MetroB: Evaluation and Simulation of Public Transportation System in Small- and Middle-size Towns

Software Design and Bus Network Indicators

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Context, Hypothesis and Constraints <

Road and Bus Network Models <

Bus Network Evaluation <

Bus Network Simulation <

Conclusion & Perspectives <
Tools for public transportation design and simulation have several drawbacks on the:

- **accessibility**: require dedicated competencies
- **efficiency**: long and difficult to create bus network models
- **visibility**: difficult to understand results provided by existing tools without experts
- **scalability**: designed for large towns, not for small- and middle-size towns

MetroB provides functionalities and tools to solve these problems
GIS Functionnalities

- MetroB is able to:
  - import data collection from Geographical Information Systems (Shape files)
  - import and display geo-TIFF pictures
  - draw several GIS data inside projects and layers (roads, buildings...)
  - export into common GIS formats and picture formats
  - edit GIS object's attributes (name, vehicle capacity...)
Bus Network Functionnalities

- MetroB provides user-friendly tools to graphically edit bus networks
  - one click to add or remove a road segment from a bus itinerary
  - one click to add or remove bus stops
  - bus itinerary overview with a line diagram
  - automatic creation of the exchange stations between several bus itineraries
Types of Indicators

- **Static Indicators (static computation):**
  - average speeds and times per itinerary and for the entire network
  - bus network cover indicators based on the population density, cover circles or several attractors (schools...)

- **Dynamic Indicators (simulation):**
  - Distance with pre-defined bus operating schedules
  - Road network bottlenecks and slow-down
  - Blocking bus stops (according to bus users)
Global Architecture

VSCS
GIS
Bus Network
Final User

VSCS Plugin
GIS Plugin
Bus Network Plugin
Bus Network Editor Plugin
Bus Network Evaluation Plugin
Bus Network Simulation Plugin
GIS Display Plugin

SETGIS MIDDLEWARE
Global Architecture

Indicators and statistics from real buses: positions, passenger counts...

VSCS
GIS
Bus Network
Final User

VSCS Plugin
GIS Plugin
Bus Network Plugin
Bus Network Editor Plugin

Bus Network Evaluation Plugin
Bus Network Simulation Plugin
GIS Display Plugin

SETGIS MIDDLEWARE
Global Architecture

GIS models and geo-localized statistics

SETGIS MIDDLEWARE

VSCS
GIS
Bus Network
Final User

VSCS Plugin
GIS Plugin
Bus Network Plugin
Bus Network Editor Plugin
Bus Network Evaluation Plugin
Bus Network Simulation Plugin
GIS Display Plugin
Public Transportation Data: Network itineraries, Bus schedules...
Global Architecture

- VSCS Plugin
- GIS Plugin
- Bus Network Plugin
- Bus Network Editor Plugin
- Bus Network Evaluation Plugin
- Bus Network Simulation Plugin
- GIS Displayer Plugin

SETGIS MIDDLEWARE
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GIS are commonly organized in map layers
Each map layer contains a type of data: roads, public buildings, schools, population density areas...

Each data is represented by a geo-localized shape: the map element
Map elements may be lines, polygons, points...
Class Diagram for GIS primitives

- Project
  - GISAttributeContainer
    - GISAttribute
      - name: String
      - value: Object
    - MapLayer
    - MapElement
      - MapPoint
      - MapPolygon
      - MapPolyline
    - MultiMapLayer
    - ElementMapLayer

Map with streets and landmarks of a location.
Class Diagram for Road Network
Spatial Tree for Road Network

- Roads are stored inside a spatial tree:
  - QuadTree with icosep heuristic
- Node: portion of space
- Roads are inside leaf nodes
- Upper nodes are divided into 4 sub-spaces
- Additional child for roads intersecting cutting lines

- Speed up operations:
  - $O(n)$ to $O(\log n)$
Bus Network Concepts

- **Bus stop**: a geo-localized point at which buses may stop.
- **Bus Itinerary**: an undirectional path along which bus is going, and containing an list of bus stops.
- **Bus Line**: a collection of bus itineraries with same name.
- **Bus Network**: a collection of bus lines.
- **Bus Station**: an exchange point, composed of at least two near bus stops.
- **Bus Operating Schedule**: set of itineraries with times for each bus stop.
Bus Network Class Diagram
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Static Temporal and Spatial Evaluation

- **Troneon sizes (distance and time between bus stops)**
- **Time to follow itineraries with standard cruising speed for buses**
  - with waiting at each bus stop
  - without waiting at each bus stop.
- **Min, max, average speeds of buses on each troneon**

<table>
<thead>
<tr>
<th>Arrêt</th>
<th>Durée sans arrêt</th>
<th>Durée avec arrêt</th>
<th>Vitesse moyenne</th>
</tr>
</thead>
<tbody>
<tr>
<td>00:17:31</td>
<td>00:31:34</td>
<td>16.4 km/h</td>
<td></td>
</tr>
<tr>
<td>00:23:23</td>
<td>00:33:39</td>
<td>16.6 km/h</td>
<td></td>
</tr>
<tr>
<td>00:21:47</td>
<td>00:31:04</td>
<td>16.8 km/h</td>
<td></td>
</tr>
</tbody>
</table>
Evaluation of the Bus Fleet Size

- Compute the number of buses required to respect constraints:
  - a predefined bus frequency at bus stops (10mn)
  - an given average waiting time for pedestrians at bus stations (5mn)
- Bus operation schedules or average speed may be both used
Evaluation of Exchange Stations

- Create a list of available exchanges in a station.
  - When a bus is arriving at a bus station, list all the possible other buses which may be taken after arrival in the same station.

