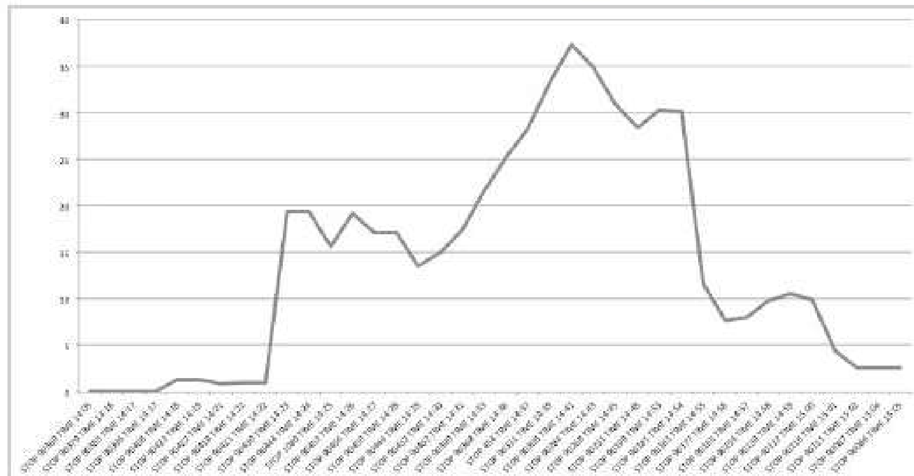
Bus occupancy predictions for two consecutive runs

- these results allows us to point out the high variation of bus occupancy over stops and times

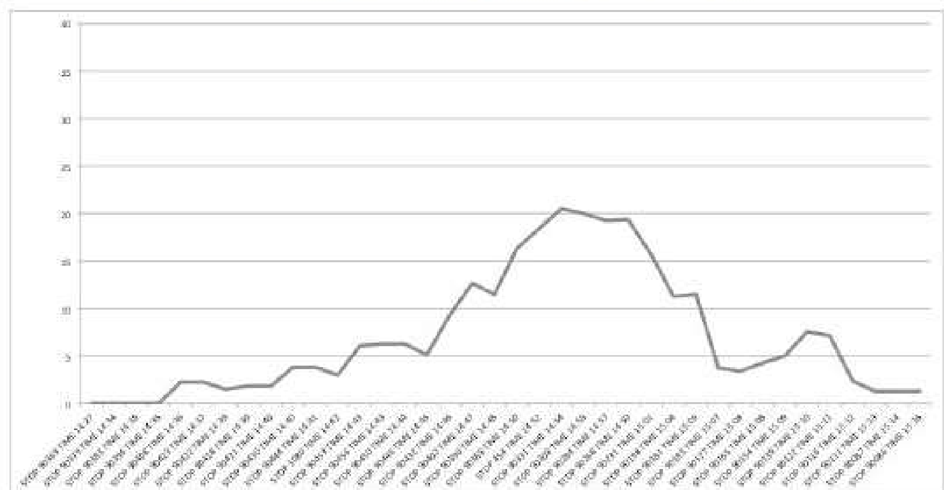
due to the dynamic variations of both

- transit demand and
- supply in the simulated period

Line 2 - Run 205 departing at 2:05 p.m.



Line 2 - Run 222 departing at 2:27 p.m.



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Reverse assignment development

Reverse assignment new formulation using also path flow counts

$$\left(\mathbf{d}^*,\boldsymbol{\beta}^*,\boldsymbol{\alpha}^*,\boldsymbol{\lambda}^*\right) = \underset{d \square S_d, \square\square S_{\square}, \square\square S_{\square}, \square\square S_{\square}, f^* \square S_f}{argmin} \left[z_1(\boldsymbol{d},\tilde{\boldsymbol{d}}) + z_2(\boldsymbol{f}^*,\hat{\boldsymbol{f}}) + z_3(\square,\tilde{\square}) + z_4(\square,\tilde{\square}) + z_5(\boldsymbol{c}(\boldsymbol{f}^*;\square),\hat{\boldsymbol{c}}) \right]$$

$\mathbf{d}^*$ = updated demand vector

$\boldsymbol{\beta}^*$ = updated model parameters

$\boldsymbol{\alpha}^*$ = updated link-cost function parameters

$\boldsymbol{\lambda}^*$ = updated path choice model parameters

z_1,z_2,z_3,z_4 = "distance" functions

S_d = feasibility domain of demand flows

S_f = feasibility domain of link flows

S_α = feasibility domain of link-cost function parameters

S_β = feasibility domain of demand parameters

$\mathbf{d}$ = $\omega(. ;\boldsymbol{\beta})$= demand vector

$\tilde{\boldsymbol{d}}$ = a-priori demand vector

$\mathbf{f}^*$ = $\boldsymbol{\Delta}\,\mathbf{P}\,\mathbf{d}^*$ = link flows

$\hat{\boldsymbol{f}}$ = traffic counts

$\boldsymbol{\beta}$ = demand model parameters

$\tilde{\square}$ = a-priori demand parameters

$\boldsymbol{\lambda}$ = path choice model parameters

$\tilde{\square}$ = a-priori path choice parameters

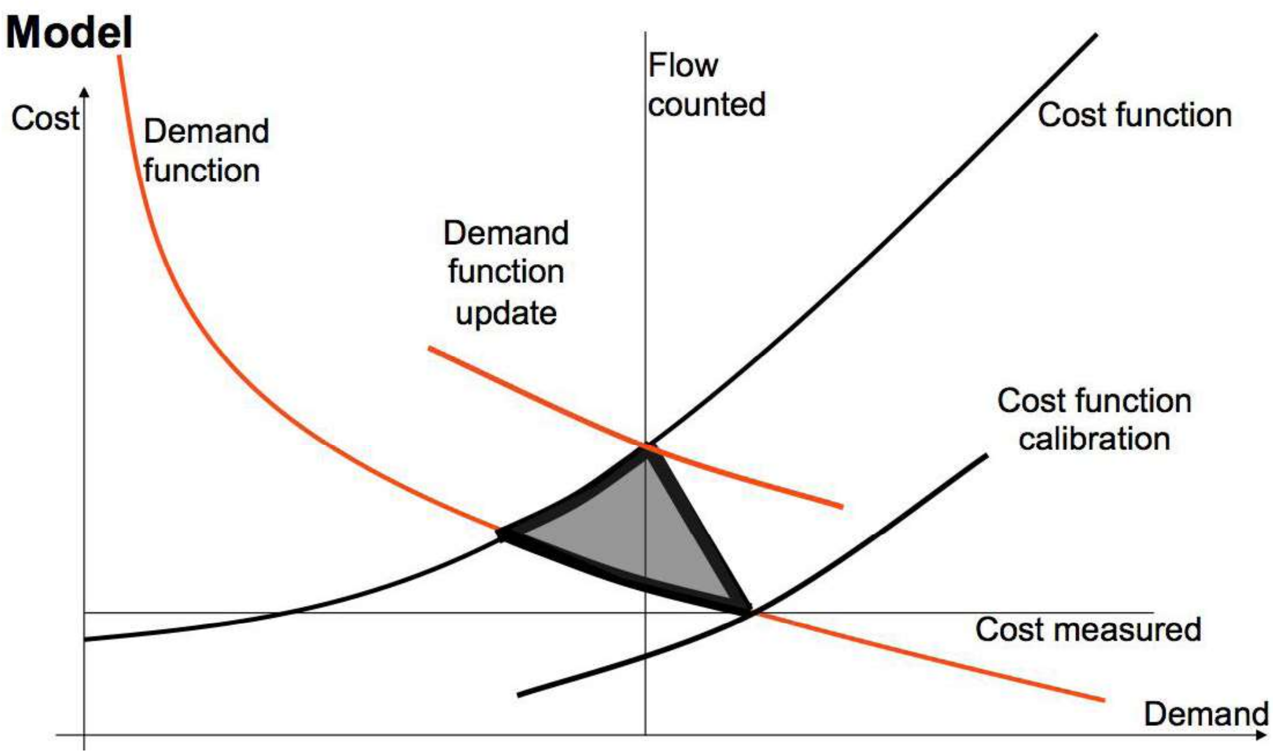
$\mathbf{c} = \gamma(\mathbf{f};\boldsymbol{\alpha})$ = link cost vector

