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GTL-VILLE: Experimental platform for urban traffic state estimation

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Abstract

The GTL-Ville is an online experimental platform for the real-time collection and visualization of traffic data for the city of Grenoble in France. The platform processes real-time traffic data to calculate macroscopic traffic indicators such as flow, density, speed, traveling time and vehicle emissions. The platform was developed by the ERC project Scale-FreeBack, to showcase the various innovative methods and techniques developed by the team, such as sensor location, density reconstruction and prediction, and travel time estimation.

Keywords: Vehicle density prediction, Traffic data, Emission/consumption estimation, Grenoble downtown

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. Although there is a large research community focused on the study of vehicular traffic [1], most of it focuses on the case of highways and motorways. Although research exists for the general case of urban networks, the use of real traffic data to validate the results and demonstrate the effectiveness of the proposed approaches is rarely available.

In this paper, we present and describe the GTL-Ville experimental platform, available through the link <http://gtlville.inrialpes.fr/>. This platform was developed to *a)* collect, process and provide real-time traffic data, *b)* validate and showcase proposed models and tools for estimation, forecasting, and control of traffic, and *c)* allow other researchers and the general public to freely access the data and results. 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.

This paper is organized as follows: Section 2 presents an overview of the structure and main modules and submodules of the platform. Section 3 describes the methods and models used to calculate the most important traffic indicators, based on the scientific work performed by the research team. Section 4 lists the sources of data used to calibrate the models and used as inputs to calculate the indicators. Section 5 describes the user interface, features, and functionality available in the platform, and how they can be accessed by the general public. Finally, Section 6 concludes the paper.

2 Platform overview

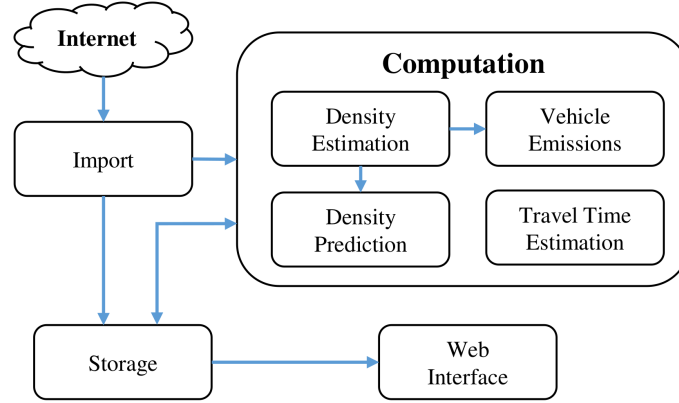


Figure 1: Modules and submodules structure of the GTL-Ville.

Figure 1 shows the basic structure of the GTL-Ville platform. It is composed of 4 main modules:

- The **Import** module collects the real-time data provided by sensors and third parties and processes this data to be used by the other modules.
- The **Storage** module deals with the database and the transmission of static/dynamic data to the Computation and Web Interface modules.
- The **Computation** module takes as input real-time data from the Import module and static data from the Storage module to calculate useful indicators to evaluate the state and evolution of congestion in the city. It is composed of 4 submodules:
 - *Density Estimation* uses flow and velocity data to compute the approximate number of cars in each road section in real-time.
 - *Vehicles Emissions* uses the density estimates and speed data to calculate the fuel consumption and emissions of CO, CO₂, Nox, CH₄, and particulate matter in each road section.
 - *Density Prediction* forecasts the evolution of the traffic density from the current state.
 - *Travel Time Estimation* uses the speed data of the network to produce estimates of the average travel time between pre-specified origin/destination zones of the region. This submodule is independent of the previous ones.
- Finally, the **Web Interface** module allows for visualizing the computed traffic indicators and the raw real-time data, such that it can be used by the general public.

A more detailed description of the Computation submodules and the collected input data is presented in the following sections.

3 Methods and models

3.1 Density estimation

The traffic density is the ratio between the number of vehicles inside of a road section and its length and is the main variable used in the macroscopic models used in the traffic research literature. In

the GTL-Ville, the density is estimated for a section of the city's downtown which covers an area of 1.4 by 1 Km and is composed of 804 road sections and 463 intersections.