- Evaluation minimal, average, and maximal waiting time to proceed the exchange for all bus stations.
Population Cover Evaluation

- Evaluation proportion of population which is « near » bus stops
- Evaluation is based on population density map:
  - Set of shapes which count of people as attribute
Population Cover Evaluation

- Put circles with selected radius (100m, 400m...) at each bus stop
Population Cover Evaluation

- For each circle, compute the amount of covered population:
  \[ p_c := \sum \frac{\text{area}(a \cap c) \cdot \text{population}(a)}{\text{area}(a)} : \forall c \in \text{Circle}, \forall a \in \text{DensityMap}, a \cap c \neq \emptyset \]

- For each intersecting circle pairs, substract intersection to one of the circles
  \[ p_b := p_b - \frac{\text{area}(a \cap b) \cdot p_b}{\text{area}(b)} : \forall a, b \in \text{Circle}, a \cap b \neq \emptyset \]

- Sum all circle's values
  \[ C := \sum p_c : \forall c \in \text{Circle} \]

- Compute global population coverage
  \[ G := \frac{C}{\sum \text{population}(a)} : \forall a \in \text{DensityMap} \]
Travelling Time Evaluation

- From a given bus stop, compute the time to reach all other bus stops
- Use default cruising speed of buses and standard stop duration at each bus stop, or bus operation schedule
Average Travelling Time Evaluation

- Compute shortest paths from the selected bus stops to all the other bus stops (Dijkstra algorithm)

\[ s_{a \to b} : = \text{dijkstra}(a, b) : \exists! a \in \text{BusStop}, \forall b \in \text{BusStop}, a \neq b \]

- Travelling duration is given by:

\[ t_{a \to b} : = \frac{s}{\text{distance}(s_{a \to b})} + \text{countBusStops}(s_{a \to b}) \cdot b \]

where \( s \) is the bus cruising speed and \( b \) is the standard waiting duration at bus stop.
A departure time must be given: \( t_0 \)

Compute shortest paths from the selected bus stops to all the other bus stops (Dijkstra algorithm)

Path is composed of troneons: segments between bus stops

\[
s_{a \rightarrow b} := \text{dijkstra}(a, b) = \{r_0, r_1 \ldots r_n\}:
\]

\( \exists! a \in \text{BusStop}, \forall b \in \text{BusStop}, a \neq b \)

Time at which a troneon was passed is given by:

\[
\begin{align*}
e_{r_0} &= t_0 \\
e_{r_n} &= \min(t): \forall t \in \text{time}(r_{n-1}, r_n), t \gg s_{r_{n-1}} \\
s_{r_n} &= e_{r_n} + \text{duration}(r_0): n \geq 0
\end{align*}
\]
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Multiagent Simulation Model

- Each bus and vehicle is simulated with a situated agent:
  - Individual behavior based on IDM,
  - realistic perception frustum, and
  - steering motion based on linear acceleration

Local Perceptions:
- Roads
- Other vehicles
- Road signs

Steering Parameter:
- Linear acceleration
Agent Behavior

- **Signal receipt**: perception of roads
- **Update path to follow**
- **Signal receipt**: perception of vehicles, road signs, and bus stops
- **Select leader object**
- **Free Driving**
- **Run car-following algorithm**
- **Signal sending**: send linear acceleration and path to follow

[Checking for path]
- [no more path]
- [has path]
- [no leader]
- [has leader]
Simulation Indicators

- Inconsistencies against Bus Operation Schedule
  - How many buses are late or early
  - How much they are late (early buses may wait)
- Congestions and Delays
  - What are the roads on which buses are stopping a long time?
- Bus filling rate
  - Does all waiting passengers may enter in the first arriving bus?
  - How many passengers are waiting at bus stops?
Simulation Indicators

- These indicators permit to study impact of the following actions on the bus network:
  
  - Create busways
  
  - Adapt traffic light policies to prioritize buses
  
  - Change itineraries
  
  - Add more buses when bus network has congestions and temporary deny of service
Design, Evaluation and Simulation of Public Transportation System in Small- and Middle-size Towns

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Conclusion

- MetroB is able to:
  - import and export data in GIS standard formats
  - draw GIS data
  - edit bus network
  - evaluate bus network
  - simulate bus network

- MetroB is dedicated to initial design of public transportation system

- MetroB was successfully used by SMTC to design Belfort's bus network during 2004-2006 period.
Support of multi-modality

Have finest passenger statistics:

- O-D matrices from individual mobilities, bus pass usages...
- Estimate passenger numbers from embedded devices (door detectors or video cameras)

Full connexion to Vehicle Scheduling Control System