A Cooperative Multiagent System for Traffic Management and Control[1]

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ABSTRACT

The main goal of an Advanced Traffic Management System is to help human road managers to improve traffic flows and road safety. This goal turns out to be especially hard due to the difficulties in getting continuous traffic information and also because this information is distributed in several equipments belonging to different traffic administrations and offices. So, if a traffic administration detects a traffic incident, the traffic administration must decide whom, when, what and how to perform the control actions to deal with this incident. Current approaches to answer these questions are completely human based. We propose that a Multiagent System (MAS) is able to almost-automatically carry out the answers to these questions. In this paper it is exposed the main features of this MAS (its ontology, agents and interaction protocols) and the behavior exhibited by this MAS when a meteorological incident is detected by a traffic administration in a real traffic scenario, the A3 Spanish freeway.

Categories and Subject Descriptors

I.2.11 [**Artificial Intelligence**]: Distributed Artificial Intelligence– *coherence and coordination, intelligent agents, multiagent systems.*

General Terms

Management, Experimentation.

Keywords

Intelligent Transport Systems, Multiagent Systems Applications.

1. INTRODUCTION

The application of new information technologies to traffic engineering has made possible the creation of more advanced systems and knowledge models to traffic control and management: the so-called Intelligent Traffic Systems (ITS) [2]. Advanced Traffic Management Systems (ATMS) are one of the main research items inside ITS. The basic task of an ATMS is to support road managers in road management tasks [11]. This task turns out to be especially difficult in both cases, urban and non urban networks due to different reasons. Urban networks have interrupted traffic flow and, usually, urban networks have to manage a big quantity of vehicles in small road sections. Non urban roads are in almost the opposite side. They are characterized by huge extensions of road sections (and several traffic administrations have overlapping and non-overlapping competences on them). Also, they have to deal with non-interrupted flow and they have few traffic sensors with big distances between them and with long time periods for data integration. These features make difficult the real time traffic management especially if incidents are detected. These incidents can have several causes: vehicle accidents, meteorological problems, road civil works, public events, etc. The human road manager must take decisions to deal with them as soon as possible. The traffic strategies to be applied for a detected incident must be in concordance with the current traffic flow and these strategies should not transfer traffic congestions due to the detected incident to other neighbour sections in the road network. The set of traffic management strategies to be developed when an incident is detected are off-line collected in the so-called Traffic Management Plans (TMPs).

The application of these TMPs usually involves negotiations between several traffic administrations. These negotiations are currently done by human road managers. In this paper it is proposed that a Multiagent System (MAS) is able to almost-automatically carry out these negotiations. The MAS proposed works with TMPs to support road managers to manage and control traffic in case of meteorological incidents. This paper is organized as follows. Next section describes what TMPs are and how they are organized. In section 3 it is exposed the components of the non urban traffic ontology used by the proposed MAS. Sections 4, 5 and 6 describe, respectively, the main features of this MAS: its software architecture, its interaction protocols and its communication ontology. Section 7 describes the inference rules to decide which dynamic messages to show in the Variable Message Signals. Finally, the implementation issues, the conclusions and future work are exposed.

AAMAS'05, July 25-29, 2005, Utrecht, Netherlands.

[1] This research has been partly supported by the Spanish research projects CICYT DPI2002-04357-c03-02 and Fundació Caixa-Castellón-Universitat Jaume I project number P1 1B2003-36

