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GTL-Rocade: Experimental platform for real-time traffic modeling, prediction and control

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Abstract

Developed with the support of the ERC Scale-FreeBack, GTL-Rocade is an experimental platform for collecting real-time traffic data from a network of wireless sensors installed on the southern bypass of Grenoble. The objective of GTL-Rocade is to collect traffic data and compute traffic indicators in real time. This data is intended to test new traffic prediction algorithms, validate mathematical traffic models, and evaluate real-time traffic statistics.

Keywords – *Travel time prediction, traffic data, pollutants estimation, Grenoble South ring*

1. Introduction

Urban traffic represents one of the biggest challenges in most large cities, which directly impacts economic, health, and societal issues. To address this issue, Intelligent Transportation Systems (ITS) have been recently proposed to provide innovative services and tools that enable users to be better informed, and that allow traffic operators to make more coordinated, targeted and effective decisions for the management and scheduling of vehicles. Thus, ITS benefit greatly on research regarding the modeling, monitoring, and control of traffic networks. A large research community is focused on the study of vehicular traffic, in particular on the case of highways and motorways.

In this paper, we present and describe the GTL-Rocade experimental platform, which can be accessed at the following link: <http://gtl.inrialpes.fr>. The objective of GTL-Rocade is to collect traffic data, compute traffic indicators in real time and calculate traffic predictions. This data is intended to test new traffic prediction algorithms, validate mathematical traffic models, and evaluate real-time traffic statistics. This platform is part of the Grenoble Traffic Lab (GTL), which considers the city of Grenoble in France as a case study. This work is developed in the context of the European Research Council (ERC) grant project Scale-FreeBack.

The structure of this paper is the following: Section 2 presents an overview of the structure of the platform. Section 3 goes over the methods and models used for the indicators used in the application, based on the work of the research team. Section 4 describes the sensors used to retrieve the input data, and the calibration of that data. Section 5 details the user interface and features available on the platform, and how users can operate them. Finally, section 6 concludes the paper.

2. Platform overview

The architecture of GTL-Rocade is divided in 3 levels (see figure 1): the physical level, the data processing level, and the display level.

- The **physical level** (level 1) is comprised of 130 magneto-resistive sensors located on 10.5 km of a two-way highway. They are distributed over 26 data collection points and provide information on several macroscopic metrics: flow, speed and occupancy.
- The **data processing level** (level 2) consists of an upper and lower layer.

- The **upper layer** takes the raw macroscopic traffic data from the magnetometers and stores them in a database. They are then passed through a series of signal-processing algorithms which perform imputations for missing or wrong data, aggregate data to reduce noise and calibrate the model for traffic-density estimation.
 - The **lower layer** uses the pre-processed data to compute several traffic indicators. These are calculated both for the current real-time data and for predictions.
- The **display level** (level 3) uses the indicators computed in level 2 to provide a visualization. At the current moment this only includes the web interface, as the mobile app and the showroom are deprecated.

Both input data and processed data are stored on a MariaDB database set up on an external physical server.

We give a more detailed description of each level in the following sections.

