Simulation of Intelligent Transportation Systems: Different Perspectives

Intelligent Systems, Interaction and Multimedia Seminar

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Outline

- Simulation and ITS: different perspectives
- Policy and Incentive Designs Evaluation: a Social-Oriented Framework for Artificial Transportation Systems
- SUMO and JADE: an integrated platform for Artificial Transportation Systems
- Multi-Resolution Simulation of Taxi Services on Airport Terminal’s Curbside
- Scheduling Crane Operation in Rail-Rail Transshipment Terminals
- Multi-resolution simulation: An HLA-based application
Typical Context in ITS

- High number of vehicles
- Flexibility
- Urban degradation
- Reduction in Social Welfare

Intelligent Transport Systems
Efficient policies
Incentives for social coordination
Efficient mobility systems

Transportation Context

- Massive Metropolitan Development
  - Weak and unreliable urban transportation systems
  - Reduction of Social welfare and increase of costs

- Transportation Domain Inherent Complexity
  - Heterogeneous entities (although mostly we consider homogeneous)
  - Individual and Social behaviors

- ITS - Intelligent Transportation Systems
  - ATIS – Advanced Travelers Information Systems
  - Intelligent traffic management
  - Autonomous vehicles
  - But also social computing applications to support commuter decision
Simulation Perspectives in ITS
Modelling & Simulation in ITS to support solutions
- Real-System dynamics and Entities representation

- There are different abstractions and subsystems of the domain;
- Different models of simulation:
  - Macro, Meso, Micro, Nano

- Different performance measures require different analysis tools and representations of the domain;
- Analysis are made separately but the problem is rather integrated;

- How can we consider all the above features in designing a transportation system?
  - Multi-resolution Simulation
  - Multi agent Systems (MAS) Design and Simulation
    - Agent-based simulation and Artificial Societies
    - Market-based, Learning-based decentralized control
    - Other structures that can emerge
Artificial Societies & Social Simulation

- **Agent**
  - "agent is anything that can be viewed as perceiving its environment through sensors and acting upon that environment through effectors" (Russell and Norvig, Artificial Intelligence: Modern approach)

- **MAS**
  - Society of Independent Agents
  - Common Environment

- **Artificial Societies**
  - Social Rules
  - Micro & Global Dynamics
  - Social Simulation
  - Heterogeneous Individuals in an Environment

Possible Organizational Paradigms in ITS

- **Hierarchical**
- **Holarchy**
- **Coalition**
- **Team-based**
- **Society**
- **Marketplace**
Policy and Incentive Designs Evaluation: a Social-Oriented Framework for Artificial Transportation Systems

Policy and strategies and ITS

Generally speaking

- Socio-technical systems like ITSs, reflect the openness and “selfishness” exposed in the complex open multi-agent systems;
  - Agents are distributed along the system’s space
  - Agents bear their own goals and tends to behave rather “selfish” and “greedy” to maximize self-welfare utility

- The “designed” emergent behavior and utility of the system are negatively affected.
  - E.g Traffic congestion
Why a Social-Oriented ATS?

- What emerges from observation in transportation is the misalignment between commuters choices and system objectives.
  - ITS alone, as technological advances, hasn’t provide efficient solutions.

- Can incentives mechanisms and other policies foster social-aware behaviors?
  - Understanding preferences of the population helps to build efficient mechanisms
  - We should account for social factors along all the dimensions of the urban system

Objectives

- Show a social agent-based model for testing the appropriateness and effectiveness of the policy and incentives introduction.
  - Assess the performance of a bimodal network when the environment is modified by means of policy intervention.
  - How can we alter commuter perspective on a behavioural-shift basis
  - Two kind of policies to consider: market-based and incentive-based
An integration of views in ITS

- A transportation network acting as part of the environment and an artificial society of commuters residing in it.
  - Macroscopic resolution of the network and a microscopic resolution of agents’ decision-making
- We leverage on the social capabilities the agent metaphor provides to represent the social space of ITS.