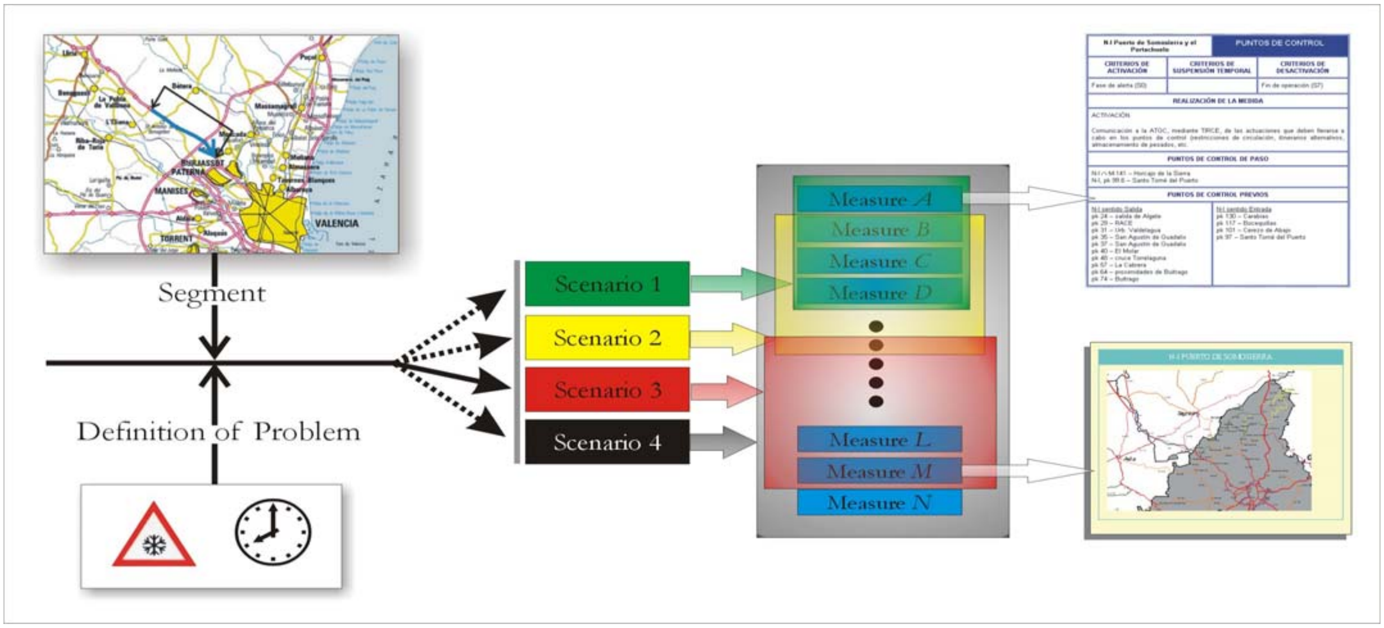

Figure 1.- Actuation scheme for a TMP

2. TRAFFIC MANAGEMENT PLANS

TMPs are specific procedures that define how to manage the detected traffic incidents. These procedures are structured in three levels of information: scenarios, measures and actions [13]. The scenario level defines the current status of the incident. The measures level defines the set of procedures suitable to be applied based on the information of the scenario level. The actions level defines the activities to develop each procedure of the measures level.

Figure 1 shows an example of how TMPs are currently used to manage a traffic incident. The scenario is determined by using the incident location and the values of several traffic parameters related to the incident (flow rates, incident severity, weather forecast, etc). Once the scenario is defined, there is a set of several measures available to run: alternative routes calculation, additional lanes, stockage of vehicles, restriction of the circulation to specific vehicles, diffusion of incident information via Internet, use of Variable Message Signal panels (VMS), etc. These measures can be classified as static and dynamic measures. Static measures are defined and developed independently of the current traffic status. Dynamic measures are defined and developed using the current traffic status.

The volume of information that a TMP compiles result in very large documents whose usage is almost impossible without a computerized appliance.

A first approach to help the application of TMPs has been done by using a HTML prototype. This prototype is a web server that stores the pages with the different levels the plan is composed of. The links between these levels follow the logical order of a TMP procedure structure. The road segment where the problem has been detected is chosen, and then the scenario and, from such scenario, the measures to be implemented. Even though the functionality of the developed plan is the one expected, the computerization of the TMPs in HTML format has some problems. The main difficult arises when the human road manager is trying to modify or update a plan. In HTML format, there is not the concept of document; that is, there is no distinction between presentation and content.

In order to avoid this problem, XML was used for writing TMPs. Using XML there is a clear difference between the document, defined by some characteristics, and the representation of such document on the screen [3]. XML also allows the creation of different types of plans and it facilitates the representation of the content of the document by using different devices.

The XML approach improves the management of TMPs but still there are several problems to solve. The TMP in the XML prototype is completely static, so it does not offer real time support to the road operator. The road operator must determine the scenario using and validating the traffic information provided by the available traffic equipment. Therefore, he must decide what dynamic measures must be activated and how to do it. So, the road traffic operator needs the help of a more advanced prototype to deal with the scenario selection and the determination of dynamic measures. The new prototype developed is a MAS in which several agents coordinate activities to almost automatically deal with the execution of the TMPs. The agents of the prototype use the same underlying traffic ontology that it is exposed in the following section.

