Coordination in Open Distributed Systems

A Playground for Agreement Technologies

Sascha Ossowski

Centre for Intelligent Information Technologies (CETINIA)

University Rey Juan Carlos, Madrid (Spain)

sascha.ossowski@urjc.es

Carmona, 16/06/2016

1 Coordination & Agreement Technologies

2 Some Applications

3 Conclusions and Outlook

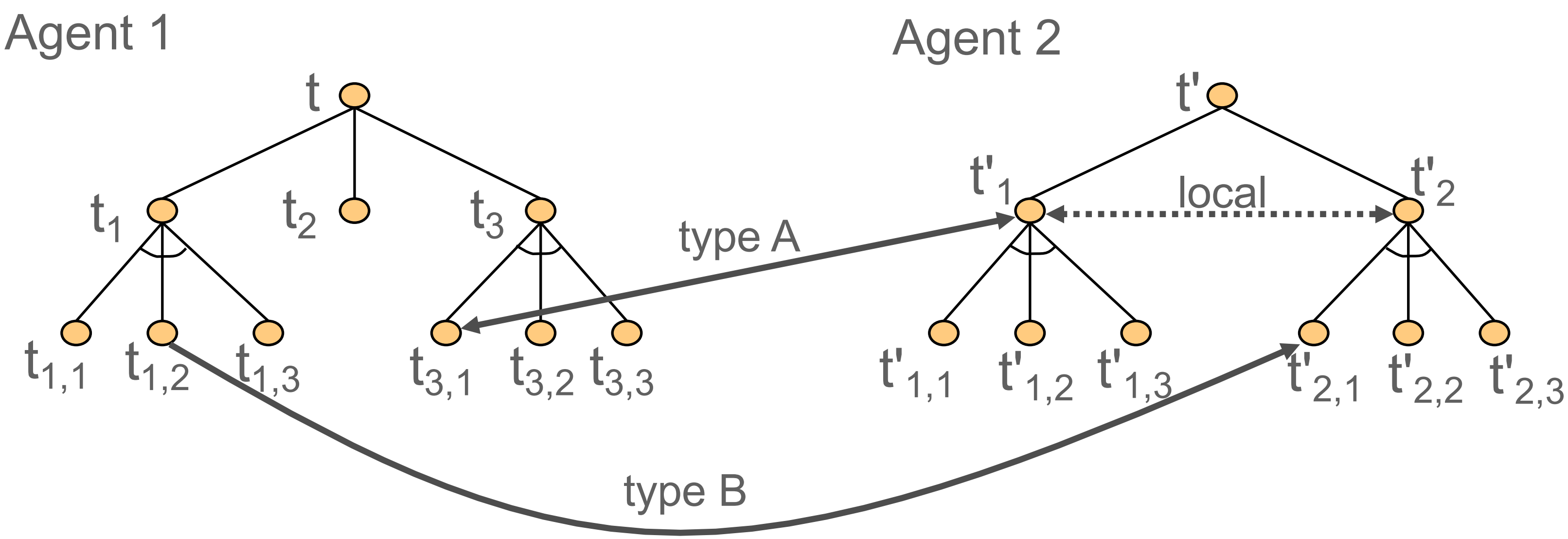
Coordination

- Coordination is a universal concept:
  - ✓Social Science, Economy, Biology
  - ✓Robotics, Software Engineering, Programming Languages, …
  - ✓Plethora of seemingly unrelated definitions, even within the same (sub-)field

- Distributed (Intelligent) Systems:
  - ✓coordination is a key feature of Distributed Systems,
  - ✓multiagent systems: capability of coordinating with others constitutes a centrepiece of agenthood.

A widely used definition

Coordination: *Management of Dependencies* … (Malone & Crowston)



Tasks involved:

- *Definition* of the coordination context: agents, goals, tasks, roles, services, etc.
- *Detection* of dependencies: shared resources, producer/consumer, etc.
- Management *decision*: scheduling, resource selection, etc.

Different perspectives on coordination in MAS

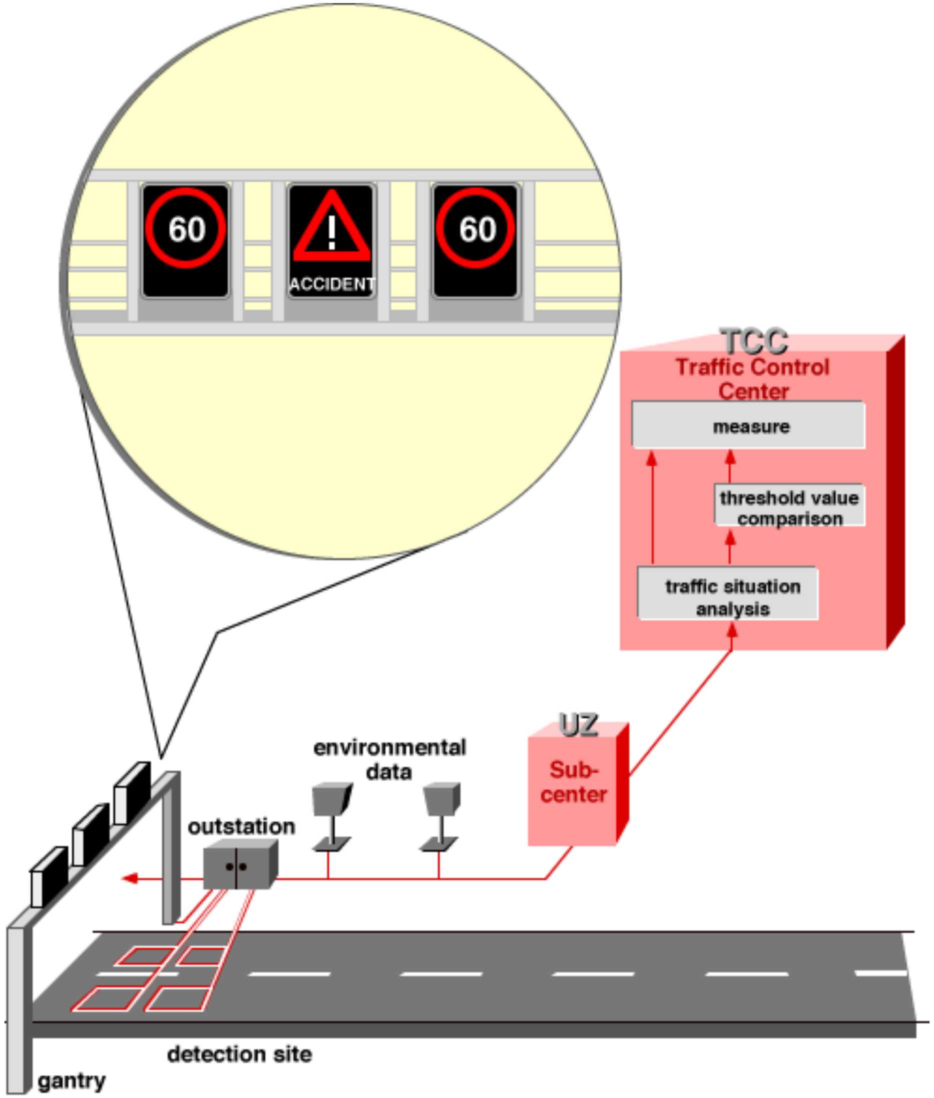
Designer's interest in coordination

- Micro-level design
- **Macro-level design**
  - **Design multiagent system with desired (global) characteristics**
    - Multiple agent designers
    - **Single agent designer**
      - **closed system**
      - **benevolent agents**

"The integration and harmonious adjustment of individual work efforts towards the accomplishment of a larger goal "
(B. Singh)

Coordination in closed systems

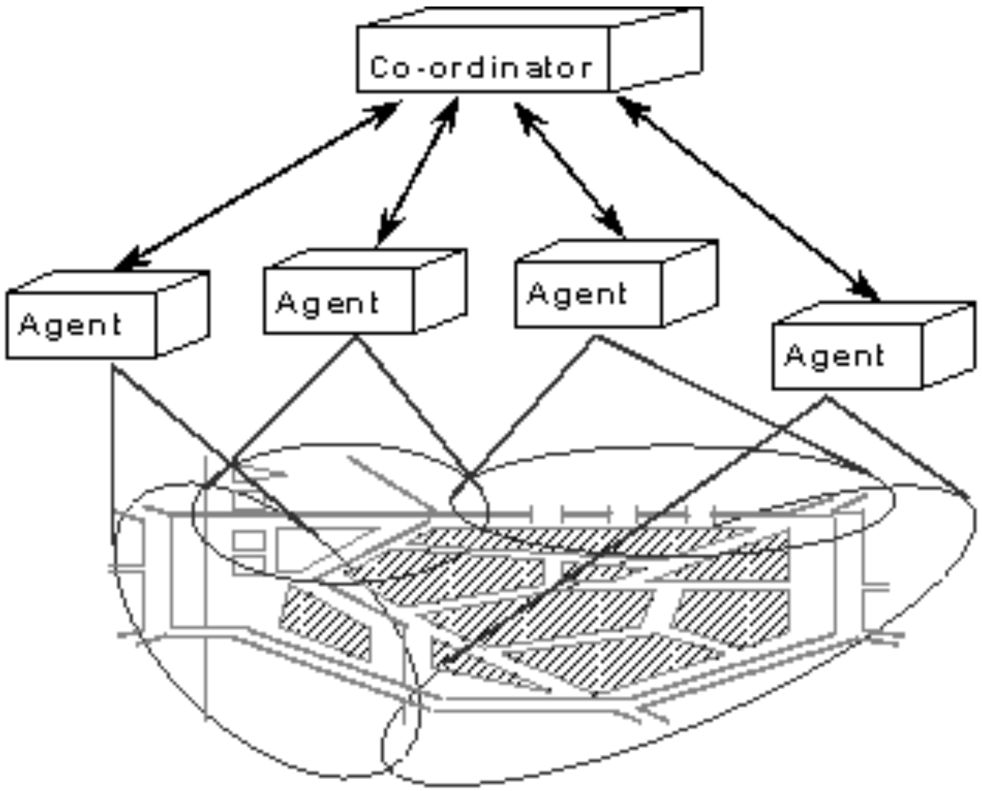
- Example: **Road traffic management**
  - Urban motorway network
  - System that generates **signal plan proposals** based on the current traffic conditions