Social-oriented Artificial Transportation Systems: Overview

Context of analysis
- Socio-technical context
  - ITS, smartification, crowd-sensing, participation
  - Social, technological, innovation, political factors
  - Agents (travellers, city managers, authorities, markets, etc.)
  - Intelligent infrastructures, traffic management, V2X,
  - Self-organization, traffic dynamics, social structures

Emergence of social dynamics & Organizations
- Environment
- ITS Artifacts

Simulation of Intelligent Transportation Systems: Different Perspectives
Social-oriented ATS: Description

- Traffic network is modeled as a graph $G = (V, L)$
  - $V$ is a set of nodes that defines origins, destinations, intersections, and $L$ is a set of directed links
  - $t_t^a = f f t_t^a \left[ 1 + \alpha \left( \frac{x^a}{c_x} \right)^\delta \right]$, a volume-delay function

- Commuters in the real system are described as an artificial population of agents
  - Agent’s utility represented along 3 dimensions: time, costs, social
  - $U_{total} = U_{time} + U_{cost} + U_{social}$

Social-oriented ATS: Utility considerations

- Time costs:
  $$U_{time}^j = \sum_{i=1}^{n} \left[ a_1 U_{access,i} + a_2 U_{wt,i} + a_3 U_{u,i} \right]$$

- Monetary costs:
  $$U_{cost}^j = \sum_{i=1}^{n} \left[ b_1 U_{fares,i} + b_2 U_{tools,i} + a_3 U_{travel,i} \right]$$

- Social costs:
  $$U_{social}^j = \sum_{i=1}^{n} \left[ c_1 U_{crowd,i} + c_2 U_{awareness,i} + c_3 U_{sociability,m} \right]$$
Social-oriented ATS: Utility & Social factors considerations

- Time and monetary costs are typically used to describe the perspective of gain/loss about commuter’s travel activity.

- Social factors are not well-defined yet in the literature.
  - Typical social aspects found in the transportation literature; equity, accessibility, safety are not always enough to explain demerging dynamics

- Activity-travel patterns can emerge from the individuals social networks
  - Social interactions during a trip or within commuter’s social network can influence his/her choice
    - E.g. Homophily
  - Attraction or repulsion for travelling with a given mode

Social-oriented ATS – an example

- Let’s consider a bimodal network
  - 2 routes
    - Each link on the network has a capacity and length

- Each agent is defined by
  - Desired departure and arrival times,
  - Experienced travel time
  - The uncertainty they experienced during the trip
  - A daily income variable.
  - Flexibility to use public transport mode
  - Car ownership
  - Temporal constraints (both for departure and arrival)

- As social components we consider pollution and comfort for the PR and PT respectively
Social-oriented for ATS

Typical agents characteristics considered in the example:

- **Decision-making**: The agents choose to travel by PT or PR mode. The decision making is based on the principle of the expected utility maximisation.

- **Adaptation**: Agents in the policy assessment scenarios have to adapt their decisions according to the modifications (policy introduction) in the environment they are situated in.

- **Objectives**: Agents try to maximise their personal goals and satisfaction, accounting for the uncertainty of the environment.

- **Sensing**: Agents perceive the level of crowding in the public transportation and the levels of congestion/pollution on PR road transportation mode.

Illustration example: Scenario and objectives

- The scenario reflects a typical daily trip from a home to a work location.
  - A three-hour morning peak is modelled from 7h30m until 10h30m.
  - Similar to “peak avoidance project” performed in the Netherlands.

- A high demand on the PR transportation mode is observed.
  - Utilisation of the route reaches the highest occupation.

- A synthetic population consisting of 2500 agents has been created.
  - Each agent is characterized by a set of attributes and a schedule.

- We want to regulate the initial demand applying temporal shift and/or the adoption of the public transportation mode.
  - To achieve this we study the introduction of 5 policies: 3 market-based and 2 incentive-based.
Social-oriented ATS – Policy intervention

- **Market-based policies:**
  - An increase in PR transportation (Policy 1) - increase in private costs from 6€ to 20€;
  - A decrease in public transportation (Policy 2) - reduce of 20% fare, from 1€ to 0.8€;
  - In addition, a policy mix (Policy 3) - a decrease of 0.2€ and an increase of 10€ in PR costs.

