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A MULTI AGENT SYSTEM MODELLING AN INTELLIGENT TRANSPORT SYSTEM

Vincenzo Di Lecce[1*], Alberto Amato[1], Domenico Soldo[2], Antonella Giove[1]
[1]Politecnico di Bari – DIASS
[2]myHermes S.r.l
Italy

1. Introduction

Nowadays, the globalization is one of the most significant phenomena of contemporary life. There are many debates about the real meaning of the globalization, its roots, effects and future. Among the most important aspects of the globalization is surely the global transportation system. In this framework it is clear how the availability of an advanced integrated transportation system, for moving goods and people as quickly as possible all around the world, is a crucial requirement that cannot be ignored in any case, but actually accomplished in the best way possible. In (Frank and Engelke, 2000) there is a remarkable work of review highlighting the steady interaction between transportation systems and human activities and how the former ones have a strong impact on the organization of the built environment. These ideas give explanation for the increasing interest that the scientific community has shown in the field of the transportation systems.

The recent improvements in ICT allow for the implementation of novel and pervasive systems. Indeed, in these days a wide spread of the Global Position System (GPS) and communication technologies (e.g. GSM, GPRS and UMTS network) has led to the implementation of interesting Intelligent Transportation System (ITS). These systems try to improve the optimization of many transportation system aspects such as vehicles, loads, routes and (overall) safety just by using these new technologies.

Route planning is an optimization problem that has been studied extensively in the past decades. Dijkstra's algorithm (Dijkstra, 1959) is the most well-known algorithm for determining the shortest path from one location to all other locations in a road network. Moreover it is noteworthy to mention other significant shortest path algorithms e, such as the Bellman-Ford algorithm (Bellman, 1958; Ford Jr. and Fulkerson, 1962), the D'Esopo-Pape algorithm (Pape, 1974), etc. An overview in this regard is given by (Bertsekas, 1998).

One of the biggest problems of these algorithms is the huge dimension of the solution space. This fact led the researchers to use parallel computing (Delle Donne et al., 1995) and/or to propose new heuristic methods often based on artificial intelligence techniques (Suzuki et al., 1995; Pellazar, 1998).

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[*] corresponding author

An interesting technique of artificial intelligence that is having a large number of practical applications in the last years is the intelligent agent technology. In (Di Lecce et al., 2004) a multi-agent system was used in an environmental monitoring system, while in (Amato et al., 2007) and (Di Lecce et al., 2008.a) it was used in databases integration.
In literature there are also examples related to the application of this technology into complex decision support systems applied to traffic control (Danko and Jan, 2000; Fernandes and Oliveira, 1999). In (Danko and Jan, 2000) intelligent agents are used to build adaptive traffic control units that are seen as proactive upon changes (short- and long term) in traffic real-time. In (Fernandes and Oliveira, 1999) the characteristic of the agents' pro-activity is used to build a strategy for controlling traffic light systems.
Within the context of a research project financed by Apulia Region (Italy), the authors designed and developed a new ITS. This system, through advanced ICT technology aims at: planning transport services in order to calculate and avoid possible high risk situations; managing transportation in order to monitor and divert the movement of dangerous goods; supporting Emergency management by delivering all relevant information for the betterment in intervention of responsible forces. Route Planning is implemented to find the best route for each transport, by using specific algorithms that consider those areas to be protected, and nearby critical infrastructure and dangerous cargos.
The authors have modelled this ITS using the Multi Agent System (MAS) technology in order to reach all these objectives. According to the well known definition, a Multi Agent System (MAS) can be seen as an organization composed of autonomous agents and proactive agents that interact with each other to achieve common goals (Faulkner and Kolp, 2003). This technology has met with significant success in the Artificial Intelligent research community because the agent-based technology can be an interesting application for realizing new models able to support complex software systems. In a project based on distributed systems, software agents are typically designed to cooperate (with other agents or humans) in an intelligent way. That is why, in this work particular attention will be given to the communication languages used by the different intelligent agents of the structure.
Information referred to vehicle locations may be seen as the experience acquired from the system that, improving day by day, ensures the reduction of false alarm dispatches, control of transporters habits and traffic conditions on their usual routes.
For the automatic recognition of anomalous situations through intelligent analysis algorithms, the data about the movement of vehicles carrying materials, subject to specific rules, prove to be useful (Bond and Gasser, 1988). These algorithms allow for the implementation of an intelligent control system, capable of interpreting the information obtained in real time by vehicles carrying dangerous materials, and therefore correlating these data with the information within the intelligence base of the system (which evolves dynamically and autonomously) and recognizing then the alarm situations.
The aim of this chapter is to describe the proposed ITS highlighting some communication aspects of the decision support system used to define vehicle routes.
This chapter will start with a brief introduction about the ITS systems followed by an overview of the latest improvements in ITC allowing for their implementation. Then, the proposed system architecture will be described from a functional point of view. At this point the proposed agent based on decision support system to route planning is introduced. The communication acts among agents are analyzed from the language theory point of