$\hat{\boldsymbol{c}}$ = measured link costs

Reverse assignment development

Reverse assignment: open research perspectives

- ✓ existence and uniqueness of problem solution



- ✓ new algorithms for an efficient problem solving

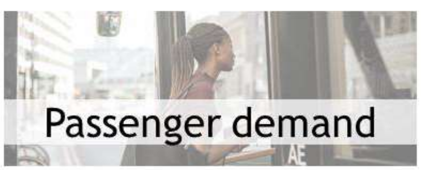
Vehicle bunching affects the reliability of bus services and causes user frustration with the travel

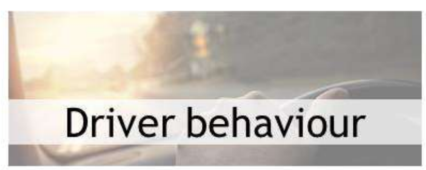
In public transport, **bus (vehicle) bunching** refers to a group of two or more vehicles, running along the same route, which were scheduled to be evenly spaced, but instead they run in the same place at the same time.

Ideal conditions

Ideally, all buses should follow their planned frequency along the line. However, in practice, many internal and external factors impact this.

Example of internal and external factors





Real-world conditions

A 3-stage: the first 2 to ensure correct data entry, the 3rd one is the core


Transportation Research Procedia

24th EURO Working Group on Transportation Meeting, EWGT 2021, 8-10 September 2021, Aveiro, Portugal

Monitoring and controlling real-time bus services: a reinforcement learning procedure for eliminating bus bunching

Data Gathering

1

Data gathering is the first step addressed, consisting of a **research phase to obtain information about the bus line**

Data Analysis

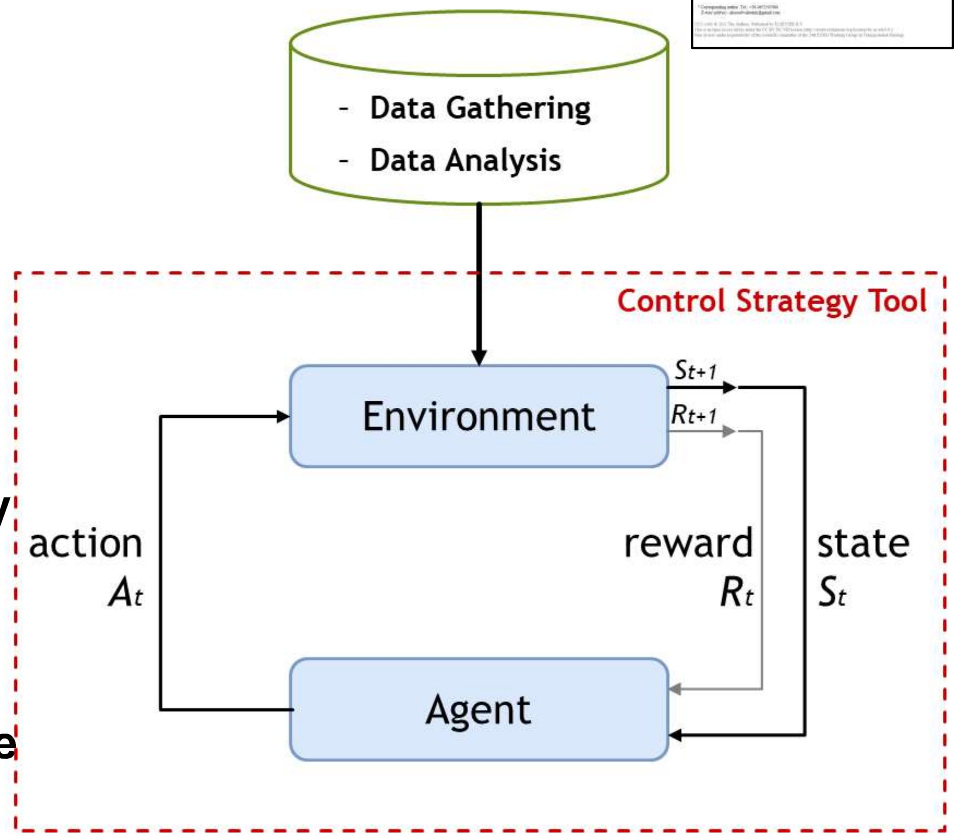
2

The second stage aims to **analyze the context** in which the service operates **to identify the main variables required when building the model**

Control Strategy Tool

3

The third step is the **core of the model**:
it takes the input data and **builds the environment that simulates the bus line** under examination



Three types of information are required in order to build the environment

Data Gathering → Data Analysis → Control Strategy Tool

Three types of information are required:

Infrastructure data

- Data used for the **construction of a representative model of the line**: stops, terminals and all the essential information about the specific route under consideration.
  - It is **necessary to identify all the stops** on the line **and those where it is possible to hold the bus in complete safety**

AVL/AVM database

- **Historical data** coming from line operation **through the AVM/AVL systems** (travel times) **are used as proxies for demand and traffic conditions.** The main data provided are:
  - Day and time of arrival
  - Identification code for each resource (bus)
  - Stop identification code (or geographical coordinates)

Contractual data

- **Constraints in service operations;** e.g., minimum waiting time at the terminal

Three main steps have been followed to analyze the context in which the service operates

Data Gathering → **Data Analysis** → Control Strategy Tool

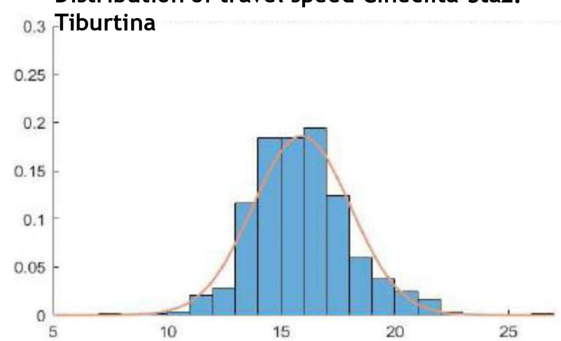
Representative route

- **Select stops called representative stops that are equidistant from each other**, preferring those in which it is possible to carry out the holding strategy.
  - Reducing the number of stops leads to a substantial reduction in computer processing time

Speed distribution

- Determine the **distribution of speed between representative stops** on the line
  - The speed **includes the vehicle running times and the dwelling times** at the stops since there may be multiple stops on a representative route