- **Incentive-based policies:**
  - A Departure Time Incentive for all the commuters (Policy 4) - Each commuters is rewarded with 2 euros before rush hour and 1 euro after rush hour;
  - A Departure Time Incentive only for commuters who travel at rush hour (Policy 5) - 2 euros before rush hour and 1 euro after rush hour.

Illustration example: Utility setup

- We assume the following utilities functions for the two modes
- **Private mode:**
  \[
  U_{private}^j = \sum_{i=1}^{n} [U_{time} \cdot (DA - (DD + ETT)) + (U_{car} \cdot (\frac{private\_costs}{income}) + (U_{pollution} \cdot (ETT \cdot pollution))]
  \]

- **Public mode:**
  \[
  U_{public}^j = \sum_{i=1}^{n} [U_{time} \cdot (DA - (DD + ETT)) + (U_{bus} \cdot (\frac{public\_costs}{income}) + (U_{comfort} \cdot \frac{EC}{bus\_capacity} \cdot ETT))]
  \]
Social-oriented ATS – an example

Illustration example: NetLogo implementation
Some results – Baseline Vs Policy intervention

Market-based policies
Policy 1 - increase in private costs
Policy 2 - reduce of 20% fare
Policy 3 - mix

<table>
<thead>
<tr>
<th>Public Transportation</th>
<th>Ratio</th>
<th>Average Travel Time [min]</th>
<th>Average Utility</th>
<th>Average Crowd</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline</td>
<td>55.4%</td>
<td>36.67</td>
<td>11.11</td>
<td>0.81</td>
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<tr>
<td>Policy 1</td>
<td>7.50%</td>
<td>-0.56%</td>
<td>-4.97%</td>
<td>5.06%</td>
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<tr>
<td>Policy 2</td>
<td>6.26%</td>
<td>-0.33%</td>
<td>-0.83%</td>
<td>3.20%</td>
</tr>
<tr>
<td>Policy 3</td>
<td>6.49%</td>
<td>-0.61%</td>
<td>-1.45%</td>
<td>3.97%</td>
</tr>
<tr>
<td>Policy 4</td>
<td>6.93%</td>
<td>-0.43%</td>
<td>-3.05%</td>
<td>2.24%</td>
</tr>
<tr>
<td>Policy 5</td>
<td>6.64%</td>
<td>-0.56%</td>
<td>-3.82%</td>
<td>2.76%</td>
</tr>
</tbody>
</table>

Incentive-based policies
Policy 4 – Commuters who travel at rush hour are rewarded before rush hour and after rush hour
Policy 5 – All commuters are rewarded before rush hour and after rush hour.

Some conclusions

- We argue that incentive design can be a viable solution to improve the transportation system efficiency, by regulating the demand
  However:
  - In within-to-day and day-to-day analysis considers cognitive and behavioural aspects of the commuter (agent) based on his preferences and past experience
  - Transportation planners should anticipate both positive and negative effects of a market-based or an incentive based policy.
    - Behavioural shift in mode/time choice needs to be followed by proper investments
Iteration Games
As test-bed to measure Policies Effectiveness

Adaptive and Self-organizing Systems in ITS

- Major research directions in adaptive and self-organizing systems are dedicated to learning how to coordinate decisions and actions of multiple agents.
- Understand whether individual agents’ decisions can lead to globally optimal or at least acceptable solutions.

- Most economics theories are deductive in origin
  - Each participant knows what is best for him given that all other participants are equally intelligent in choosing their best actions

- In the real world the actual players do not have the perfect foresight, most often their actions are based on trial-and-error inductive thinking
El Farol Bar Problem (Arthur, 1994)

- Size N population of people. Every Thursday night, all of these people want to go to the El Farol Bar. However, the El Farol is quite small, and it's no fun to go there if it's too crowded.

The preferences of the population can be described as follows:
- If less than 60% of the population go to the bar, they'll all have a better time than if they stayed at home.
- If more than 60% of the population go to the bar, they'll all have a worse time than if they stayed at home.
- The players can only make predictions about the attendance for the next time based on the results of the previous \( m \) weeks.
- The player always selects the strategy that predicts the outcome of the last weeks most accurately.