3. ROAD TRAFFIC DOMAIN ONTOLOGY

The need of integrating and sharing traffic information is not only fundamental for traffic detection and evolution activities, but also to study, calculate and coordinate the TMP proposed and to survey its execution. Therefore, it is needed to define and use a common ontology around the road traffic domain. This ontology is composed of three subdomains.

The road subdomain (figure 2) describes topological features of the roads. This subdomain is composed of the following objects:

- *Roads*: They represent a way between an origin and a destination. It is composed by a set of segments and links that belongs to the same road.
- *Itineraries:* They represent a way between an origin and a destination. It is composed by segments and links that belong to different roads.
- *Segments*: They represent one way road sections with the same number of lanes (i.e., a two way road section is represented as two one way road sections).
- *Links*: They represent the road network areas where two, or more, adjacent segments are connected.

The link objects are subdivided in:

- *Origins*: input source to the modelled network.
- *Destinations*: output source from the modelled network.
- *Bifurcations*: Represents deviations points in the network. The traffic flow in one segment continues by two or more segments.
- *Unions*: Represents the joint points between two or more segments in a unique segment.
- *Weavings*: represent crossing points of traffic streams. The traffic flow in a weaving is affected from a link (origin or union) to another very closed link (destination or bifurcation).
- *Merges*: Represents road links between segments with different characteristics. (number of lanes, capacity, etc).

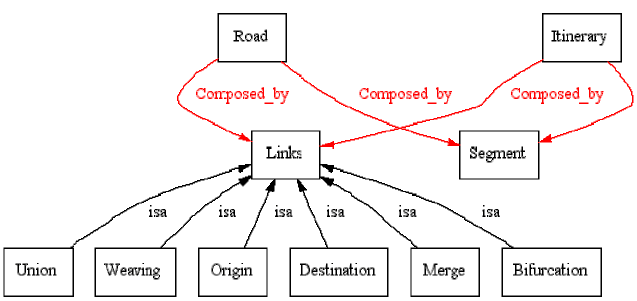

Figure 2. Road subdomain ontology

The second subdomain of this traffic ontology defines the traffic behavior model. In this subdomain (figure 3) it is described the traffic behavior and its related parameters. It is subclassified in two main groups: traffic parameters and weather parameters.

The traffic parameters are:

- Volume: the total number of vehicles on a section or lane during a given time interval (annual, daily or hourly periods).
- Flow rate (intensity): the rate at which vehicles pass on a section or a lane during a given time interval smaller than 1 hour (usually 15 m).
- Speed: It is a rate of motion expressed as distance per time unit.
- Density: the number of vehicles on a given length of a section or a lane in a particular instant.

The weather parameters affecting traffic behavior are:

- Visibility: It determines the recommended security distance between vehicles and the maximum speed drivers can drive.
- Road surface: the state of the surface defines the road vehicles adhesion
- Precipitations: Both, rain and snow have impacts on visibility and road surface status.
- Wind: Strong gusts can modify the trajectory of vehicles.

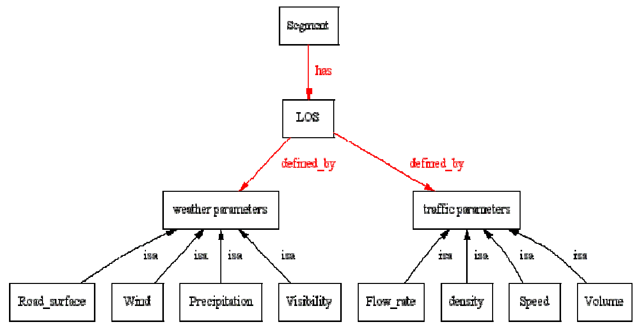

Figure 3.- Traffic behavior domain ontology

Next parameter is used to qualitatively express the quality of traffic status over time:

- Level of service (LOS): It defines the manoeuvre freedom of drivers in the traffic streams [14]. It is influenced by traffic and weather parameters.

