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Models for optimising dynamic urban mobility (MODUM)

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Abstract

MODUM (Models for Optimising Dynamic Urban Mobility) is a European Commission 7th Framework (FP7) project that aims to develop a new optimisation approach to traffic management, capable of dynamically adapting the overall flows of traffic to unexpected disturbances to minimise carbon emissions within an urban complex environment. In particular, MODUM employs the multi-agent system paradigm, which is used in a novel setting, i.e., for distributed coordination and forecasting (of, e.g., travel times) by means of self-organising virtual ants. In addition, multi-modal solutions are provided through a noticeboard and bidding approach using real-time data and declared destinations. The system syntheses both approaches into a single integrated model, incorporating the many telecommunication challenges of a realistic demonstrator. As there are many components in the system, we also provide an evaluation and validation framework that asserts that the software is of high quality, the traffic models are verified to reproduce realistic phenomena, and the definition of parameters and indicators for setting up and carrying out field trials. These take place in the cities of Nottingham (United Kingdom) and Sofia (Bulgary). There, a series of simulation experiments of realistic complexity are constructed using historical and real-time data feeds available from available transport sensing infrastructure.

Keywords: Route advice; Demand-responsive management; Ant-based modelling; Agent-based modelling.

Résumé

MODUM (Modèles pour optimisation dynamique mobilité urbaine) est une Commission européenne 7e programme-cadre (7e PC) de projet conception privée de développer une nouvelle approche d’optimisation pour la gestion du trafic, capable de s’adapter dynamiquement le débit global du trafic à des perturbations inattendues de mini-émissions de carbone mise dans un milieu urbain environnement complexe. En particulier, MODUM utilise le paradigme de système multi-agent, qui est utilisé dans un cadre nouveau, à savoir, la coordination distribuée et de prévision (ou, par exemple, les temps de déplacement) par des moyens de fourmis virtuelles auto-organisation. En outre, les solutions multi-modales sont fournies grâce à une approche de panneau d’affichage et de l’offre en utilisant des données en temps réel et destinations déclarées. Les synthèses du système les deux approches dans un modèle intégré unique, intégrant les nombreux défis de télécommunication d’un démonstrateur réaliste. Comme il ya de nombreux éléments dans le système, nous aussi fournissons un cadre d’évaluation et de validation qui affirme que le logiciel est d'une grande qualité, les modèles de trafic sont vérifiées à reproduire les phénomènes réalistes, et la définition des paramètres et indicateurs pour la mise en place et la réalisation de essais sur le terrain. Ceux-ci ont lieu dans les villes de Nottingham (Royaume-Uni) et Sofia (Bulgarie). Là, une série d’expériences de simulation de complexité réaliste sont construites en utilisant des données historiques et en temps réel RSS disponibles sur les infrastructures de transport disponibles de détection.

Mots-clé: Conseils d’itinéraire, la gestion à la demande, la modélisation basée sur des fourmis, la modélisation multi-agents.

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Nomenclature

ATOP	Automotive Telematics On-board unit Platform
BDI	belief / desire / intention
FCD	floating car data
FP7	7th framework programme
GPRS	general packet radio services
GPS	global positioning system
MAS	multi-agent system
MDH	MODUM deployment harness
MECA	MODUM experimental control algorithm
MODUM	Models for Optimising Dynamic Urban Mobility
MSI	MODUM subscriber interface
MSU	MODUM subscriber unit
SCOOT	split cycle offset optimisation technique
SUMO	Simulation of Urban MObility
UTMC	urban traffic management control

1. Introduction

1.1. General description

MODUM (Models for Optimising Dynamic Urban Mobility) is a European Commission 7th Framework (FP7) project that aims to develop a new optimisation approach to traffic management, capable of dynamically adapting the overall flows of traffic to unexpected disturbances to minimise carbon emissions within an urban complex environment. The project started in October 2011 and will end in October 2014. MODUM considers commuters, in combinations of both private and public transport, facing dynamic conditions such as unexpected disturbances typical of urban environments.

In particular, MODUM employs the multi-agent system paradigm, which is used in a novel setting, i.e., for distributed coordination and forecasting (of, e.g., travel times) by means of self-organising virtual ants. In addition, multi-modal solutions are provided through a noticeboard and bidding approach using real-time data and declared destinations. Both mechanisms have proven successful in other application domains and have the potential of utilising vehicles' computational power and networking capabilities for achieving their active participation in the demand-response management of urban traffic.