Minority Game (Challet, Zhang, 1997)

- A simplification of El Farol Bar Problem
- A minority game is a repeated game where \( N \) (odd) players have to choose one out of two alternatives (say 1 and 0) at each time step. Those who happen to be in the minority win.
- They base their decision only on the knowledge of the \( M \) (M for memory) last winning alternatives, called histories
  - there are \( 2^M \) histories.

=> The players are limited in their analyzing power
- Each player has a finite set of strategies
- At the beginning of the game, every player gets a limited set of \( S \) strategies; he uses them inductively, that is he uses the strategy with the highest virtual value
Minority Games and EFBP as Metaphors in Transportation

- The metaphor of rewarding the decision that is made by the minority of the players (or agents) is interesting in many scenarios.
- For instance, in agent-based simulation of traffic, a minority game is clearly useful to model route choice and/or departure time.
- Similarly, in public transport, the choice of the departure time is one of the few dimensions of choice for a passenger.
- As public transport systems usually observe a peak demand during the rush hour, it is an important dimension when it comes to crowdedness. This option reflects the possibility to stay at home in the El Farol Bar Game.
- The MG and the EFBP are gradually becoming a paradigm for complex systems.
Initial Setup and First Results

Simulation of Intelligent Transportation Systems: Different Perspectives

Behavioral Parameters Tests

Variables

<table>
<thead>
<tr>
<th>Variables</th>
<th>Average Utility</th>
<th>Average Utility</th>
<th>Average Travel Time</th>
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<td>History-SIZE 2</td>
<td>1.89</td>
<td>2.72</td>
<td>34.15</td>
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<td>History-SIZE 5</td>
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<td>Learning 0.1</td>
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<td>35.17</td>
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<td>Learning 0.5</td>
<td>2.00</td>
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<td>Learning 0.9</td>
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<td>2.72</td>
<td>27.49</td>
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<td>2.75</td>
<td>27.49</td>
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<tr>
<td>Num-Predictors 10</td>
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<td>2.75</td>
<td>27.49</td>
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<tr>
<td>Average</td>
<td>1.97</td>
<td>2.78</td>
<td>31.86</td>
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</table>
Experiments with a Heterogeneous Population

<table>
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<tr>
<th>Policies</th>
<th>PR-mode</th>
<th>PT-mode</th>
<th>Total</th>
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<tr>
<td></td>
<td>Total vs. Baseline</td>
<td>Total vs. Baseline</td>
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<td>100%</td>
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<tr>
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<td>0.89%</td>
<td>1161</td>
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OD Pair

<table>
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<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
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<th>8</th>
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<td>34.63</td>
<td>24.44</td>
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<td>32.06</td>
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<td>30.01</td>
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<td>Average</td>
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<td>34.89</td>
<td>34.57</td>
<td>24.49</td>
<td>28.47</td>
<td>32.11</td>
</tr>
</tbody>
</table>

SUMO and JADE: an integrated platform for Artificial Transportation Systems
A different approach to implement an ATS

SUMO – JADE integration: towards an ATS platform

SUMO (Simulation of Urban MObility)
- Open-source tool
- High portability
- Microscopic simulator
- API for external interoperability (TraCI)

JADE Framework (Java Agent Development)
- Free software
- High portability
- Simple MAS development
- FIPA compliance
- Distributed architecture
SUMO – JADE integration: towards an ATS platform

SUMO – JADE integration: towards an ATS platform
SUMO – JADE integration: towards an ATS platform

- Heterogeneous artificial society of drivers
- Each Driver is responsible for one SUMO Vehicle

SUMO – JADE integration: towards an ATS platform

Delegate Agent

- Tactic Layer + Strategic Layer
SUMO – JADE integration: towards an ATS platform

- Service Provider to Drivers
- Gathers surrounding information – Blackboard
- Informs drivers about network complications
SUMO – JADE integration: towards an ATS platform

Radio Broadcast
ATIS

Variable Message Sign
ATIS

Informative Traffic Light
ATIS

SUMO – JADE integration: towards an ATS platform
Intelligent Traffic Control

- Using the SUMO-JADE toolchain allow us to build MAS-based traffic control systems
- We use Q-learning to endow the control system with adaptive characteristics
- Similarly as in the case of drivers:

![Diagram showing JADE, TraSMAPI, TraCI, and SUMO interfaces]

