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Real-time traffic monitoring and forecast through OPTIMA - Optimal Path Travel Information for Mobility Actions

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Abstract

OPTIMA is an innovative ITS (Intelligent Transport Systems) platform for traffic monitoring and management, that provides off-line estimates and real-time forecasts concerning the use (vehicle flows) and the performances (travel times) of the road networks.

To this end, OPTIMA exploits an advanced methodology for modelling transport demand and vehicle congestion, through which the behaviour of drivers and the propagation of queues are explicitly represented. The connection to actual conditions is guarantied by field measures at discrete points (loop detectors, speed radars, video cameras, probe vehicles) that are collected in real-time and sent to a control room, where sophisticated algorithms allow to reconstruct the current and future traffic pattern on the entire network, hence extending the available data in time and space to achieve a useful information for driver navigation and transport optimization.

1. Introduction

1.1 Overview of the technology

OPTIMA relies on a priori estimations of the traffic evolution during each day-type that are accomplished through the simulation of the whole transportation system, which reproduces the path choices of drivers travelling on the congested road network from their origin to their destination at specific instants. Then, the real-time measures are used to calibrate and correct such a mobility model, adjusting the base estimation to the current traffic conditions, thus providing a very robust and reliable prediction.

Our approach, primarily based on the physical interpretation of the traffic phenomena, differs substantially from the mere interpolation of field measures through artificial intelligence methods. Most monitoring systems apply,

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in fact, data mining techniques to match the current time-series with historical patterns, thus providing forecasts only on local conditions. However, statistical inference alone may not allow to deduce the traffic state of non monitored links from the observed data or to figure out the consequences of unpredictable and atypical events such as road accidents.

OPTIMA is specifically conceived for metropolitan contexts, where the congestion is strongest, while the day-to-day variability and the within-day fluctuation of vehicle flows and travel times is not negligible; but it can also be applied in extra-urban frameworks, that are less complex by their nature.

The main advantage of OPTIMA, compared to the existing methodologies, is certainly the limited amount of real-time information that it needs to reconstruct the traffic pattern. This feature makes this technology suitable to set-up a traffic monitoring system also in smaller towns, where budget constraints are tight considering the number of potential users, or complementary to rapidly expand an existing system in terms of space (covered area) and density (controlled links).

OPTIMA integrates traffic monitoring and prediction with route guidance and vehicle routing, thus letting its comprehensive information system fully available for many off-line and real-time applications concerning mobility management and transport services.

The platform is constituted by three main components:

- OPTIMA Traffic, an efficient control system for real-time traffic monitoring and short-term prediction of its evolution, based on the actual dynamics of vehicle flows and queue propagations;
- OPTIMA Navigator, a powerful navigation system that continuously updates the driver's path toward its destination, based on the traffic conditions that are estimated and predicted for the entire road network;
- OPTIMA Fleet, an easy management system for vehicle tracking on the road graph and optimal routing, to be employed in public transport and freight distribution.

1.2 Context and motivations

The mobility of goods and people is a critical issue for our society. Thus, the ability to predict traffic conditions on the network and to make decisions about the optimal trips of users and vehicles allows for a more efficient activity planning by individuals and companies, achieving substantial savings for the society as a whole.

To faced these needs, in recent years there has been a significant technological development of the so-called Intelligent Transportation Systems (ITS). The diffusion of automatic systems for monitoring urban and extra urban road networks, has made now available a vast amount of data (flow, density and speed of vehicles on given sections), both historical and real-time, describing the state of many links and their evolution over time.

In parallel, the current deployment of technologies for mobile communications and satellite positioning permits providing to individual travellers real-time information to support dynamic decisions and adaptive strategies. We consider in particular the possibility of suggesting to drivers optimal paths with respect to actual and forecasted traffic conditions on the entire network, and in particular to the estimations of travel times.

