An agent-based architecture for urban transportation systems

L. Ippolito & P. Siano
Department of Electronic and Electrical Engineering,
University of Salerno, Italy

Abstract

Today, transport networks, because of increased density in urban population centers, are affected by more and more congested traffic which produces economic, social and political problems quantifiable in terms of fuel economy, pollution and increased level of stress due to bad service quality.

Telematic infrastructures combined with automotive technology, by improving the operational efficiency of urban transport systems, can reduce the environmental and economic impacts. In this paper a Multi-Agent System (MAS) is proposed in order to manage a modern bus fleet equipped with sensors and communication devices. The multi-agent approach adapts well to describe complex systems characterized by geographical and functional distribution like transport networks where many subsystems with different dynamics and autonomy interact and for which real time control, high adaptivity and robustness are essential requirements.

The proposed MAS represents a suitable decision support system for problem identification, diagnosis, action planning and prediction and can be used to plan, implement, and manage bus fleet operations. Moreover, the implemented MAS, by means of sensors and communication devices along the roads and on the bus fleet, can help to reduce traffic, gas emissions and to improve fuel economy, assuring at the same time a better service quality.

Keywords: multi agent systems, intelligent traffic management systems, intelligent transportation systems, bus fleet management, hybrid electric vehicles, urban transportation systems, energy flow management.
1 Introduction

In recent years, the growth of public and private vehicles population caused both urban air contamination due to exhaust gas emissions, both a great increase of traffic flows, especially in urban areas.

In order to remedy to the overcom ing of pollution danger levels to recurrent and enduring and traffic congestions, state authorities have imposed traffic restriction.

Public transportation companies could help solving these problems only if they will be able to offer an adequate level of service to their customers.

In fact, in modern road networks the respect of the planned departure and arrival times of the vehicles at the different stops in the network becomes harder and harder.

Since the roads network is often congested, the traffic volume can be sometimes enormous, and many incidents can occur, customers could be forced to wait for a long time, or to loss the trip in many cases.

The use of new communications and computing technologies, described by the generic term of Intelligent Transportation Systems can help to manage the complexity of the task of vehicles fleet management and to rise the level of service to the customers.

In order to help human decision makers to take decisions in real-time, in presence of a great amount of information that has to be treated immediately, many authors have proposed to exploit intelligent reasoning systems for traffic management and intelligent supervision.

At the same time, some authors have preferred the multi agent paradigm for traffic management implementing agent-based architectures that allow for an efficient construction of scalable software systems [1-2-3-4].

In this paper, in order to manage a modern bus fleet equipped with sensors and communication devices a Multi Agent System (MAS) is implemented and described.

The multi-agent approach well adapts to describe geographically distributed complex systems like transport networks, where agents have to act in a distributed and continuously changing environment, in which events, like for example an unexpected fault can appear, and so they have to be responsive and adaptive.

Moreover since vehicles in modern bus fleet are equipped with devices providing information, agents can exploit mobility to take the necessary actions and to manage at the same time the subsystems on each bus, assuring high scalability, adaptivity and robustness.

The proposed multi-agent based architecture, consisting of four layers of agents: the road layer, the bus layer, the line layer and the control layer, enables a distributed control and supervision of the network and can help to reduce traffic, gas emissions and to improve fuel economy assuring at the same time a better service quality.
2 Multi Agent Systems approach to bus fleet management

Multi Agent Systems (MAS) can be regarded as an integration of many interacting, active, purposeful agents.

MAS represent suitable software systems when the system to manage is distributed in nature, for example across a number computing nodes, which are frequently geographically distributed.

In order to make such systems work effectively, an agent able of autonomously interacting with other agents must be associated to each node.

Moreover, exploiting concurrent and distributed computation MAS can contribute to a better control system management, in terms of efficiency, flexibility, maintainability and scalability.

In fact in a MAS, tasks such as problem identification, diagnosis, action planning and prediction can be performed locally by each agent and then the management between local proposed actions can be realized by means of agent coordination mechanism.

Furthermore MAS represent powerful tools since they allow one to incorporate legacy systems into modern distributed information systems and are open systems allowing design flexibility and autonomy.

In many cases, in fact, at design time of a software system, the knowledge of the components that will constitute it and their use and interaction is not possible so autonomy and flexibility are of crucial importance.

Therefore MAS paradigm well adapts to the bus fleet management since it permits to deal with a complex, geographically distributed system in a simple way, enabling an high level of abstraction by dividing the system into many agents, each of which tries to achieve a determinate task.

Task achievement for the proposed bus fleet management system is pursued by agents’ communication and collaboration.

Moreover agents are able to operate in real time and to manage a huge amount of data by resource sharing and expandability capacity.