The model used to estimate the density in each road of the network is presented in [2]. This data-based method is based on the conservation law for vehicles on each road (the change of density in a road is only due to the difference between inflows and outflows), and vehicle flows are estimated as the product between the current density estimate and the average road speed obtained from real-time measurements. The resulting equation is a Linear Time-Varying system, which was proven to converge under certain assumptions. The required parameters of the model are computed using network characteristics and measured data described in Section 4. The validation of the method showed accurate results, with a median relative error of 15%.

3.2 Density prediction

Although useful, as the density estimation method requires real-time speed data it cannot be used directly to make predictions about how the traffic congestion will evolve in time, or evaluate the performance of potential control strategies. To achieve this objective, the GTL-Ville platform also has implemented the multi-directional continuous traffic modal proposed in [3], also known as the NEWS model. In contrast to the density estimation method, the NEWS model does not consider each road individually, but instead considers the 2D space as a continuum, such that each point (x, y) in space has associated a density value, which can be interpreted as a representative density of the roads around that point.

The NEWS model works by considering four layers representing the direction of propagation of vehicles (North, East, West, South), each with a flow conservation PDE. The four layers are coupled with flow interchange terms, which are determined by parameters dependent on the geometry of roads around each point. This model can then take as input the initial state from the current density estimate, predict the future evolution of traffic, and can also take control inputs to evaluate their performance.

3.3 Vehicle emissions

Some important indicators calculated by the GTL-Ville are the energy consumption and vehicle emissions, which are obtained using the well-known COPERT model described in [4], and is currently used for calculating European emission inventories according to the European Environment Agency. The model provides formulae to compute speed-dependent emission factors (units: grams per vehicle per kilometer), which depend also on the pollutant, vehicle age, and technology. To compute the total emissions per road, the Total Travelled Distance (TTD, with units vehicle-kilometers) during a time period is multiplied by the emission factor. To calculate the TTD, the density and flow estimates from the previous method are used.

3.4 Travel time

The platform also can estimate the average travel time between two zones. This is done using the method proposed in [5], which applies to very large networks, and does not require the calculation of a specific route. Instead, this method cuts the complexity by clustering adjacent sections based on the similarity of their speeds. Then, to each cluster, attributes such as the average speed, length, and heading are computed. It is then shown that this method can provide travel time estimates with errors under 25%, with a very high computational complexity reduction.

4 Calibration and input data

The platform collects input data in real-time with a sampling rate of 1 minute from heterogeneous sources, through contracts established with third-party companies. The real-time data sources are:

- Floating Car Data (FCD), which refers to vehicle traces usually obtained from GPS for a sample of vehicles in the network. During each sample period, equipped vehicles transmit their current position and velocity, which can be used to obtain properties of the entire traffic flow. To protect user privacy, FCD is usually aggregated, and only the average speed of each road section with a confidence index is available. This information is provided by the navigation assistance company TomTom.
- Magnetic induction loops are located in many places of the network. This technology is widespread in traffic operations and consists of a coil installed under the pavement which can measure changes in its inductance due to the presence (or lack) of a vehicle on top of it. The available indicators are then the number of detected vehicles during a sample time (also referred to as flow), an estimate of the speed of each vehicle, and the percentage of time a vehicle was on top of the sensor (known as occupancy). The loops installed in the city are managed by the MetroMobilité agency, which shares the data with the team.
- Microwave radars were located in specific locations around a selected area of the city's downtown. This technology periodically sends pulses of light and then measures the properties of the reflected beam. From this, the sensors can detect the presence of vehicles in front, but also their speed and length. This data is provided by the company Karrus.

In addition to the real-time data sources, other sensors were used during limited-time measurement campaigns to calibrate model parameters known as the Turning Ratios. These parameters specify how traffic flow is split at intersections, indicating the proportion of flow from each inbound road that turns to each of the outbound roads. Using the sensor location method proposed in [2], 12 intersections were selected to be equipped with Turning Ratio measurement sensors.