Coordination in closed systems

TRYS architecture (*Cuena et al.*):

- Problem solving agents
  - each agent is responsible for a **problem area**
  - generate **alternative signal plan proposals** and send them to the coordinator
- Coordinator agent
  - **resolves interdependencies** between local plans
  - sends the **adapted local signal plans** to the agents for execution



Different perspectives on coordination in MAS

Designer's interest in coordination

Micro-level design

- **open multiagent environment**
- **design an additional agent with desired characteristics**

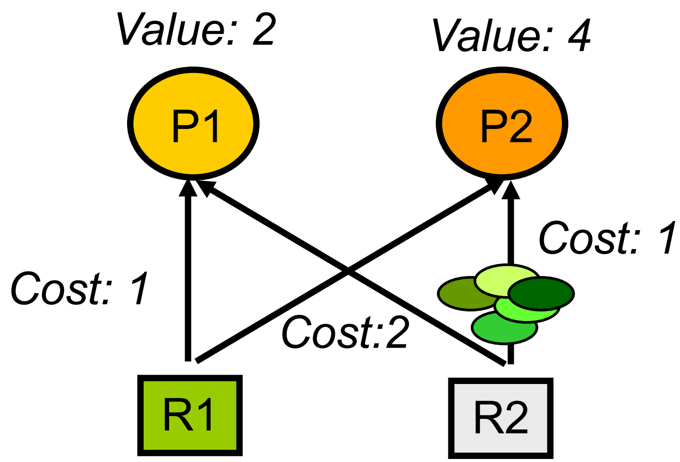
"Co-ordination is a way of adapting to the environment "
(von Martial)

Multiple agent designers

Single agent designer

Coordination in open systems: micro-level

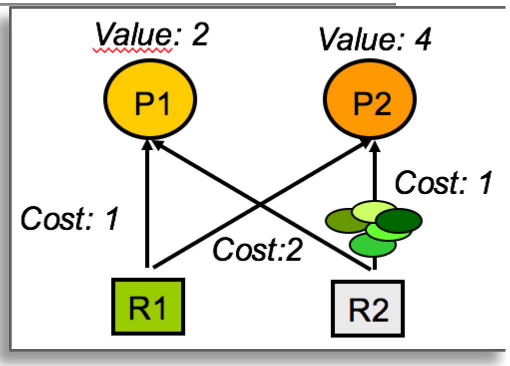
Example (*Gmytrasievicz & Durfee*):



- Agent $\boldsymbol{R_1}$ performs surveillance of an area
  - there are two observation points ($\boldsymbol{P_1}$ and $\boldsymbol{P_2}$)
  - they provide a value (altitude) and a cost (distance)
  - Actions: $\boldsymbol{A_1}$ (go to P_1), $\boldsymbol{A_2}$ (go to P_2) y ***N*** (nop)
  - In a multiagent world with R_2:
    - **Utility** of agent R_i: $U_{Ri}(A_i)$ = value($\{P_i, P_j\}$) – cost (A_i)
    - R_1 **knows** its three action alternatives and its results
    - R_1 **does not know** if R_2 is aware of alternative A_2
    - Suppose that no communication between R_1 and R_2 is possible

Coordination in open systems: micro-level

RMM Method (*Gmytrasievicz & Durfee*):



R1's model of its own situation

p=0.75 (A2), p=0.25 (N)

R1 \ R2	A1	A2	N	
A1	1	5	1	4
A2	4	2	2	
N	2	4	0	

[0.25, 0.75]

R1's model of R2's action alternatives

R2 is not aware of P2

R2 \ R1	A1	A2	N	
A1	0	–	0	
A2	–	–	–	
N	2	–	0	1

R2 is aware of P2

R2 \ R1	A1	A2	N	
A1	0	4	0	
A2	5	3	3	11/3
N	2	4	0	

R1 doesn't have information wrt R2's model of it

[0.5, 0.5]

[1/3, 1/3, 1/3]

Different perspectives on coordination in MAS

Designer's interest in coordination

"Coordination is governing interaction" (Wegner)

Micro-level design

Macro-level design

Multiple agent designers

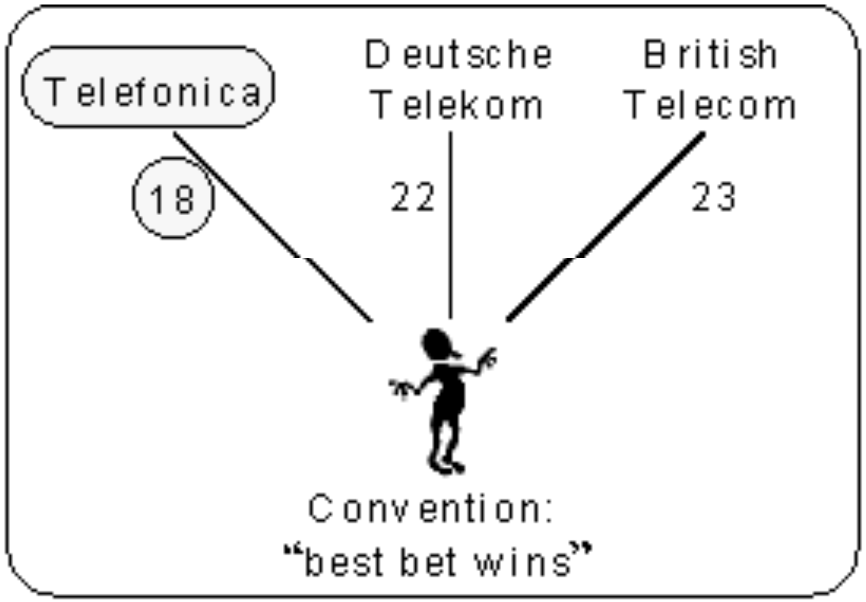
- **"open" system**
- **no direct control on agent behaviour**

Single agent designer

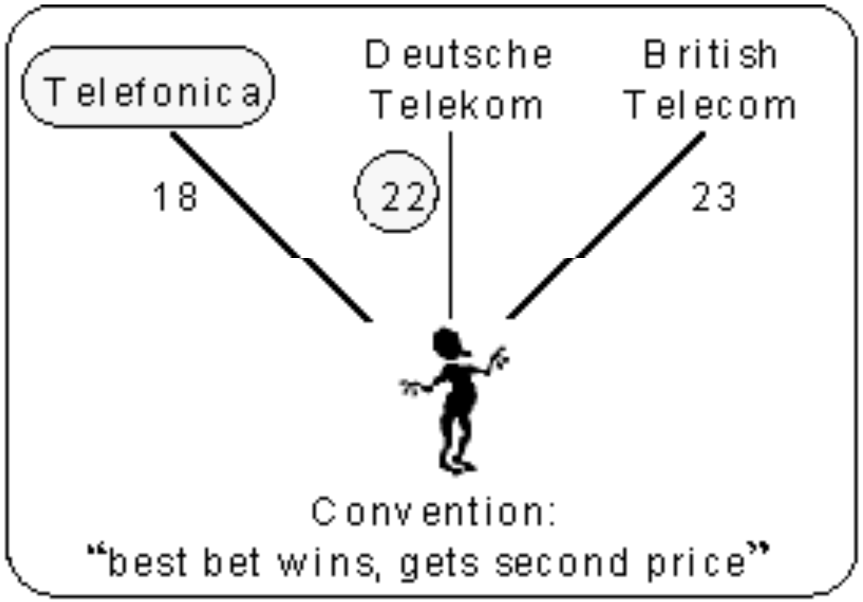
Coordination in open systems: macro-level

Example (*Zlotkin & Rosenschein*):

- **Convention 1** ("standard" auction):
  - **best** bid wins gets **first price**
  - problem: promotes **strategic behaviour**



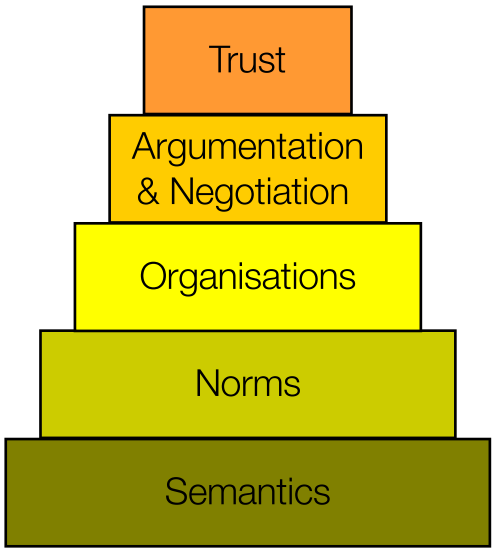
- **Convention 2** (Vickrey auction):
  - **best** bid wins gets **second price**
  - **no incentives** for strategic behaviour



Agreement Technologies

Vision and strands of research

- Large-scale **open distributed systems**: Area of enormous social and economic potential
- **Vision**: A paradigm for next-generation open distributed systems, based on the concept of **agreement** between **computational agents**.
- Fundamental and applied research:
  - ✓ **Semantics**: Semantic mismatches & alignment of ontologies
  - ✓ **Norms**: Specify and verify constraints on agreement
  - ✓ **Organisations**: Structure the processes of reaching agreements
  - ✓ **Argumentation & Negotiation**: Reach agreements that respect the constraints imposed by norms and organisations
  - ✓ **Trust**: Summarise the history of agreements and agreement executions in order to build long-term relation