The metrics for the comparison are extracted from traffic control centres and from transport users in the cities of Nottingham (United Kingdom) and Sofia (Bulgary). As the metrics are defined, a series of simulation experiments of realistic complexity are constructed using real-time data feeds available from available transport sensing infrastructure. Results from these profile the two approaches against certain traffic disturbance scenarios. We will then develop a synthesis of the two approaches. As there are many components in the system, we provide an evaluation and validation framework that acts on 2 levels. On a more academic level, it asserts that software behind the developed traffic models is of a high quality, and that the traffic models themselves are verified so that they reproduce realistic phenomena. On a more global level, we devised a methodology that is based on earlier work in CONVERGE and MAESTRO, in order to define the parameters and indicators for setting up and carrying out field trials (Van Den Bergh and Maerivoet, 2013).

Software implementation of the synthesised approach focuses on the telecommunication challenges of a realistic demonstrator. The developed prototype is validated by staging real-life experiments, embedded in the context of the previously developed evaluation and validation framework. They are evaluated by the respective traffic management centres of the cities. The experiments include historical data and simulations in combination with real-time data feeds from existing infrastructure and vehicles going through a section of a city with a number of congestion profiles.

1.2. The goal of the project

Generally speaking, MODUM has developed a new approach for pro-active and demand-responsive management of traffic. At the moment, these aspects are rarely found in an integrated systems, that can handle both the inquiries from the end-users side (i.e., the travellers on the road) and the management-level of traffic operators and controllers. By intelligently combining both, we can decrease travel resistances, leading to less congested roads and consequently a more environment-friendly surrounding. This energy efficiency is achieved by employing multi-modal route guidance, giving end-users various transport choices that take into account the current state of the network. By accommodating dynamic variations within traffic demand and supply, the MODUM system provides a powerful tool to the end-user, surpassing already existing typical multi-modal routing solutions. In addition, the MODUM system can be installed in cities that already have a very active traffic management system, as well as cities with little to no existing traffic management schemes. The diagram in Figure 1 presents the use of the MODUM system in a nutshell. Here we can see how a user request is processed internally in order to return a suggestion on a possible route and accompanying travel mode. It also clarifies the link between the various components in the system, as well as the relation with the external information (e.g., loop detectors, floating cars, …).

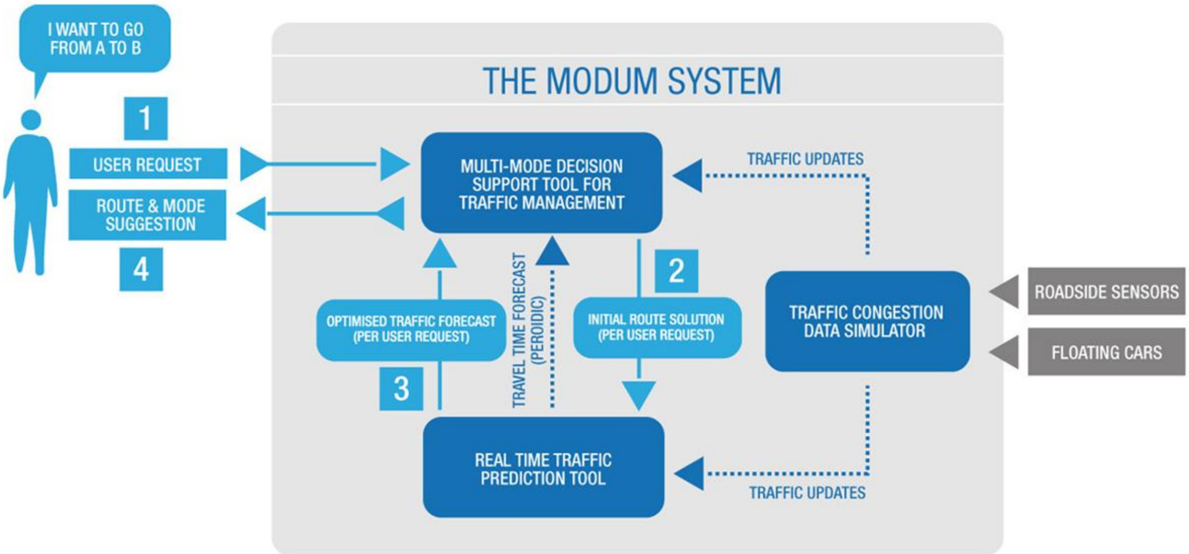

Fig. 1. A diagrammatic overview on the use of the MODUM system in a nutshell, showing how a user request is processed internally in order to return a suggestion on a possible route and accompanying travel mode.

