METROB: EVALUATION AND SIMULATION OF PUBLIC TRANSPORT SYSTEM

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Abstract

In this paper, we present models and the corresponding decision-support tool, MetroB, for evaluating the Public Transport Networks (PTN). Firstly, we define the geo-referenced mode underlying our approach. Then, the PTN model is explained, and various evaluation and assessment methods are explained. These models and evaluation algorithms are specifically designed to address to the design of PTN for small- and medium-size towns. This approach has been successfully implemented in a decision-support tool, which have been used by the public transport authority of the region of Belfort in France to design its new PTN.

1 . Introduction

In this paper, we present a solution for Public Transport Network Design (PTND) [1] in the context on small- and medium-size towns (less than 100,000 people). Indeed these towns are too small to use the same methods and tools than bigger cities, because they are too expensive in time, money and competences. Moreover, they are more sensible to the private operating costs, the social costs of the restructured system, and the investment costs for the bus fleet and the road infrastructures. MetroB [2] is a decision-support tool implementing the various models and evaluation algorithms presented in this paper. It enables Public Transport Authorities (PTA) to introduce an important number of modernizing measures fare increases.

Unfortunately traditional tools for PTN evaluation and simulation have several drawbacks in the context of small- and medium-size towns:

- Accessibility: specific and high competencies and skills are required to use these tools;
- Efficiency: it is still long and difficult to create bus network models;
- Understandability: it is difficult to understand outputs provided by the existing tools without the help of (expensive) experts of the domain;
- Scalability: they are designed for large towns, not for small- and medium-size towns.

MetroB provides models, features, and tools to solve these problems (see Figure 1). It enables to (a) import data collection from Geographical Information Systems (GIS), e.g. shape files; (b) import and display geo-referenced pictures; (c) draw several GIS data inside projects and layers (roads, buildings...); (d) export into standard GIS and picture formats; and (e) edit GIS object's attributes (name, vehicle capacity...). MetroB provides user-friendly tools to edit bus networks graphically: one click to bind or unbind a road segment to a bus itinerary, add or remove bus stops, automatically create exchange stations among bus lines.

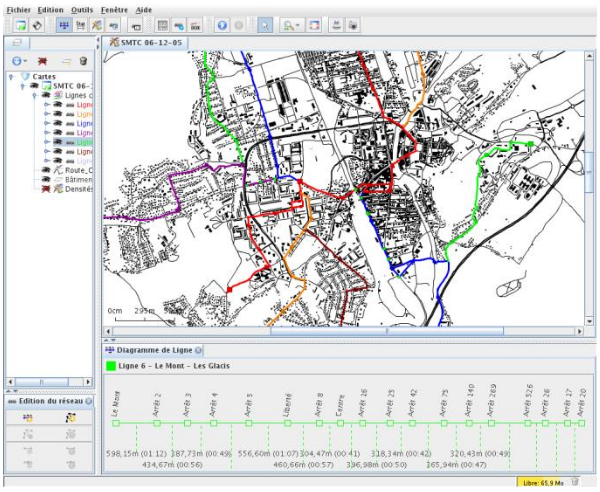

Figure 1: Screenshot of MetroB Application

In the rest of this paper, we present the model of the GIS primitives used by the MetroB meta-model. In Sections 4 and 5, static and dynamic evaluation indicators are respectively presented. Finally, Section 5 draws some conclusions and describes some future work directions.

2. Road and Bus Network Models

In this section, we present the concepts used to build the geographic objects of an urban environment. Additionally, the considered bus network model is also presented through UML class diagrams.

2.1. Model of Geographic Primitives

Geographical Information Systems (GIS) are software designed to store geo-referenced data in dedicated databases. Basically, they organize their map data in a collection of layers. Each layer contains a type of data: layers, roads, public buildings, schools, population density areas, etc. Each data in a layer is a geo-localized shape: the map element. As illustrated by the UML class diagram in Figure 2, map elements may be lines, polygons, or points.

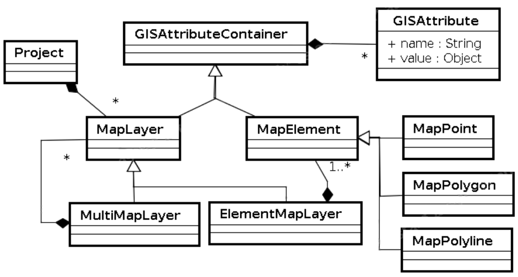

Figure 2: GIS Model

All the objects in a GIS data-structure may contain a collection of attributes for all the information associated to these GIS objects: name, element's type, width, length, etc.