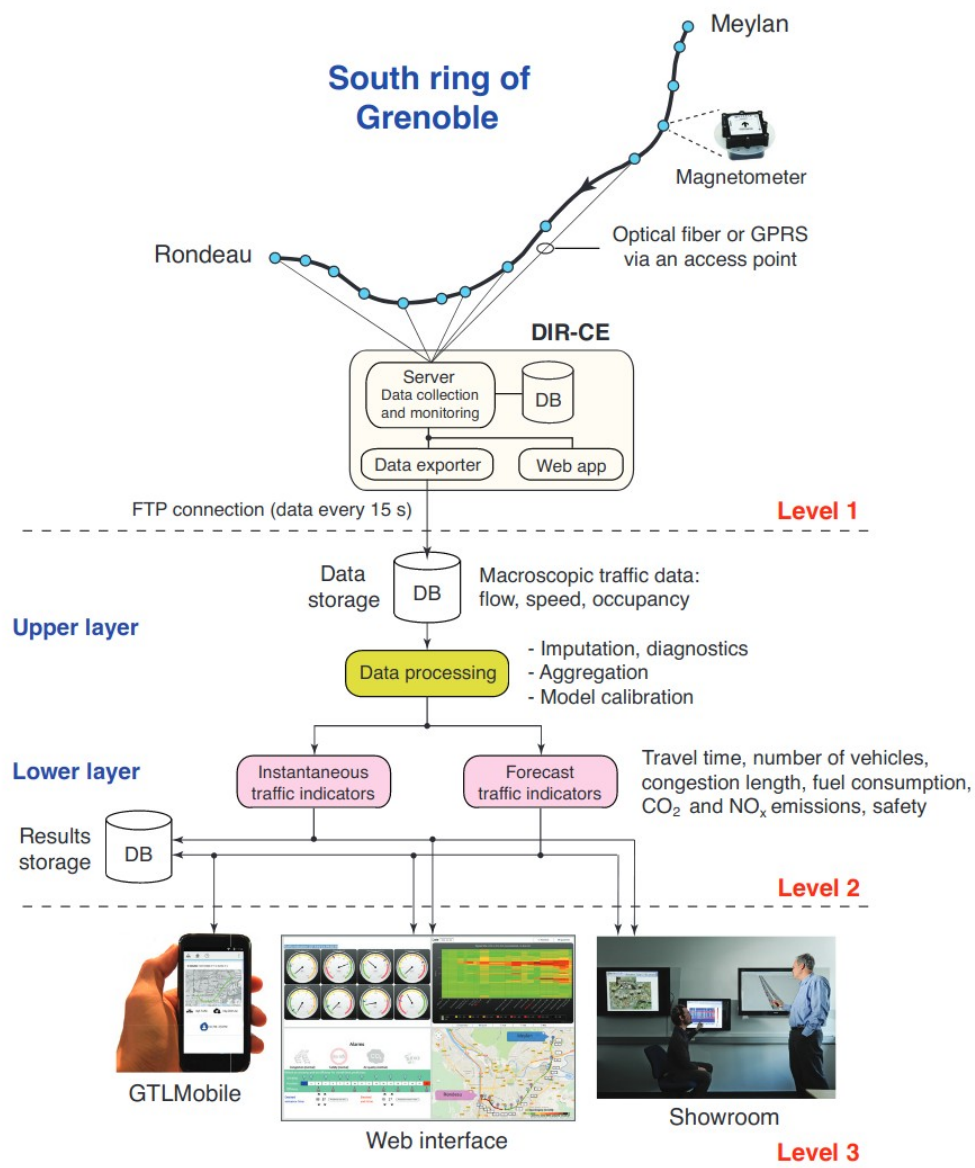


Figure 1: Three-level architecture of GTL. Level 1: physical layer, Level 2: data processing and applications, Level 3: results display.

3. Methods and models

3.1 Indicators

Pre-processed data is used to compute, for present data and predictions, the following traffic indicators :

- the travel time [min]
- the number of vehicles
- the congestion length [km]
- the fuel consumption [L/100km]
- the CO₂ emissions [kg/100km] and NO_x emissions [g/100km] for an average family car
- the safety index (s)

The fuel consumption and CO₂ emissions are estimated using a physics-based modal consumption model [1] for a Diesel-powered vehicle while for the NO_x emissions we relied on the statistical model proposed in a 2006 paper [2]. Finally, the safety index is computed according to a constant time-headway spacing policy with a nominal time headway of two seconds as a reference [3]. This is based on the “two second distance rule” that tells a driver the *minimum* distance needed to reduce the risk of collision with the vehicle directly in front, under ideal driving conditions: two seconds is a safety buffer, and the rule attempts to respect a distance which is consistent with human reaction time (approximately 1.5-2 s).

3.2 Prediction

In order to forecast travel time within the highway, we use the measurements describing travel times for the different origin-destination (OD) pairs. A network model is then used to infer travel time between origin and destination based on a reduced number of states. The forecast strategy is based on both current day and historical data. Historical data is organized into several clusters; for each cluster, a predictor is designed based on the Kalman filtering strategy. Then a fusion algorithm, described in [4], is used in order to merge the predictions. Applied over traffic data from the South ring of Grenoble, the error is guaranteed to be less or equal than 35% in 90% of the cases.

4. Calibration and input data

Implemented in collaboration with local traffic authorities (DIR-CE), GTL Rode consists of 130 magneto-resistive sensors located on 10.5 km of a two-way highway. They are distributed over 26 data collection points at 20 locations and provide information on several macroscopic metrics: flow, speed and occupancy (the fraction of time during which the cross-section is occupied by a vehicle). Microscopic information is also provided, such as single-vehicle speed, inter-vehicle gap and vehicle length.