2. Software models

At the core of MODUM lie two primary traffic management systems: (1) a multi-agent system and (2) an ant-based system. These architectures are used as the foundation for all the implementations and development efforts within MODUM, and form the backbone of the MODUM overall system. Each model offers a unique solution to search for the most CO_2-efficient travel routes between an origin and a destination within a transport network. In addition, a third model (SUMO) is used to provide an accurate representation of reality. All information herein is referenced through (Namoun and Saint Germain, 2012).

2.1. The multi-agent system

The goal of our multi-agent system is to model the transport infrastructure and optimise its use according to metrics based on efficient traffic flow, minimised congestion, and reduced CO_2 emissions. By transport infrastructure we particularly refer to road segments, rail segments, bus routes, cycle paths and pedestrian routes. Our architecture makes the assumption that each road or route is composed of multiple adjacent segments, each of which is represented by a single transport agent. For instance, a road agent would represent a segment of a road and reflect the properties of this segment (e.g., length, flow rate, density, … etc). As such our definition strictly excludes dealing with intersections, roundabout and traffic signals directly. Therefore our multi-agent system does not simulate these as physical entities as the case for segments, but rather treat them as properties that contribute to defining attributes of transport segments.

We rely on static properties of traffic network segments, such as length and capacity, coupled with dynamic traffic updates obtained from live traffic sensors, such as flow rate and average speed, to optimise traffic streams. In addition we take into account user preferences and choice, such as locations of travel and time of travel, to propose personalised travel routes. Another advantage brought by our multi-agent system is its ability to combine multimodal traffic information to recommend a multimodal route that combines various means of transport. It is worthwhile to point out that this traffic management simulation does not aim to model and optimise dynamic driving behaviour. Instead this will be handled by the ant-based traffic management system as discussed in the next section.

> Among the most traditional and common ways to model and program the behaviour of an agent is the belief-desire-intention (BDI) model (Rao and Georgeff, 1995). Agents developed according to this model possess and implement a number of mental attitudes: a set of beliefs representing their knowledge of the world state, a set of desires representing their goals or system goals (as long as they are consistent) and a set of intentions representing plans for achieving the desires. In theory agents are selfish entities but can cooperative with each other to achieve a high level goal of the system as long as it does not conflict with their own goals.

Each transport agent is unique and represents only one segment of the transport network. A transport agent holds some knowledge about itself, its neighbouring network agents regardless of their type, and external environment (e.g., IDs, real-time traffic information). Information about self, neighbouring transport agents, and realtime traffic news are collected by the sensor agent. Whilst the transport agent holds a microscopic view of the traffic situation, the sensor agent holds a holistic view of the traffic situation. In this respect each transport agent is concerned about acquiring information that relates to identity or adjacent neighbours. An overview of the interplay between the different types of agents is shown in Figure 2, with MODUM inputs and outputs located at the left-hand side. Figure 3 presents a visual representation of the road network and the agents therein.