The last subdomain is devoted to the available *equipment* along the non urban network (figure 4). The basic equipments that had been identified in this subdomain are:

- Data capture stations: These equipments are in charge of the transmission of road information. It can be subclassified in:
  - Traffic data capture station: It provides data about the traffic behavior (flow, speed, density).
  - Meteorological station: It provides information about weather parameters.
- CCTV cameras: provides road images in real time that can be used to survey traffic status in concrete places.
- Emergency phones: These phones are directly connected to traffic control centers. They allow drivers to communicate directly with road operator.
- Variable Signals: A Variable Signal is a signal with the purpose of displaying messages that may be changed or switched on or off as it will be required. Depending on the message composition it can be classified in:
  - Sign: composed by only one pictogram.
  - Flag: composed by a pictogram and text.
  - Text panel: composed by text.
  - Variable Message Signal panel (VMS): composed by two pictograms (left and right) and text.

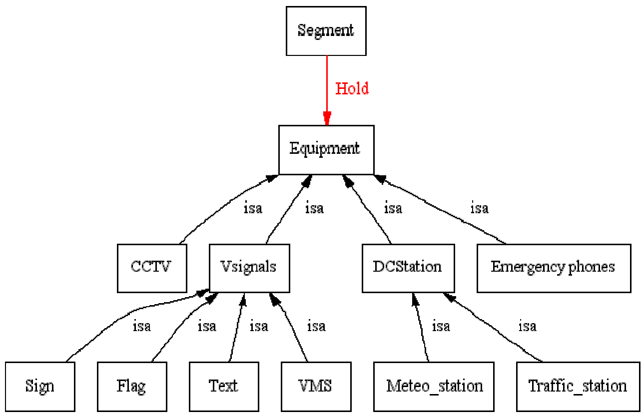

Figure 4.- Basic equipment ontology.

4. MAS ARCHITECTURE

The MAS prototype developed is composed by several kinds of agents: Meteo agents, Manager agent, XML Plan agent, Web agent, DF agent and Interface agent. Figure 5 shows the software architecture of this MAS prototype.

4.1 Meteo Agent

The Meteo agents monitor the weather evolution over time in concrete road network areas through specific sensors. They can monitor [15]:

- Air levels including temperatures, humidity, wind speed and visibility.
- Road surface status monitors the presence of snow and ice in the road surface.

When a meteo agent is initiated, it is registered in the DF agent. The registration message includes the service that provides – weather monitoring- and the information about the service: 1) the name and the kilometre point of the road where the meteorological station is placed, 2) the weather parameters that can monitor (because not all agents have the same type of sensors). The meteo agents receive subscriptions from the manager agent. The subscription message contains the weather parameters the sender agent is interested in.

4.2 Manager Agent

The main purpose of the manager agent is to provide support to the road traffic operator. This support is focused on the determination of the TMP scenarios and on the definition of the dynamic measures to be developed. An event is fired when an incident is detected. The event is composed by the incident location and the associated weather problem. The location is obtained from the position of the meteorological station (road name and kilometre point) and the weather problem is obtained from data provided by sensors.

The event allows determining the current scenario situation. Once the scenario is defined and validated by the user, the manager agent sends the weather incident information to the XML Plan agent. Furthermore, the manager agent begins to calculate the information to be provided via variable signals (Vsignals entity described in the equipment subdomain ontology). This procedure is deeply exposed in section 7.

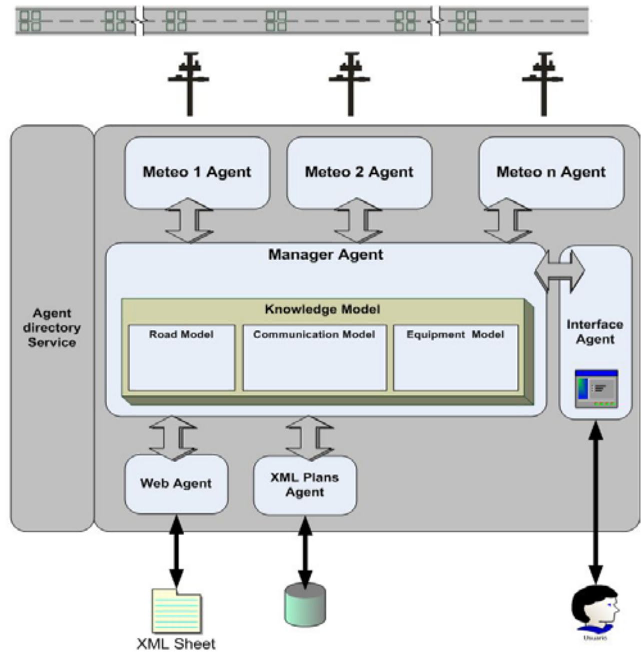

Figure 5.- Software architecture of the proposed MAS.