view. Then some experimental results will be described for highlighting some interesting aspects of the proposed system. Finally, the conclusions will close the chapter.

2. Technologic Improvements

The key technological elements of an ITS are: positioning system, communication channels and computing elements. In the latest years, various technologies implementing very reliable wireless communication channels also with high throughput were developed. Examples of such channels are GPRS, UMTS and EDGE technology.

As it is well known, the computing power grows according to the Moore's law. So today there are ever smaller and faster computation units.

In the latest years also the positioning systems have had interesting developments as the progresses, achieved by the Global Positioning System (GPS), shows. It consists of a constellation of continuously orbiting satellites run by the United States Department of Defence (DOD). Two levels of positioning accuracy are available: Standard Positioning Service (SPS) using the Coarse/Acquisition (C/A) code signals and Precise Positioning Service (PPS). PPS is encoded and not accessible to civilian users. SPS was intentionally degraded to obtain an accuracy of 100m (95% probability). This error source was eliminated after May 1, 2000 (Mosavi et al., 2004).

A GPS receiver antenna is used to detect signals from several of the DOD's NAVSTAR satellites at the same time. The receiver utilizes precise time and satellite position data, as well as other information in the transmitted signals, to calculate position coordinates. The time that the signal uses to travel from the satellite to the receiver is one of the essential values that the receiver must process. The variable atmospheric conditions, affecting how fast the signals travel, can generate small errors in the calculated coordinates. Under some conditions the receiver can get unclear signals from one or more satellites due to reflections of the same signals from water surfaces or buildings that are nearby (multipath). The most relevant elements influencing the GPS position accuracy are:

1. Satellite clock and position errors
2. Atmospheric delay of the transmitted satellite signals
3. Receiver noise and receiver clock errors
4. Multipath
5. Sky Satellite position relative to receiver

This latter element, satellite positions related to the receiver, refers to the satellites that a receiver is using to compute its position coordinates. Once or twice each day there is a short period of an hour or two when the only satellites, whose signals the receiver, can detect are in positions that do not allow for accurate coordinate determinations. The effect of this improper satellite positioning is to multiply the effects of the actual sources of error.

Several methods are known to improve the GPS position accuracy. Some methods use only a GPS receiver, while others use two or more receivers. An example of method based on a single GPS receiver is the averaging method. This method works averaging the latitudes and longitudes of computed GPS positions. This operation can reduce error and get better position accuracy. To reduce error by any great measure, positions must be computed at frequent intervals over a period of several hours and then averaged. It is difficult to predict exactly the amount of error reduction to be expected from averaging a certain number of positions over a given time period. This method is widely used when an accurate localization of a given fixed point is required, while it is not usable in dynamic conditions.

Various methods based on two or more GPS receivers are exploited in the differential correction in order to improve the position accuracy. Differential correction can remove most of the effects of Selective Availability (S/A) and other ordinary sources of error in GPS computed positions. In this method a reference station broadcasts corrections on common view satellites on a regular basis to the remote GPS receiver, which provides a corrected position output. A typical application of this method is the navigation guidance. On the other hand, any interruption of DGPS (Differential GPS) service will lead to the loss of navigation guidance, which can get into a vehicle accident, especially in the phase of precision approach and landing (Mosavi, 2005).
In agreement with a large number of experimental observations and the work in (He et al., 2005), and in (Di Lecce et al. 2008.b) the authors propose a method to improve the GPS position accuracy using a single receiver.