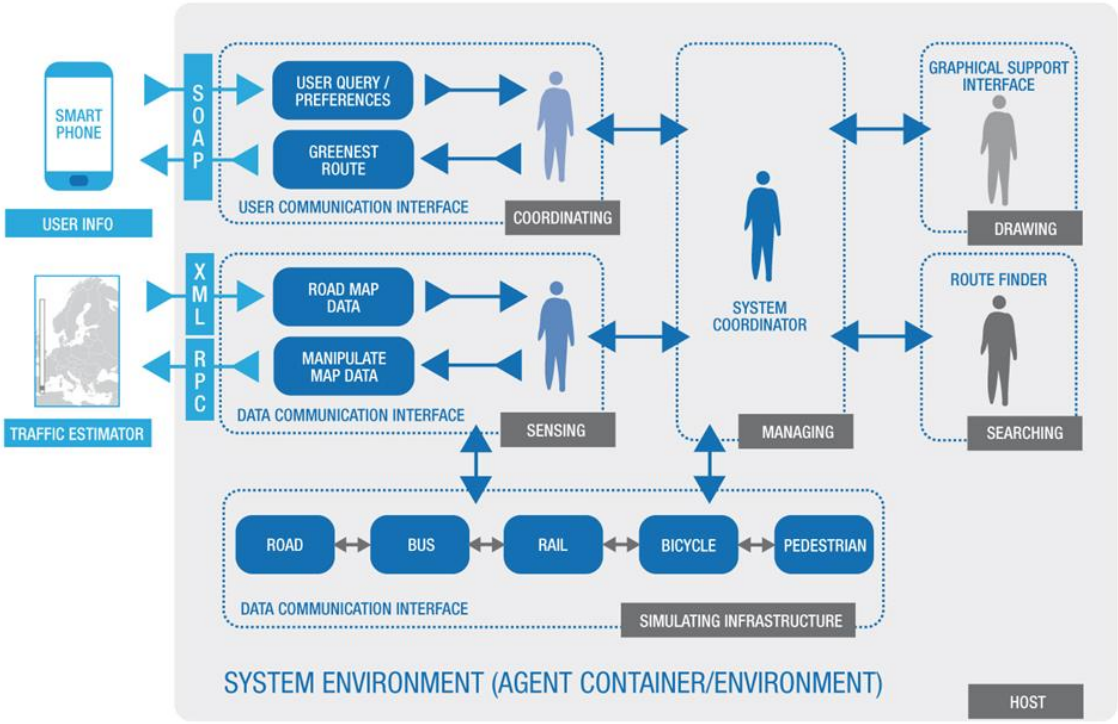

Fig. 2. The layered structure of the architecture for the MODUM multi-agent system, showing the different types of agents within the model, as well as their interconnections and message exchanges.

The multi-agent system will calculate for each transport segment a CO_2 cost (which is calculated, not measured) and update this cost continuously as soon as the traffic conditions (e.g. average speed vehicle, flow rate, and delays) change. Messages are then exchanged between neighbouring transport agents to update each other with their new CO_2 cost. Now that the CO_2 cost for each segment is calculated, the multi-agent system can search for CO_2 efficient routes as per user travel requests and preferences. The shortest paths are calculated using the fast A* algorithm (Hart et al., 1968). In addition to using CO_2 emissions as the cost for each segment, another innovative aspect in our multi-agent system lies within a bidding algorithm which, given the cost of concurrent multi-modal transport segments (e.g., road, rail and bus segments), will negotiate the optimal travel route for the commuter. In this manner, transport segments, and thus agents, will compete by lowering their respective cost to be part of the travel route.

The whole model is implemented with A-GLOBE, which is a set of tools to help develop software with agents, i.e. an agent helps you to accomplish your task.

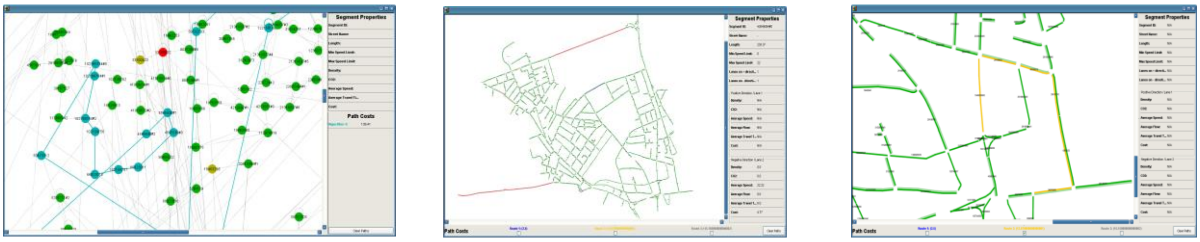

Fig. 3. *Left*: schematic overview of the various agents and their interconnections within the network. *Middle*: the implemented road network of agents in the city of Nottingham. *Right*: closeup of the network.

2.2. The ant-based system

The ant-based traffic management model provides a traffic coordination infrastructure. The infrastructure supports multi-modal traffic and goes beyond an ICT infrastructure, offering communication and computation services, and traffic coordination related services. Simultaneously, it does not impose specific mechanisms on the user. The model provides an infrastructure on which those choices can be executed. This system visualizes (i.e., makes observable by humans and software processes):

- Current and past traffic situation (track and trace).
- Predicted traffic situation accounting for user intentions. For instance, accounting for user intentions allows visualising to what extent the traffic participants have managed to coordinate cooperatively before intervening.
- On-line searchable solutions space. This allows users to find and evaluate alternatives, accounting for the predictions.