The technology used for this purpose was Bluetooth (BT) Vehicle Identifiers. These sensors work by detecting the unique identifiers of BT devices in equipped vehicles and then matching these identifiers with BT sensors in other locations. To measure the Turning Ratios, BT sensors are located on each of the inbound and outbound roads for each of the selected intersections. By comparing the identifiers and time of passage of detected vehicles, it is possible to determine the specific turn (given as a pair of inbound and outbound roads) taken by the vehicle. To protect the privacy of users of the network, the data is anonymized and aggregated, and only the number of vehicles making each turn during a sampling period of 1 hour is known. For each intersection, a measuring campaign was conducted for a 1-week duration. The campaigns were conducted between September 21 and October 21, 2020.

5 User interface

In this section we describe the interfaces and functionality of the web platform available to the general public. The welcoming page of the GTL-Ville is shown in Fig. 2.

In the bottom-right corner of the interface, the user can find the color bar associated with the current variable being displayed, and a short description of the indicator. In the top-right of the figure, a menu allows choosing the indicator and visualization to be displayed. The options are:

- **Fluidity:** this can be shown for each road, or as a heatmap. Allows visualizing the speed data obtained from the FCD.

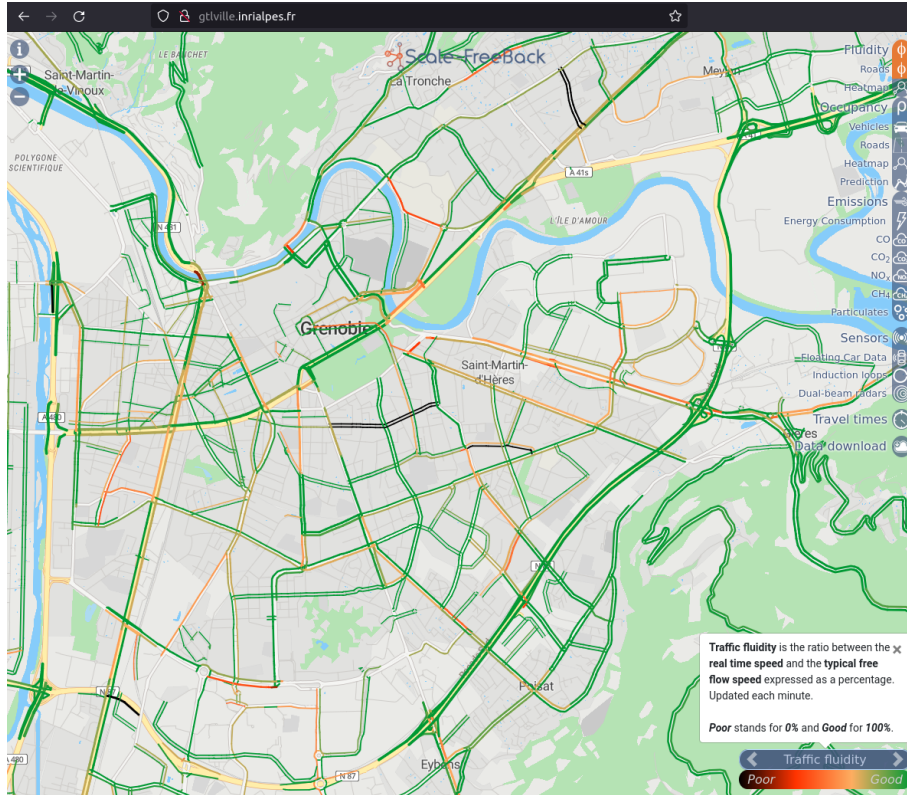


Figure 2: Welcoming page of the GTL-Ville website

- **Occupancy:** corresponds to the density (estimated or predicted). Can be visualized for each road, as a heatmap, or showing the likely position of individual vehicles.
- **Emissions:** shows the heatmap for a list of given pollutants emitted by the vehicles in the network.
- **Sensors:** show the raw data provided by the induction loops or microwave radars at each location.
- **Travel times:** shows the estimated travel times between selected origin-destination areas.