4.3 Interface Agent

The two basic tasks of this agent are: 1) to communicate the road manager with the MAS and 2) to display graphically all the components of the MAS: road network, equipment status, TMPs, etc.

When a weather problem occurs, the manager agent presents the overall information about the problem (event, TMPs, dynamic signalization) to the road operator via the interface agent.

4.4 XML Plan Agent

The XML plan agent contains a database with the TMPs in XML format. When this agent receives information about a detected incident, it looks for the associated fired event in the database. If a TMP for this incident exits, the agent returns to the manager agent the traffic measures to be applied.

4.5 Web Agent

The web agent translates the incident information received from the manager agent in a DATEX [7] format. DATEX is a standard format used to exchange traffic information between traffic control centres. Later, this DATEX coded information is sent to traffic control centres.

4.6 DF Agent

The directory facilitator used is the DF JADE agent [9] specified by FIPA. The DF provides a yellow pages service by means of which an agent can register, deregister and search for other agents or services in the MAS environment.

5. INTERACTION PROTOCOLS

Interaction protocols define way agents can communicate between them. The interaction protocols proposed follow the interaction protocols defined by FIPA [5]. They are implemented using the JADE libraries [6] and coded in FIPA-ACL (Agent communication language) [4].

The communication protocols are classified in two groups: Inner protocols used in communications inside the MAS prototype and Outer protocols used in communications between the MAS and the road traffic operator via the interface agent.

The inner protocols are:

1. ManagerReg: subscription protocol between the Manager agent and the DF agent. First, the manager agent is registered in the DF with the service *traffic_manager* and the road network coverage as properties. This subscription allows the manager to be informed the future meteo agents that will be registered (see fig. 6).
2. MeteoReg: request protocol between the meteo and DF agents. When a meteo agent starts its execution, it is registered in the DF with the service *weather_monitoring* which includes the weather parameters provided by the meteo agent (see fig. 6).
3. AlarmReq: subscription protocol between the manager agent and a meteo agent. The manager agent is subscribed to a particular weather parameter for a specific range of values.
4. PlanMeasures: request protocol between the manager agent and the XML Plan agent. The manager sends to the XML agent a message with the current event (weather info, road and kilometre point) and the XML agent returns the set of measures to be developed.
5. WebInfo: request protocol between the manager and the web agents. The manager agent sends the incident information and the web agent broadcast it in the different traffic web servers associated.

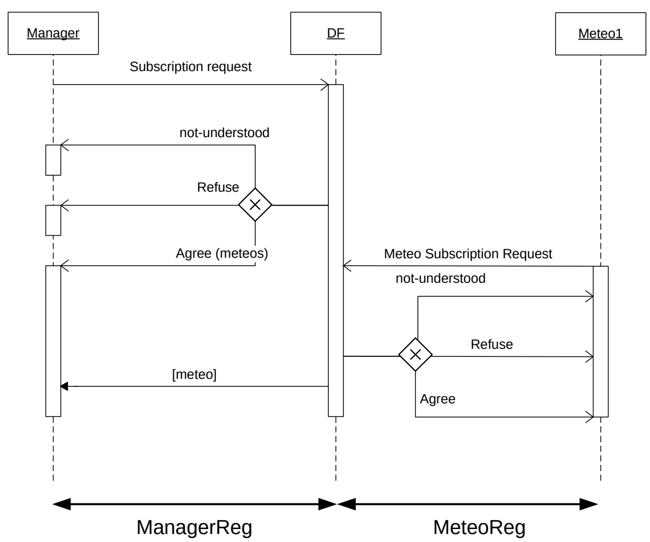

Figure 6- Managerreg and Metreoreg protocols expressed in AUML. The manager agent tries to register in the DF agent. If there is an agreement, the DF agent sends to the manager agent a list with the current meteo agents available for its road network coverage. Later, a new meteo agent tries to register in the DF. If the registration is ok, the DF adds this new meteo service to the DF. And, finally, if the new meteo services are under the area of coverage of the manager, the DF sends to the manager the new meteo information.