The sensors, buried in the Grenoble south ring under the pavement, are magnetic and wireless, with a lifespan of 10 years; self-calibrated, they can be remotely managed from a central console. Their data are received by access points, whose range can be extended by repeaters.

Access point are used to maintain two-way communications with sensors and battery-powered repeaters; using either wired and/or wireless connections, access points relay data to road-side controllers, remote servers, traffic management systems, or other vehicle detection applications.



Figure 2: Sensys Networks VDS240 magnetometer

Every 15 seconds, raw data is stored on the database and passed through of series of signal-processing algorithms which perform:

- **Imputation and diagnostics:** if some data are lost or erroneous (for instance, as a result of communication problems or temporary sensor malfunction), suitable imputation algorithms [5], [6] are run for filling in the missing data with estimated values.
- **Aggregation:** high-resolution traffic data tend to be noisy. In order to capture dynamics that are physically meaningful, it is then fundamental to aggregate the data into time slots of 1, 5 or 6 minutes, depending on the scenario under investigation.
- **Model calibration:** model-based algorithms are used for computing the traffic indicators. The parameters of the fluid-dynamic models are automatically estimated from the data.

5. User interface

The platform's web interface features several tabs at the top:

- The **Status** tab displays the different indicators for each section of road and each moment of the day. It shows sensor data such as average speed, but also data calculated in real time. These include the travel time across the bypass, the number of vehicles, the length of any congestion and the CO₂ and NO_x emissions.
- A **Predictions** tab, providing travel time predictions along the bypass, is also available. The user can select an entry point and an exit point of the road to see the travel time given the departure time, calculated from prediction algorithms using sensor data.
- On the **Pmv** tab, it is also possible to get information about the traffic on the highway in the form of variable-message sign. By clicking on the desired entry point, you can see the current travel time and the traffic flow.
- The **Statistics** tab allows you to consult the state of the network measured and calculated for the previous days using the data stored in the database. The evolution of different indicators over a chosen period (day, week or month) can be displayed in the form of graphs and histograms.
- The **Data Quality** tab provides information on the status of the sensors. It shows in details the information available for each sensor and their evolution over a chosen period.
- On the **Data Download** tab, users have the option to submit a download request for the selected raw or imputed data. Creating an account is required to make this request.

Status module

Shown on figure 3 is the interface for the status tab. It is divided into 3 parts.

On the left panel, a heat map shows the value of the selected indicator for each section of the road (21 in total, from East to West) over time. It shows the average speed for the current day by default, but you can select a different day or a different indicator above the histogram.

In the upper panel, several bars show the current average value of each indicator for each sector. There is a map on the right panel to show the level of the selected indicator on the highway, with the same color map as the histogram.

If you hover over a point on the heat map, you can see the exact value for that section and that time. It will also show you on the map where the section is located and update the displays accordingly.