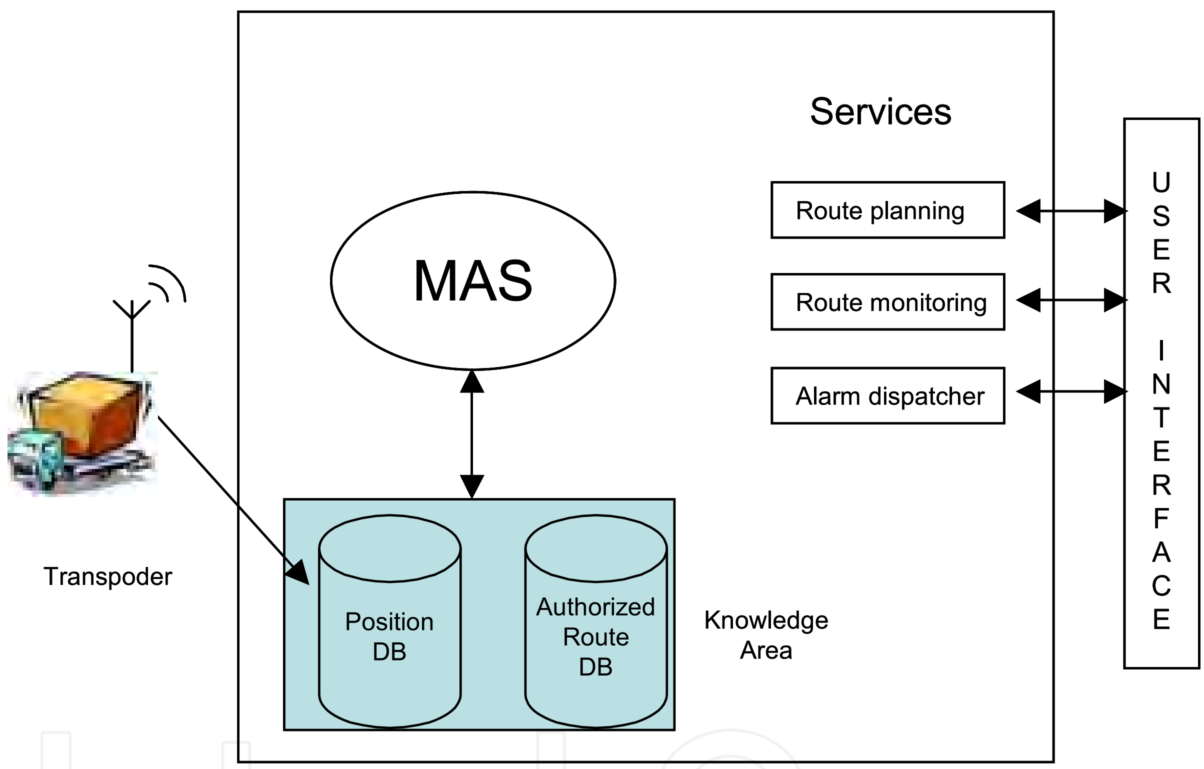


Fig. 1. A schematic overview of the proposed system

3. Proposed system

This paragraph deals with a comprehensive description of the whole proposed system for the management of hazardous material transport. Figure 1 shows a schematic overview of the described system. The goal of this system is: planning transport services in order to predict and prevent possible high risk situations; managing transportation in order to monitor and divert the movement of dangerous goods; supporting emergency management by providing all relevant information for the improvement in intervention of responsible forces, etc.
The implemented user interface is web based. It consists of two main sections:

1. transport manager: this section allows a transport manager to query the system in order to obtain an authorized route compliant with all the constraints imposed by the system (minimization of transport risk according to the law of this field).
2. monitoring interface: this section allows for monitoring the actual state of each vehicle involved into transportation.

All the vehicles involved in the transport are equipped with a transponder able to communicate its position and other data to a central system (DB positions in figure 1). The transponder uses the GPS technology for its localization and the GPRS as communication channel with the central server. The information sent by each transponder is acquired and catalogued by a computer system. These data become the knowledge base of the system that can be used to evaluate a large number of parameters (traffic conditions, mean time required for a route, etc.). These data are used to identify preferential routes and possible infringements of existing rules concerning this type of transport.

A fundamental component of the project regards an intelligent system for detecting infringements and distinguishing the alarm level of danger in order to simplify the development of institutional control tasks (often slowed down by false alarm dispatches).

The bodies in charge for the control of this transport modality are so informed in real time of any infringement occurring, thus obtaining more efficient operations.