In contrast to many state-of-the-art models, this model aims to coordinate the traffic flow in real-time, i.e., an online model. Users are not known upfront and appear on the traffic management system as they plan a trip. Real-time traffic conditions are taken into account, e.g., car accidents, weather conditions, etc. The solution is centred on a high participation mode and subsequently expands the applicability range of its systems and mechanisms later (e.g., for lower penetration rates or participation). Two main architectural assets enable the distributed real-time coordination:

- <u>The PROSA++ architecture:</u>
  The ant-based traffic management application uses a holonic architecture, which is a multi-leveled hierarchy of semi-autonomous subwholes, branching into sub-wholes of a lower order. Sub-wholes on any level of the hierarchy are referred to as holons. In the context of traffic, a holon is defined as an autonomous and cooperative building block of a traffic control system for informing and guiding traffic entities. The holonic architecture used in this management model is adopted from a well-studied and widely used architecture in manufacturing control systems, PROSA. The architecture was originally developed in the manufacturing domain. It has also been applied in other application domains (railway systems, logistic systems, robotic systems, and others). This architecture is further elaborated towards PROSA++ which appeared to be well-suited for traffic control systems.

- <u>The delegate MAS pattern:</u>
  This is an architectural pattern that allows an agent to delegate a responsibility to a swarm of lightweight agents to support this agent in fulfilling its functions. The issuing agent can delegate multiple responsibilities, each of them applying the delegate MAS pattern. The agent may use a combination of delegate multi-agent systems to handle a single responsibility. The delegate MAS may also provide services to other agents. The pattern translates insights from the food foraging behaviour in ant colonies into the software design.

The ant-based traffic management model uses local models to make a short-term forecast of the traffic situation. These models represent one particular entity in the traffic system. Two entity types are considered, i.e., (1) resources that are entities which are part of the traffic network (e.g., links, nodes, public transport organisations, etc.) and (2) products/activities that are entities making use of the traffic network (e.g., a person driving to his/her destination). The representation of congestion and congestion dynamics is essential to ensure the generation of a trustworthy short-term forecast. First-order traffic flow theory is universally acknowledged to represent traffic propagation and congestion dynamics. The road network is represented by directional links (each link has an associated link holon) and knows the amount of traffic that passes through the link (from these we extract the travel times); the propagation of traffic flows is modelled by the link transmission model, developed at the KU Leuven. It is used to calculate travel times using capacity constraints and forward and backward propagation to identify congestion within the model. Vehicle holons are then sent out as explorers to calculate the forecast. Figure 4 presents an illustrative overview.

The model hinges on Erlang/OTP that works massively parallel and distributed. It is a programming language and framework that is well-suited for highly dynamic processes such as traffic flows.