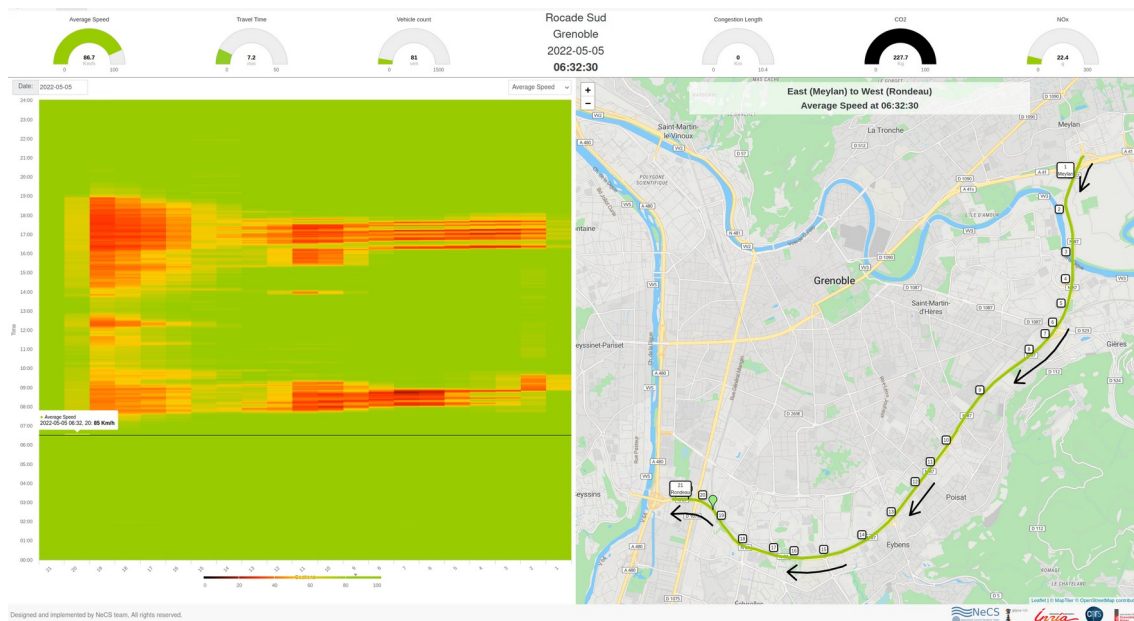


Figure 3: Interface for the current status module

Prediction module

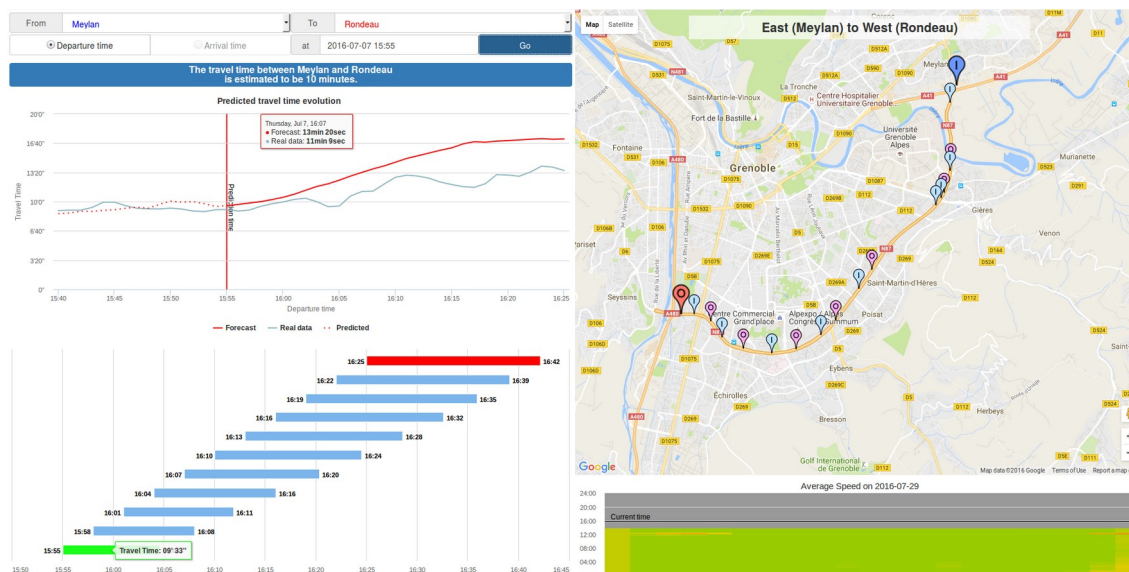


Figure 4: Interface for the prediction module

Shown on figure 4 is the interface for the prediction module

On the right panel, a map is used to represent the whole south-ring. The blue pins show the on-ramps, the purple ones the off-ramps. When you select a pin, its name is displayed in the panel From / To on the left side. A path is defined by an on-ramp and an off-ramp. You can select a blue pin as an origin and a red pin as a destination to trace a particular path. You can change at any moment.

There are 2 main panels in the left side. The first panel in the upper part displays the origin/destination names and the time information about the prediction. The second panel

contains time series information of Dynamic Travel Time (DTT) computed from real data received in real time and the prediction algorithm. Real-time data and data predictions are displayed by default for past days or once real data is available. Data is collected every 15 seconds by sensors located in the south-ring, however predictions are available each minute.

To display a prediction go into the left panel and determine one origin and one destination by selecting in the dropdown menu or click on the bullets located in the right hand side of the map (blue for inputs, red for outputs). Then then a time of departure or time of arrival and select a particular time. Finally click on Go to obtain the data. Computations are based in measurements taken up to the actual time and the travel time is predicted in a future horizon of 45mins. Once data is collected, (past days) the dynamic travel time is computed based on the real measurements taken in the highway. The two curves can be distinguished as red (predictions) and blue (real).

Once the system performs the prediction in addition a recommendation system selects the best and worst options for the predicted travel time. The optimal departure time is displayed with a green color bar and the optimal departure time is shown in the left part of the bar. The longest time trip is displayed in red.