COST Action on Agreement Technologies

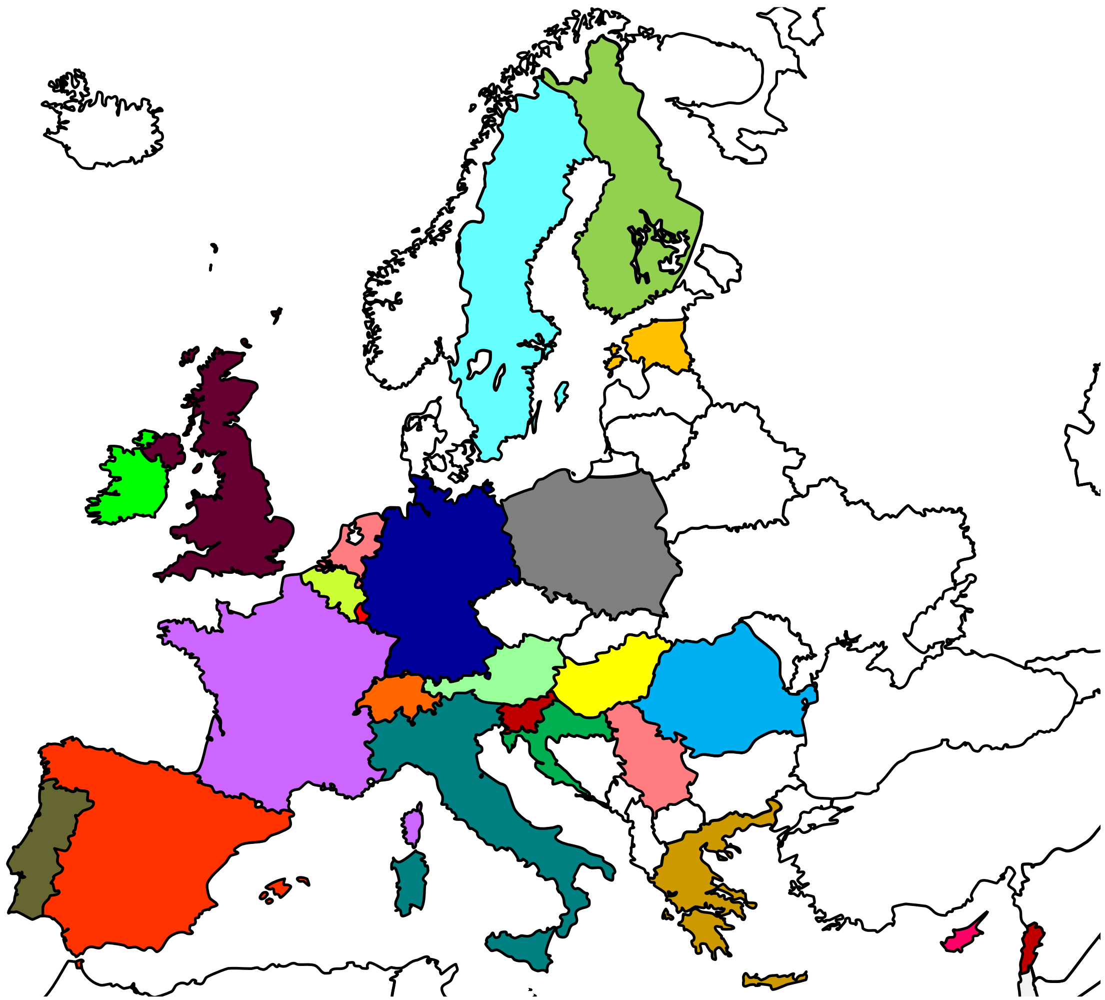
- COST Action IC0801 on "**Agreement Technologies**"
- Overall **mission**:
  - ✓ *"to support and promote the* ***harmonization*** *of nationally-funded* ***high-quality research*** *towards a new paradigm for next generation distributed systems based on the notion of agreement between computational agents..."*
- **Networking** activities: coordination of research & training

COST Action on Agreement Technologies

Members and Activities

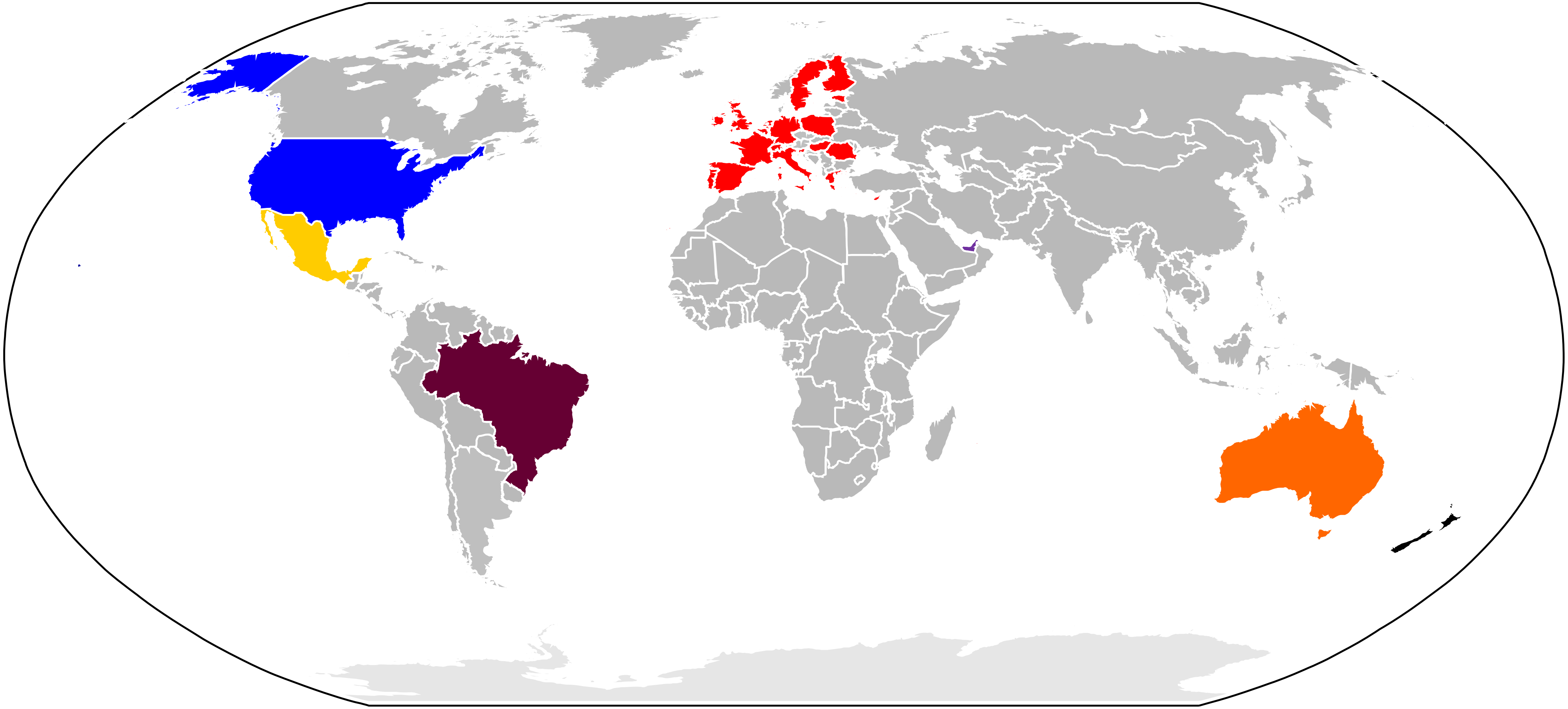
- Action members:
  - ✓ **25** COST countries
  - ✓ **8** non-COST institutions
  - ✓ **190+** WG members (~50% early-stage researchers)

- Activity:
  - ✓ **95** Short-term research visits (**STSMs**)
  - ✓ Co-organisation / contribution to **30+** WS and 6 Training Schools
  - ✓ 20+ events with Action label
  - ✓ ...



COST Action on Agreement Technologies

COST Countries and non-COST Institutions



Applications of AT

Regulation of large-scale open systems

- **Example: Traffic management**
  - ✓ **Large number of self-interested driver agents**
  - ✓ **Traffic norms and management devices regulate the system**
  - ✓ **Smarter vehicles and infrastructure open up a whole range of new opportunities**

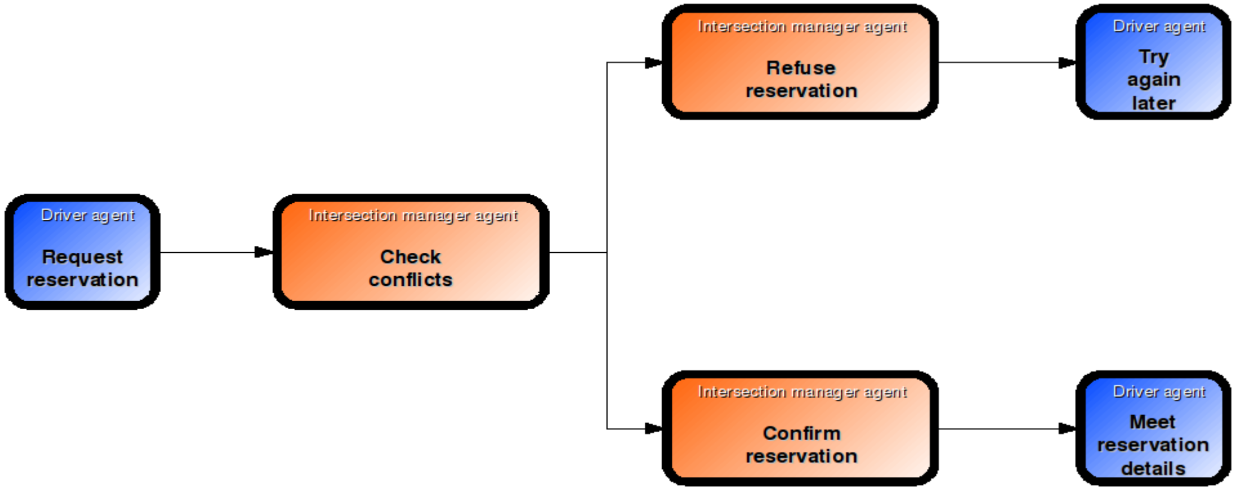
A market-inspired approach for intersection management in urban road traffic networks

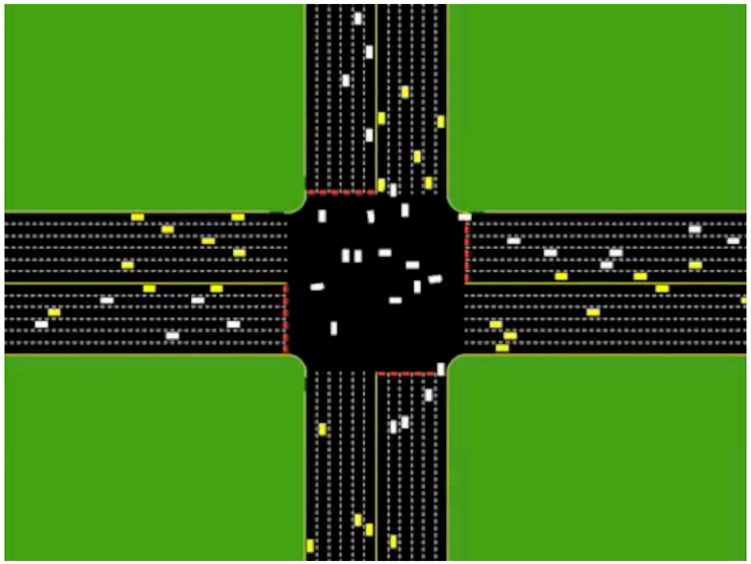
Published in:
Journal of Artificial Intelligence Research 14: 1314-1322 (2012)