3 Description of the multi-agent based architecture for bus fleet management

The proposed multi-agent based architecture for bus fleet management consists of different layers of agents, each layer is correspondent to a series of monitoring and operation functionality and is geographical distributed in the space enabling a distributed control and supervision of the network.

Each layer consists of different kind of agents that can communicate both with agents of the same layer, both with agents of the other layers; all the agents have to achieve one or more tasks and in this activity must coordinate themselves with other agents following a determined hierarchy and in agreement with a knowledge base of rules and data.

The proposed MAS architecture consists of four layers: the road layer, the bus layer, the line layer and the control layer as depicted in fig. 1.
3.1 Road layer

The road layer is located on the city roads and is geographically distributed in different areas each of which is coordinated by a different agent and consists of two kind of agents: the event/alarm agents which are road supervisors and make use of a series of sensors, cameras, and communications devices and the scenario identification agents one for each area whose task is to detect alarm situations and to identify the possible road scenarios on the basis of the information acquired by the event/alarm agents.

The division of a city or a region into a set of distinct areas where traffic conditions are different and which are coordinated by different scenario
identification agents allows a better comprehension of the causes of traffic problems.

The event/alarm agents are responsible of acquiring information about traffic conditions and in some cases also environmental information in order detect possible traffic congestions or car accidents. Moreover they have the task to monitor road conditions, by sensors measures or by information received from weather stations, police and motorway authorities.

The task of the scenario identification agents is to make use of the information provided by the event/alarm agents so as to interpret the different states of the traffic flow and of the road: they are equipped with a knowledge base supplied by the human operators about the structure and the dynamics of the controlled area.

Figure 2: Scenario identification agents distribution.

The scenario identification agents regularly communicate signals between them and to other layer agents or directly to the control layer.

The signals are interpreted as events by agents of the other layers which can use them as the basis of contingent decisions.

In this way, each scenario identification agent has to watch over a road area and the buses that may run in this area and to communicate information at the upper level.

3.2 Bus layer

The bus layer is geographically distributed on the bus fleet and consists, typically, of bus agents and engine management agents. When electric or hybrid buses are present in the fleet a motor controller agents, a battery agents and a hybridization degree agents, associated to each non conventional bus of the fleet are included. The bus agents are the coordinators of the bus layer, they use the signals emitted by the road layer agents in order to analyze the actual road scenario and to recognize the events.
The road scenarios furnished by the road layer agents are integrated in a coherent way by the bus agents, that resolve possible conflicts between them by making use of a knowledge base of rules.

### 3.2.1 Hybrid electric bus management agents

The proposed MAS architecture, in general realized for the management of public vehicle fleets of any kind, was endowed, in the design phase, also with the ability to manage full-electric and hybrid electric buses.

Hybrid electric vehicles, in fact, can improve the emissions and fuel economy of public vehicles contributing significantly to the reduction of pollution in the major cities of the world [5,6,7].

The assumed hybrid bus is endowed with a set of sensors measuring engine temperature, engine oil pressure, lambda sensor for AFR measure, engine revolution counter, fuel consumption, pollution emissions, motor temperature, battery state of charge, break usage, bus door position.

The bus agent is the supervisor of the bus layer agents, (engine management agent, motor controller agent, and battery agent), and in case of a fault or of an inefficient functioning on a component a worrying signal is sent to the line layer agents.

Engine management agent, motor controller agent, and battery agent are in charge of monitoring the on bus sub systems by the sensors for each macro-system such as engine, motor, battery and of detecting possible faults, as shown in fig. 3.

![Figure 3: Bus layer agents.](image)

The engine management agent is, besides detecting possible faults related to the engine, in charge of engine air to fuel ratio optimization in order to minimize the pollutant emissions by means of a fuzzy based control.
The motor controller agent and battery agent have the tasks of managing the right functioning of motor and battery, by inspecting motor and battery temperatures, the state of charge of battery, the motor voltages and currents.

The hybridization degree agent has the task of finding the optimal power flow between the two power sources on the parallel hybrid bus, making use of a database on the bus or by requesting a support call to the control agents of the control layer.

The optimal hybridization degree is obtained by acquiring the data relative to the bus state variables and power demand which are measured by sensors and communicated by other agents of the bus layer (motor agent, engine agent, battery agent) and by comparing them with the data of the database as described in [5,6,7].

In the case, instead that a support call request is sent from the hybridization degree agent to the support call agents of the control layer, the hybridization degree is calculated at a control layer level by simulating the bus with a model implemented in Matlab®/Simulink® and making use of the powerful Grasshopper/Matlab communication, already presented in [8-9], that allows the use of Matlab computational resources.