Statistics module



Figure 5: Interface for the statistics module

The statistics module shows the statistics for each indicator over a selected period of time. It is divided in several parts:

In the middle, the heat map for each day of the month is visible. By default, it shows the average speed for the current month, but it is possible to select another month and another indicator at the top. For each day, a percentage of data that has been correctly received is displayed.

There are several plots on the sides and the bottom. They show the following indicators over time: travel time, fluidity index, congestion length, average speed, total travel time and total travel distance. If they select time frame is a day, each figure will feature a blue plot line and a horizontal red line for the average value. If the selected value is a week or a month, total travel time and total travel distance will turn into histograms to show the total value for each day. The

other plots will also show the average value for each day, but with also the range from minimum to maximum values.

Data quality module

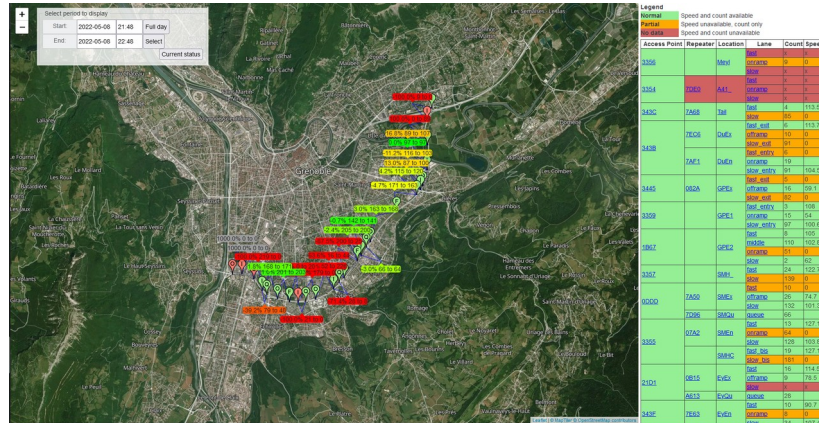


Figure 6: Interface for the current sensor status submodule of the data quality module

The data quality module is divided into 3 sub-modules: current sensor status, data quality statistics and data quality statistics per lane.

The **current sensor status** module, as shown in figure 6, shows a map of the city with each sector marked with pins, colored based on the data quality. By zooming in, it is possible to see the different sensors (circle), repeaters (triangle) and access points (rectangle) installed. Between each sector, a percentage shows the counting errors. This correspond to the difference of counted vehicles between the sectors: ideally it should stay in the same order of magnitude. A large difference can be indicative of low data quality in some of the sensors of those sectors. On the right panel, a table for the data and current status of each sensor can be seen, with the current vehicle count and average speed measured for the current time frame (in the last hour by default). It is possible to click on the name of the elements in the table to focus on them in the map. The time period of the displayed data can be selected at the top of the interface.

The **data quality statistics** module, shown in figure 7, is divided into 3 parts. On the bottom is heat map of the number of counting errors for the selected day, for each sector at each hour. On the right is an area chart of the data status, divided in 3 categories: correctly received, partially received and not received. It shows the proportion of data from sensors that has been received or not. Finally, on the left is a histogram of the percentage of sensors in operation. That is to say the number of sensors that sent either full data or partial data.



Figure 7: Interface for the data quality statistics submodule of the data quality module



Figure 8: Interface for the data quality statistics per lane submodule of the data quality module

Figure 8 shows the **data quality statistics per lane** submodule of the interface. It is possible to select any number of sensors in the table on the right to display their statistics. Similarly to the previous submodule, this includes the data status for those sensors on the left of the page. On the bottom, a histogram of the percentage of time those sensors were operational over the selected time frame. Finally, a plot of the selected raw data (average speed by default) shows what the selected sensors measured for the chosen day.

6. Conclusion and perspectives

In this article we described the Grenoble Traffic Lab Rodeo (GTL-Rodeo), an experimental platform for advanced traffic research. The objective of this platform is to use real-time traffic information using sensors to calculate and provide macroscopic indicators. Furthermore, we can use this data to compute traffic predictions.

The data collected by this platform has been subject to several internships and been used for research works. GTL-Rodeo serves as the basis for GTL-Ville, a more ambitious project that

extended our network of sensors to the major urban arterials of Grenoble in order to have wider city-level coverage of traffic behaviour and combines it with traffic data coming from heterogeneous sensors (e.g., magnetometers and GPS-equipped vehicles).

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