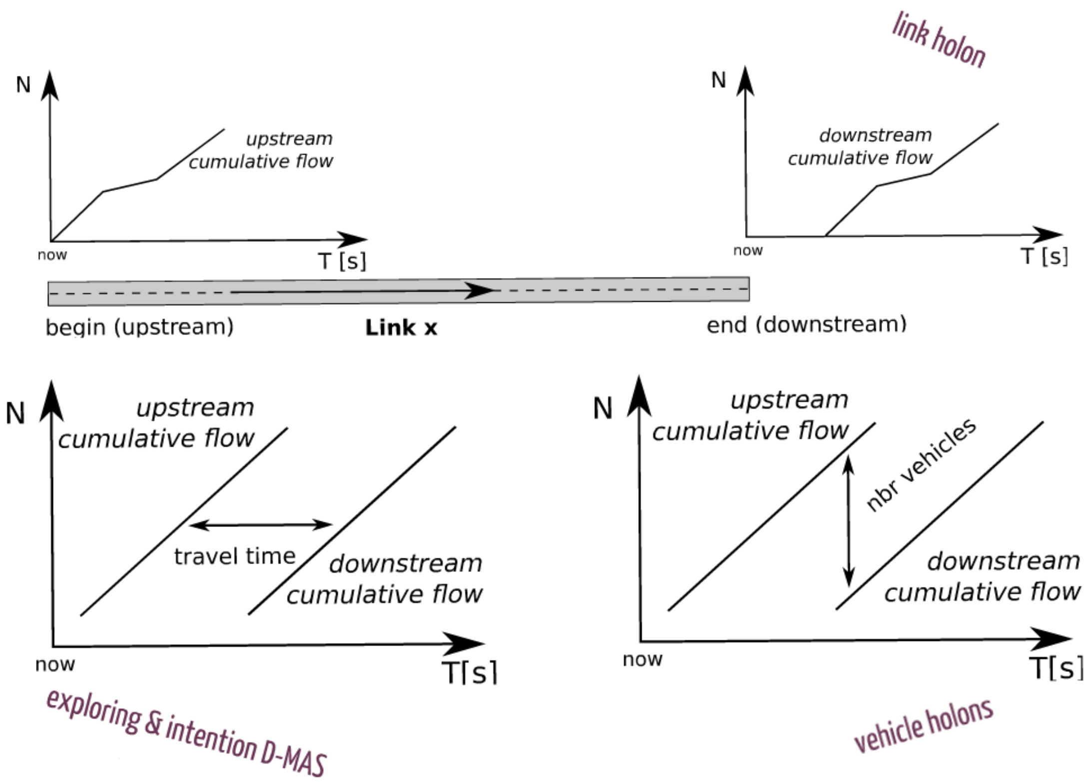

Fig. 4. An illustrative overview of the link transmission model that dynamically propagates traffic flows through a network of road links, and the relations to the link and vehicle holons of the ant-based model. The traffic flows are modelled both downstream and upstream, in order to deduce the travel time and the number of vehicles per link.

2.3. Simulation of Urban MObility (SUMO)

Both agent- and ant-based models interact with each other: the ant-based model sends traffic forecasts to the agent-based model, which in turn sends its calculation of the most ecofriendly, cheapest, fastest, … routes to the ant-based model. Because traffic measurements are geographically scattered, we use an existing open source simulation tool (SUMO), to obtain a realistic picture of reality. This allows us to have information on the traffic flows on all the streets within the network, as opposed to limited information at discrete locations. SUMO is a microscopic traffic flow model that propagates individual vehicles through a street network, based on their locations and speeds at every time step (e.g., 1 second) in the simulation (Maerivoet, 2006). An example screenshot is shown in Figure 5. Here we have set up the SUMO system to connect to real-time traffic information feeds from the street network in Nottingham, which updates the traffic signals within the urban simulation environment.

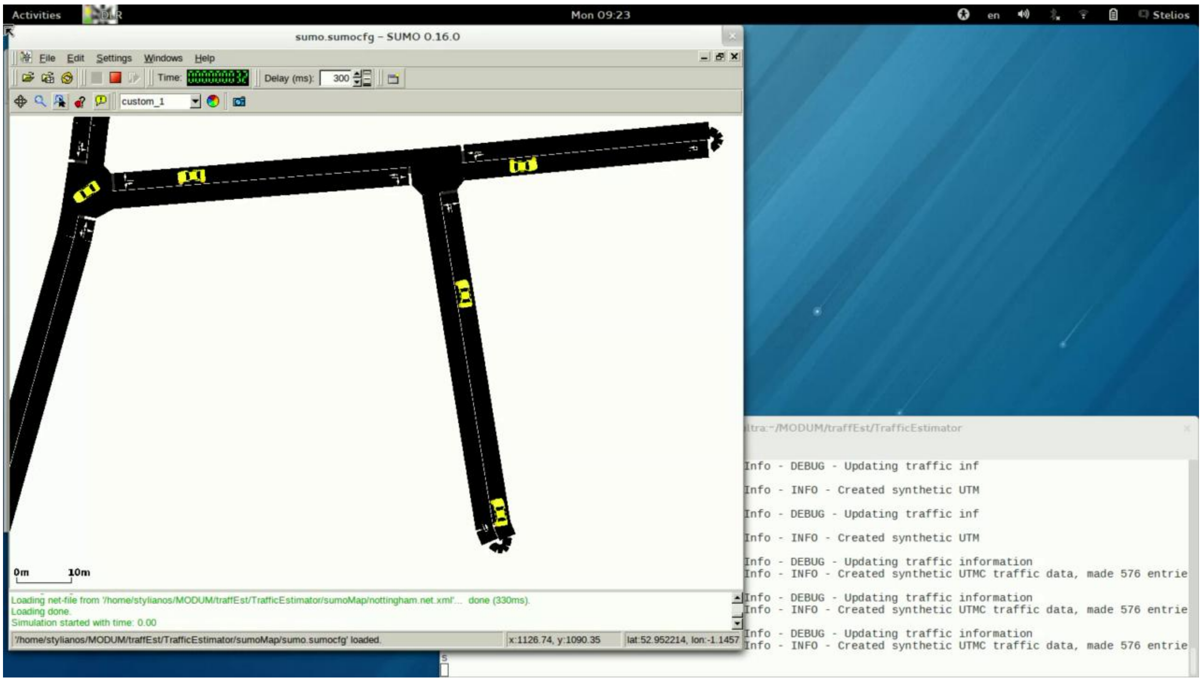

Fig. 5. A screenshot taken from the SUMO simulation system adapted to the local MODUM street network in Nottingham.