Along the route, the system automatically provides the central server with data about the vehicle position and other parameters described further in the next sections. This information is used to:

- Check the actual vehicle route and travel condition, for security and statistical purposes and control operations performed by relevant authorities.
- Assess any possible suspicious behaviour such as: route changes, prolonged stops, unsafe load conditions or driving style, etc.
- Update a database about travelling times in the covered areas.
- Monitor the driver behaviour and the vehicle state.

4. Proposed route planning system and agents communication

In this section, the decision support system handling the route planning service implemented in the proposed system is described. Aim of this system is to find the route for a given transport that satisfies a big number of constraints such as: minimizing the hydro-geologic risk, minimizing the impact of the transport on the anthropic activities (i.e.: school, places with high density of human presence, etc.), minimizing the transport execution time, etc. The main characteristics of the proposed system are its scalability and its flexibility. The number of constraints satisfied by the proposed system as the number of handled transports are virtually unlimited. This result is due to the use of the multi agent system approach and the implemented negotiation algorithm.

Traditional systems, based on multi-objective functions optimization, have serious limits regarding the scalability both of the considered parameters and the number of vehicles involved into transport. The current technological advances in computing offer potential for deployment of agent-based negotiation systems. Negotiation can be seen as a search process where the participants are jointly searching for, in a multi-dimensional space, a single point at which they reach mutual agreement and meet their objectives. As shown in (Dospisil and

Kendall, 2000), the main approaches to design of negotiation strategies are: analytical (based on game theory), evolutionary (genetic algorithm) and intelligent agents' negotiation.
In this work the authors used the agent negotiation method due to its flexibility and scalability. One of the most relevant aspects of agents' negotiation is the inter-agent communication process. Agent communication acts are processes of paramount importance in designing MAS because the building block for intelligent interaction is knowledge sharing that includes both mutual understanding of knowledge and the communication of that knowledge. Agents communication has been widely investigated in literature and some standard agent communication languages (ACL) were proposed. Two interesting examples of such languages are:

1. KQML (Knowledge Query Manipulation Language) is a common framework via which agents could exchange knowledge. This language can be seen as composed of two modules:
    a. an "outer" module that defines the intended meaning of a message by using simple LISP-like format.
    b. A separate Knowledge Interchange Format (KIF) defining the content of messages using a first-order predicate logic. KIF is not considered part of the KQML standard.
2. the Agent Communication Language (ACL) defined by the Foundation for Intelligent Physical Agents (FIPA). Similarly to KQML, it defines an "outer" module for messages but it does not mandate any specific language for message content. The FIPA ACL defines a formal semantics in terms of a Semantic Language (SL) that is a quantified multi-modal logic.

An interesting contribute in the clear identification of the conditions bounding agent communication languages is to be found in (Wooldridge, 1998). Indeed, in that work the author investigates the possibility of defining an abstract formal framework to verify the semantics of agents communication languages. A framework of this type is useful because its implementation could address the problem of inter-operability of independent agents. The main problems that the author outlines in building such a framework are:

- the semantics of SL are expressed in the normal modal logic of Kripke semantics that are not connected with computational systems. In other words, given a generic program (written in any programming language) there is not a known way to characterize its states in terms of a SL formula (in this situation the SL are defined ungrounded).
- Computational complexity: the problem of verifying if an agent communication act is compliant with a given semantics can be reduced to a logical proof problem. This fact makes the complexity of this problem well-known. If a SL has an expressive power equal to a propositional logic, the problem is computable. This fact is not valid for first order logic and multi-modal logic.

Starting from these considerations, the authors proposed in this work an ontological based approach. In computer science, ontology is defined as "a specification of a representational vocabulary for a shared domain of discourse - definitions of classes, relations, functions, and other objects" (Gruber, 1993). In other words, ontology can be considered as the formal specification of conceptualizations of certain domain knowledge. Ontology models the world of interest through assertions in a given language.

The key objects of our model are: routes, nodes and risk index. A node is a generic point (typically a crossroad) described by means of geographic coordinate (latitude and longitude). A route is a set of sequential nodes joining the starting and the ending points. The risk index refers to a weight associated to each route and it is in inverse proportion to the satisfaction level of a given constraint. Each constraint is modelled as a risk map that is a map associating the level of risk, concerning that constraint, with each point (with a resolution of 200 meters per pixel).