Reservation-based traffic management

- Management of intersections:
  - ✓ Fixed traffic “norms”: e.g. right before left
  - ✓ Self-organised: possibly risky and slow
  - ✓ **Infrastructure controlled**: e.g. traffic lights

- Reservation-based intersections
  - ✓ Introduced by Dresner and Stone (U Texas)
  - ✓ **Intersection manager** agents: control the space of an intersection and schedule the drivers’ transit through it
  - ✓ **Driver agents:** operate their assigned vehicle and request reservation of time-space slots at the intersection

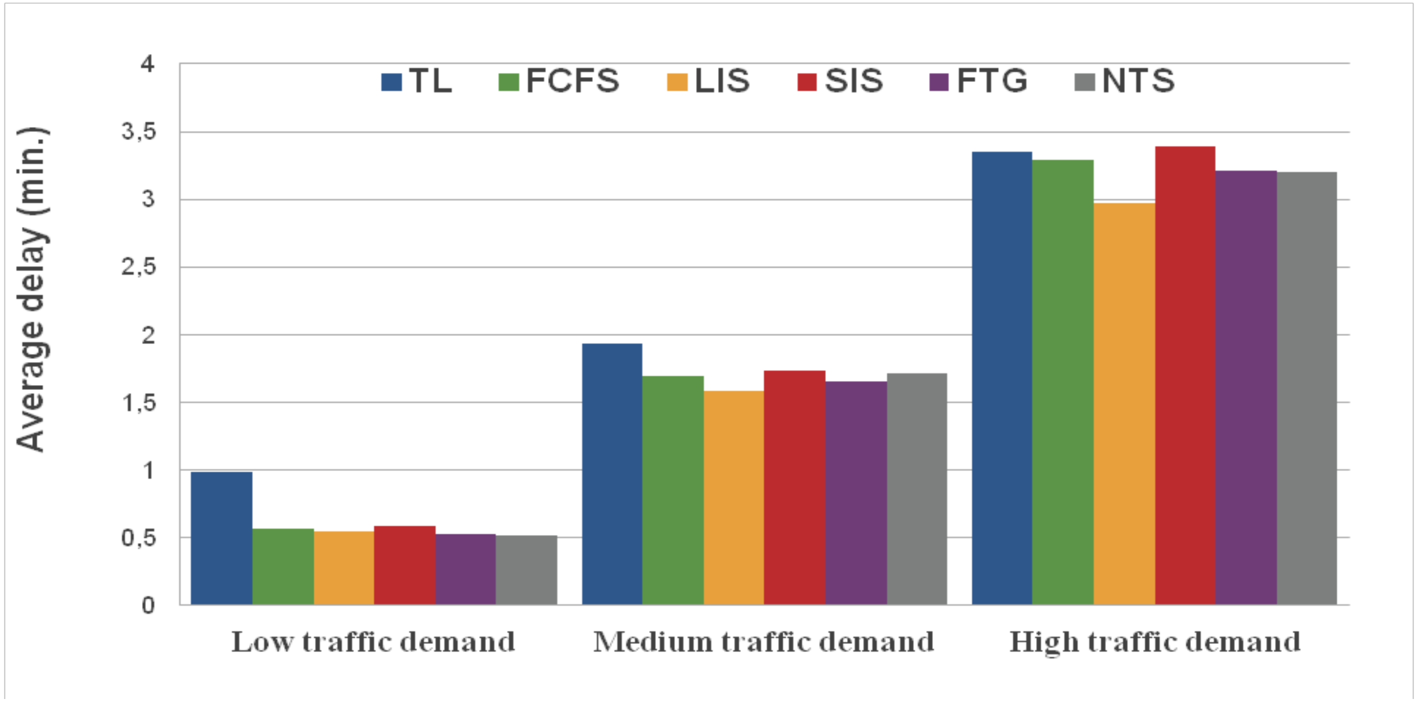




Single Intersection

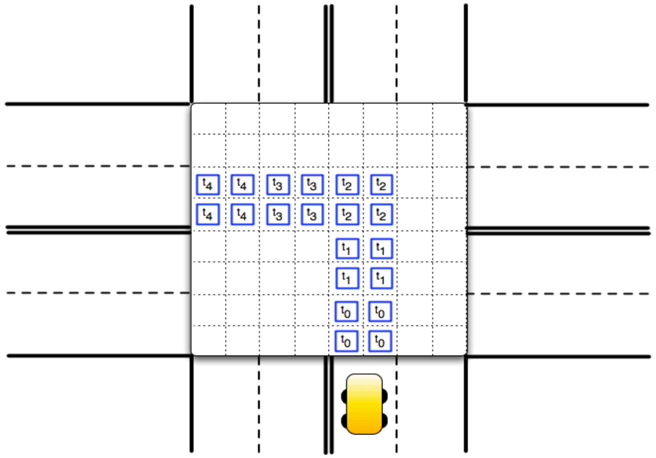
Alternative slot assignment strategies

- Manage networks of reservation-based intersections:
  - ✓ **external** agents: **individually rational** driver agents
  - ✓ **organisational** agents: set of IMs jointly **biasing** the choices of external agents
- Intersection manager slot assignment strategy:
  - ✓ Comparison: Traffic lights (TL) / FCFS (Dresner-Stone) / Adversarial Queuing Theory
  - ✓ Result: Advantage over TL is the more significant the lower the demand

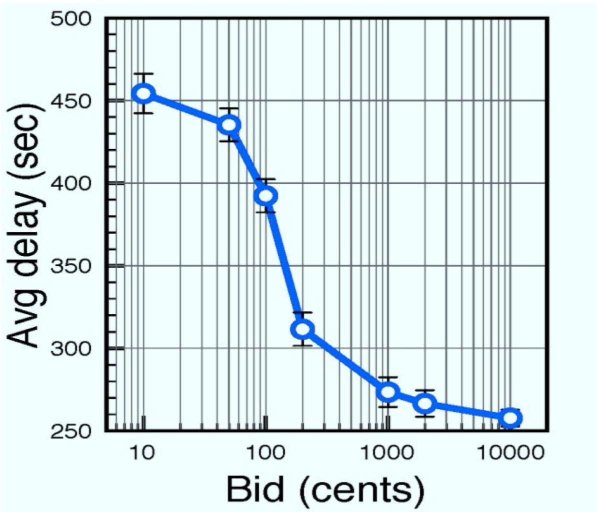


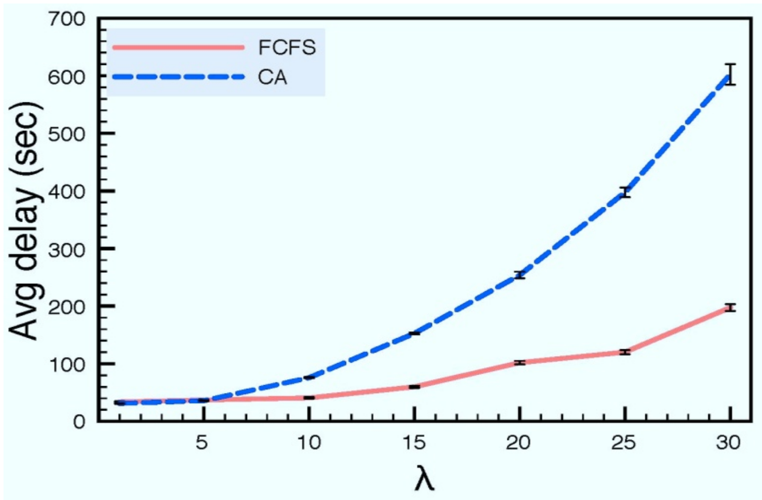
Single Intersection
Combinatorial Auction Strategy

- Combinatorial **Auction** strategy (**CA**):
  - ✓ Goal: Assign slots based on the drivers' **needs**
  - ✓ Bids for **bundles** of time-space-chunks
  - ✓ Extend the **protocol**: agents that lose in an auction need to slow down and try again later



- Results:
  - ✓ Inverse relation between bid value and **individual delay**
  - ✓ Social cost: increase in **average delay** (especially at high densities)





Multiple Intersections
Competitive Traffic Assignment

- Idea:
  - ✓ Travel times (and, in particular, the social cost of CA) increase above certain densities
  - ✓ Divert ("assign") traffic flows to **less used intersections** (and possibly longer routes)
    - IMs charge a price for vehicles to pass through their intersections
    - Drivers change their routes on-the-fly, considering the price fluctuations

- Competitive traffic assignment (CTA): market-based coordination
  - ✓ IMs compete for traffic to assure a desired density (**supply**)
  - ✓ IM price update tends to **minimise excess demand** (approximates market equilibrium)

Minimum price *Current price* *Excess demand*

$$p^{t+1}(l) \leftarrow \max\left[\delta, p^t(l) + p^t(l) \cdot \frac{z^t(l \mid p^t(l))}{s(l)}\right]$$

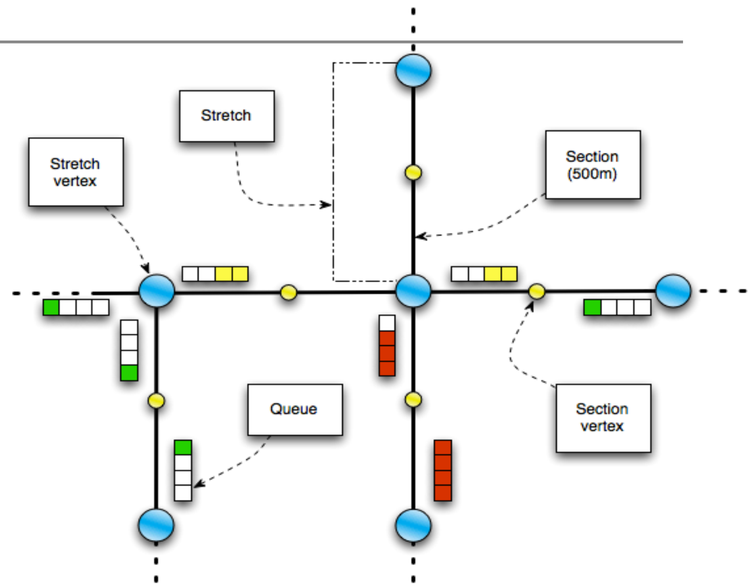
Supply

- Competitive traffic assignment (CTA-CA):
  - ✓ The minimum price is the **reserve price** of each IM's combinatorial auctions