3. Hardware implementation

MODUM is an interactive system that combines different components. Figure 6 presents an illustrative block diagram that shows how all these components interrelate (Marples, 2013).

From the diagram we can see several blocks related to the various inputs and outputs of the system.

- On the left hand side of the diagram we have the MSI as a central building block. This '*MODUM subscriber interface*' acts as an interface between all different end-user '*MODUM subscriber units*' (MSUs), which are devices in the field for collecting floating data and, optionally, for providing information back to consumers. Examples of the MSUs are smart phones and FCD vehicles equipped with a GPS/GPRS ATOP device (see also Figure 7).

- On the right hand side of the diagram we have the core components of the MODUM system, comprising the '*MODUM experimental control algorithms*' (MECAs), the '*MODUM deployment harness*' (MDH), and the '*MODUM system management console*' (MSMC).

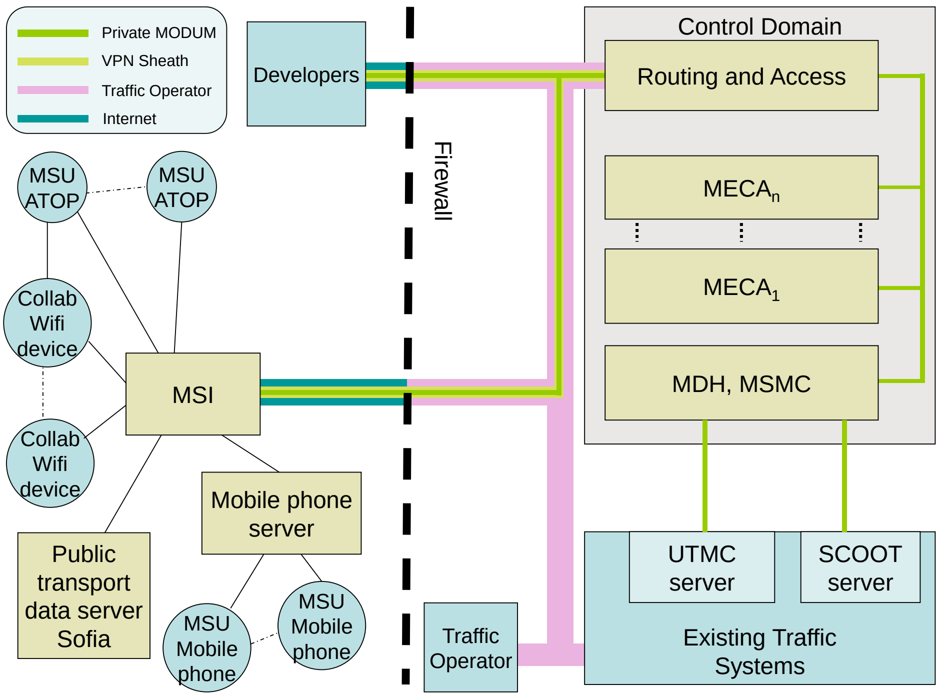

Fig. 6. A block diagram detailing the operating building blocks of the MODUM system.

The MECAs form the physical embodiement of the various models described in the previous section. As such, there are three communicating MECAs:

- The SUMO simulation which acts as a proxy of the real world; it sends out the state of the network every 5 minutes.
- The agent-based model that provides ecoroutes based on user requests.
- The ant-based model that calculates and automatically sends travel time forecasts every 5 minutes.

Fig. 7. *Left*: the ATOP device installed in a vehicle, showing how text messages can be sent to a user in real-time. *Right*: the graphical user interface of the MODUM end-user prototype running on an Android smartphone.