Therefore the bus agents continuously check the functioning of the bus macro-system such as engine, motor, battery and the information from the road layer; in the case that a worrying scenario is detected, both for a fault on the bus and for an alarm on the road, the bus agents communicate an alarm message to the line layer agents. The following type of alarms can be, for example, detected on the road: dense traffic, traffic congestion, incident congestion.

### 3.3 Line layer

The line layer consists of the line agents, one for each line of the network, these kinds of agents continuously receive information, concerning the functioning, the position, the speed of all the corresponding line buses, from the bus layer agents and from the road layer agents.

They are endowed with a virtual model of the line, based on previous experimental data which can be adjourned periodically, consisting of the network structure, the past traffic flow information, the bus fleet timetable, the desired speed and position of all the line buses, all the assumable traffic situations, and all the possible control actions.

Making use of such virtual model the task of the line agents is to identify problems on the line they manage by comparing the real data of buses arrivals/stops, position and so on with the data expected from the virtual model. The comparison of real world data with the virtual model allows them to make an estimation and a prediction of traffic load levels all over the network, improving in such a way traffic monitoring and control operations.

Moreover they are also capable of identification and prediction of traffic congestions so that to make control operations at the right time.

Therefore line agents can detect what buses are delayed, or in advance in a line, when some passengers will miss one or more buses or when it is necessary to replace some buses on a line.
Hence line agents can use the virtual model of a line not only for identification and diagnosis of problems but also for prediction and action planning.

In fact all the possible future scenarios are simulated basing on the real data information and on the virtual world model and the best control action planning is selected.

Even if for problem solving and action planning a knowledge base of rules is used by each line agent, the coordination, that can be collaboration or competition, among the bus line agents is fundamental because the problem solution may involve more than one line agent in some scenarios.

Each line agent tries to hit his target, that is to assure the correct operation of the line it manages, and for this target achievement it can collaborate or compete with other line agents. In the case for example that a bus has to be moved from a line to a different one a relation of collaboration will exist between two line agents. Moreover there will be situations in which two different line agents, in order to reinforce the line, require to a third line bus agent to transfer a bus, in this case there will be a competition relation between two line agents for task achievement.

Hence line agents represent a valid decision support system to manage the bus fleet since they in order to solve problems in the best way, minimising the impact of possible incidents, traffic congestion, fault on buses and other kinds of fatal events, can quickly propose control actions. Relating to this aspect it is important to underline that time factor is of crucial importance in bus fleet management.

3.4 Control layer

The control actions proposed by the line layer agents are communicated to the control layer which consists of four kinds of agents: the information agents, the control agents, the command agents and the support call agents.

The information agents are in charge of collecting all data coming from the layers below in a coherent way and distributing these data to the control agents or to the support call agents when requested.

All the data are stored in a database from which can be extracted and analyzed both in functioning mode of the system, both in a possible phase of updating of the agents knowledge base.

The control agents have the tasks of approving the control actions proposed by the line layer, eventually by interacting with a human supervisor, which can directly change, depending on contingency, the list of allowed control actions.

Moreover in case of competition among line agents, the control agents can decide which control action is to be performed, on the basis of a knowledge base or of an operator.

Through an interface, the human supervisor can request a prediction of the effects of a proposed action, moreover he can also request more accurate diagnosis, and estimation of a problem or of a planning action.

Hence the control agents in this way help the supervisor, by human-computer dialogues, recommending a control action, or assisting him in the selection of a control action, or can automatically make a decision regarding the control action
and the overall fleet management. Relating to the support call agents, these kinds of agents can interact directly with Matlab® in order to make complex processing, such as optimization routines or heavy computations.

In fact Matlab® is well known in the scientific world and has already been used for many hybrid and electric vehicle simulations, so the support call agents are endowed with the interaction with Matlab® thanks to a Matlab-Grasshopper agent platform communication channel already implemented [9].

The interaction is full duplex and is based on Remote Method Invocation (RMI) connection from Matlab to Grasshopper and on Java Native Interface from Grasshopper to Matlab. In order to guarantee more flexibility in terms of computation effort scalability and to better distribute the calculus on heterogeneous knowledge sources these agents can exploit mobility, i.e. they can be dispatched on remote machines when different computational resources are demanded as shown in fig. 4.

![Figure 4: Support call agents mobility.](image)

The support call agents are used for example to calculate the hybridization degree: an hybrid bus is simulated by using a Matlab®/Simulink® implemented simulation model while the optimization routines are based on the goal attainment multiobjective optimization strategy already presented in [5]. In fact the optimization of the power flow management can be led to the resolution of a multiobjective mathematical programming problem, which is concerned with the attempt to reach different objectives, such as emissions and energy consumption minimization. With the goal attainment method the best compromise power flow distribution between the internal combustion engine and the electric motor is founded introducing a set of design goals that are associated with the set of design objectives, jointly with a set of under or over attainment factors [5].
Finally the command agents are in charge of receiving the control actions from the control agents and of sending orders to the agents of the line and bus layers involved in the control actions: in this way all the agents are coordinated to achieve the final task. The functional scheme of the implemented and described MAS architecture is shown in fig. 5.