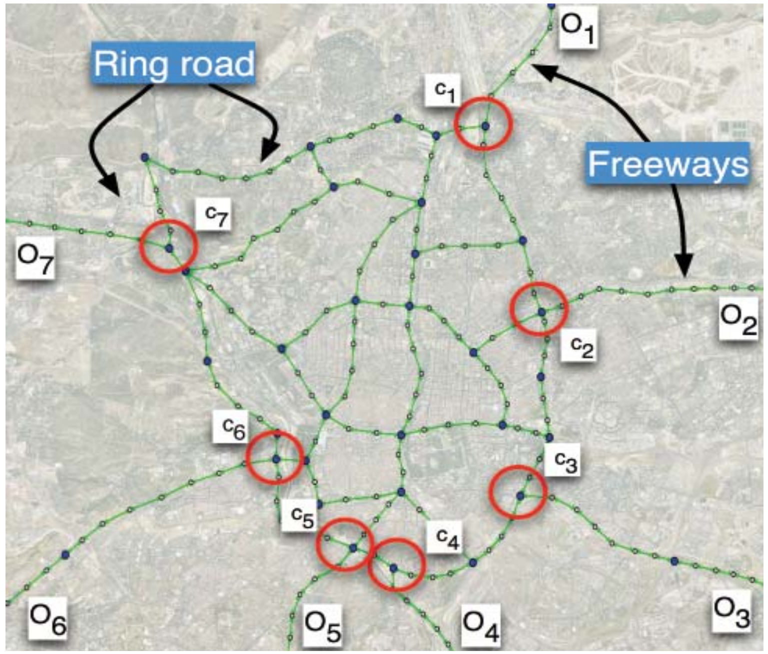
Multiple Intersections

Simulation Environment

- Hybrid microscopic-mesoscopic simulator
  - ✓ **mesoscopic** model (based on Schwerdtfeger): simulate traffic flow along the **links**
  - ✓ **microscopic** model (based on Nagel-Schreckenberg): simulate traffic flow inside the **intersections**
  - ✓ A queuing system manages the boundary



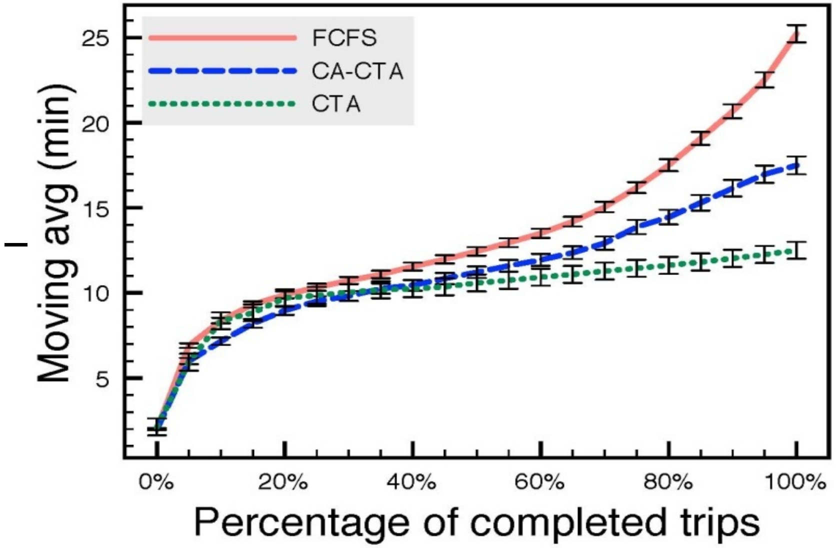
- Experimental set-up:
  - ✓ **Topology** based on Madrid urban road network
    - Freeways connected by ring-roads
    - Dark vertices: reservation-based intersections
    - 7 origins/destinations (O_1 to O_7)
    - 7 critical intersections (c_1 to c_7)
  - ✓ Driver model: choose the shortest route you can afford
  - ✓ O-D Matrix representing **morning peak** load



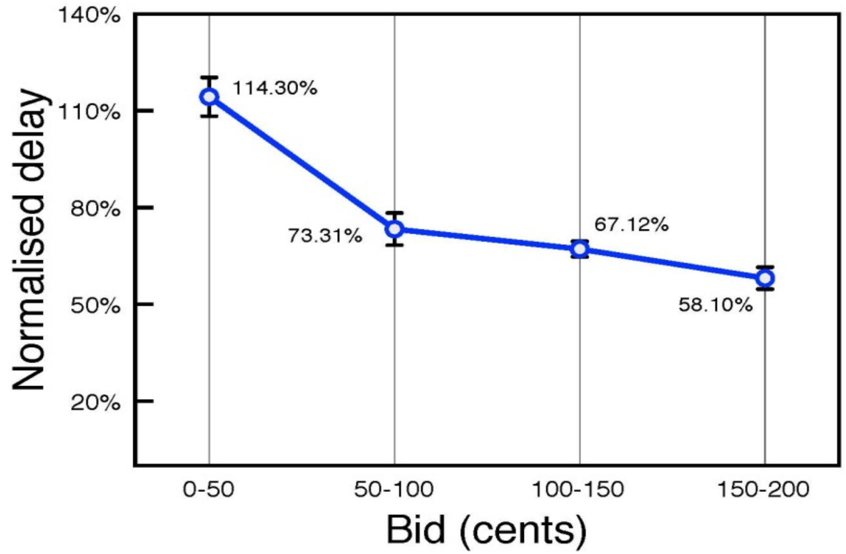
Multiple Intersections

Simulation Results

- At **network level**: average travel time
  - ✓ **CTA**: traffic assignment – best
  - ✓ **CA-CTA**: traffic assignment with combinatorial auction – pays a "social cost" compared to CTA
  - ✓ **FCFS** (no traffic assignment): worse than CA-CTA

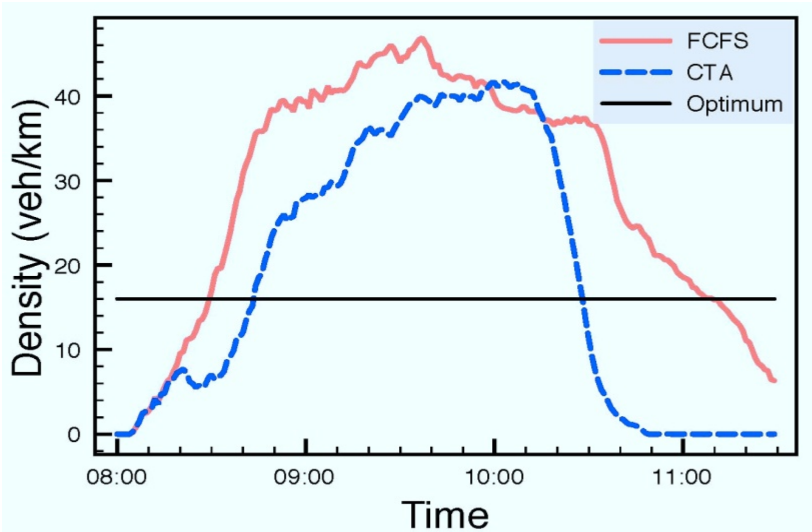


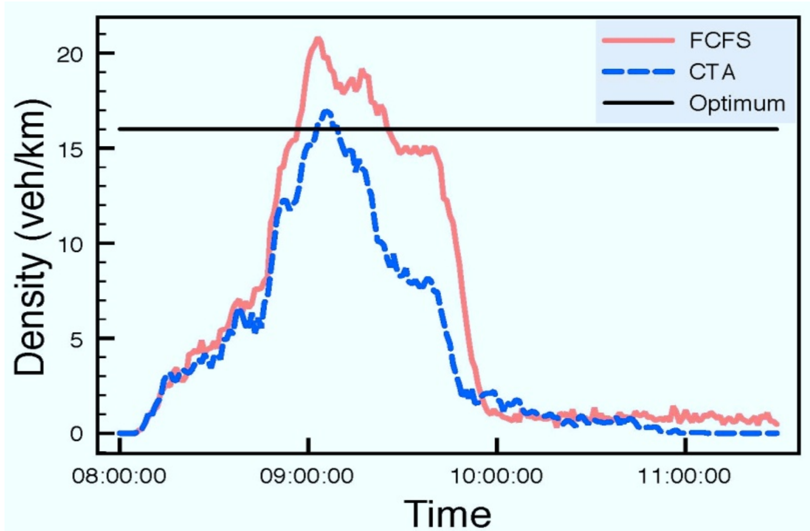
- At intersection level (CA-CTA)
  - ✓ Inverse relation between delay and bid value still holds
  - ✓ **Reduced traffic density** at intersections (especially at highly demanded ones): accounts for CA-CTA outperforming FCFS