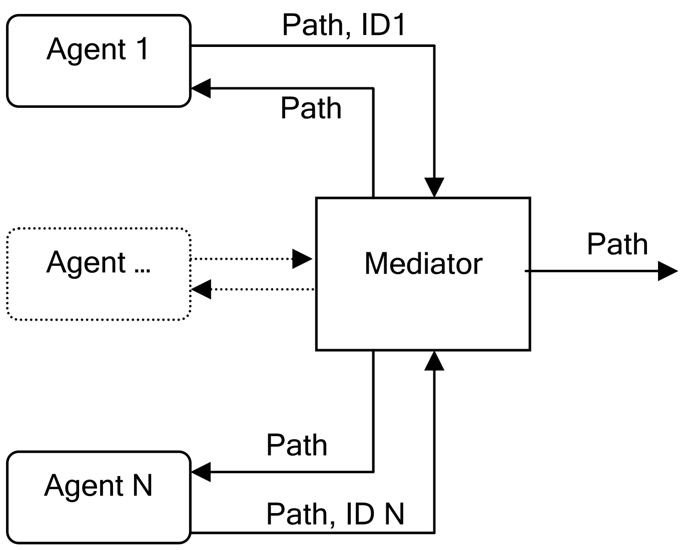


Fig. 2. A block diagram of the proposed negotiation process

The levels of risk are quantized in six values (the numbers between 1 and 6) where 1 indicates low risk and 6 indicates very high risk. These maps are geo-coded in order to associate the corresponding geographic coordinate (the latitude and longitude couple) with each pixel in the map. Using each one of these maps it is feasible to correlate a risk value, concerning the parameter modelled by the given map, with each route.

The system includes various "path agents" and a mediator agent. Each "path agents" has the ability to compute a route and associate a risk value, using a single risk map, to it. In other words, each agent is able to compute a route analysing only one constraint. In the agency there are as many path agents as many constraints are required. This fact introduces a strong level of system scalability indeed adding a new constraint to the system does not require a re-engineering of the whole system but it requires the simple creation of a new path agent. Each intelligent agent has the ability to interact with the mediator agent.

From a linguistic perspective, the agents communicate by means of performative messages (Wooldridge, 1998).

Figure 2 illustrates a schematic overview of the negotiation process. When the route planning process starts up, each agent computes N routes and the corresponding risk levels. After this stage, each path agent proposes the route with the lowest risk level to the mediator. The main task of the mediator is to assist the path agents in finding a shared solution that minimizes the overall risk associated to the chosen route. This solution is reached through a phase of cooperative negotiation, namely an interleaved succession of proposals and counter-proposals that goes on until the proposals of the agents converge to a stable agreement or a timeout expires (agency optimization).

The following pseudo-code shows the main aspects of the negotiation phase:

```
10) Each path agent:
      computes a route and its associated risk level and sends them to the mediator
20) The mediator chooses the route with the lowest risk level and asks each agent to evaluate
      this new proposal
30) Each agent computes the risk level associated to this proposed route according to its risk
      map (namely the constraint that it is handling) and sends the computed risk level to the
      mediator
40) The mediator computes the overall risk level (riskID) associated to this path and
      IF riskID is less than a given threshold T
            choose this path
            goto (50)
      ELSE goto (10)
50)  END
```

The following characteristics of the proposed algorithm should be highlighted:

- Each path agent memorizes its last analysed route and it generates the various proposals introducing variations in this route.
- Each agent proposes different paths in the step (10) but they converge to a single path in step (30).
- Each path agent is characterized by a parameter regulating its bent for the change. This optional parameter is useful to introduce a mechanism of flexible priority among the various considered constraints.

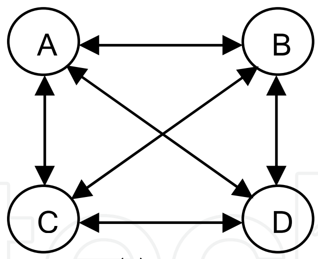
5. Experiments and results

With the intent of testing the effectiveness of the proposed negotiation method, a heavy stage of simulation was carried out. After this first stage, the system was applied to the real case. Both stages are described in this section.

5.1 Simulation stage

This simulation begins by considering a hypothetic travel between two points: A and D. These points are components of a network composed of N full connected points as shown in figure 3. In the real world, this structure represents a generic travel between a source point and a destination with N possible intermediate legs. Each couple of legs is connected by a route.