The outer protocols are:

6. ShowPlan: request protocol between the manager agent and the interface agent to show the measures of a TMP to be activated.
7. ShowSignals: request protocol between the manager agent and the interface agent to show the message to be put in a variable signal.
8. ForceSignal: request protocol between the interface agent and the manager agent to force a message to be put in a variable signal.
9. ValidateScenario: query protocol to validate a scenario proposal. The manager agent sends a message to the interface agent with the detected incident and the scenario proposal. The interface agent must validate the proposal.

6. PROPOSED MAS COMMUNICATION ONTOLOGY

The communication ontology has been developed using the JADE content language and its support to develop ontologies [6]. The JADE content reference model classifies all possible elements in the communication domain in predicates and terms. Predicates are expressions that specify something about the status of the world. Terms are expressions that identify entities and they can be classified as concepts, agent actions, primitives, aggregates, variables or referential expressions. The concepts used are (see fig. 7):

- Range: the maximum and minimum values for a measure.
- Measure: a specific named weather parameter.
- Station: it contains the location in the road and the measures that can be provided by this meteo station.
- Alarm: it appears at specific values of a weather parameter.
- Event: it is a concept that defines a road incident due to weather problems informed by an alarm.

And the agent actions are:

- Force_signal: It is executed by the road manager to put a mandatory message in a concrete variable signal.
- Draw_signal: When the manager modifies the state or the message of a variable signal, it sends to the interface agent this agent action.
- Update_range: It is executed by the road manager to update the range for firing an alarm in a meteo agent.

7. DYNAMIC MEASURES INFERENCE

The development of TMPs can involve to develop dynamic measures, i.e. traffic measures that can change over time depending on the traffic behavior.

There are two kind of dynamic measures: the calculation of alternative itineraries and to give information to drivers via dynamic signal. The first kind of measures implies to develop methods to coordinate resources between several traffic control centres. These methods are not exposed in this paper because they are currently being developed.

The second kind of measures implies the developing of an inference model to automatically configure the information to be showed in a variable signal. This inference model uses three components that are exposed in subsections 7.1, 7.2 and 7.3.

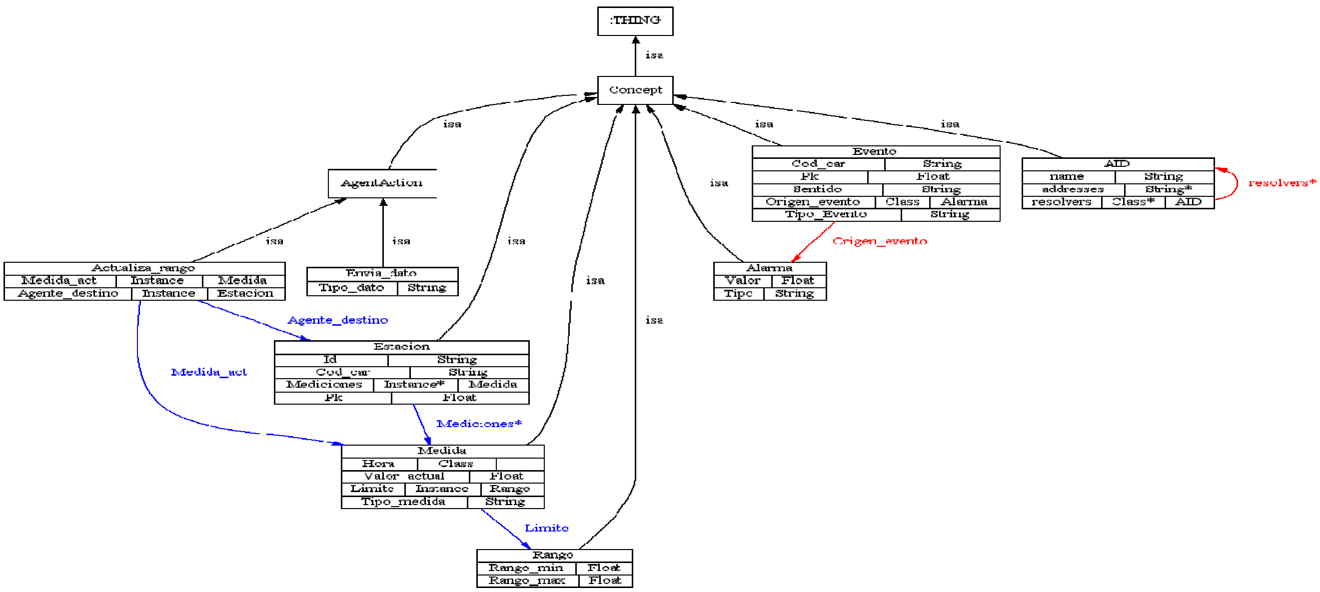

Figure 7.- Concept elements composing the proposed MAS communication ontology.