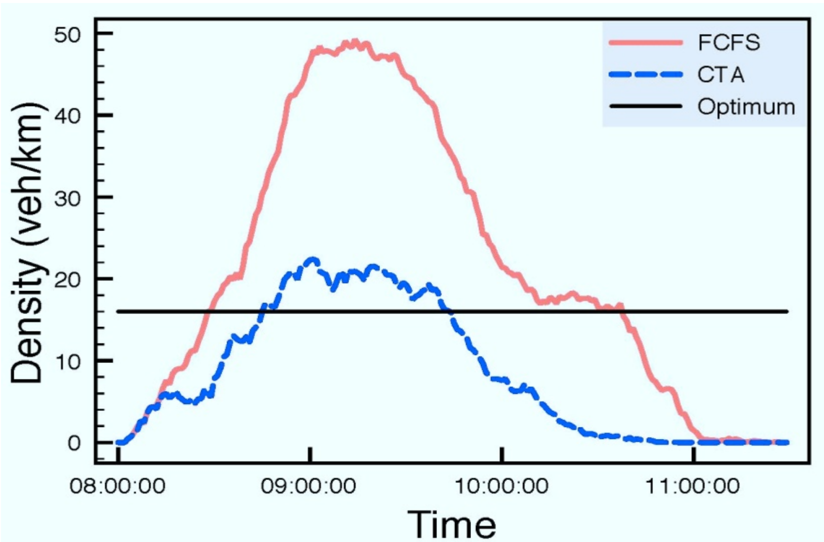


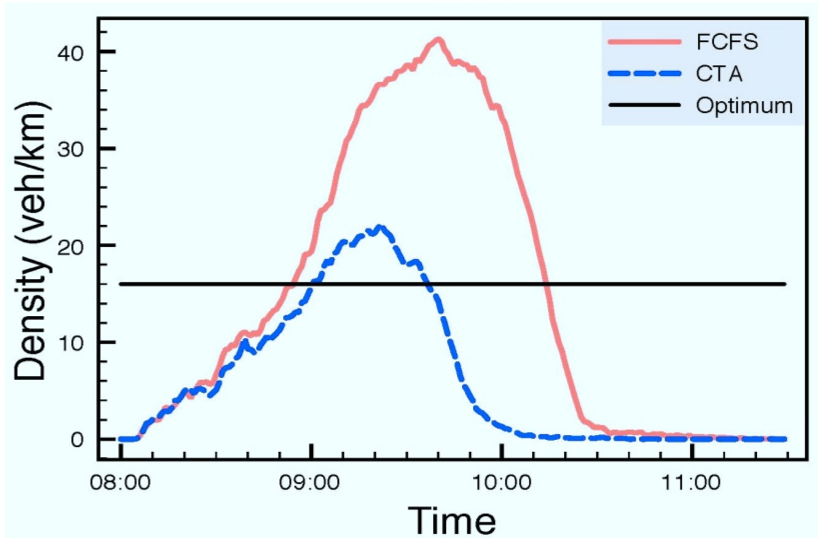
Multiple Intersections

Density of highly demanded intersections



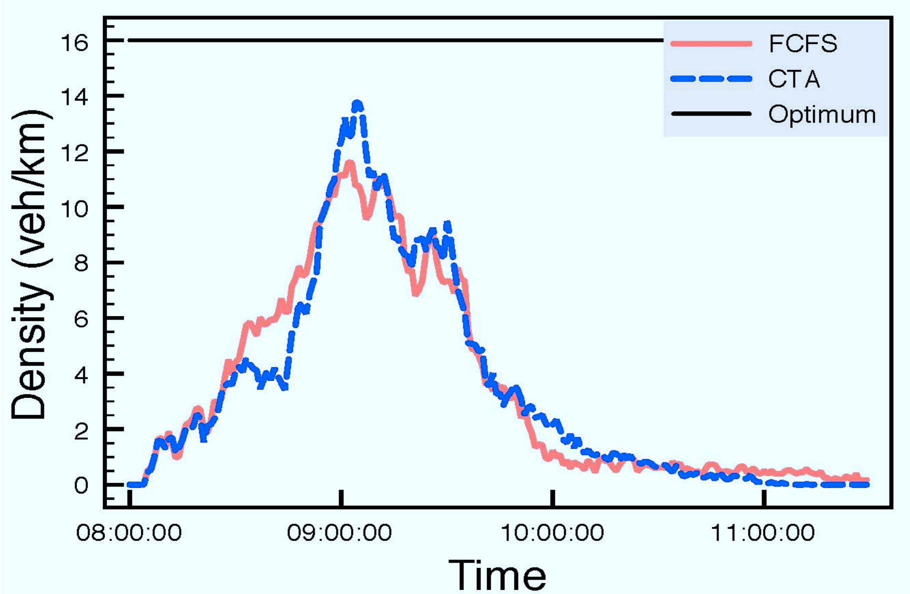


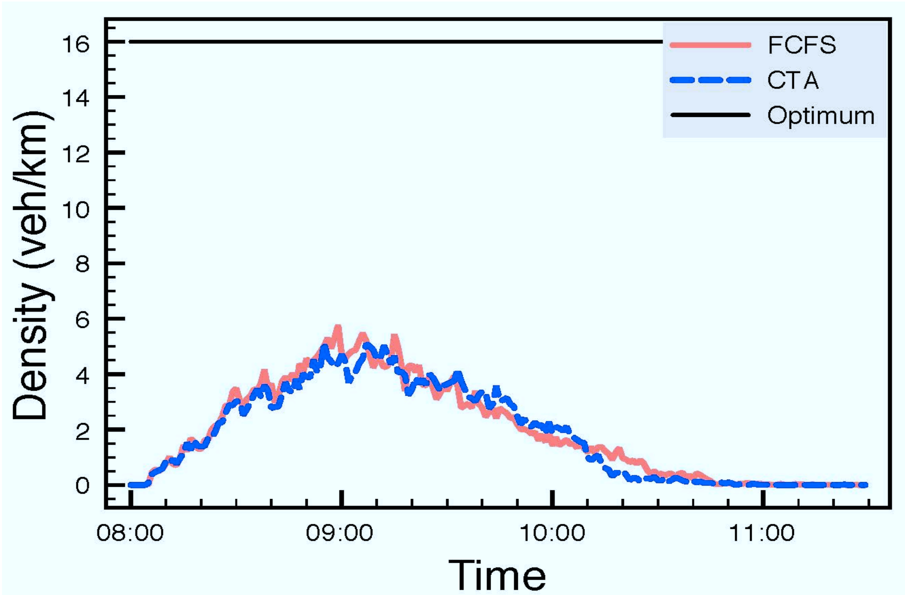


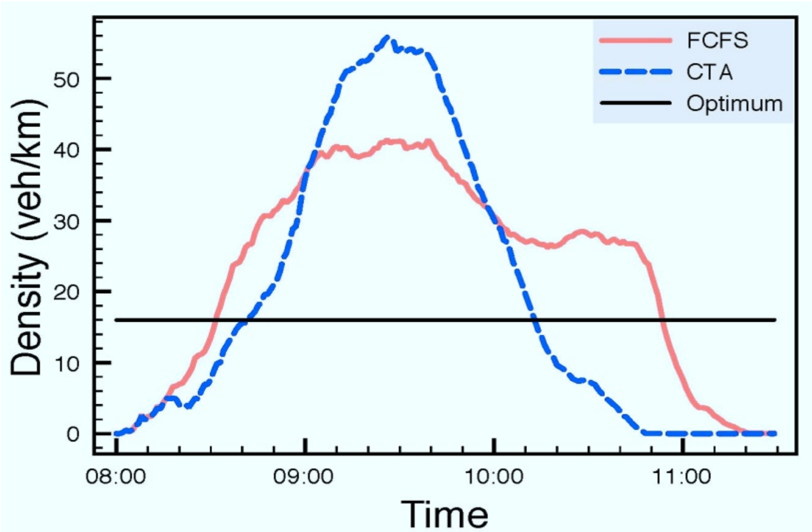


Multiple Intersections

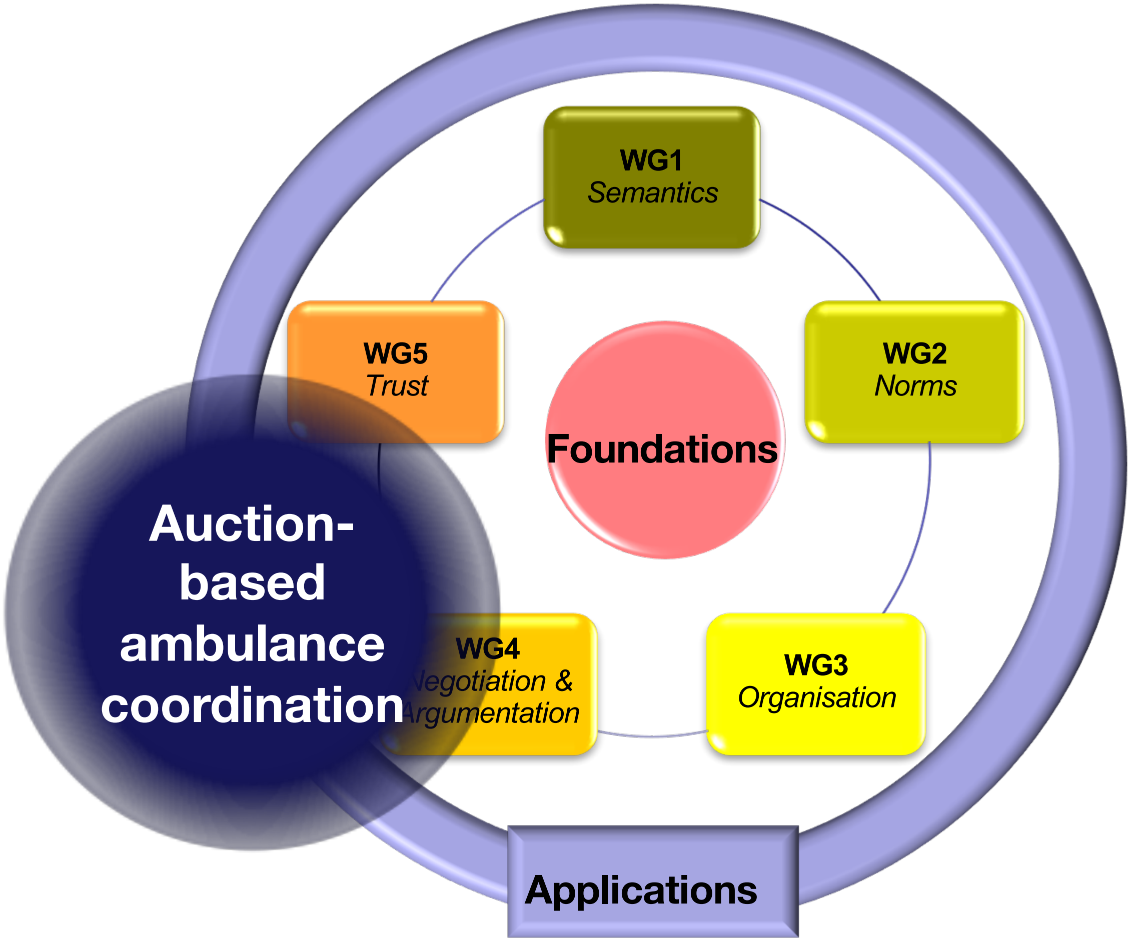
Density of other intersections







Dynamic Coordination of Ambulances for Emergency Medical Assistance Services



Published in:
Knowledge-based Systems 70: 268-280 (2014)