However, it is evident that the methodologies used so far for infomobility are now totally inadequate to exploit the enormous potential of the ITS sector described above. Suffice it to say that the navigation systems, now increasingly spreading on the market, provide indications based on static speed limits, denying any explicit effect of road geometry and of traffic congestion.

1.3 Objectives and outputs

OPTIMA is conceived to bridge the gap between information widely available but not sufficiently complete to be usable by the decision maker (whether a supervisor or an individual), and a set of mobile communications technologies that become mature to receive and transmit real-time information to users.

The primary objective for OPTIMA is to make a decisive step forward in providing traffic information and optimal routing that are more effective, reliable and useful.

In particular, OPTIMA is able to:

- infer the flow state (flow, speed and density, i.e. queue) occurring on some links, from observations of traffic conditions carried out on the network, especially in the form of vehicle trajectories;
- extend the measures made for a limited number of links by obtaining an estimate of the full network status and of its evolution in the next future;
- retrieve, based on these state variables, an estimation of travel times on each link of the network depending on the entering instant;
- identify, based on the travel times and costs on the network, an optimal path between any pair of nodes depending on the departure instant;

• operate navigation and routing in real-time, that is continuously updating the estimates of travel times and of optimal paths on the basis of the data collected from the network.

1.4 Key features and advantages

Compared to the existing approaches and methodologies for the estimation and prediction of road travel times, OPTIMA presents the following innovative features and key differences:

• it provides travel times that are not constant over time, but instead are varying during the day depending on the estimated and/or observed traffic congestion; these are definitively more accurate and reliable than those actually provided by other technologies;

• based on the above information and on the time-varying characteristics of the road network (i.e. limited access zones), it is able to perform real time calculation of optimal paths depending on the departure time;

• both the off-line and the real-time estimation and prediction of travel times do not require a massive or extensive collection of traffic data; on the contrary, they just need a limited amount of observed data; in particular about one moving (vehicle) or fixed (camera) probe for every km of monitored road network: to make an example, the principal network of the Rome municipality, Italy, that consists of about 1000 km of roads and serves about 3 Millions of citizens, requires about 1000 probe vehicles or traffic cameras; the system is able to extend both in time and space these field measures by means of a sophisticated methodology, integrating them with historical mobility data;

• traffic information are collected, transmitted and elaborated automatically, without the need of human operators; this results in a dramatic reduction of the time needed to make traffic information available for mobility decisions (down to few minutes);

• it is scalable and replicable, since it is base on commercial standards or publicly available data regarding transportation mobility and socio-economical activities; moreover, it doesn’t rely on external information sources prided by municipalities, police, or transport network operators (although it can use these data, if available), since observations may come from the same vehicles that use the system and act as automatic moving probes.

2. Functional description of the platform

OPTIMA Traffic is a software system for monitoring traffic in real-time and forecasting its short-term evolution; it constitutes the beating heart of the ITS platform and represents its more innovative module from a methodological point of view.

OPTIMA Traffic is indeed based on advanced models and algorithms for the dynamic assignment of transport demand on road networks, that allow to estimate travel times, traffic flows and vehicle queues in their daily variation during the day, even starting from an extremely contained number of observations about the congestion state, with respect to other existing methodologies that are based on statistical inference of field measures.

OPTIMA Traffic is a modular system based on a client-server architecture that is founded mainly on four software components; the first two off-line and the second two on-line.

OPTIMA Traffic is based on a methodological framework whose functional structure, depicted in the diagram of Figure 1, is briefly described below by identifying the modelling components (rounded gray), the input and output (rectangular blank) and their relationships (arrows).

The base model of the transportation system is build starting from Census and network data by means of semi-automatic procedures stored within the TMB.

The base model is firstly used off-line to calculate an a priori estimation of travel times and path choices applying the DUE algorithm. The latter are represented by turn splitting rates.