7.1 Message classification

Variable signal messages are classified as:

1. Exposure messages*:* they show general information not specifically related to the road status or traffic behavior (e.g., road safety civil advertisements).
2. Information messages: they are used to advise drivers of traffic incidents downstream (like congestions, civil works, etc) by showing traffic recommendations.
3. Mandatory messages*:* The current traffic behavior (or even the road status) can imply the modification of traffic control restrictions (e.g. the reduction of the maximum speed in a road).
4. Force messages: they contain information the road operator want to show.

The exposure messages have the lowest priority whilst forced messages have the higher priority. The weather parameters and their influence in the traffic flow are also classified in order of priority:

- Snow > road surface > Visibility > Wind

7.2 Messages dictionary

This dictionary is needed to harmonize the information provided by road managers to drivers (as it is recommended [10).

The dictionary is composed of pairs [event, messages associated] and it has been obtained from the TMPs by using three parameters. The first parameter is the weather parameter and the values related with the event. The second parameter is the variable signal relative position and it is calculated with respect to the detected traffic incident location. The variable signals can be in the coverage area of the event or nearby this area. Each case defines a different type of message. The third parameter is the type of variable signal that can be used. The content and structure of the message to be showed is constrained by the chosen variable signal.

PARAMETER	VALUE	INFLUENCED
Visibility	600-200 m.	
	< 200 m.	

Table 1.- Row of the dictionary messages table for visibility problems.

7.3 Message Selection Algorithm

The manager agent executes the following procedure to determine the overall configuration of the messages for an event *ev*:

```
SignalList = InfluencedSigns(ev);
For each sign in SignalList{
        Msg = defineMessage(sign, ev)
        If (sign is not active) then {
            PutMessage(Msg, sign);
            Sign.active = true;
        } Else CalculatePriority(Msg, sign.msg) }
```

When an event is fired, the manager agent looks for the available variable signals. These variable signals must fulfill two rules: 1) they are located upstream from the incident location; and 2) they are in the same road of the incident or they belong to a main itinerary. The manager agent defines for each selected variable signal the message associated. Each message contains its classification type and the values obtained from the messages dictionary (an example of a messages dictionary row is showed in Table 1).

If the variable signal is not active, the manager agent puts into the signal the selected message (msg) and then, the variable signal is set as active. If the variable signal is active, the manager agent must determine if the current message in the signal is more important than the new proposed message.

The most priority message is calculated by using the following protocol: each message is evaluated using the classification previously exposed. If the two messages belong to the same level, it is calculated the distance from signal to the incident events related to both messages. If they have the same distance value, it is evaluated the priority of each weather parameter. If there is not an agreement about the most priority message, the manager agent sends a request to the interface agent to determine (via road operator) the message to be put in the variable signal. The function CalcPriority implements this process:

```
CalcPriority(msg, sign.msg) {
    If (msg.type > sign.msg.type)
        PutMessage(msg, sign);
    Else If (msg.type == sign.msg.type)
            If (msg.ev.dist > sign.msg.ev.dist)
                PutMessage(msg, sign);
            Else If (msg.ev.dist == sign.msg.ev.dist)
                If (msg.ev.wparam >  sign.msg.ev.wparam)
                    PutMessage(msg, sign);
                Else SendIAmessagerequest(msg,sign.msg)
}
```

8. IMPLEMENTATION

The system has been implemented using the JADE platform. JADE is a software framework to develop agent applications in compliance with FIPA specifications for interoperable intelligent multiagent systems [1].