Emergency Medical Services in Madrid

- Autonomous Region of Madrid (Spain)
  - ✓ Surface: 8.021,80 km^2
  - ✓ 6.489.680 inhabitants (2011)
  - ✓ 26 Hospitals

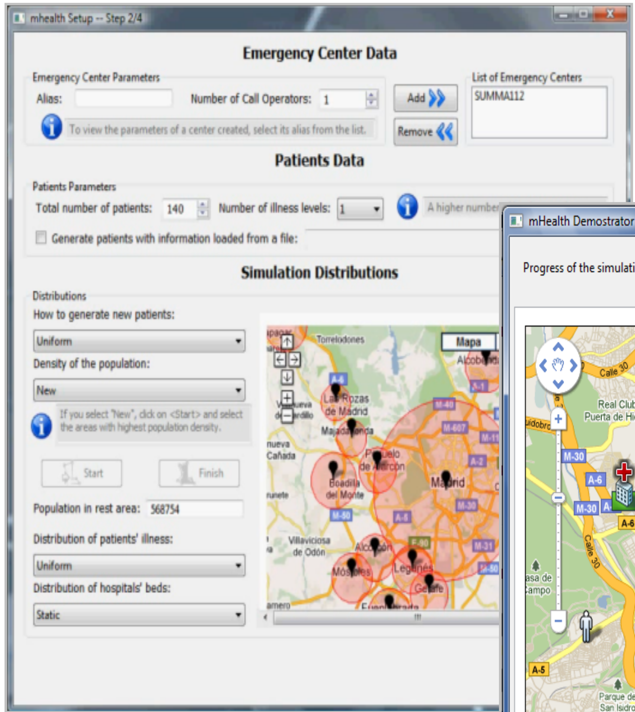
- SUMMA 112:
  - ✓ Emergency Medical Service of the Madrid Region
  - ✓ 26 Ambulances with **Advanced Life Support** (ALS)
  - ✓ Other means: helicopters, BLS ambulances, patient transport ambulances
- Services (2007):
  - ✓ 1.134.873 calls dispatched (> 3100 per day)
  - ✓ 418.561 ambulance services (> 1145 per day)
  - ✓ 41.807 **level-0 services** (require ALS ambulances) (> 110 per day)

SUMMA 112
SaludMadrid
Comunidad de Madrid

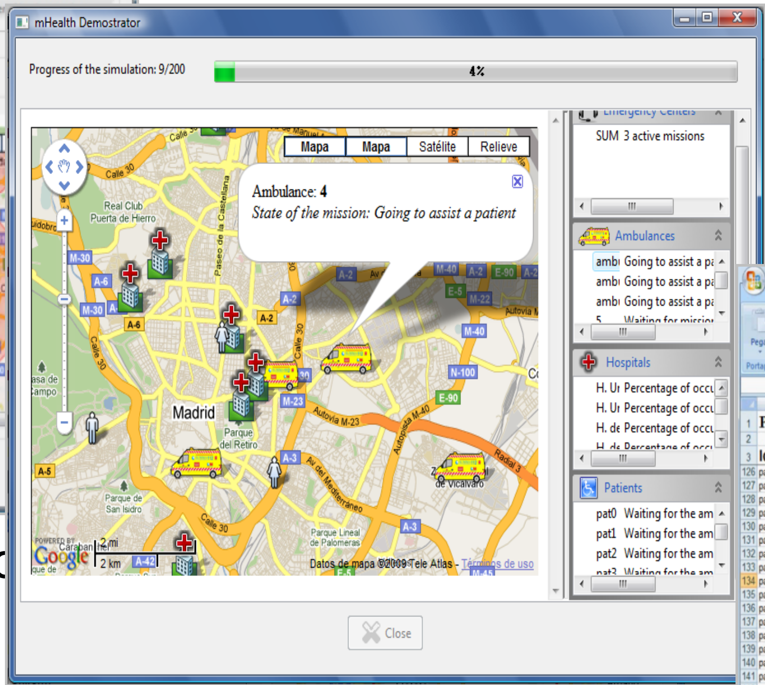
Emergency Medical Services in Madrid

- SUMMA vehicle dispatch strategy:
  - ✓ Idle ambulances wait at their bases (hospitals)
  - ✓ If a new emergency patient is reported…
    - Select the idle ambulance **closest** to its location
    - Select the hospital **closest** to its location
  - ✓ …in a **first come first served** manner
- Key Performance Indicator: **Patient Waiting Time (PWT)**
- Several approaches for lowering PWT
  - ✓ Ambulance **re-assignment: Auction**-based optimisation
  - ✓ Ambulance **positioning**: **Self-organised** coverage
  - ✓ Ambulance **profiling**: **Trust** mechanism
  - ✓ ...

Madrid EMA Simulator



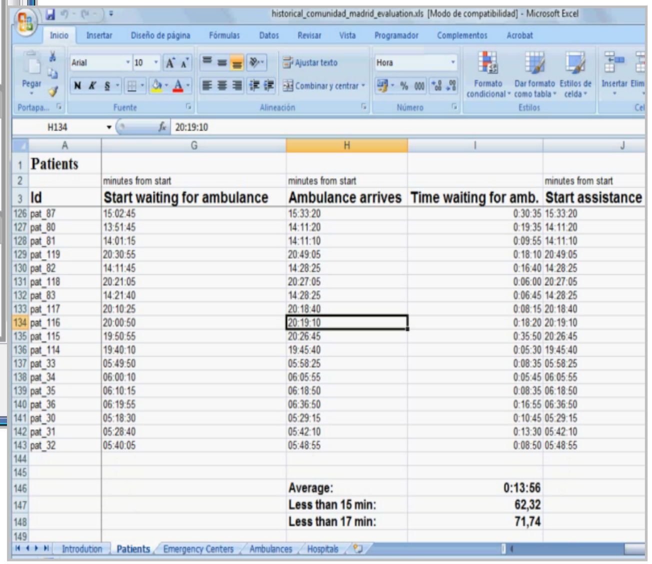
Configuration Module



Simulation Module

Various simulations

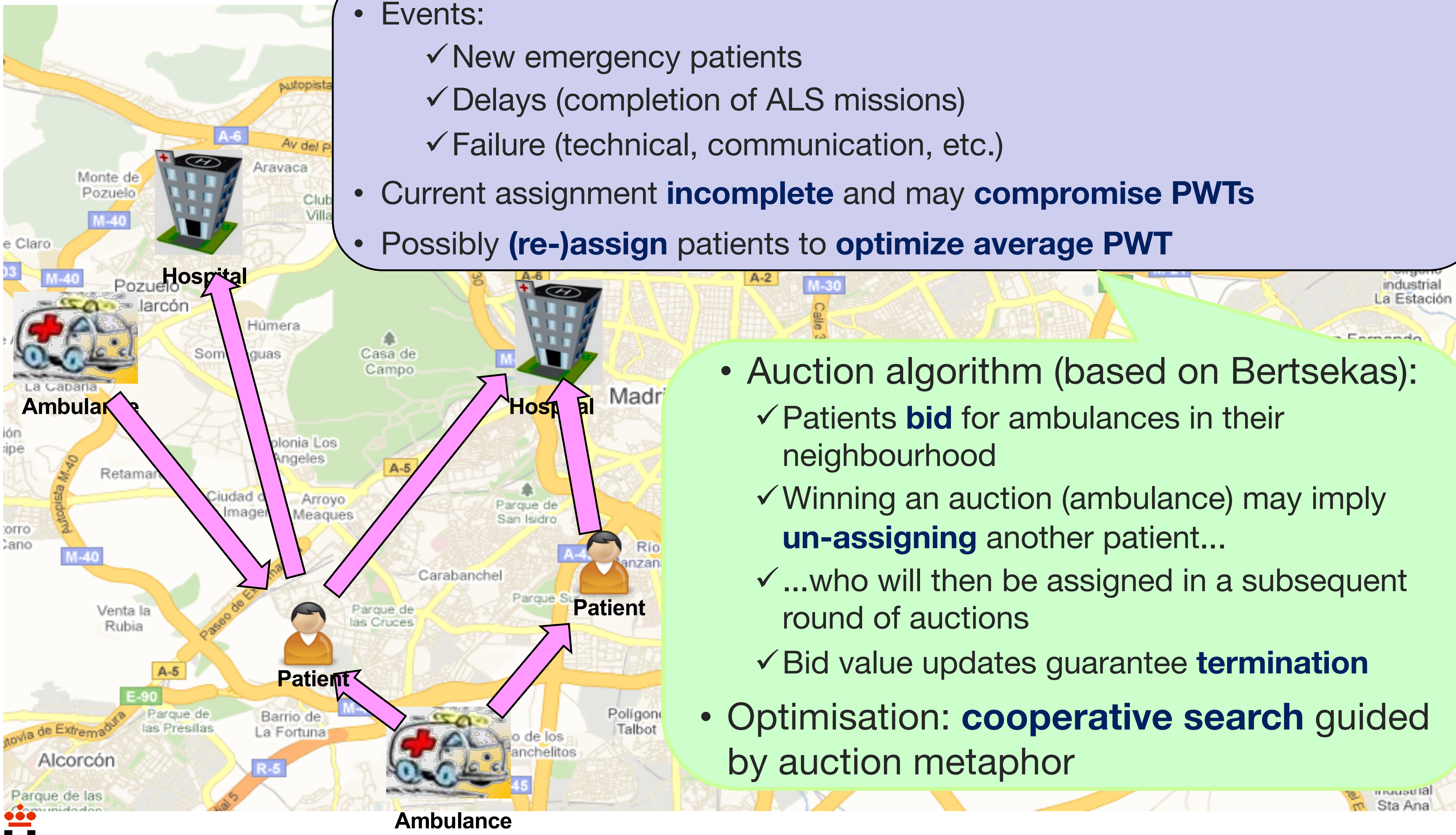
- ✓ SUMMA Historical Data
- ✓ “Worst case”:
  - January 12th, 2009
  - 224 level-0 (ALS) patients