Real-time data on the state of the road network are collected by moving probes (equipped vehicles) and/or fixed probes (e.g. loop detectors), in the form of space-time trajectories or flows and speeds, respectively. The Vehicles Tracker module transforms the observed trajectories into traffic measures of speeds and capacities on the monitored links of the road graph.

The SDNL software is responsible for putting together the real-time observed data with the simulation providing the a priori estimation. This is done by correcting in rolling horizon the resulting vehicle queues while taking into account the base path choices of drivers to reproduce as closely as possible the actual traffic conditions on the network. The calibrated simulation constitutes then the forecast of travel times that can be used in the route guidance module to provide optimal paths.

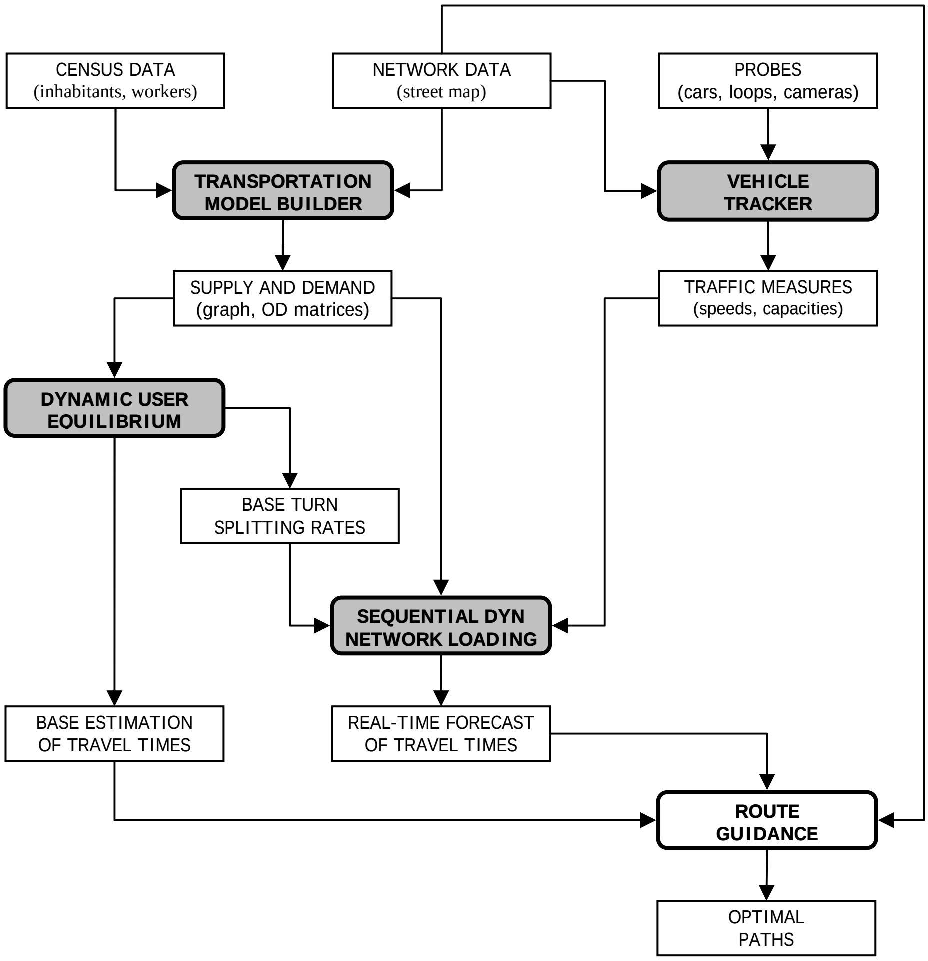

Figure 1. *OPTIMA Traffic functional diagram.*

2.1 TMB - Transportation Model Builder

This software integrates into a GIS graphical interface a methodology that allows to determine, through a chain of models and algorithms, a transport graph, a territorial zoning and origin-destination demand matrices, starting from commercial street networks (e.g. Navteq, TeleAtlas) and standard socio-economical data (e.g. ISTAT, ISFORT, for Italy) in a totally automatic manner. Thus TMB allows the creation of truly predictive traffic simulation for large urban areas with few days of calibration by relying mostly on publically available data. This tool lets to set-up reliable data bases for traffic assignment algorithms with low costs for planning studies aimed at mobility management and for monitoring systems aimed at navigation/routing.

