Dynamic Organization of an agent-based simulation model: application to bus network management

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ABSTRACT

This paper presents a Multi-Agent Based Simulation (MABS) system which is embedded into a Decision Support System called SATIR (Système Automatique de Traitement des Incidents en Réseau - Automatic System for Network Incident Processing). The objectives of our proposed system are to simulate feasible solutions for bus regulators to improve network management decisions. This simulation model is based on two original concepts: a disturbance model taking into account the context of the disturbance and a dynamic organization of agents. The paper describes the components of the MABS system and the way in which using the multi-agent paradigm opens perspectives regarding the development of new functionalities to improve the management of a bus network.

INTRODUCTION

Designing, implementing, and adjusting urban public traffic control systems involves quite effort and knowledge. The effectiveness of urban traffic control systems greatly depends on its ability to react upon changes in traffic patterns (for example traffic jams, road work, one-way streets, passenger clusters, etc.). The hypothesis is that it is useful for human regulators (the staff in charge of monitoring the network) to design Transportation Simulation Systems that are able to take into account environment changes and to automatically propose solutions to improve the traffic flow in order to increase the person and vehicular throughput and to decrease delay.

A variety of approaches have been used to simulate urban transportation network, going from object-oriented simulation, process-based simulation, discrete event simulation to agent-based simulation. Parunak et al. (1998) recently compared these different approaches and pointed out their strengths and limits. They concluded that “...agent-based modeling is most appropriate for domains characterized by a high degree of localization and distribution and dominated by discrete decisions”. While MABS has been used mostly in social domains, it presents several interesting properties, for instance, it supports structure preserving modeling of the simulated reality, simulation of pro-active behaviour, parallel computations, and dynamic simulation scenarios (Davidsson 2000). However, very few models are based on the multi-agent paradigm because one of the difficulties in both the design and the understanding of MASs comes from the lack of central controls and the ensuing conflicting, uncertain, incomplete and delayed knowledge on the part of the agents. Lind et al. (1998) has used the multi-agent approach for transportation scheduling and simulation in a railroad scenario. Brezillon has designed a simulator to help human regulators of the Parisian subway (Brezillon et al. 1997). A good review of the literature can be found in (Balbo 2000) (Niittymäki 2001).

David et al. (2000) define agent-based simulation according to “the model level of abstraction in relation to the real world as well as to the representation granularity of agents in the model". Our research takes place in the “simulations with representations of the real world” domain. The simulation of the real activity of the transportation network enables agents to propose feasible solutions to disturbances on the network taking into account their own constraints.

Urban public transportation systems are naturally open systems (vehicles appear in or disappear from the network according to their activity) and distributed systems (vehicles move on a network). The multi-agent paradigm makes it possible to model and simulate those systems where the distribution of control and knowledge facilitates problem solving. Therefore, a multi-agent approach was chosen to model the system in order to 1) diagnose disturbances in the bus lines (bus delays, bus advances), 2) detect inconsistency in positioning data sent by buses to the central regulator, 3) dynamically compute schedules, 4) monitor and process disturbances 5) simulate and choose feasible solutions. This research was part of the SATIR project done with the participation of the French Transportation Research Institute (INRETS).

The second section presents notions of the urban public transportation domain. In the third section, the overall
architecture of our MABS system is presented. In our model, buses and stops are modeled as autonomous agents that cooperate to detect faults (disturbances) in the transportation network. The last sections show how the system operates and present the implementation of the system and its validation on data coming from the Brussel bus transportation network (STIB).

NOTIONS OF THE DOMAIN

Regulators (the staff in charge of monitoring the bus network) use systems known as Automatic Vehicle Monitoring (AVM), which were developed in order to better ensure the success of the transport plan. They process data coming in real time from buses. By comparing the theoretical information (theoretical timetables) with the real information, the AVM system tries to adjust the supply to the real operating conditions. At the diagnosis level, it provides a number of primary alarms: advance/delay running, non-ensured next departure, bus train, problems with connections. At the control level some automatic procedures based on the departure control or on the interval control can be applied. However these procedures are limited to cope with disturbances linked with unanticipated demands, with traffic conditions or with problems of resource management (equipment failure, staff unavailability). The regulators have a number of procedures which enable them to modify the transport service according to the state of the network and of the possibilities offered by the buses on the line. Each of the regulation procedures can be broken down into a succession of new or cancelled departures. What the regulator does is to cancel or modify its timetable in order to shift the service to another point on the network (Balbo et al. 2002).

Whereas some research proposes solutions for particular points (management of connections (Bookbinder et al. 1992), real time timetable management (Li et al. 1991)), none of these systems is able neither to manage all the difficulties relating to the management of a bus network nor to propose feasible solutions.

