A Cooperative Game in Urban Mobility Systems

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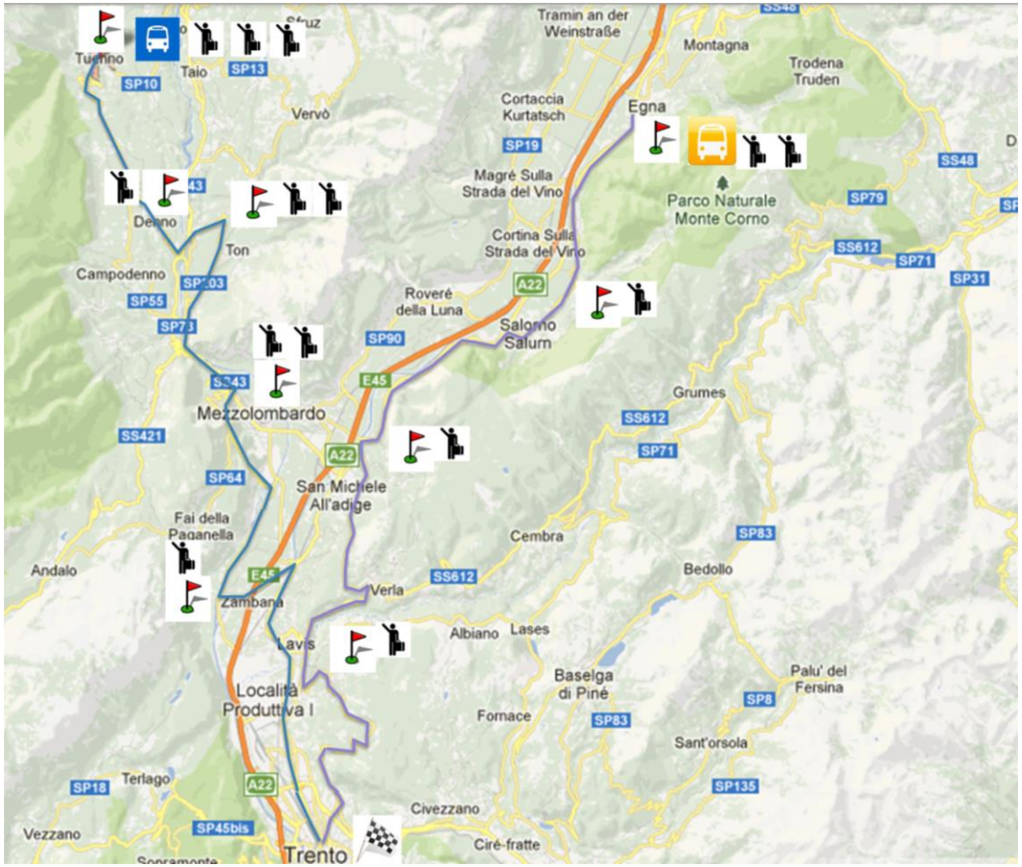
Outline

- Smart City
- Urban Mobility System
- The ALLOW Ensembles Model
- Game Theoretic Approach
- Conclusions and Future Work

Smart City

- Passengers
  - Objectives
  - Preferences
  - Utility functions
- Transportation companies
  - Dynamic Routes
  - Collective Routes
  - Adaptive
- Environmental Changes
  - Traffic
  - Breakdowns
- Urban Mobility System
  - High service quality
  - Cost Optimization
  - Eco friendly



Urban Mobility System

- A multi-modal transport system
  - Supervises three means of transportation: Regular bus, FlexiBus and Car pooling
  - Smart services
    - provide the passengers with a universal tool for planning complex trips involving more than one modes
    - creates integrated notification and support system
    - exploit related services on the go (ticket purchase, car pool reservation, …)

Allow Ensembles, 7th Framework EU FET project

FlexiBus Scenario

- A FlexiBus system manages and operates FlexiBuses for different routes at the same time
- A route is a set of pick-up points
- We consider two phases in the lifecycle of a route:
  - The pre-booking phase: a route is going to be executed if a certain number of requests is reached until a certain deadline
  - The execution phase: the route is bound to start or it has already started
- The pick-up points of a route are bound to change at the execution phase
  - Add a pick-up point due to a new request
  - Remove a pick-up point after a cancellation

FlexiBus Scenario: Entities

- **Passengers**
  - Make requests specifying origin, destination, desired arrival time and other preferences
- **Bus driver**
  - is assigned a precise route
  - communicates with an assigned **Route Manager** to ask for the next pick-up point and to communicate information
- **FlexiBus Manager**
  - collects necessary information (i.e. traffic, closed roads, events, etc.) and available resources (i.e. available buses)
  - generates alternative routes
- **Payment Manager**

Entity’s Utility

- The ***utility*** of an entity is a measure of satisfaction experienced by the entity for using a service (e.g. participating in a route)
  - Calculated by the entity according to
    - Its preferences (that are publicly known)
    - Private information
  - Entities make choices to maximize their utility

Entity's Utility (Example)

- Consider Peter sending the request (Destination: Lions square, arrival time: 21.30) to Urban Mobility System with preferences
  - Non-smoking bus (demanded)
  - Window seat (desired)
- Consider the following candidate routes
  - Route A (at a cost of 10 Euros): non-smoking bus, window seat
  - Route B (at a cost of 12 Euros): non-smoking bus, aisle seat
  - Route C (at a cost of 7 Euros): non-smoking bus, aisle seat
- Route A has higher utility to Peter than Route B but not clear for Route C (it depends on how Peter values money)

A model of Collaboration in a FlexiBus Route

- We consider a route between an origin and a destination as a number of pick-up points assigned to a number of passengers that share a common FlexiBus in order to decrease transportation costs and benefit from cooperating
- Objectives:
  - Identify and measure the collective benefits they get by sharing a common mode of transportation
  - Determine travel costs so that all passengers benefit from cooperation

Cooperative Games - Basics

- A **cooperative game** is a pair (N, u), where
  - N is a finite set of players
  - $u\colon\ 2^N \rightarrow R$ associates with each ***coalition*** $S \subseteq N$ a real-valued payoff $u(S)$ that the coalition's members can distribute among themselves (characteristic function)
  - We assume that $u(\emptyset) = 0$
- Focus is on what groups of agents, rather than individual agents, can achieve

Cooperative Games - Basics

- Cooperative game theory is used to answer two fundamental questions:
  - Which coalition will form?
  - How should that coalition divide its payoff among its members?