Distribution of travel speed Cineciità-Staz. Tiburtina

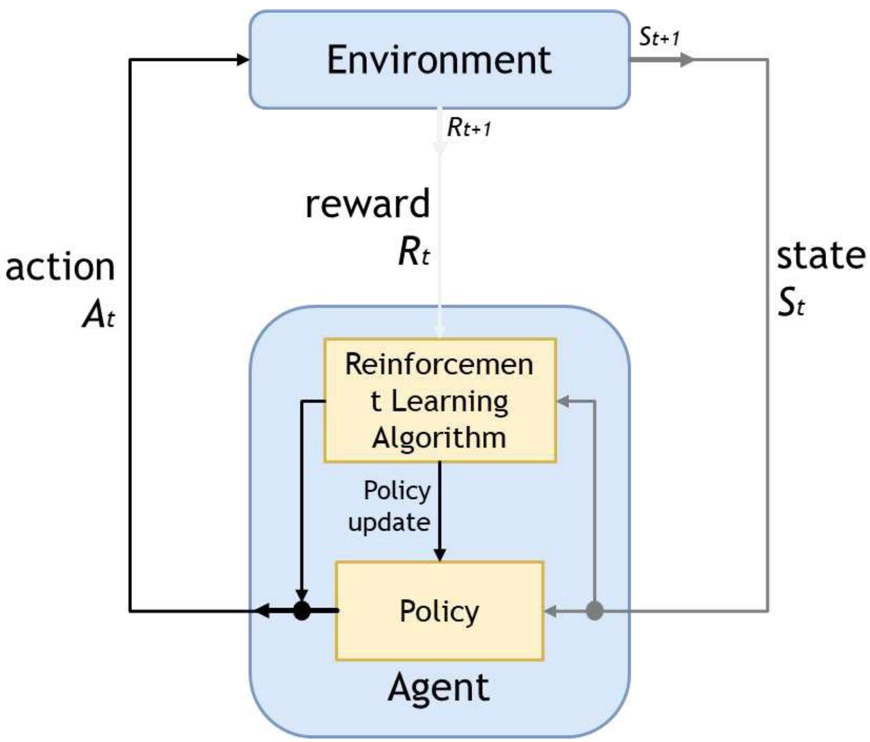


Average number of passengers

- Determine **the average number of passengers boarding and alighting at the stops in a period**, simulating the effect that demand has on bus speed, **using the dwelling time conversion method** proposed by Fricker (2011)

The AI algorithm

Data Gathering → Data Analysis → **Control Strategy Tool**



1 SARSA Scenario

The SARSA scenario relies on space discretization of the current positions of the buses in the line and on the implementation of SARSA (state–action–reward–state–action) multi-agent algorithms in the state-space of the discretized model.

This algorithm consider transitions from state-action pair to state-action pair, and learn the values of state-action pairs through the corresponding equation:

$$Q(S_t, A_t) \leftarrow Q(S_t, A_t) + \alpha[R_{t+1} + \gamma Q(S_{t+1}, A_{t+1}) - Q(S_t, A_t)]$$

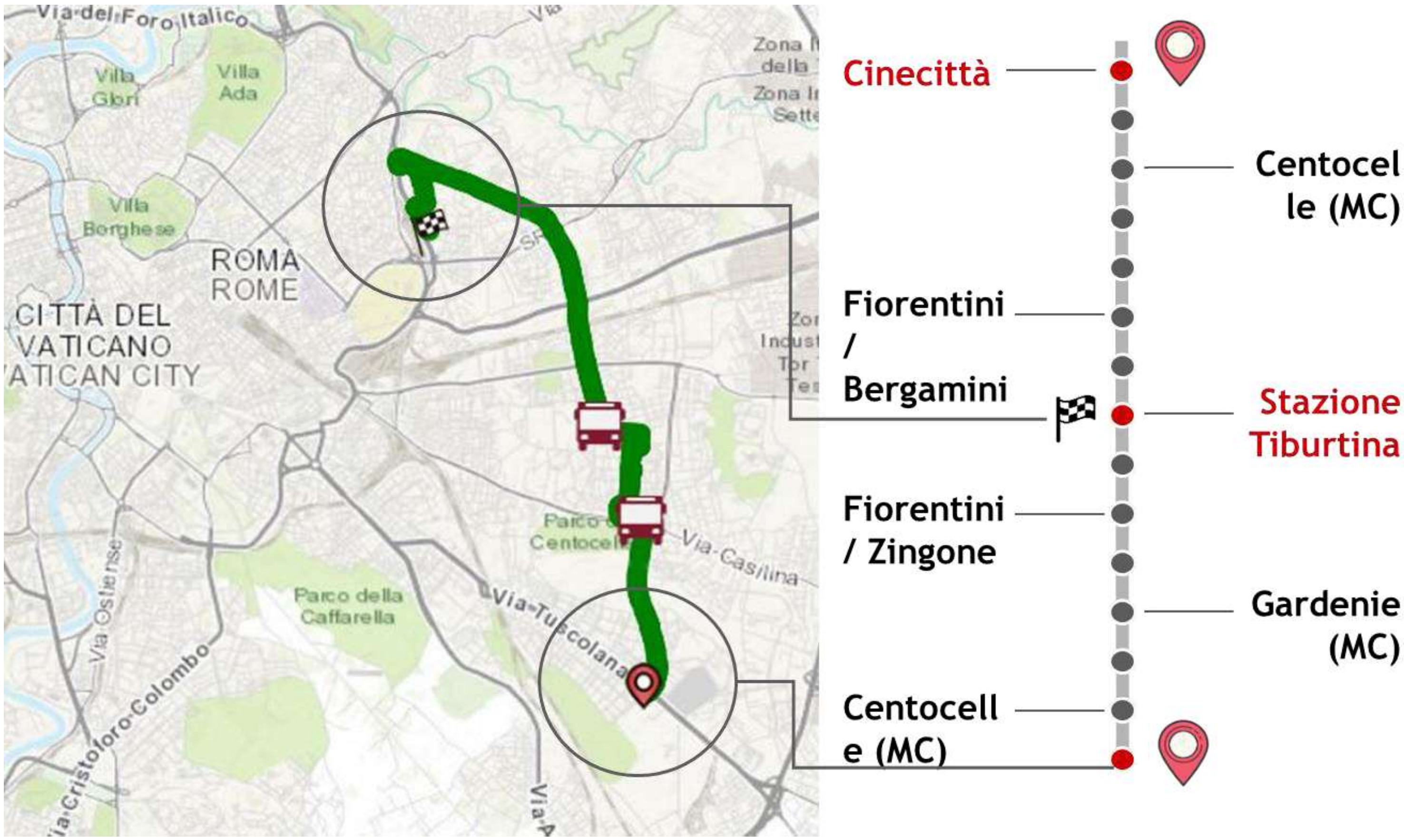
2 ANN Scenario

A materialization of the value of each possible state-action pair does not take place; rather, an attempt is made to have the neural network estimate the behavior of the value function by modifying its internal weights w, using the update rule Semi-Gradient SARSA:

$$w \leftarrow w + \alpha[R_{t+1} + \gamma Q(S_{t+1}, A_{t+1}, w) - Q(S_t, A_t, w)]\nabla Q(S_t, A_t, w)$$

The neural network used is an RBF network an artificial neural network that uses radial basis functions as activation functions. The output of the network is a linear combination of radial basis functions of the inputs and neuron parameters w.