2.2 DUE - Dynamic User Equilibrium

This software solves in suitable computing time the Dynamic Traffic Assignment to large road networks, simulating the formation, the dispersion and the retro-propagation (spillback) of queues during the day both in metropolitan and extra-urban areas. For a given time-varying demand of trips from origins to destinations, DUE provides the within-day trend of car flows, vehicle queues, travel times and polluting emissions for each road link at equilibrium, together with the generalized costs of each user and the corresponding trip choices, in particular his trajectory on the network.

DUE allows to analyze multiuser and multimodal contexts with elastic demand, including the departure time choice. It can calculate the dynamic equilibrium (consistency among, costs, times and flows within the path choices) or simply the dynamic network loading (traffic mechanics for given path choices). A module for the adjustment of o-d matrices and their daily evolution from traffic counts is also available.

DUE is the first software that can handle detailed metropolitan networks, simulating a whole day in real-time. This result is possible because DUE manages relations among entire temporal profiles, allowing thus to consider long time intervals (minutes), contrary to micro and meso simulators that require short time intervals (seconds).

2.3 Vehicle Tracker

This client-server application is designed to track on the road graph the trajectory of a vehicle that carries on-board a mobile device (e.g. a cellar phone) equipped with a satellite positioning system (e.g. GPS and in the next future Galileo) and with an internet connection (GPRS or UMTS). The client side records the time sequence of the space positions (geographic coordinates) followed by the mobile device and sends these data to a server at regular intervals through the wireless connection. The server side collects the packets of space-time points sent by the mobile device and project them on the road graph, filtering out the data that imply unrealistic trajectories through a graph matching algorithm, so as to reconstruct the path actually followed by the vehicle and determine the trend of its speed.

2.3 SDNL – Sequential Dynamic Network Loading

This software is designed to provide real-time estimates and short-time forecasts of congestion conditions on all road links, starting from traffic data (speeds and flows) continuously retrieved at discrete points on the network from moving probes (equipped vehicles) and/or fixed probes (video cameras, speed radars, loop detectors). The underlying mathematical model is based on the explicit representation of mobility on the network as a dynamic equilibrium between transport demand and supply, that simulates, on one side, the vehicle trips of and the path choices, and on the other side, the dynamic of flows and the propagation of queues, using the General Link Transmission Model.

SDNL aims, therefore, at reproducing the traffic phenomena following a deductive approach, rather than an inductive one, as done instead by the expert systems that are often utilized for infomobility applications. The advantage is to obtain a comprehensive picture of the traffic pattern and of its short-term evolution, even under conditions never experimented before such as road works or accidents, by projecting the available point measures of speed and flows in space and time. But to this end, SDNL needs more information on the road network features and on the transport demand characteristics; in particular, it requires to pre-determine for the different day types and the different hours the splitting rates at nodes, that can be obtained using TMB - Transportation Model Builder and DUE - Dynamic User Equilibrium.

SDNL operates in rolling horizon: the current measures of flow and speed are transformed in vehicular densities on the road links that periodically correct the number of cars predicted by the model; then, the process that simulates the propagation of flows and queues is restarted. Differently to flows, queues have a certain persistency; consequently, the effect of a correction goes way beyond the travel time to reach the destination employed by the vehicles that generated it. The current forecast is then influenced by all the measures arrived so far. Moreover, the corrections propagate following the node splitting rates, and not the vehicles that generated them, spreading onto the network and updating the travel times of non monitored links.

References

We list below only a few references to our own works that present the models used in the platform and can be used as an entry point to the really vast existing literature on dynamic traffic assignment and route guidance.

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