Figure 3 is a schematic representation of this model. In this figure only four points are represented for its readability. Figure 3.a shows the topologic model of the possible routes while figure 3.b represents a model of the risk map owned by each agent (see section 4). In this model, the punctual and distributed information in the risk map has been concentrated in a single cell of the matrix (called risk matrix) in figure 3.b that represents the whole risk level associated to that route. In the proposed example (figure 3), the risk level associated to the travel between the points A and C is 4 while that between the points B and D is 2. In other words, 4 is the mean risk level associated to the path between A and C. This value is the mean of all the values related to the points in the risk map falling on the (real world) road joining the point A and C.



(a)

	A	B	C	D
A	0	1	4	6
B	1	0	3	2
C	4	3	0	5
D	6	2	5	0

(b)

Fig. 3. Schematic representation of the proposed model

As result of this model, the risk matrix is symmetric. In each simulation the first column of the matrix represents the starting point, while the last one is the destination point of the route (so figure 3 represents all the possible routes between A and D).
This matrix is realized in a semi-random way, namely, its elements are generated randomically, but the direct route between source and destination point (A-D in the above example) is penalized imposing the max level risk.
The experiments were conducted by using the Matlab® environment.
Aim of the simulation was to understand the performance of the proposed system in terms of its ability to find a solution. The problem could be briefly formulated in the following way:
Given a network composed of N full-connected legs, find a route between 2 points (let say A-D) satisfying M different constraints within a threshold value T.

Number of experiments (asked routes)	100
Number of constraints	5+1
Mean number of iteration	16.27
Number of routes without solution	5
Maximum number of steps	100
T	2.5
N	5

Table 1. Results achieved through the proposed experiments

After looking into this problem it is clear that there are cases where there is no solution, while in other cases it is possible to find it. In order to handle the cases in which the solution could not exist, a limit in the number of negotiation steps has been introduced. Table 1 provides a schematic view outlining the obtained results. In these experiments, the system was queried 100 times (Number of experiments (asked routes)) with a route between two given points. The number of possibly legs was N=5. There were five specific constraints each one handled by an intelligent agent plus the constraint regarding the general low level risk that should be less than T (2.5 in these experiments). The results show that the negotiation phase requires a mean number of 16.27 steps to reach a good solution in the cases in which it exists. When the solution does not exist (or it is not found in the prefixed 100 steps), the mediator chooses among the various proposed solutions the one with the risk level closer to T.

5.2 Real case application

The proposed system was put in practice for specific reasons in the context of concrete cases under analysis, namely it was the kernel of the prototypal decision support system developed by the authors and tested for handling the transport of hazardous material in the Apulia Region (Italy).

This system implies the use of 4 agents facing the following constraints: hydro-geologic risk, road traffic, archaeological zones and sensible targets (schools, fabrics, etc.). As explained above, each constraint was modelled as a risk map. The possible risk values vary between 1 (very low risk) and 6 (very high risk). It should be noticed that the road traffic map may present variations during the different hours of the day. In this work, the day was divided into six time bands each one of four hours. The agent handling this constraint uses a risk map according to the time of the transport.

As stated before, the proposed system relies on a web based interface (figure 4) and it uses as routing engine the Google-map API and the AJAX technology to obtain the various routes. When the system is queried with a route request between a source and a destination location each agent works with the routing engine to get various routes and with the mediator to find the best route satisfying all the imposed constraints as explained above.