Benefits through a case study in Rome



Total distance	25 km
Total number of stops	64
Number of buses in the line	7 bus
Average lap time	~ 2 h
Operating frequency	3.5 bus/h

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SARSA scenario present le lowest holding percentage between the 3 scenarios, preferring other strategies

Holding percentage

AS-IS Scenario

Bus	E[X]	Var[X]	σ_x
# 1	4.55%	0.09%	3.00%
# 2	7.40%	0.09%	2.98%
# 3	10.12 %	0.08%	2.75%
# 4	12.48 %	0.08%	2.82%
# 5	15.39 %	0.06%	2.50%

Description

As expected, the **first buses are less affected by the impact of the terminal control than the last buses** since in the AS-IS scenario there is no holding control during the route

SARSA Scenario

Bus	E[X]	Var[X]	σ_x
# 1	2.08%	0.02%	1.49%
# 2	4.94%	0.04%	1.87%
# 3	6.66%	0.03%	1.58%
# 4	10.84 %	0.04%	1.92%
# 5	12.35 %	0.04%	1.91%
# 6	12.65 %	0.03%	1.86%

Description

The holding percentage is lower on average compared to the AS-IS scenario, **preferring other strategies such as the regulation of speed**

ANN Scenario

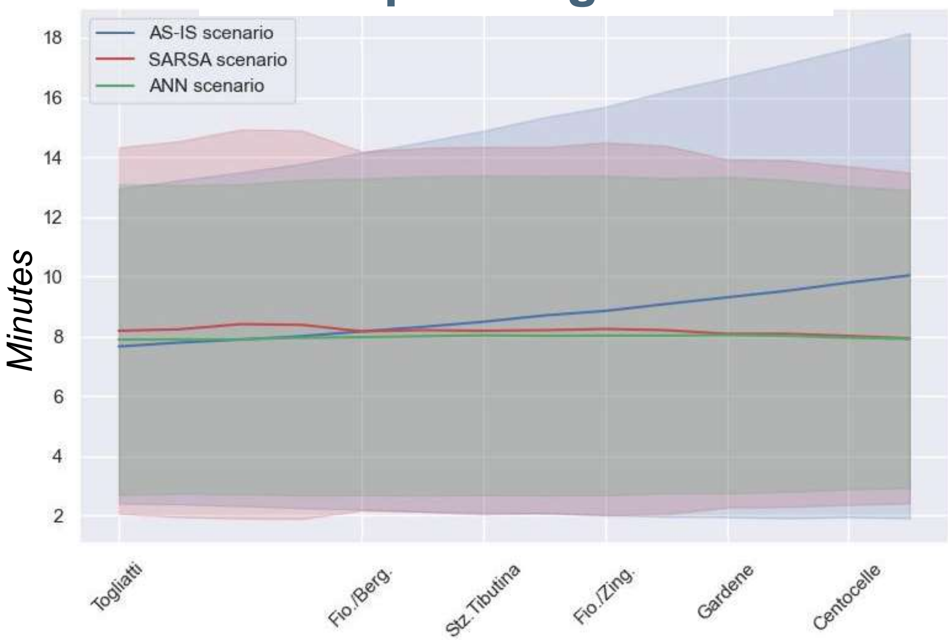
Bus	E[X]	Var[X]	σ_x
# 1	8.55%	0.05%	2.15%
# 2	11.58%	0.04%	2.11%
# 3	14.32%	0.04%	1.96%
# 4	16.67%	0.04%	1.99%
# 5	18.87%	0.03%	1.78%
# 6	21.22%	0.03%	1.86%
# 7	23.49%	0.04%	1.98%

Description

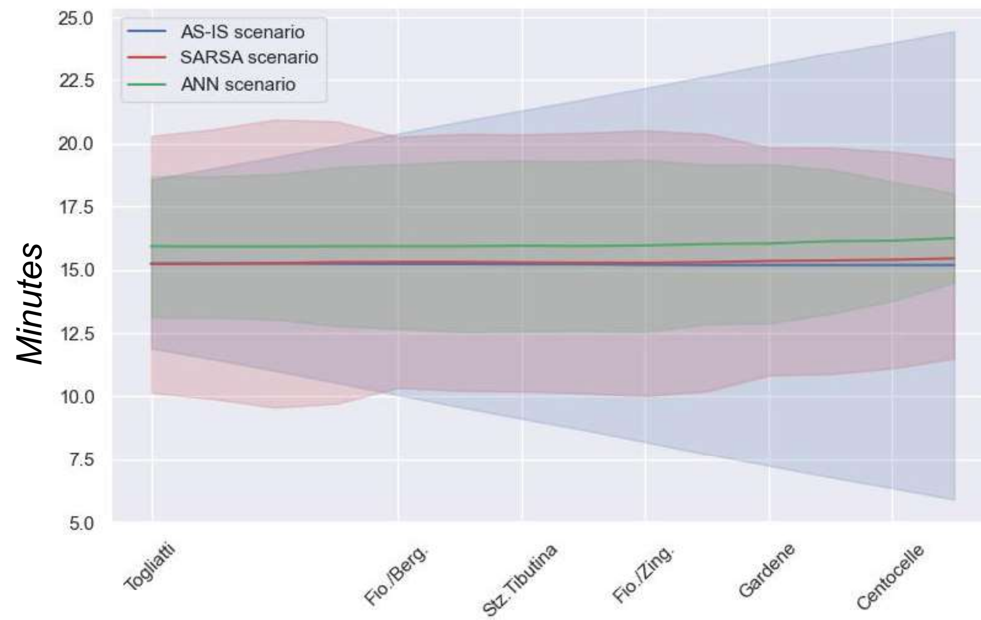
In this case a **holding action is preferred over the other strategies**: on average, the percentage of holding time is higher for each bus compared to the other scenarios

ANN scenario is the most stable one with the lowest standa both metrics

Waiting time per passenger



Headway time



Description

In the **AS-IS scenario** the average waiting time per passenger **increases** during the route due to the bus bunching **while the other two scenarios remain stable**.
In the **ANN scenario** performance appears to be **better** in both the mean and standard deviation recorded at each representative stop.

Description

In the **AS-IS scenario** the standard deviation in the headway time increases by **three times** versus the standard deviation of the first stop due to the **significant effect of bus bunching**. The controlled scenarios, instead, appear to be more stable with a significant reduction of the standard deviation, especially for **ANN scenario**.

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Conclusions and future work for eliminating bus bunching phenomenon

Conclusions

- The use of **RL merging two control strategies**, holding control and adjusted cruising speed, **in a realistic environment** (applying AVL data) **leads to**:
  - **Elimination of bunching phenomenon** in the line providing a **more regular service**
  - **Optimization of the resources required** throughout the day for the transit line
- The **two proposed solutions** turn out to be different:
  - **SARSA**, compared to ANN, **has a lower percentage of holding time** and **average headway and waiting time**, thus also lower total travel times, but with

Future work

- Use more **up to date data collection systems** which **improves the reliability of the input data** that the system processes
  - More advanced AVL systems are envisaged, capable of providing more in-depth data (e.g., APC – automated passenger counter s)
- **Test both algorithms in a real-world with larger pilot setting** (e.g., at multiple transit lines) to investigate network effects and understand users' reaction to these changes and the level of customer satisfaction achieved
  - It may be **incorporated in a decision support system to assist operators** (drivers) **in taking corrective actions throughout the day**, improving bus service operations

Real-time Traveller Information System

(**mobile device applications** that)

support the routing of individual travellers **before** (pre-trip) and **during** (en-route) the **trip** on a (multi-service) **stochastic transit** network with **real-time** information about traffic conditions and **individual** preferences (e.g., advice based on maximum accepted travel length on foot)

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Transit trip (route) planners

Google Transit, OpenTripPlanner, Moovit, ….

- Input data:

  traveller current position,

  destination,

  some path requirements (maximum values of some attributes),

  ….

- Output data:

  (alternative) minimum travel time (disutility) available path(s),

  some (scheduled or predicted) attributes: waiting time, on board time, …

  ….

Trip planners can be seen as intelligent utility-based agent that carries out sequential decisions in deterministic or stochastic environment.

In general, the existing (transit) trip planners assume deterministic environment. The new ones consider stochastic multiservice transit networks.