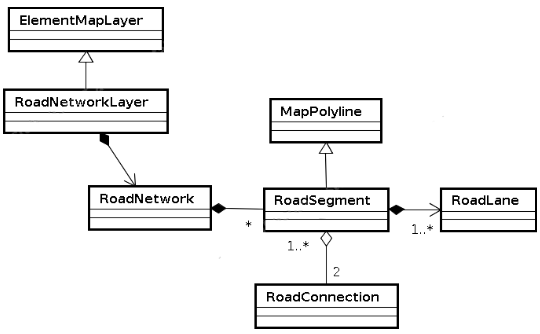

Figure 3: Road Network Model

Evaluating a PTN may be a hard task and in many cases, it requires an expert of the domain. In collaboration with the PTA of Belfort, we propose a set of useful indicators to evaluate the efficiency of a PTN. Firstly, considered static indicators are: the average speeds and times per bus itinerary and for the entire network, and the bus network cover indicators based on the population density, covering circles and several other attractors (schools...). Secondly, dynamic indicators are: the distance/error between the simulated system and the pre-defined bus operating schedules, the road network bottlenecks and slow-down points, and the bottleneck bus stops for the passengers.

Roads constitute a specifically subset of the GIS objects. They are lines, named road segments, connected to other road segments. Figure 3 shows the UML class diagram of the road model. Each road segment is connected to other road segments through road connection: cross road, etc. Road segments and connections are gathering into a common structure: the road network, put inside a dedicated GIS layer.

Because the road network is a central and very used data-structure in any GIS-based software, its implementation must be efficient to retrieve the roads and their associated attributes as fast as possible. MetroB provides a dedicated spatial quadtree. Trees are well-known to improve software performances. Here the tree cuts the map in four parts, and cuts each of them in four subparts, and so on. Each road connection is located inside a leaf of this tree and may be retrieved with a complexity of O (log n), where n is the number of road connections in the road network.

2.2. Bus Network Model

PTN may include different types of transport means, but in this paper, only the public bus systems are described. Figure 4 introduces the UML class diagram of the bus network model.

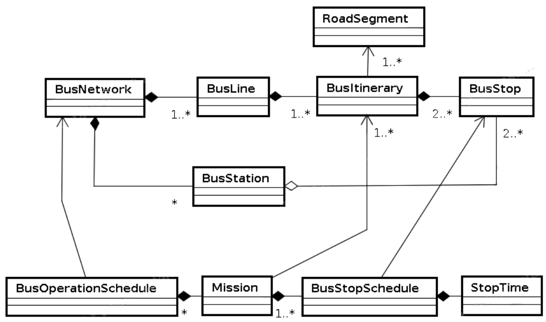

Figure 4: Bus Network Model

The finest GIS primitive in a bus network is the bus stop. A bus stop is a place where buses stop allowing passengers to board or get off the bus. Bus stops are normally positioned on the roadside and are distinct from facilities such as bus stations. The construction of bus stops tends to reflect the level of usage. Stops at busy locations may have shelters, seating and possibly electronic passenger information systems; fewer busy stops may use a simple pole and flag to mark the location. Bus itinerary is a unidirectional bus route from a terminal to another, and containing an ordered list of bus stops. Bus line is a collection of bus itineraries with same name or label. Bus stations are exchange points, composed of at least two bus stops, which are near together. All these concepts constitute the bus network.

Bus Operating Schedule is also known as the time tables of the bus network. It contains the departure times of the buses at each bus stop. This information is used to compute temporal evaluation of the bus network.

3. Bus Network Static Evaluation

In this section static evaluation indicators are presented. They are computed directly from the bus network model and do not support hazardous phenomena.

3.1. Static Temporal Evaluation

Temporal evaluation of a PTN is one of the first requirements for a PTA. Troneon[1] sizes are estimated in time and space. Let the spatial distance of the troneon starting at the bus stop s_1 and ending at the bus stop s_2:

$$D(s_1, s_2) = \sum_{s \in S(s_1..s_2)} D(s) - P(s_1) - D(S(s_2)) + P(s_2) \quad \textbf{(1)}$$

where $S(T)$ is the set of segments covered by the troneon T, $P(a)$ is the position of a, and $D(b)$ is the spatial distance of b. Let the average time for a bus to travel along the troneon s_1, s_2:

$$T(s_1, s_2) = D(s_1, s_2)\ C - W \quad \textbf{(2)}$$

where C is the cruising speed of the buses and W the average duration of a halt at a bus stop. These indicators enable PTA to estimate bus stop location pertinence. Additionally the time to follow the itineraries by buses with standard cruising speed is defined by $D(i) = \sum_i T(s_i, s_{i+1}) + W$.