- **Super- additive game**
  - $\boldsymbol{u(S \cup T) \geq u(S) + u(T)\ for\ all\ S, T \subset N : S \cap T = \emptyset}$
  - The value of two coalitions will be no less than the sum of their individual values
  - The grand coalition has the highest payoff among all coalitions

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Cooperative Games - Basics

- Why use cooperative games
  - Helpful tool **if** performance of an intelligent system and its entities can be improved when several players cooperate

A Cooperative Game in FlexiBus – Static Case

- Assumptions
  – Consider a FlexiBus route with predefined origin, destination and intermediary pickup points
  – The number of passengers and the respective pickup points are known
- We define a cooperative game to model **collectiveness** of passengers that results in
  – Improving their utility through cost sharing

A Cooperative Game in FlexiBus – Static Case

- Definition of the game
  - **Players**: set *N* of passengers of the route who make coalitions and create a cost (the cost of the route) that is to be allocated to them according to their utilization of the route
  - **Cost function** c: $2^N \rightarrow \mathbb{R}$, where $c(S)$ is the cost of the route used by the set $S \subseteq N$ of the passengers

$$c(S) = F + \sum_{i=1}^{|S|} n_i G$$

where *F*,*G* are constants and n_i is the number of pickup points through the origin and destination of the i^th passenger in S

A Cooperative Game in FlexiBus – Static Case

- Objectives
  1. Determine the coalition that will eventually be formed
  2. Allocate cost incurred for final coalition

- Game outcome
  1. **Grand coalition**: all players have an incentive to cooperate
     - $c(S_1 \cup S_2) \leq c(S_1) + c(S_2), for\ all\ S_1, S_2 \subset N$
  2. Allocation $x(c) = (x_1, \ldots, x_n)$ of $c(N)$ among passengers:
     - $x_i(c) = \sum_{S \subset N, i \epsilon S} \frac{(|S|-1)!(n-|s|)!}{n!} [c(S) - c(S_{-i})]$ (SHAPLEY VALUE)

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A Cooperative Game in FlexiBus – Static Case

- Costs are shared in such a way such that individual users each have an incentive to cooperate
  - the cost of running one bus along a route is in principle cheaper than having two buses doing different routes between the same origin and destination points, and
  - the cost of having two passengers in the bus is less than the sum of the costs of having each one of the passengers alone in the bus.

A Cooperative Game in FlexiBus – Static Case

- The properties for allocation x are the following:

- $\sum_{i \epsilon N} x_i = c(N)$: feasibility of the grand coalition (costs are reimbursed)

- $x_i \leq c(\{i\})\ \forall i \epsilon N$: no player pays a higher price in the grand coalition than he would do independently

A Cooperative Game in FlexiBus – Dynamic Case

- The route consists of a predefined and fixed number of pick-up points.
- The passengers that will use the route are not known prior to the beginning of the route (a new passenger may enter the route during its execution)
- Passengers may not have the same destination
- The number of passengers is less than bus capacity, so that there is no need for occupying another bus

A Cooperative Game in FlexiBus – Dynamic Case

- During the execution of a FlexiBus we may have the following events:
  - New passenger request
  - Cancellation
  - Bus failure
- Each time an event occurs, a new cooperative game is played (repetition of the game)
  - Calculation of cost, time, utility for each passenger
  - Decisions taken according to new utility
- As more passengers come to the route, the individual costs tend to decrease but the estimated travel times tend to increase

A Cooperative Game in FlexiBus – Dynamic Case

1. New passenger request
   - Passenger sends a request to the FlexiBus manager
   - The FlexiBus manager calculates new travel times for all current passengers and checks for time constraints
     - If there is one or more violations, new request is rejected
     - If there is no violation
       - the cooperative game is repeated and the manager calculates new costs of all passengers
       - manager sends his availability including expected travel time and expected cost for the new request

A Cooperative Game in FlexiBus – Dynamic Case

- If new request is accepted
  - Cost of current passengers is decreased
  - Time for current passengers is increased
  - Utility of current passengers is increased for specific types of functions

For example:

$$u(t, \mathrm{c}) = w_1 \frac{e^{a(t_{max}-t)}}{e^{|t_{max}-t|}} + w_2 e^{-\frac{bc}{c_{max}}}$$

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A Cooperative Game in FlexiBus – Dynamic Case

2. Cancellation (FUTURE WORK)

- The passenger pays a reservation price
  - Costs of other passengers are not affected, times are decreased, utilities are increased
- The passenger pays nothing
  - Costs of other passengers are increased, times are decreased, utilities might increase or decrease

A Cooperative Game in FlexiBus – Dynamic Case

3. Bus failure (FUTURE WORK)

- The driver makes a request for another bus to the FlexiBus company
- The FlexiBus manager sends a set of alternatives to the passengers
  - Each passenger might choose a different solution
  - QUESTION: how can we combine passengers' individual preferences (COLLECTIVE UTILITY) to derive a common solution for all of them?