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Dynamic Optimal Travel Strategies in Intelligent Stochastic Transit Networks

Adaptive routing problems

Rambha *et al.* (2016) refer to the adaptive transit routing (ATR) problem, formally defined as follows:

"*given a stochastic transit network, in which the transit travel times are time-dependent and random with known distributions, the initial state of the system and a destination D, an adaptive policy that minimizes the total expected travel time is sought, subject to a constraint that D is reached within a threshold TH with probability 1*".

Ramba *et al.* (2016) present an **MDP-based method** to solve the ATR problem.

Nuzzolo and Comi (2021) propose Dynamic Optimal Travel Strategies (heuristic method).

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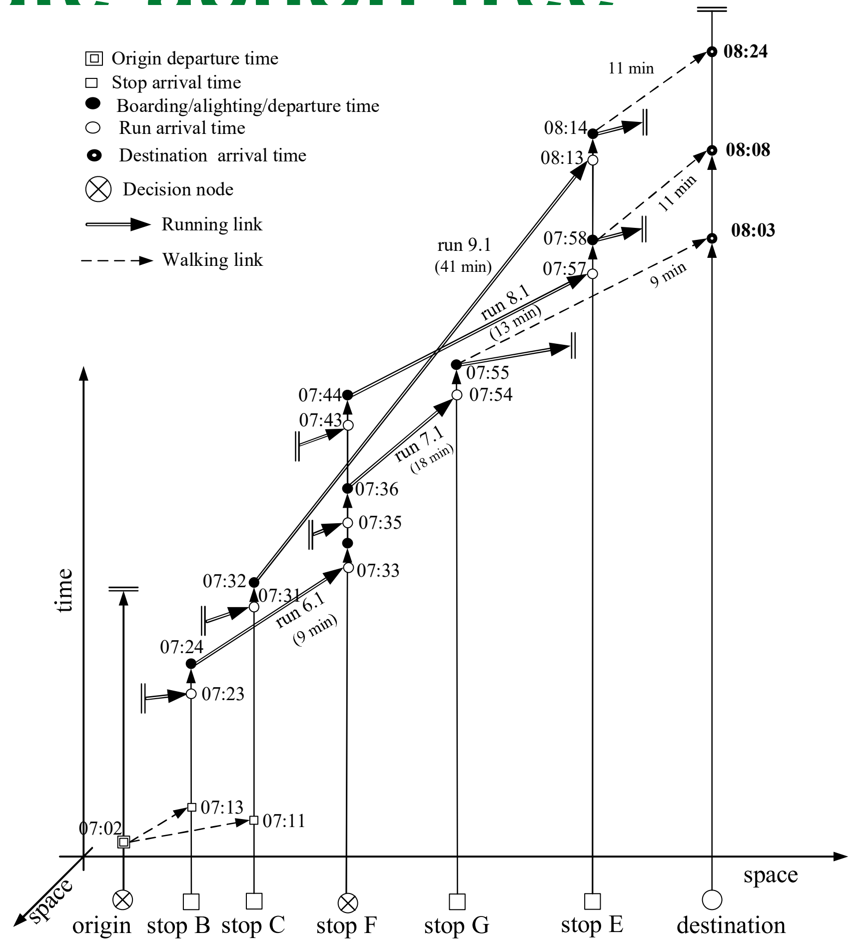
Example of application: state-action tree

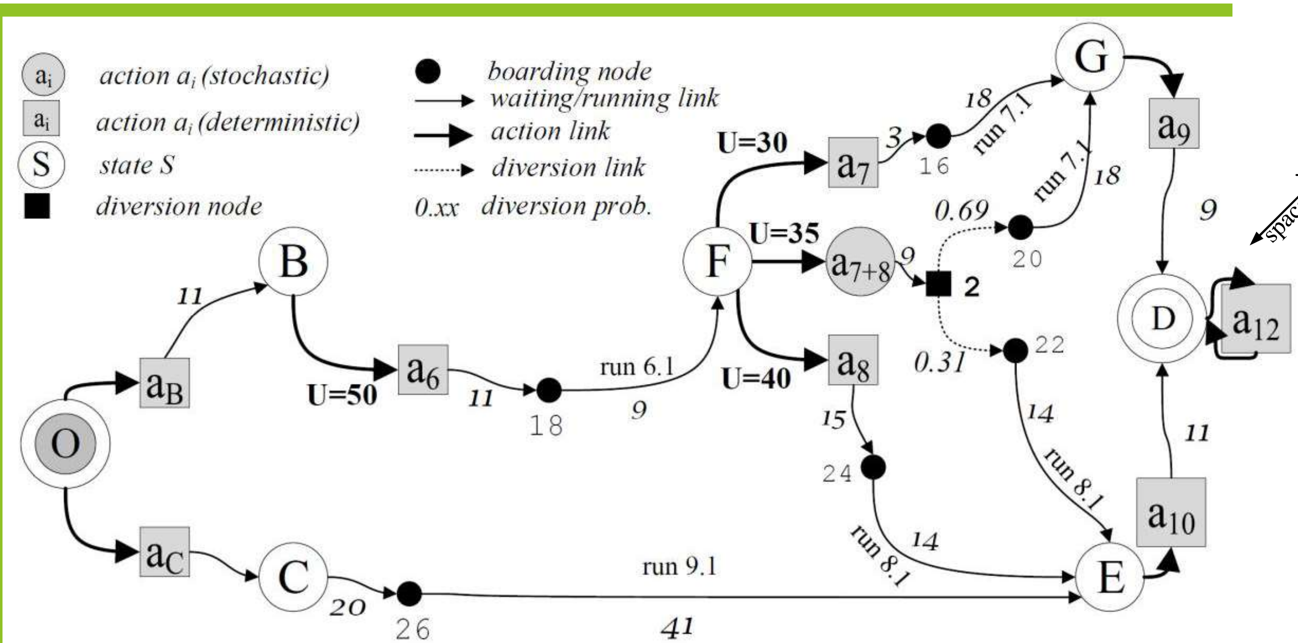
$$\sigma_\varepsilon = \underset{(2.98)}{6.10} \cdot FH \qquad R^2 = 0.91$$

σ = standard deviation and FH = forecasting horizon

Rome (2018)

Random residual	Forecasted arrival time at destination	When choice is made	Forecasting horizon [minutes]	Estimated standard deviation [seconds]	Estimated variance [minutes^2]
$\eta_O^{r_{8.1}}$	08:08	07:02	66	402.60	45
$\eta_O^{r_{7.1}}$	08:03	07:02	61	372.10	38
$\varepsilon_F^{r_{8.1}}$	08:08	07:35	33	201.30	11
$\varepsilon_F^{r_{7.1}}$	08:03	07:35	28	170.80	8
TOTAL					**102 (10.10^2)**





Open research questions

Because of the large number of states, the heuristic literature methods inherit the curse of dimensionality, and therefore ***state-space reduction through pre-processing is proposed and applied.***