The originality of our approach is that it proposes a global approach to the regulation function (Scemama et al. 2000) using a multi-agent based simulation. The analysis of the work station of the network regulators from the Brussels Intercity Transport Company (Société de Transport Intercommunale de Bruxelles – STIB) enabled us to identify three phases in the regulator's activity (Caruso 1997): 1) network monitoring; 2) analysis of the significance of a disturbance (which we consider as a delay); 3) the search for solutions to the problem. For each of these phases, our system makes a proposal: 1) dynamic timetable management; 2) modeling of a disturbance; 3) dynamic organization of the MABS system, 4) feasible solutions (Figure 1).

Figure 1 : A global approach of the regulation function

DYNAMIC TIMETABLE MANAGEMENT

To detect the delay of a vehicle, the time when the bus is theoretically due has to be compared with the current time. Timetable management involves three steps: 1) making up the theoretical timetables; 2) monitoring the network activity (modifying the timetables according to where the vehicles actually are); 3) managing the inconsistencies of the data coming from the sensors which locate the vehicles.

To automate these three functions, we propose two categories of agents:

1. The STOP agents, which represent the theoretical structure of the network (organized in lines and routes) and compute the theoretical timetables.
2. The BUS agents, which represent the dynamic part of the network. Every BUS agent is the abstract model of an actual vehicle running on the transportation network and reports its movements to the STOP agents.

We have chosen to allow the agents to compute the theoretical timetables themselves in order to ensure that the multi-agent system is autonomous. The STOP agents have the knowledge used by the graph makers (traffic problems and passenger flow) to make up a theoretical timetable. This knowledge is also used in the assessment process and in the search for solutions to a disturbance. Ten minutes before a vehicle departs, the STOP agent computes its timetable, taking into account the time of day.

When a vehicle passes a stop on the simulated network, a warning message is sent from the BUS agent to the STOP agent concerned. The STOP agent updates its timetable by removing this vehicle from the list of vehicles due (Fig. 1). A STOP agent which does not receive any message detects an anomaly and triggers the disturbance processing.
One of the difficulties of timetable management concerns the management of inconsistencies which arise from the data sent by the location sensors located in built-up areas. Some vehicles may not be located at a significant number of stops and this may result in the triggering of false alarms. The incorrect location of a vehicle may lead to inconsistent situations with "virtual overtakings" (a vehicle is announced before the vehicle which precedes it). In order to limit the consequences of these anomalies, we propose two protocols based on the communication between the STOP and BUS agents involved (Figure 2):

1. **Interception Protocol**: when a vehicle is no longer located, the STOP agents on the bus route have not been warned about the passage of the bus, but they will intercept all new transit announcement sent by vehicles not running to timetable. The interceptor agents receive the message and update their timetable.

2. **Update Protocol**: in the case of "virtual overtakings" a STOP agent receives a transit announcement of a vehicle which is not the bus it is expecting. The receiver of the transit announcement detects an anomaly and sends a message to its STOP predecessor on the route in order to announce this event. If the STOP agent is expecting this BUS, it updates its timetable and forwards the message to its own predecessor. If the receiver is not expecting the BUS, it will not forward the message (the interaction protocol called ESAC is described in (Balbo 2002)).

By drawing a distinction between the **Delay** and **Critical** areas it is possible to compare incidents in terms of seriousness. For two incidents with the same number of points between the late bus and its predecessor, the incident with the greater number of stops in the Critical area is considered as the most serious.

**A DISTURBANCE MODEL TAKING INTO ACCOUNT ITS CONTEXT**

In order for an alarm to be triggered it is essential to have information about the delay of a vehicle. However, describing a disturbance using the delay of a vehicle is not enough, it is important to be able to reconstruct the context of the decision. For example, a vehicle may be running late, but the distance between the previous and the following vehicles is preserved. In this case, a regulator will not take the disturbance into account. He will be more interested in a vehicle with a shorter delay, but which leads to an imbalance along the line. To measure qualitatively the importance of a delay, we have taken into account its consequences on the activity of the network.

The STOP agents have knowledge on the theoretical structure of the network. For example, each STOP agent has information about passenger flows and traffic problems. Similarly, the BUS agents have knowledge about the actual activity of the network and also the theoretical activity of the vehicles (each BUS agent manages its own timetable). We propose to put together within a specific organization called the **Incident model**, all the STOP agents and the BUS agents which are concerned with a given disturbance. For this purpose, we define three information sets, also called areas (Figure 4):

- a **Successor** area: This area brings together all the stops waiting for the successor of the late bus, it measures the risk assessment of a bus train (the late vehicle is caught up by the following one).

- a **Critical** area: This area brings together all the stops where the vehicle is late, it measures the risk assessment of a gap (the late vehicle is left behind by the preceding bus).

- a **Predecessor** area: This area brings together all the stops where the late vehicle is due but not yet late, it measures the risk assessment of a gap (the late vehicle is left behind by the preceding bus).