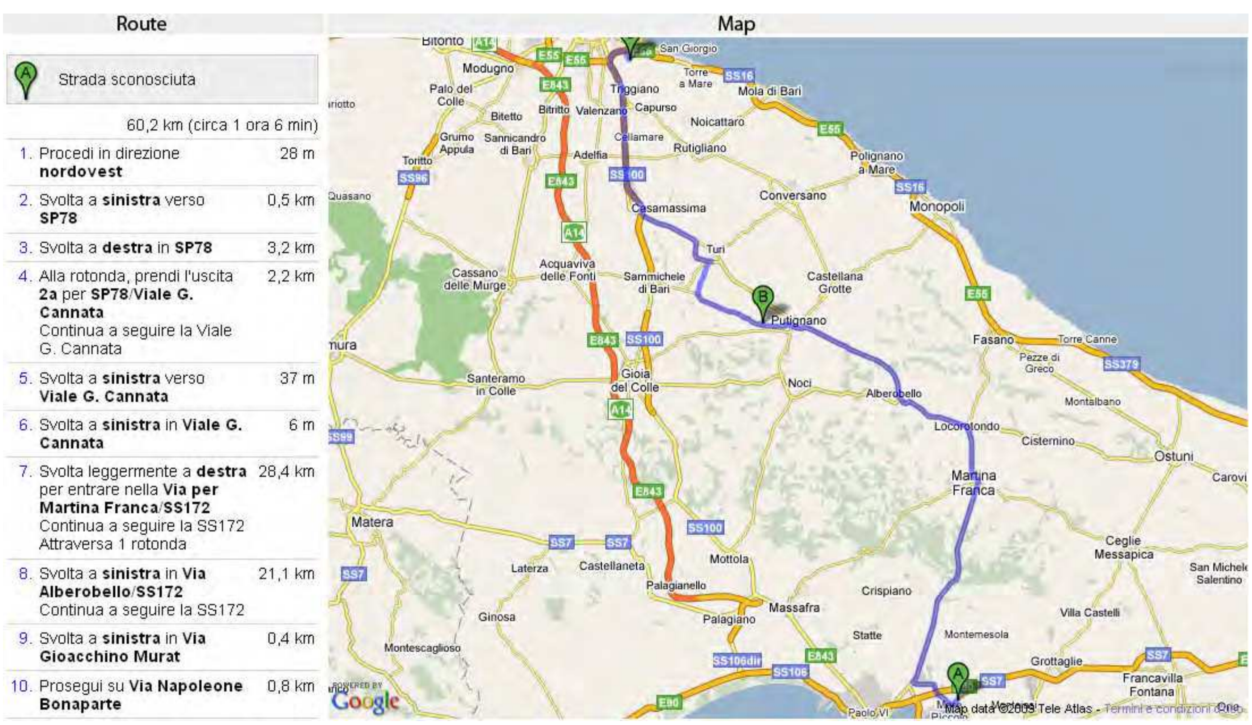


Fig. 4. A screen shot of the proposed system interface

6. Conclusions

In this work the authors have presented a new ITS, developed in the framework of a research project funded by Apulia Region (Italy), focusing the attention on some aspects related to the route planning module.
The proposed route planning module is based on a multi-agent cooperative negotiation paradigm. For this reason, particular attention was paid to the linguistic aspects of the problem and an ontological approach was used to define the communication acts among agents.
The achieved results reveal how a multi-agent cooperative negotiation paradigm can be useful in solving the problem of multi-objective route optimization. The proposed approach considers individual agent optimization (the process that each agent uses to choose a new route) and agency optimization, performed according to our negotiation protocol, by which the agents achieve a global agreement.
The implementation of a multi-agent paradigm gives great flexibility and scalability to the system. As the proposed real case application shows, this system is able to handle time variant constraint. The presence of the mediator introduces a significant level of scalability into the system. Indeed, if there is the need to tackle a new constraint, it will be sufficient to create a new agent dealing with it. The proposed results demonstrate the suitability of the proposed system as support decision system in route planning problems.

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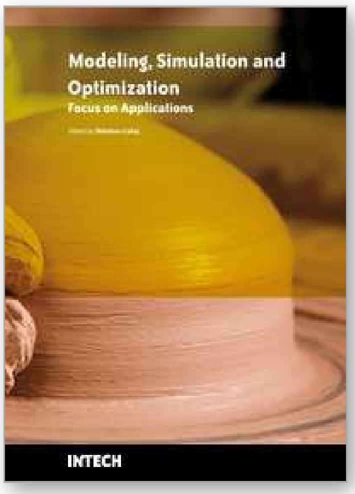

Modeling Simulation and Optimization - Focus on Applications
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The book presents a collection of chapters dealing with a wide selection of topics concerning different applications of modeling. It includes modeling, simulation and optimization applications in the areas of medical care systems, genetics, business, ethics and linguistics, applying very sophisticated methods. Algorithms, 3-D modeling, virtual reality, multi objective optimization, finite element methods, multi agent model simulation, system dynamics simulation, hierarchical Petri Net model and two level formalism modeling are tools and methods employed in these papers.