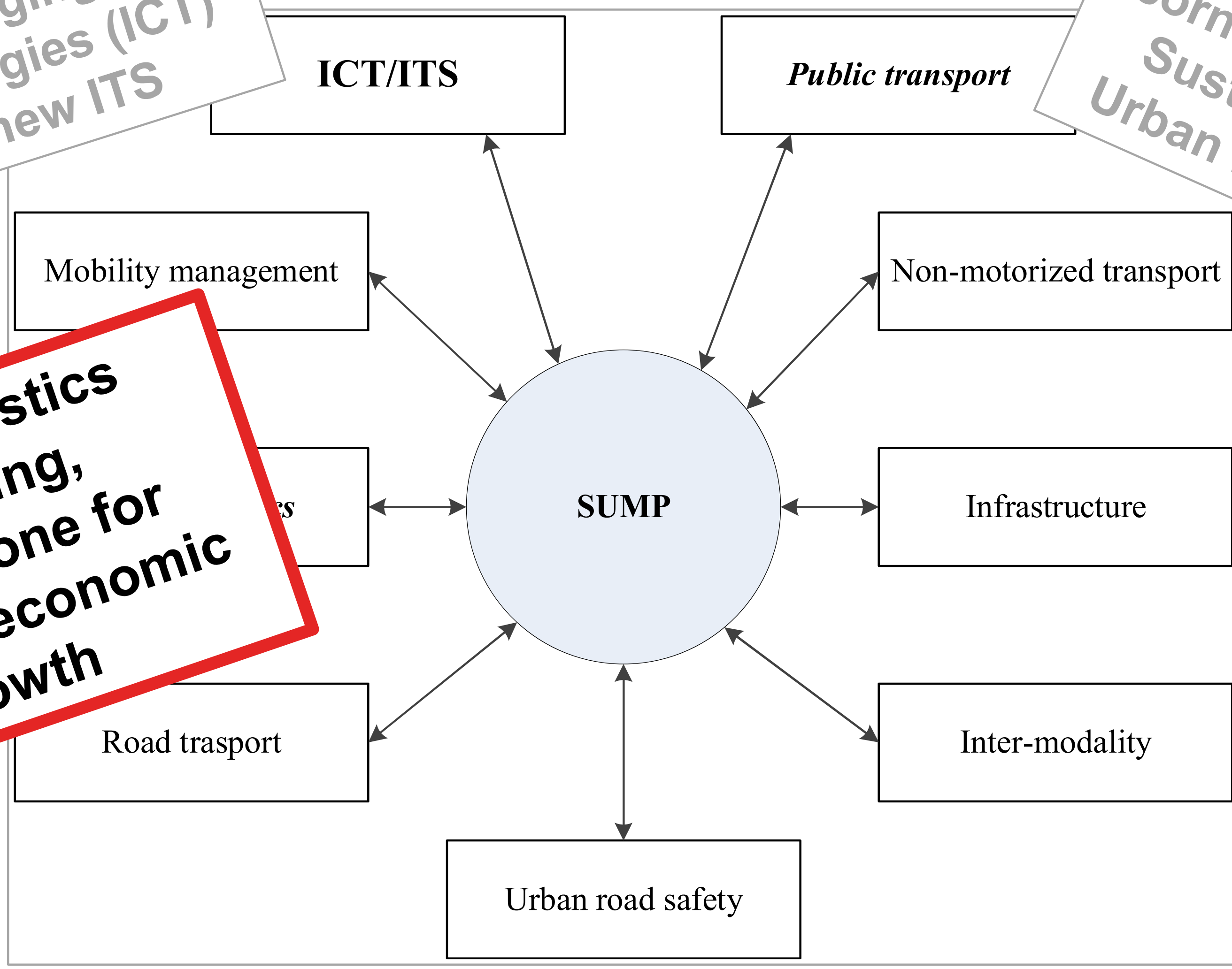
The **heuristic** search method was proposed to avoid the explicit determination of the bus transition probabilities, **using only the transition probabilities among traveler states.**

- However, several research issues still need to be resolved. These include
  - the application on larger test networks and real networks,
  - analyses of time complexity and convergences properties, and
  - the development of methods based on a decision theory approach within theories other than that of expected utility

Sustainable Urban Mobility Plan *versus* urban ~~issues~~

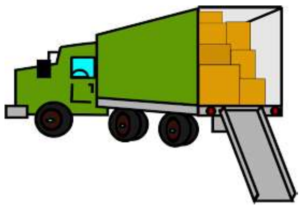
Promototing the emerging technologies (ICT) and new ITS

Public Transport Planning, the cornerstone of Sustainable Urban Mobility



Urban logistics managing, cornerstone for assuring economic growth

Urban freight stakeholders$_1$



Transport and
logistics operators

Retailers
(ho.re.ca.)

End-consumers

Public
administrations

Urban freight stakeholders$_2$

- transport and logistics operators (*transport enterprises*) could **optimize** their choice including **vehicle load**, **routing** and **scheduling**, as well as the **delivery travel time** in terms of last mile operations, i.e., at-customer deliveries, and their part of reverse logistics;
- retailers could optimize their **restocking** process and integrate the freight receiving operations within their selling activity, considering also the **payments**; they could also optimize their part of reverse logistics reducing their estate costs and minimizing (or nulling) the inventory cost;
- end consumers which can **benefit**, from one side, as citizens for the **traffic reduction** due to city logistics optimizations and then to increase of livability for the increase of safety and the reduction of pollution emissions, and from another side as consumers for the future instant deliveries.

Urban freight stakeholders$_3$

- public administration, in its different levels and branches, could optimize the **sustainability/liveability** of the city in terms of better **use of urban public space** (both those destined to driving and those destined to park) respect to all the different demand components (i.e. passengers and freight) using different mode-services; it can be noted that the role of public administration is twofold,
    - from one side, it has the commitment to *organize public s*paces for freight vehicles mobility and parking in a strategic view and then in an off-line design;
    - from the other side, it can have the role of supply information on park and path in real time and to manage reservation;

therefore, the main role of emerging ICT is linked to the dynamic real-time connection, using in the case of large city, and all the new options coming from there.

Urban freight stakeholders$_4$

Benefits for classes of stakeholders

Each actor class uses the e-ICT, obtaining a reduction of own cost and then a modification of cost at fixed flow.

E-ICTs allows among the other

- to collect,
- to store and
- to share data and

then to use advanced real-time or off-line procedures to analyse data for improving existing urban freight transport systems.

The emerging technologies$_1$

The e-ICTs that impact directly on city transport and logistics refer:

- *internet of things* (IoT); it describes the set of two meta-elements: ***physical* objects** - “things” - that are embedded with sensors, software, other technologies for the purpose of exchanging data and a network qualified to link these objectives with other devices and systems;
- *big data* (BD); although it is difficult to find a shared and joint definition, it is possible to speak of big data when the **data** set is so **large** and **complex** that it requires the definition of new tools and methodologies to extrapolate, manage and process information within a reasonable time;
- *block-chain* (BC); it is defined as a chain of blocks, in which each block contains **value data** that are shared and validated;
- *artificial intelligence* (AI); although a large and diversified classification of AI exists, it synthetically indicates the **algorithms**, that analysing a set of (normal or big) data take a decision.

The emerging technologies$_2$

Benefits for classes of stakeholders

- transport and logistics operators (*enterprises*) optimize their operations using real-time **route advice**, routing and scheduling actualized by information from public management and private retailer; they optimize the delivery travel time in terms of last mile with time slot and using area for freight operations (delivery bays) as well as the at-customer deliveries considering actualized information, e.g., info on their availability;
- public administrations optimize freight vehicle paths and parks. On the time other than in the space, shared services for supporting integrated dynamic platform to manage and control city logistics system are provided; they can introduce local or global intelligence as it will be recalled below;
- retailers optimize their daily schedule for restocking; they optimize their part of reverse logistics considering the dynamic actualization of loading space availability;
- end consumers which can benefit, as consumers (freight receivers), of the optimization of at-home deliveries and can have real-time information about the home delivery.