Experimental Setup

<table>
<thead>
<tr>
<th>Phase</th>
<th>M1</th>
<th>M2</th>
<th>M3</th>
<th>M4</th>
<th>M5</th>
<th>M6</th>
<th>Duration</th>
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<td>g</td>
<td>r</td>
<td>r</td>
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<td>y</td>
<td>y</td>
<td>y</td>
<td>r</td>
<td>4</td>
</tr>
</tbody>
</table>
Scenario

- Correlation between number of steps and simulation time
- Different traffic scenarios
- 4-day simulations

Q-Learning Traffic Control

- Two variables to learn:
  - Phase durations
  - Period of the day
- Reward
  - Traffic Light private reward
  - Neighboring rewards
- Parameters
  - 50% Learning Rate
  - 50% Discount Factor
MAS for Traffic Control

MAS for Traffic Control
Preliminary Results

Q-Learning Demo
Market-based Intersection Control

- Consider market-based intersection control
  - Use Auction to define the crossing order
  - Vehicle-to-Infrastructure communications

- Sealed first price auction
  - Sealed bids
  - Wins the highest bid
  - Pays the bid

Space-Time Slot Reservation

- Intersection agent
  - Auctioneer

- Driver Agents
  - Bid for space-time slot
Sequence Diagram

- 3 Driver Agents, 1 Auctioneer

Scenario

- Single intersection
- 8 links
- 100m length of each link
Demo

Multi-Resolution Simulation of Taxi Services on Airport Terminal’s Curbside
Outline

- Problem Description
  - Proposed Scenarios
- Aims
- Modelling the problem
  - Basic Approach
  - Experimental Results
- Conclusions
- Future Works

Problem Description

- Problem proposed by GlobalVia, during 74th European Study Group with Industry
  - New curbside layout
  - A ticket-based system for the “waiting line”
- Airport terminal’s curbsides are the critical interfaces
  - Design and capacity are essential to the successful performance of airport infrastructure
- How to prove the efficiency of the new designs?
Proposed Scenarios

- A set of two parallel lanes next to the door of the airport terminal with four stop areas

- Eight stop areas for picking up passengers
- Stop areas arranged at 45 degrees
- Stop areas aligned parallel to each other
Proposed Scenarios

- To replicate the proposed scenarios experimentally
- Evaluate their performance
- Implement a finer grained perspective based on pedestrian behavioral models

Modelling
Basic Approach

- As the modelling
  - \( t_{\text{waiting}} \) \( \rightarrow \) SIMUL8 Simulator
  - \( t_{\text{walking}} \) \( \rightarrow \) Netlogo pedestrian model
  - \( t_{\text{loading}} \) and \( t_{\text{leaving}} \) \( \rightarrow \) Results by previous studied
  - \( t_{\text{total}} \) \( \rightarrow \) Used Excel to sum the factors and trace graphs

SIMUL8 Models: Dynamics [1]

1. 
2. 
3. 

![Diagram of SIMUL8 Models: Dynamics](image-url)
Pedestrians set-up

- Passengers are assumed to be into a “waiting” status in the airport internal premises
  - Each group is assigned a (virtual) ticket.
  - The scenario is represented as a discrete grid-based environment, cell represent an area of 0.25 m²
- 3 type of pedestrian: Child, Adult, Elder
  - Different walking velocities: {1, 1.4, 0.8} m/s
  - Population age distribution: 25%, 50%, 25%
  - Pedestrian movement(behaviour) mimics as if follow indication signs.
twalking: Paths

Parallel with 6 Taxis

Dependent with 6 Taxis

Results: Taxis Using Rate

Dependent with 6 Taxis

Parallel with 6 Taxis

Blocked – 34%
Results: Comparing Scenarios
Average and maximum queuing time - length

Results: Walking Times

- Proposed scenarios always present lower walking times.
Results: Total Time

Conclusions

- We suggest a broad model for curbside scenarios aiming to evaluate their performance according to GlobalVia proposal.

- For small number of taxis the two scenarios present almost the same result, with advantage of the GlobalVia proposal.