3.2. Evaluation of the Bus Fleet Size

One of the concerns of PTA is to optimize the bus fleet, i.e. the number of buses, to ensure a high-quality of service. The computation of the number of buses is constrained by the following PTA constraints:

- a predefined bus frequency at each bus stop, 10mn in the Belfort's PTN;
- A given average waiting time for passengers at bus stations, eg. A value of 5 mn is used in the Belfort's PTN.

Bus operation schedules or average durations are both used to compute the indicators.

3.3. Evaluation of Exchange Stations

Exchange stations are evaluated through several indicators: (a) 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; (b) the minimal, average, and maximal waiting times to proceed with the exchange for all bus stations.

3.4. Evaluation of Population Cover

PTA for small- and medium-size towns use a global indicator to estimate the quality of the PTN: the population cover expressed in percent. The cover of the population is the proportion of the population of the town, which is "near" a bus stop or a bus station. This concept of proximity is a standard national parameter of the evaluation. Basically, in France and Europe, people are assumed to be near a bus stop when they are at most 400 meters to one of them.

The population cover evaluation is based on the population density map. This map is composed of the area in which a given density of population is located.

The evaluation uses the union shape of circles centered on each bus stop (see Figure 5).

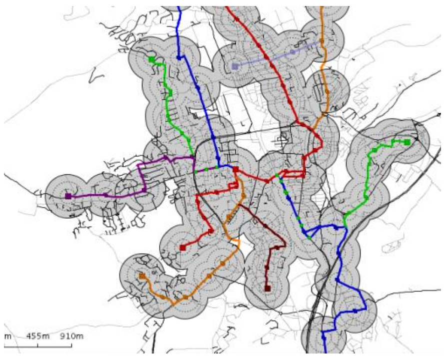

Figure 5: Population Cover Evaluation

Let the amount of covered population for each circle:

$$\rho_c = \frac{A(a \cap c).N(a)}{A(a)} : \forall c \in Circle, \forall a \in DensityMap, a \cap c \neq \emptyset \quad \textbf{(3)}$$

where *N(a)* is the number of people in the area *a* and *A(b)* is the area covered by *b*.

[1] The route between two bus stops

For each intersecting circle pair, the intersection must be counted only one time:

$$p_c = \rho_c - \frac{A\ \ a \cap b\ \ .\rho_b}{A\ \ b} : \forall a, b \in Circle, a \cap b \neq \emptyset \quad \textbf{(4)}$$

Let the global area for all the circles:

$$C = \quad p_c : \forall c \in Circle \quad \textbf{(5)}$$

Let the global population cover:

$$G = C \quad N(a) : \forall a \in DensityMap \quad \textbf{(6)}$$

.

3.5. Traveling Time Evaluation

Traveling time evaluation computes the time to reach all the other bus stops from a given bus stop (see Figure 6). The default cruising speed and stop duration are included in the computation. Let the shortest paths from *a* to *b*, according to the Dijkstra algorithm:

$$s_{a\to b} := \text{ dijsktra } \ a, b \ \ = \{r_0, r_1 \dots r_n\} : \exists!\, a \in BusStop, \forall b \in BusStop, a \neq b \quad \textbf{(7)}$$

Traveling duration from *a* to *b* is given by:

$$t_{ab} = \ C \ \ D \ \ s_{a\to b} \ \ + \text{count } \ s_{a\to b} \ .W \quad \textbf{(8)}$$

Alternatively, the bus operation schedule may be used in place of the cruising speed and stop duration.

Let the departure time from the first bus stop t_0. The time at which a troneon was passed by the bus is given by:

$$\begin{gathered} T \ \ e_{r_0} \ \ = t_0 \\ e_{r_n} = \min \ t \ : \forall t \in T \ \ r_{n-1}, r_n \ \ , t \gg s_{r_{n-1}} \\ s_{r_n} = e_{r_n} + D \ \ r_0 \ \ : n \geq 0 \end{gathered} \quad \textbf{(9)}$$

4. Bus Network Dynamic Evaluation

This section introduces the collections of considered dynamic evaluation indicators of a PTN. These latter are computed from simulation of the bus network and support the hazardous phenomena.

Simulation and the associated indicators enable to study the impact of the following actions on the PTN:

- Creation of bus way infrastructures: does the PTA may invest in infrastructures dedicated to buses? Or simply use the standard roads;
- Adapt traffic light policies to prior buses;
- Change bus itineraries to optimize the schedule according to frequency constraints;
- Add more buses when the bus network is congested and temporary denying service.