Example of benefits for transport and logistics operators

Carriers can and should have:

technological solutions to improve

the **sustainability** and **efficiency** of their urban freight transport operations

as asked both by international and local authorities

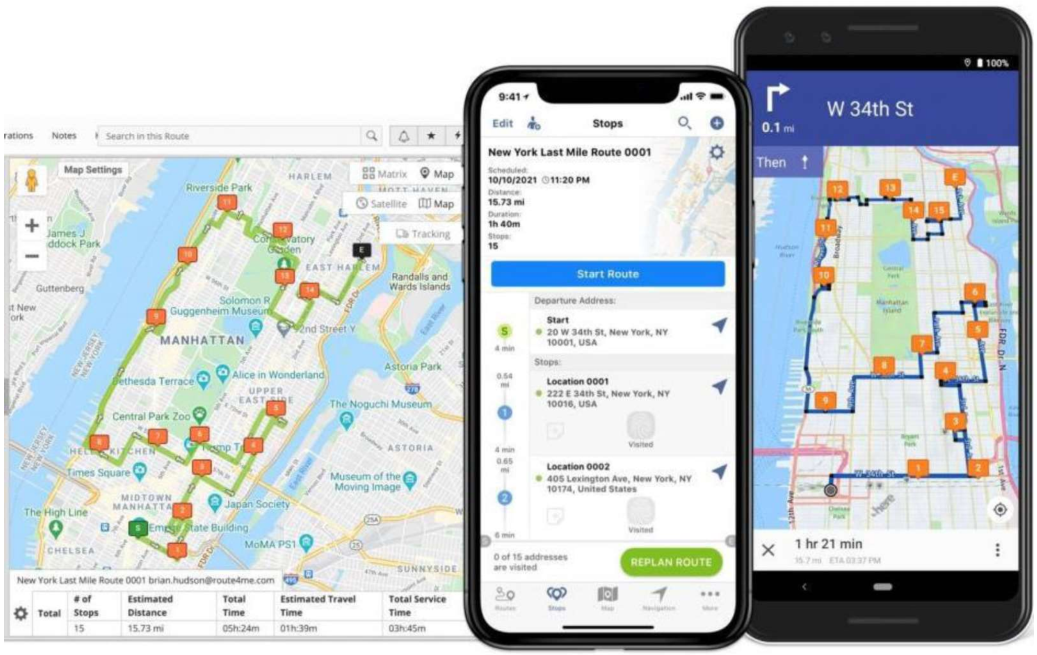
vehicle technological solutions <u>do not change</u> the <u>number of truck kilometers</u> increasing safety

Solutions based on **emerging ICTs** can <u>reduce the number of kilometers</u> driven in urban areas, increasing safety, reducing environmental impacts

Co-funded by the Erasmus+ Programme of the European Union

New generation of navigation systems

- Among the ICT-based solutions, navigation systems allow carriers to identify optimized paths.



Navigation systems:

- provide specific route guidance exploiting the information about traffic regulations (e.g., road works, lane directions).
- can determine the best paths among destinations (customers to serve) according to the average configuration of the road network

New generation of navigation systems: *smart routing* (proactive and tailored-user advices)

Smart routing

- Proactive implies that the information is designed in such a way that it affects the behavioral choices of road users preferably before congestion occurs.

In order to make optimal route choices, information about the traffic situation at the moment of departure is often not helpful.

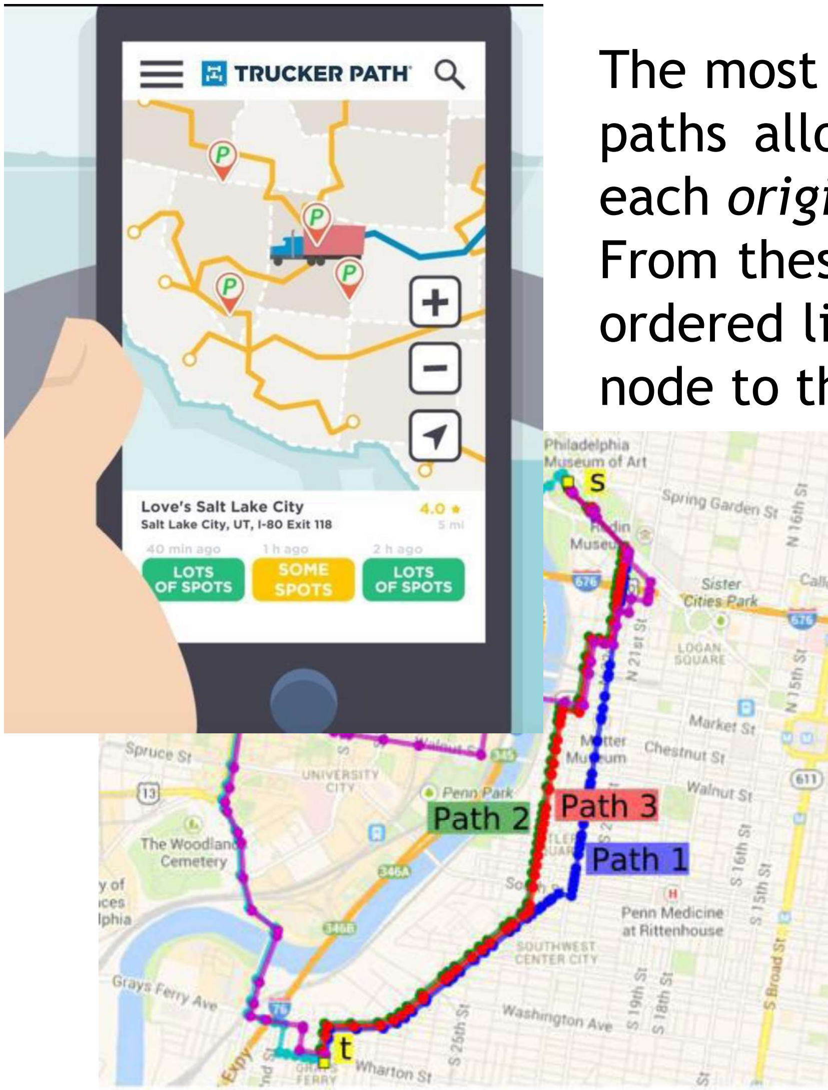
This is because it takes time to drive to the point where a route choice becomes relevant.

At that point in time, the traffic situation could be changed. Hence, a prediction of the traffic situation is much smarter. This prediction even includes weather forecasts.

Smart routing provides individual truck drivers with travel advice that is tailed to their personal preferences and refined based on previous travel advice.

Current navigation systems

The navigation systems exploit the potentiality offered by **minimum path algorithm on a network**



The most used algorithms for the search of the minimum cost paths allow to calculate the minimum cost trees rooted in each *origin* (or destination).
From these, it is possible to derive the minimum path (or the ordered list of shortest paths) that connects each destination node to the root node.