- With high number of taxis the proposed scenario is much better than the current one, as intuition suggests.
Scheduling Crane Operation in Rail-Rail Transshipment Terminals

Outline

- Introduction to Rail-Rail Transshipment Terminal
- Scheduling Crane Operations
- Case Study
- Agent-based Simulation Model
- Results
- Conclusion
Introduction to Rail-Rail Transshipment Terminal

Hub & Spoke Network

- Higher frequency of transport
- Higher range of covered terminals
- Increase in economies of scale

Legend:
- Main route
- Feeder/local route
- Hub Terminal
- Origin/Destination (Regional) Terminal
Problems in Rail-Rail Terminal

- Train Location Problem
- Scheduling Service-slots Problem
- Scheduling Shuttle-car Problem
- Rail-Rail Transshipment Problem
- Train Destination Assignment

- Scheduling Crane Operation
- Yard Partition Problem
- Load-plan Determining Problem
- Transshipment Sequence Problem
Schedule crane operations

Load Plan Determining Problem

Wagon
- Length
- Configuration

Container
- Destination
- Size
- Type
- Weight

Final Position

Yard Partition Problem

(a) Direct move
(b) Indirect move

Working area of crane 1
Working area of crane 2

Indirect moves

Static Assignment with Overlapping area
Share workload evenly among cranes

Static Assignment without Overlapping area
Schedule crane operations

Transshipment Sequence

✓ Objective:
  Minimize the makespan

✓ Subject to:
  Precedence constraints

Agent-based Simulation Model

- The solution need to answer to three questions:
  1. Which container to process?
  2. Where to put the container on outbound train?
  3. Which crane will execute the transshipment
Case study

Rail-Rail transshipment terminal near Antwerp, Belgium

- **Yard**
  - 8 Tracks
  - 2 Cranes
  - Crane area %60 of yard (%20 overlapping area)

- **Wagon**
  - 60 feet
  - 85 feet

- **Container**
  - 20 feet
  - 30 feet
  - 40 feet

Agent-based Simulation Model

- The model follows agent metaphor
  - Composed of autonomous entities (agents)
  - Situated in an environment with discrete space (patches)
- The agents sense the environment and act based on it

- Agents ➔ Gantry Cranes
- Agent-crane decide for own schedule locally

Where to put a container?

- Nearest unprocessed container
- Nearest wagon with available capacity
- Nearest unprocessed container on the train with the highest priority

**Agent-Crane Algorithm**

1. Check if it is loaded
2. Loaded? Yes: Move one step to destination
   - At the destination? Yes: Set loaded
   - At the container? Yes: Pick up
   - No: Go to next container
3. No: Set the next container

Drop the container
   - Set loaded
   - Yes
   - No

Set the next container
Results

- Instance from literature (Soufrriau et al., 2009)
- The load factor is defined as the total container length divided by the total train length

<table>
<thead>
<tr>
<th>Range of load factor</th>
<th># problem per load factor</th>
<th>Total number of instances</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>[0.1, 0.2, 0.3, ..., 0.9]</td>
<td>5</td>
<td>45</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th># Trains</th>
<th># Destinations</th>
<th># Cranes</th>
<th># Tracks</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>5</td>
<td>2</td>
<td>8</td>
</tr>
<tr>
<td>Load factor</td>
<td>#Container</td>
<td># non-allocated containers</td>
<td>time</td>
</tr>
<tr>
<td>-------------</td>
<td>------------</td>
<td>----------------------------</td>
<td>------</td>
</tr>
<tr>
<td>0.2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.4</td>
<td>MAS 63%</td>
<td>VND 62%</td>
<td></td>
</tr>
<tr>
<td>0.6</td>
<td>168.2</td>
<td>0</td>
<td>6.89</td>
</tr>
<tr>
<td>0.8</td>
<td>237</td>
<td>6.4</td>
<td>10.94</td>
</tr>
</tbody>
</table>

The average improvement

# containers left behind

- Load factor 0.7: MAS 0, VND 0
- Load factor 0.8: MAS 6, VND 4
- Load factor 0.9: MAS 14, VND 12
Conclusions

- Agent-based simulation model for Rail-Rail Transshipment Terminal
- Study deals with the scheduling crane operations (SCO) problem in RRTT.
  - Define the position of containers on outbound trains
  - Assign transshipments to cranes
  - Sequence transshipments for each crane
- The model achieved up to 75% improvement (in a fraction of time)