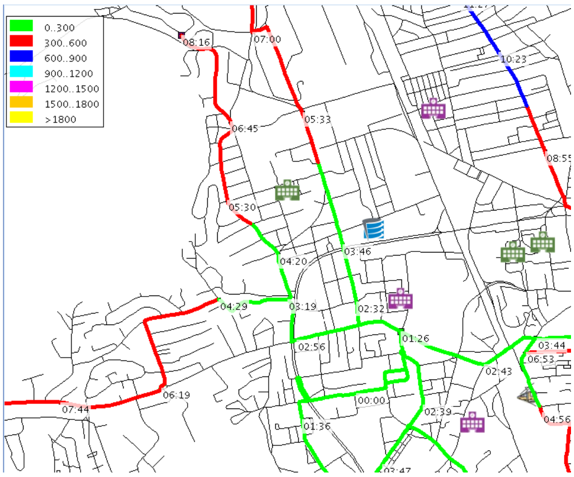

Figure 6: Traveling Times

4.1. Simulation Model

Each bus and vehicle are simulated with a situated agent. A multi-agent system (MAS) is a system composed of multiple interacting intelligent agents. Multi-agent systems can be used to solve problems that are difficult or impossible for an individual agent or a monolithic system to solve. Multi-Agent System is successfully used to simulate vehicles [4].

The behavior of each vehicle is based on the famous Intelligent Driver Model (IDM). In traffic flow modeling, the IDM is a time-continuous car-following model for the simulation of freeway and urban traffic. It was developed by [4] to improve upon results provided with other “intelligent” driver models such as Gipps' Model [4], which loose realistic properties in the deterministic limit.

Figure 7 presents the state machine describing the behavior of a vehicle. The agent behavior is based on the Perception-Action loop. Each agent perceives its environment, decides what to do for the next simulation step, and computes linear acceleration and the path to follow.

After receiving its perceptions, the agent updates its knowledge, i.e. the path it wants to follow. Then it selects a vehicle to follow, or not. This leader vehicle is used by the IDM behavior. If the agent has not selected a leader, it uses the free driving behavior.

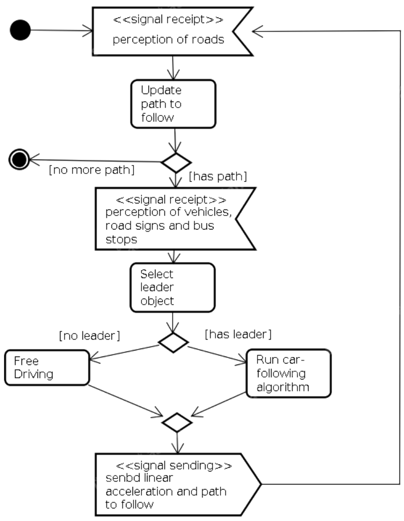

Figure 7: State Machine for Bus Agents

4.2. Simulation Indicators

Several indicators are provided by MetroB simulation model. Figure 8 illustrates the simulation of buses and vehicles in a PTN. The roads are drawn in black, the bus itineraries in color, and the vehicles with colorized circles.

Firstly, inconsistencies of the simulated buses against an official bus operation schedule may be detected. In this way, it can detect late or early buses, determine the corresponding delay, or how long they must wait. Secondly, congestions and delays are detected: how many vehicles are in the congestion or delayed, and where they are. A third indicator is the filling rate of buses. For example, it is possible to evaluate the number of waiting passengers entering in the first arriving bus, and who's waiting for the next buses.

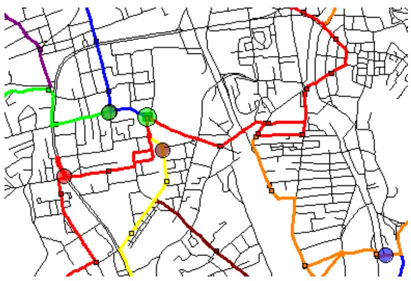

Figure 8: Simulation of Buses and Vehicles

5. Conclusion and Perspectives

MetroB can (a) import and export data in GIS standard formats, (b) draw GIS data, (c) edit a bus network, (d) evaluate a bus network, and (e) simulate a bus network. MetroB is dedicated to the initial design of public transport systems. It is successfully used by the Public Transport Authority of Belfort to design its bus network since 2004.

Future works will mainly focus on the management of the multi-modality models (train, shared-cars, etc.). In addition finest passenger statistics based O-D[2] matrices will be generated from the individual use of the mobile-phone network, and the estimation of the passenger number from embedded bus devices. MetroB extensions are planned to replace the Vehicle Scheduling Control System used by the bus network manager partly.

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