The shortest path problem has been intensively investigated over years, due to its extensive applications in topological theory, computer network and the design of transportation systems *(Dijkstra, 1959; Zhan and Noon, 1998; Cascetta et al., 2002; Flinsenberg, 2004; Zhang et al., 2010; Bast et al., 2015; Chondrogiannis, 2017)*

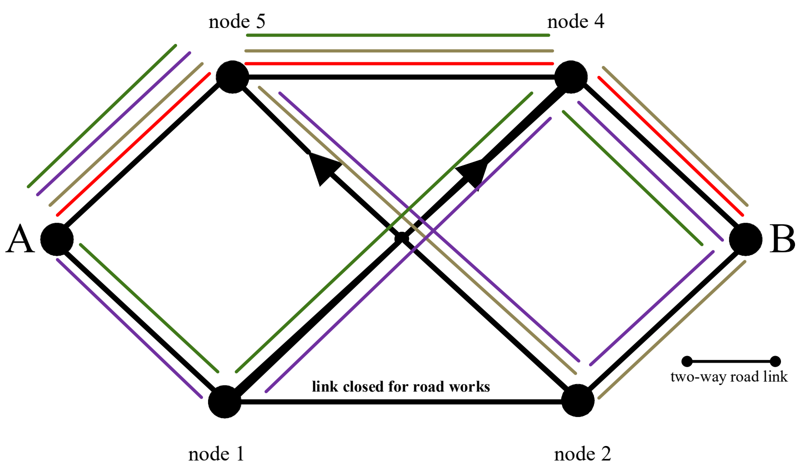
New navigation systems

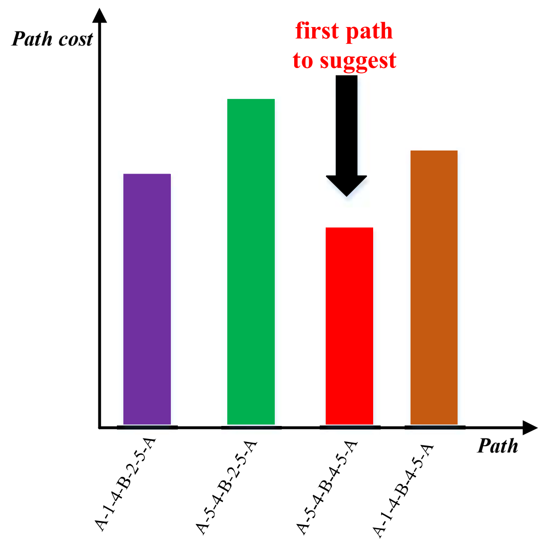
Common tools were designed to solve the single-source shortest path problem for a **static network**,

then guided by the needs to find the shortest path in stochastic and congested network several **advancements were performed**:

- **stochastic network,** i.e., the actual link travel times may differ from historical or forecasted one
- the outcome of any decision depends partly on the **user's decisions** and partly on randomness.
- Therefore, the new navigation systems provide not a complete single origin-destination (O-D) path, but they suggest rather one **optimal travel strategy based** on the **learning process of the user enhanced by the emerging ICTs at disposal**.

Navigation systems: new challenges





User is asked to go from a point *A* (i.e., depot/warehouse) to a point *B* and back *A* (i.e., customer 1).

Different paths are available, and some changes could occur according to the *within-day* or *day-to-day* dynamics.

The use of the **past stored** and **current (real-time) information** on the network working can suggest the best path allowing time savings and operational cost reduction, and on the other hand to reduce the vehicle-kilometres.

Learning process of path costs$_1$

Path attributes can be estimated by users according to a learning process.

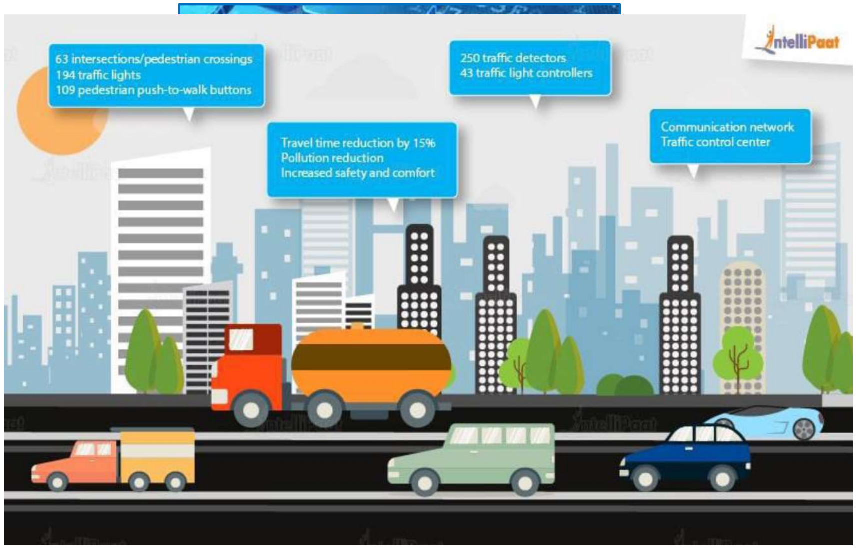
Learning occurs both with the evolution of τ (time) and the evolution of t (day):

- for some attributes, the value experienced (tested) in previous periods ***X**[t-1]*, ***X**[t-2]*
- for other attributes, the updating which users perform for each time τ in day t.

$$C[\tau,t]=\psi\left(X[\tau],X[t-1],X[t-2],\ldots\right)$$

real-time network configuration obtained through *IoT* (e.g., real-time vehicle sensors)

Learning process of path costs$_2$



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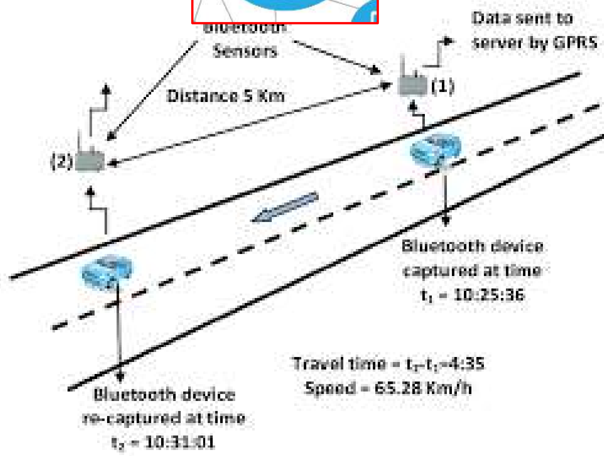

$$X_{hk}^{fo}\left[\tau,\,\bar{t}\right]=\xi\cdot X_{hk}^{BD,fo}\left[\tau,\,\bar{t}\right]+\left(1-\xi\right)\cdot X_{hk}^{IoT}\left[\tau,\,\bar{t}\right]$$

value of attribute X_{hk} without real-time info, given by *BD* at time τ of day $\bar{t}$

value of attribute X_{hk} realised at τ of the current day $\bar{t}$

Learning process of path costs$_3$

Advanced navigation systems

- The new challenge is the generation of a set of paths more than the shortest one, i.e., not only the first best, but also the second best, …, the *g* best until to obtain a set of specific paths
- User's choice can be updating his/her utility to modify the path costs

For example, when a path *k* is chosen, and during the travel, user is informed that another path can become attractive (e.g., along the path *k* there is a road accident or a specific event and the traffic is delayed), the user can update his/her utility in an intelligent *en-route* way.

Open research questions$_1$

The evolution of route advisors can be briefly recalled:

- moving **from** those that used historical data for characterize the road performances
- **to** those developed for providing dynamic time-dependent advice,
- **to** those that take into consideration drivers' attitudes.

the newest tool introduce uncertainty into minimum path searching and new way to suggest route advice (e.g., travel strategy).

Open research questions$_2$

- The evolution in relation to the impacts of these emerging technologies on generalised path costs is started to be pointing out showing how the current structure of costs can be in depth modified by the technology, which significant benefits for improving travel experience by truck drivers.

- The dynamic learning process needs to be thus detailed and formalised.

Open research questions$_3$

- The evolution of what currently proposed pushes towards a further advanced level providing:
  - the formal unitary treatment of the inclusion of e-ICT in the traveling salesman problem (TSP; i.e., **routing**);
  - the opportunity to design a multilevel delivery path (tour) with nodes (points) where walking for reaching the final customers (e.g., retailers or end consumers' homes) are introduced (i.e., **courier problem**);
  - the users' *choice* behavior (i.e., *choice updating* model);
  - double dynamic assignment process.

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Questions?

- A very big THANK YOU!

მადლობთ

Дякую

Grazie

Dziękuję Ci

Dankeschön

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