Multi-resolution simulation: An HLA-based application
Outline

- Introduction
  - Context
  - Motivation
  - Objectives
- HLA Concepts
- Integrated Simulation Platform
  - Description
  - Illustrative example
- Conclusions and Future Work

Context of the Project

High number of cars + Flexibility = Urban Chaos

- Public Transport
- Zero Tailpipe Emission
- Zero Sound Pollution

= Electric Buses

Poor Air Quality
Introduction

Motivation

- Evaluate electric buses within the urban traffic environment
  - Effect of traffic volumes, route/network-geometry, and driver behaviour on bus performance
  - Lack of appropriate tools for integrated analysis

- Traffic simulation
  - Different resolutions (Micro and Nano)
  - Traffic simulators as standalone tools
  - Separate studies on complex problems

Objectives

- Integrate microscopic and nanoscopic traffic simulation models
- Multi-resolution analysis tool for electric vehicles (buses) operation under different urban traffic conditions and interactions
  - Traffic simulator - Microscopic model
  - Electric Bus Powertrain Subsystem (EBPS) - Nanoscopic model
- Evaluate the advantages of multiple resolution studies
Background

- **Distributed Simulation**
  - Distribution of the computational efforts
  - Multiple applications/threads

- **High Level Architecture (HLA)**
  - Adresses the interoperability and reusability of different units of simulation
  - Provides a common architecture for distributed simulation
  - Is an IEEE standard architecture

Multi-resolution simulation: An HLA-based application

HLA ecosystem is divided in its major functional elements:

- **Federate** – “An application that may be or is currently coupled with other software applications under a federation object model (FOM) and a run-time infrastructure (RTI).”

- **Federation** – “A named set of federate applications and a common federation object model (FOM) that are used as a whole to achieve some specific objective.”

- **Run Time Infrastructure** – A common interface services during a High Level Architecture (HLA) federation execution for synchronization and data exchange

- **FOM** – “A specification defining the information exchanged at runtime to achieve a given set of federation objectives.”
HLA View

Integrated Simulation Platform

Requirements

- Representation of two different systems
  - The traffic system: road network & vehicle-entities
  - The electric bus system defined in terms of a powertrain:
    - Set of battery and traction motor, other components.
- Associate the electric bus system to a vehicle entity (class bus) in the microscopic traffic model
- Access to the respective model variables
  - Communication protocols & a flexible API
- Middle-Ware application for synchronization and data exchange between simulators
Integrated Simulation Platform

**SUMO**

- Urban Microscopic traffic simulation suite
- Highy portable
- Open source (Licensed under the **GPL**)
- TraCI API for interaction with external applications
- Implements different vehicle types
- Strong commitment with the academia and research community

### Electric Bus Powertrain System

- Electric Bus Powertrain Subsystem (EBPS) model - Simulink
  - EBPS – FEUP’s project
  - Model’s code and validation data available

![Diagram of EBPS model](chart.png)
Integrated Simulation Platform
*HLA-based* Developed framework architecture

**SUMO Federate**
- SUMO
- TraCI
  - Sumo Communication Module
  - Federate Ambassador
  - Local RTI AMB

**EBPS Federate**
- Electric Bus
- Simulink Model
  - Matlab
  - Matlab Communication Module
  - Federate Ambassador
  - Local RTI AMB

Run-Time Infrastructure

Integrated Simulation Platform
*HLA / RTI*

Middle-ware application

HLA / RTI (Run-Time Infrastructure) – Pitch pRTI

- Implements the HLAevolved standards
- Provides good support
- User-friendly graphical Interface
- Federates and FOM Samples
Integrated Simulation Platform