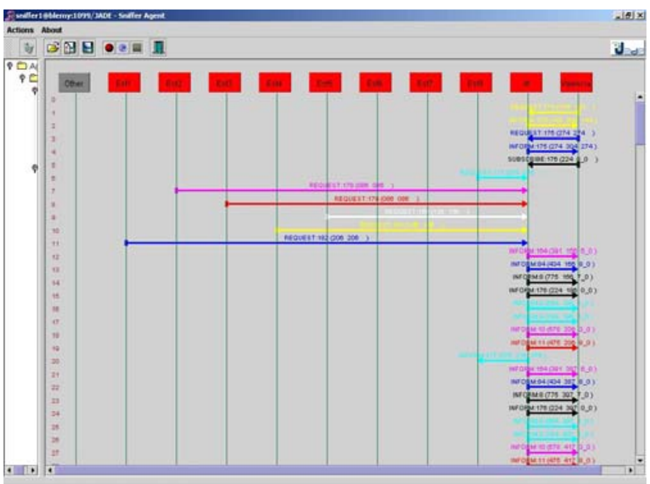

Figure 8.- Interaction protocols. This image shows the process of the manager agent registration to the DF and, later, the way several meteo agents are also being registered.

The ontologies described in section 3 and 6 have been defined by using the PROTÉGÉ-2000 ontology tool [12]. This is due to the facilities that this tool provides for editing ontologies and for developing knowledge acquisition tools from the edited ontologies.

The Javabean generator PROTÉGÉ plug-in has been used [8] to convert the edited ontology to java classes. This plug-in generates automatically the java classes using the JADE specification.

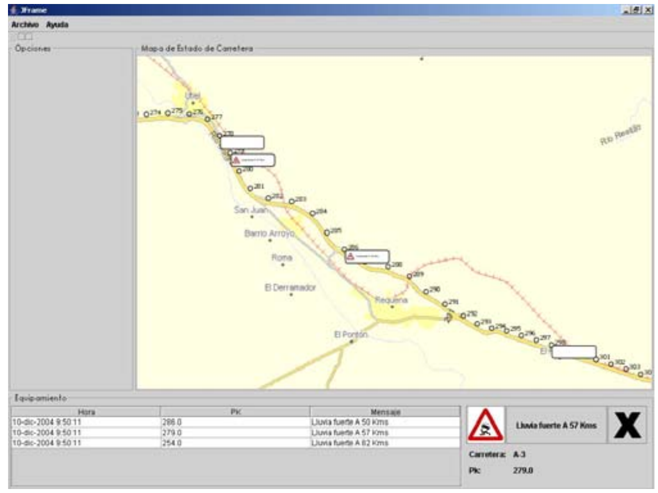

Figure 9.- Interface agent window. The upper right part is used to show the road network and the VMS panel locations. The lower right part is used to force a message to be showed in a concrete VMS panel (which it will be selected from the road network). The lower left part is used to show the fired events and the upper right part is used to show the chosen TMP to be executed (in this snapshot there is not a TMP chosen yet).

A real non urban road network has been modelled to evaluate the MAS prototype, the Spanish A-3 freeway. The main characteristics of this freeway are:

- 2 main roads A-3 and A-31.
- 16 Segments.
- 20 Links.
- 13 Meteo stations.
- 22 VMS.
- Real TMP for weather problems in the A-3 freeway.

Data provided by meteo stations have been reproduced in a XML file. Using this file, different weather situations have been simulated.

9. CONCLUSIONS AND FUTURE WORK

In this paper it has been exposed the need of defining and developing an ontology for non urban traffic. This is due to the fact that the management of non urban traffic usually involves: 1) the traffic monitoring with several distributed equipment along the road network. 2) the exchange of traffic information and traffic control plans that must be executed in a coordinated way by several traffic administrations. This traffic ontology has been developed from scratch, i.e. there are not available public non urban traffic ontologies. This ontology has been used as the base component for the coordination in the proposed MAS.

The proposed MAS improves the way TMPs are executed. First, it automatically monitors weather problems that can appear in big road networks. Second, the proposed MAS facilitates the context and the measures to be applied. And, third, dynamic measures of TMPs are estimated continuously over time and over traffic behavior.

The proposed MAS manages traffic incidents due to weather problems inside the coverage road network of a Traffic Management Centre. It also allows to communicate the incidents detected to other centres and traffic administrations. However, some incidents can imply the execution of coordinated strategies between several Traffic Management Centres. The definition, implementation and the way these coordinated strategies can be done are currently being developed.

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