Figure 2: Monitoring the network activity

Figure 3: Inconsistencies management

Figure 4: The representation of a disturbance
THE DYNAMIC ORGANIZATION OF OUR MABS SYSTEM

The initial organization of the multi-agent system (in lines and routes) is completed with a hierarchical organization of the agents in order to aggregate information and to compute feasible solutions (Figure 5). At each level of the hierarchy, information is aggregated by the agents. The two new types of agents are the STOPAREA agents and the INCIDENT agent. The lowest level of the hierarchy is composed of the elementary entities, the STOP agents. The middle level is composed of the STOPAREA agents that make a first information synthesis. They collect basic information such as theoretical traffic evaluation and passenger flow from the STOP agents linked to them and they compute the progression coefficient. The INCIDENT agent represents the top of the hierarchy where feasible solutions are computed and is the link between regulators and the system.

This organization is created and evolved during the simulation run. The simulation is run on data recorded every 40 seconds, coming from buses position, which implies that, during the simulation run, the three areas involved in the Incident model are updated through cycles. This organization is dynamic because at each cycle, STOP agents move from one area to the other cycles. The agents linked to the disturbance, the late vehicle and its following one, to inform them about the disturbance; 3) it facilitates the space-time analysis of a disturbance.

THE SIMULATION OF FEASIBLE SOLUTIONS

When a disturbance has been detected and assessed, our MABS system simulates the feasible regulation procedures. Initially, the transport service matches the theoretical demand to the supply. However, when a disturbance appears, there is a discrepancy between the service provided and the passenger flow. Thus, the task of the system will to adjust the initial supply in order to satisfy the needs according to the changes of the network.

The regulators have a number of procedures which enable them to modify the transport service according to the state of the network and to the possibilities proposed by the buses on the line. Each of the regulation procedures can be broken down into a succession of new or cancelled bus departures. What the regulator does is to cancel or modify the bus timetable in order to shift the service to another point on the network. At the beginning of its activity, each BUS agent receives the list of the runs it is supposed to do (timetable) and which it can modify, thus acting as a regulator.

The timetabling processing and simulation within the multi-agent system is implemented in three steps:

- Firstly, the availability and profile of the vehicles are studied and each BUS agent positions itself relatively to the characteristics of the disturbance (is it available, where is it located relatively to the late bus?). For each profile, the regulation procedures will be the same.
- Secondly, additional information is collected such as the length of the journey. According to their profile, the BUS agents collect information from STOP agents, STOPAREA agents or BUS agents.
- Finally, the feasibility of the solutions is examined. Every regulation procedure has constraints that the BUS must satisfy in order for the solution to be considered feasible. For example, a vehicle cannot make a U-turn, if there is no location to do so.

EXPERIMENTATION AND INITIAL RESULTS

A prototype has been implemented in C++. In order to study the feasibility of our proposal, the prototype was tested using real data recorded every 40 seconds from buses on the Brussels Intercity Transport Company network (STIB). The data were recorded over 8 days and 300 incidents were assessed.
The simulation was run over time through cycles representing the move of buses on the network. Figure 5 shows the interface proposed to the regulator. This interface gives a summary of all of the data related to the problems on the network. For each disturbance its location is represented by a color code. For every disturbance, it is possible to access to its description by clicking on the reference of the late vehicle (here 54806) and of the following one (54830). The information concerns its timetable. The assessment of the risks is given by a triangle, the distortion of which informs the regulator of the relative seriousness of the risks. If the letter P appears in the list of the disturbances, then some solutions have been proposed to reduce the problem. In our example, a bus can either stop for alighting passengers only or go to another point on the line without any passengers (a dead run). The proposed dead run covers 15 stops (from MAELBECK to ST DENIS) and makes up the initial 7 min. delay of vehicle 54806.

CONCLUSION

In this paper, we have presented a multi-agent based simulation system that represents a global approach to the regulation task on a transportation network. The originality of our approach is that our MABS system is integrated into a decision support system allowing simulation of feasible solutions. For this purpose, we have defined a model, called the Incident model, that allows information synthesis that is useful for decision making.

It detects disturbances, manages them and looks for a solution to reduce the problems resulting from a vehicle being late.

The use of the multi-agent paradigm for network simulation opens new perspectives Since our system reproduces the network activity, we can run it:

1. to simulate new timetables. When disturbances are detected, the regulators and graph makers solve the problems by changing the timetables; the simulator could validate the changes by reproducing the network activity using data concerning recurrent difficulties. One way to measure the improvement of the service would be to look at the new number of disturbances.

2. to serve as a training tool. The behavior of the vehicles could be simulated in order to create disturbances while the system could assess the behavior of the regulator according to the number of disturbances on its test network.

BIBLIOGRAPHY


AUTHOR BIOGRAPHIES

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