Implementation

- For each attribute
  - Type specification

- For each class and attribute
  - Publish and Subscribe specification

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Type</th>
<th>Publish Subscribe</th>
</tr>
</thead>
<tbody>
<tr>
<td>Name</td>
<td>HLAunicodeString</td>
<td>PS</td>
</tr>
<tr>
<td>Velocity</td>
<td>VelocityFloat64</td>
<td>PS</td>
</tr>
<tr>
<td>Acceleration</td>
<td>AccelerationFloat64</td>
<td>PS</td>
</tr>
<tr>
<td>Power</td>
<td>PowerFloat64</td>
<td>PS</td>
</tr>
<tr>
<td>Torque</td>
<td>TorqueFloat64</td>
<td>PS</td>
</tr>
<tr>
<td>Efficiency</td>
<td>EfficiencyFloat64</td>
<td>PS</td>
</tr>
<tr>
<td>TotalCycleEnergy</td>
<td>TotalCycleEnergyFloat64</td>
<td>PS</td>
</tr>
</tbody>
</table>

Integrated Simulation Platform

Testing the integration

- Functional tests were performed
  - Testing communication and RTI connections
  - Validating the integration with real data.

- Oporto’s network modelling
  - For performance tests
  - For demonstrate possible studies
Integrated Simulation Platform

A demonstration of usage

Illustration example – 1

Traffic Volumes case studies

Two different case studies

- Analyse EBPS outputs from different traffic volumes
  - Changing vehicles entrance rate
- Analyse the influence of driver’s behavior in the EBPS outputs
  - Changing bus acceleration and deceleration values

Performance test were performed for first case study

- Same number of buses
- More traffic volumes
Illustration example – 2

Some results

Different traffic conditions affects the behaviour of the EBPS

- Possible studies with the developed framework

<table>
<thead>
<tr>
<th>Acceleration (m/s²)</th>
<th>Total Energy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low traffic</td>
<td>Intense traffic</td>
</tr>
<tr>
<td>Time (s)</td>
<td>Energy (kW)</td>
</tr>
</tbody>
</table>

Conclusions

- HLA offers a stable integration
  - Seamlessly capable of including new federates
  - Able to easily create new federations
- MatLab FederateAmbassador
  - Communication with Simulink
  - Control of Simulink models
- SUMO FederateAmbassador
  - Communication with SUMO
  - Control of SUMO simulations
- Some advantages of such an integration we have identified:
  - Correlation between traffic volumes and the amount of energy spent during the EPBS operation.
  - Potential for recovering part of wasted energy on braking.
Modelling Smart-Grids in NetLogo
in collaboration with Thiago Reis Pedroso Munhoz Rúbio

Introduction to Smart Grids

- Decentralised Distribution
- Sustainable power sources
- Prosumers
- Dynamic market
  - Variable prices and tariffs
A Smart Grid in NetLogo

Agent-based Model

- **Bulk Generation**
  - Represent the big supply sources
  - Can serve as a backup energy
  - Expensive energy

- **Consumers**
  - Follow real consumption patterns
  - Contract energy from brokers
  - Keep an eye on cheaper tariffs
Agent-based Model

- Producers
  - Sustainable “clean” energy
  - PV production model

- EVs and Batteries

Simulation Variables

- Number of individuals
- Weather (simulation)
- Energy balance on the grid
- Susceptibility to mimic neighbours
Sub-Models

- Agents inner models
- Consumption
  - Mean energy consumption (household scenario)
- Production
  - Based on the energy type (solar, eolic, etc.)
- Interest on selling or use
  - Conceptual inferences on the reasoning process
- Market
  - Tariffs
  - Contracts
  - Norms

Metrics to consider

- Total amount of energy traded
- Energy prices
  - Supply Market
  - Prosumers
- Imbalances of energy on the grid
Some project proposals for the coursework

1. NetLogo – GIS integration: Traffic application for the city of Porto

2. Multi-agent area-based pricing scheme for traffic demand control (NetLogo or SUMO/JADE)

3. Extend the Social-oriented ATS framework:
   1. Consider a larger network with multiple routes, or
   2. Account for more complex social interaction among agents, e.g. social networks and their potential influence on their choices, or
   3. Improve agents adaptation and learning mechanism to obtain a more realistic decision making, or

4. Electricity markets and Smart-grid
   1. Consider the evaluation of the market prices using minority games
   2. Coordination mechanism for the EV charging

5. Negotiation-based operation scheduling in Train-to-Train operations

6. Implementation of a Demand Rapid Transit system
Social Simulation of Intelligent Transportation Systems: Different Perspectives

Thank you!

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