The MDH is responsible for the marshalling of all other MODUM subsystems, the handling and routing of data and for logging and monitoring of system operation. In addition the MTH provides a subsystem for providing a test environment to the MSI and MECA components. Both MDH and MTH are mutually exclusive and only one of these will be operational at any one time. The MSMC finally forms the interface between MODUM and the traffic operator. This is the interface by which the traffic operator is able to monitor the operation of the MODUM system and to provide updates to its operational status (any, by extension, to any MECAs that may be running). The subsystems communicate with each other via a set of protocols such as CORBA, SOAP, XMS, HTML, tunnelled UTMC, …

4. Field trials in cities

For the purposes of the MODUM project, there are two urban environments considered; Nottingham in the United Kingdom (52° 57′ N 1° 09′ W) and Sofia in Bulgaria (42° 42′ N 23° 20′ E). The former provides a mature and rich infrastructure, whereas the latter forms an immature traffic management environment with a lot of opportunities to collect traffic information and steer traffic (Namoun et al. 2013).

- The Nottingham environment represents a mature Urban Traffic Management (UTC) capability in a modern city centre with SCOOT widely deployed and good levels of instrumentation and traffic sensing throughout. Nottingham has implemented Urban Traffic Management Control (UTMC) via a Siemens COMET system and feeds data into this system including SCOOT traffic flow information, fault and accident data, car park occupancy data, and real-time bus transit data.

- In comparison with Nottingham Sofia has very little active traffic management. Traffic lights are controlled independently through local controllers and the strategy for dealing with incidents is reactive, rather than proactive. Although there are moves afoot to re-equip a number of traffic light controllers in the city centre, which may lead to some level of co-ordinated functionality and the availability of data for traffic management purposes, it is to be expected that information collection and action delivery will primarily be via communication directly with mobile devices associated directly with end users. GPS data is also available from public transport vehicles which can be used to determine flow information. There is some statistical data available for public transport load/usage from Automated Fare Collection (AFC) systems but there is no car park occupancy data available. Integration issues will be addressed by the project local delivery partner as part of the deployment activities

The goals of the field trials are (i) to implement the software, (ii) to deploy test vehicles and users, and (iii) to perform policy-related evaluations. The focus of the MODUM systems lies on commuters (by means of private and public transport), and city traffic in general (with dynamic variations in traffic). In general there will be 50 cars asked to participate in the trials, equipped with mobile devices, some in-car ATOP devices, … All trials will run for approximately 1 week, starting around April 2014. An example of route advice via a webinterface is shown in Figure 8.

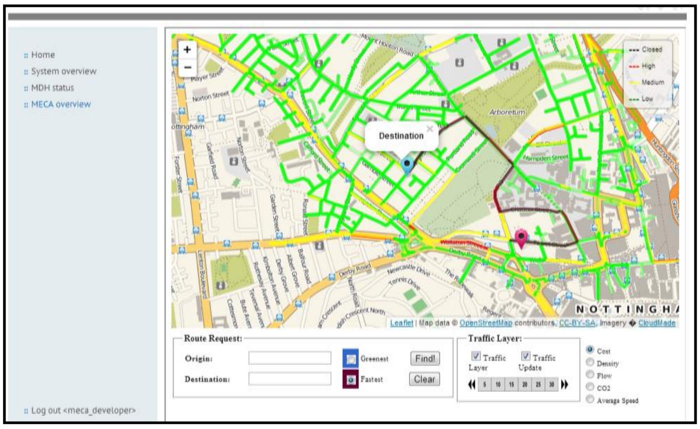

Fig. 8. A screenshot of the webinterface that displays route advice based on a MODUM-processed user request.

5. Conclusions

MODUM is a challenging project. At the moment of writing, we are two-thirds through the project. The underlying mathematical models are completed, allowing us to calculate and predict optimal routes based on congestion and emissions, taking into account the current traffic situation. The hardware implementation of the MODUM system has also been finalised, and all of the models are implemented in hardware. Currently, we are deploying the MODUM prototype in two cities. Both Nottingham in the UK, and Sofia in Bulgary, will provide the background for the field trials using a plethora of available traffic information, as well as smartphones and in-car devices. MODUM is unique in the sense that it provides a short term potential and added value by (i) augmenting traffic information where needed, (ii) increasing benefits when scaling up, and (iii) providing dynamic information and optimisation with respect to traffic information and traffic flow management.

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We also invite you to visit our website at http://www.modum-project.eu/, which contains deliverables on both academic information related to the models, as well as useful material associated with the setup of the field trials.

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