Evaluation Module

Auction-based ambulance re-assignment

- Events:
  - ✓New emergency patients
  - ✓Delays (completion of ALS missions)
  - ✓Failure (technical, communication, etc.)
- Current assignment **incomplete** and may **compromise PWTs**
- Possibly **(re-)assign** patients to **optimize average PWT**



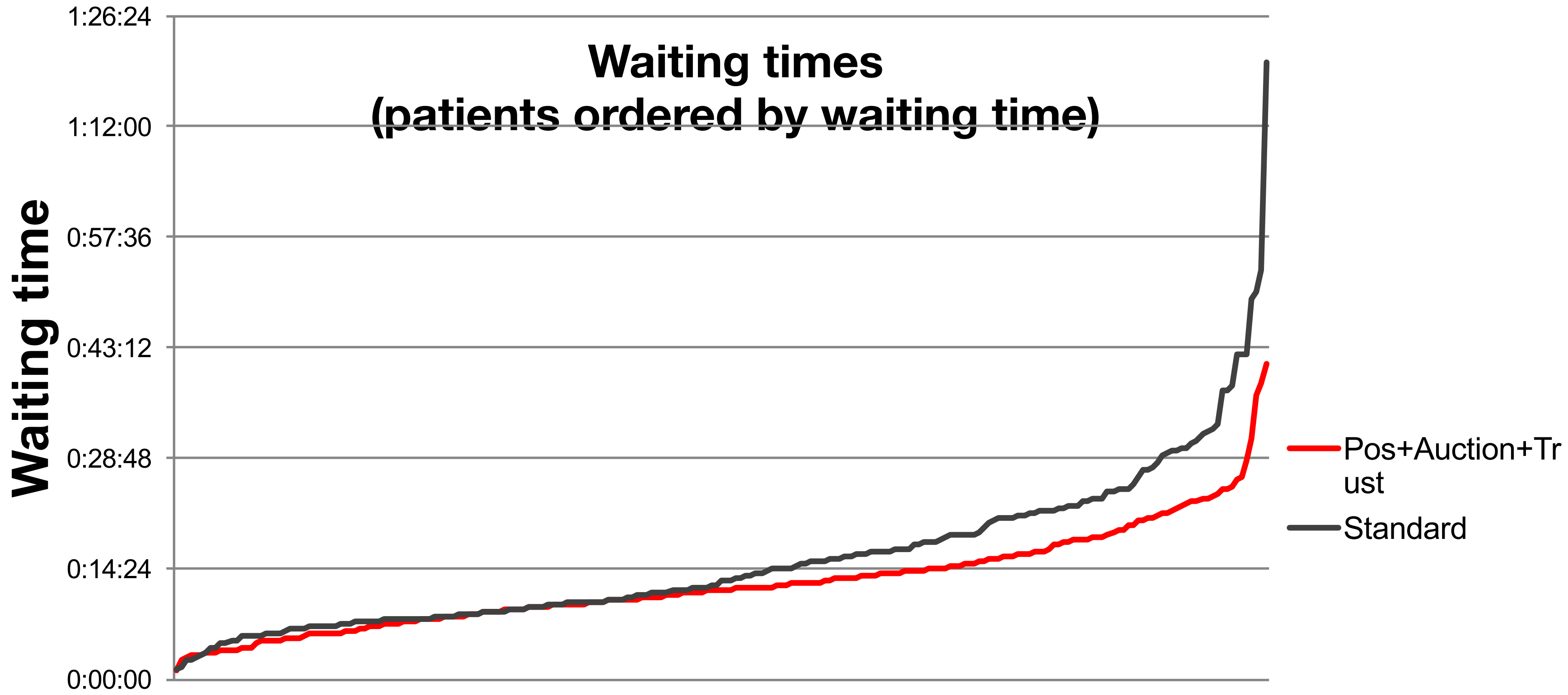
- Auction algorithm (based on Bertsekas):
  - ✓Patients **bid** for ambulances in their neighbourhood
  - ✓Winning an auction (ambulance) may imply **un-assigning** another patient...
  - ✓...who will then be assigned in a subsequent round of auctions
  - ✓Bid value updates guarantee **termination**
- Optimisation: **cooperative search** guided by auction metaphor

Self-organised coverage

Video:

Ambulances move to optimal positions

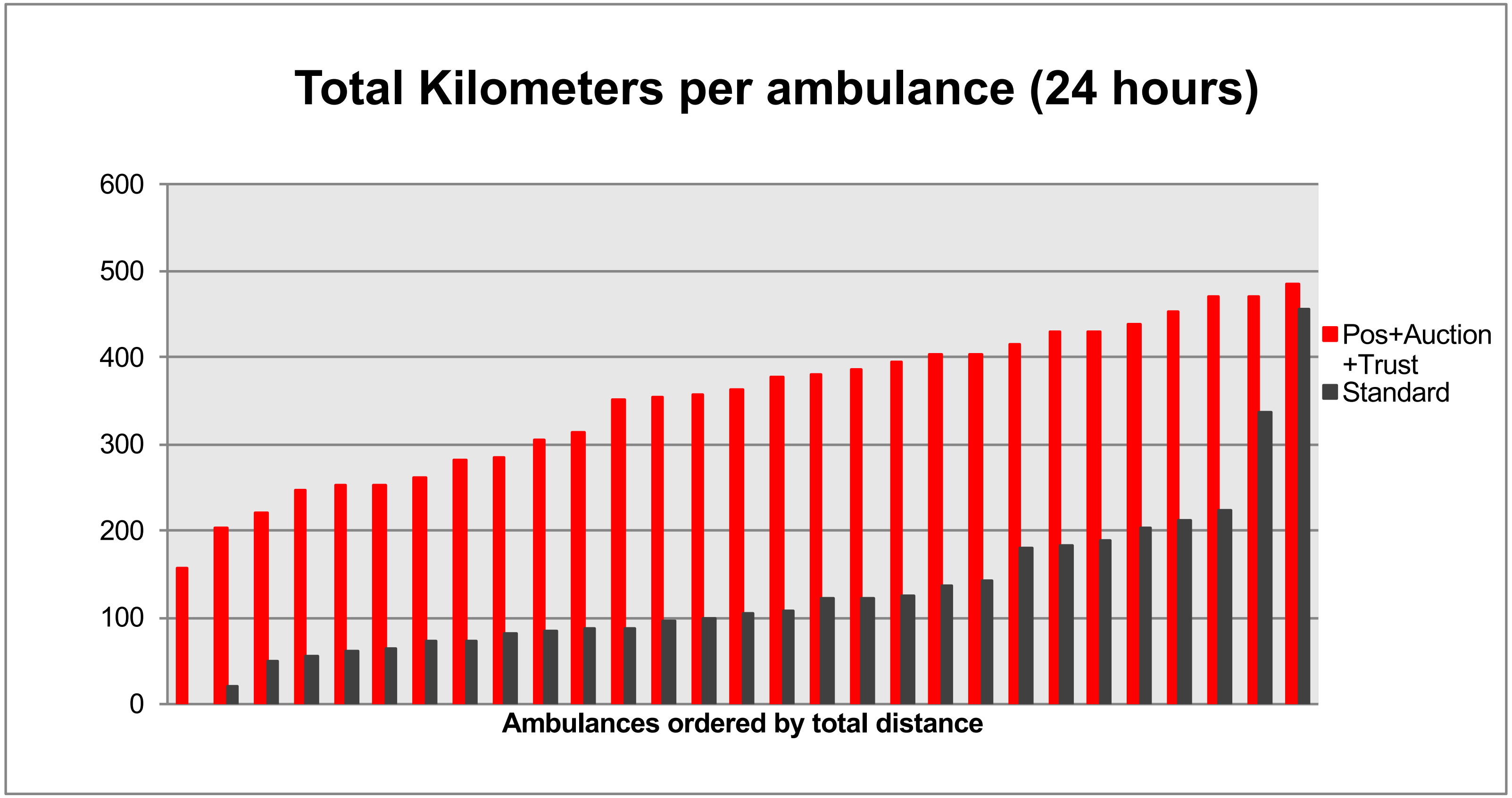
Results (12/01/2009 Madrid)



Current strategy: 15:35 min

Pos+Auction+Trust strategy: 12:40 min

Results (12/1/2009 de Madrid)



Current strategy: **130,2 km**

Pos+Auction+Trust strategy : **350,0 km**

Conclusions

- Overview of Coordination and Agreement Technologies
  - ✓ Different perspectives on coordination
  - ✓ **5 key areas** of AT and their relation
  - ✓ Research coordination through **COST Action**
- Examples of Smart Traffic AT applications
  - ✓ **Market-based** intersection management
  - ✓ **Auction-based** ambulance coordination

Conclusions

- Outlook
  - ✓ Advances in the **integration** of the key technological areas
  - ✓ Other "**Smart Traffic**" problems:
    - **Fleets** as *Cyber-Physical Systems*,
    - **Platoons** of intelligent vehicles,
    - …
  - ✓ "**Smart Energy**" problems:
    - Plug-in Electric Vehicle (**PEV**) Charging
    - User participation in **DSM**,
    - Demand-Response through **coalition formation**,
    - …
  - ✓ Other domains: **District Heating**,…

Outlook

- **Book** on Agreement Technologies
  - ✓ Springer's Law, Governance & Technology series (LGTS)
  - ✓ Published 2013
  - ✓ **State of the Art** in Agreement Technologies
  - ✓ VII parts, 37 chapters, 645 pages

- **Conference series** on AT
  - ✓ **AT-2012**: October, Dubrovnik (Croatia)
  - ✓ **AT-2013**: August, Beijing (China)
    - ▪ Co-located with IJCAI-2013
  - ✓ **AT-2015**: December, Athens (Greece)
    - ▪ Co-located with EUMAS-2015
  - ✓ **AT-2016**: December, Valencia (Spain)
    - ▪ Co-located with EUMAS-2016

Universidad Rey Juan Carlos

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A Playground for Agreement Technologies

Work in collaboration with

Holger Billhardt

Moser Fagundes

Alberto Fernández

Marin Lujak

Radu-Casian Mihailescu

Matteo Vasirani

Carmona, 16/06/2016