4 Potential benefits expected from the implemented multi-agent based architecture

The implemented multi-agent based architecture can be easily adapted to modern transportation systems and handled by human supervisors by an user-friendly graphical interface as shown in fig. 6.

The realized interface allows operators to control all the levels of the architecture; by the monitoring all signals and environmental information coming from cameras and sensors distributed on the city operators can detect possible traffic congestions or car accidents and can decide about the control actions proposed by the line layer agents.

The main advantages offered by the implemented architecture are:

- high levels of abstraction to design in a modular way functionally and geographically distributed systems like transportation systems;
- high robustness, flexibility and adaptivity of the system which is able to rapidly react to contingency, such as car accidents and traffic congestions;
- high security and capacity to manage great amount of data and information by means of distributed resources;
- high computation effort scalability by distributing the calculus on distributed computational resources;
- possibility of integrating legacy systems;
- possibility of integrating soft computing methodologies in order to manage transportation systems;
- increase of the levels of service and security for the drivers and customers by reducing waiting times, missing of buses by passengers;
- increase of the served customers by a more rational system management;
- increase of intermodality and of the security of travel and efficiency of vehicles;
- reduction of the impact on environment by reducing fuel consumption and emissions;
- real time coordination of all lines by a distributed decision support system endowed with intelligent skills such as identification, diagnosis prediction and action planning of problems;
- implementation of preventive maintenance strategies;
- distributed surveillance of the whole transportation infrastructure;
- communication, integration and coordination between different regional public transportation systems, such as train and underground, in order to offer high flexibility and more secure and comfortable urban travels to customers;
- possibility for the customers of an integrated payment for transportation by means of one ticket for all interconnected regional public transportation systems.
Figure 5: MAS functional scheme.

Control Layer
- Matlab interaction
- Human supervisor
- Support call agents
- Command agents
- Information agents
- Orders about actions to line agents
- Control action proposed by line agents
- Information concerning buses functioning and road conditions to the correspondent line bus

Line Layer
- Line agents
- Identification, diagnosis, prediction of problems and action planning by means of coordinations
- Information concerning possible road scenarios to bus agents
- Support call request to the support call agents

Bus Layer
- Hybridization degree agent
- Motor controller agent
- Battery agent
- Engine management agent
- Bus agents
- Check the functioning of a bus by means of a series of sensors
- Information about congestion alarm, car accidents, weather conditions
- Orders about actions to bus agents

Road Layer
- Event/alarm agents
- Scenario identification agents
- Sensors, cameras and communications device
5 Conclusions

New communications and computing technologies such as Multi Agent Systems provide a set of potentialities and techniques to deal with the complex task of vehicles fleet management.

The main advantages of such a kind of approach, in design phase, are, principally, connected to the possibility of high levels of abstraction that allow to deal with functionally and geographically distributed systems, such as vehicles fleets, in a simple, modular way. Complex systems can be in fact divided into a series of less complex subsystems by encapsulating different functionalities, frequently distributed, into autonomous, active entities like agents, which exploit a social behaviour by coordination.

In operation phase, by means of collaboration between autonomous, reactive agents, MAS exhibit great real time problem solving skills, but also great robustness, flexibility and adaptivity.

These characteristics make MAS appropriate systems to deal with traffic and transportation systems allowing to increase the level of service to the customers.

In this paper a Multi-Agent System has been proposed in order to manage a modern bus fleet equipped with sensors and communication devices.

The proposed architecture is based on agent coordination and is based on a knowledge base of data and rules, distributed on the transportation network, and that can be periodically adjourned, or managed by human operators.

The described architecture has been conceived as a decision support system, capable of proposing and accomplish control actions whether in autonomy whether under human supervision.
Moreover, since nowadays there is a great interest in equipping vehicles, such as cars, buses, trains, trucks, with mobile communication devices, the proposed multi agent system represents a powerful tool to integrate different intelligent transportation systems. In fact multi agent systems allow one to incorporate legacy systems and are open systems with great design flexibility and autonomy.

In particular MAS can be applied to other types of public transport systems, such as train and underground, allowing to integrate these systems in a unique agent based distributed architecture. Public transport systems integration and coordination allows to improve the benefits for customers who, with a unique ticket for all kinds of public means, can plan more secure and comfortable urban travels. The future researches will aim to realize, on the basis of the presented architecture, a multi agent architecture that allows to integrate different transportation intelligent systems, and to manage the communication and coordination aspects of integration between them.

References