5.1 Fluidity interface

Fluidity is defined as the ratio between the current speed of a road and its maximum value. This indicator is calculated directly from the real-time speed data from FCD. When the Fluidity option is chosen in the menu, the user can then click on any of the highlighted roads on the map. Then, a panel opens to the left of the website, as shown in Fig. 3.

Three plots are available in the panel: *a)* the confidence index for the speed values, which depends on the number of vehicles providing FCD and the variance of their speeds; *b)* the calculated fluidity value; and *c)* the raw speed. These indicators are shown in as a time series for the selected day. The values shown are averaged with a moving window of 10 minutes to smooth out fast oscillations. The envelope around the solid lines corresponds to the minimum and maximum values obtained during the 10-minute window.

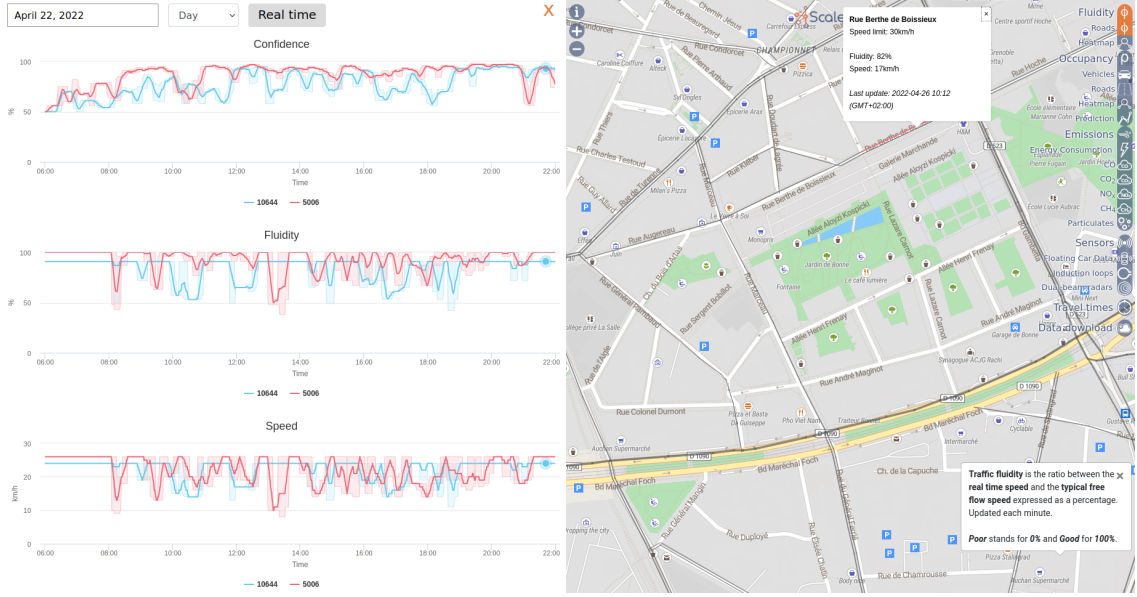


Figure 3: Road fluidity and speed data



Figure 4: Heatmap visualization for A) the estimated density, and B) the predicted density.

5.2 Occupancy interface

The occupancy button allows to access the density indicators calculated by the methods described in Sections 3.1 and 3.2. Three visualizations are possible:

Roads: this option highlights the roads inside of the considered downtown section and colors them according to their density value.

Vehicles: this option shows the estimated position of vehicles as points on each road. By multiplying the density and road length, we obtain the number of vehicles inside each road. This number is then distributed along the road's length.

Heatmap: this is a two-dimensional representation of density, using the Kernel Density Estimation (KDE) method described in [6], by drawing a 2D Gaussian on top of the position of each estimated vehicle.

Figure 4 shows the heatmap visualization for the density indicator (estimated and predicted) using the previously described methods.

5.3 Emissions interface

When the user clicks on the *Emission* button, they can then select one of the available indicators: energy consumption, carbon monoxide CO, carbon dioxide CO₂, nitrogen oxides NO_x, methane CH₄, and particulate matter PM. The indicator is then visualized as a 2D heatmap using the KDE method as shown for CO₂ in Fig. 5.

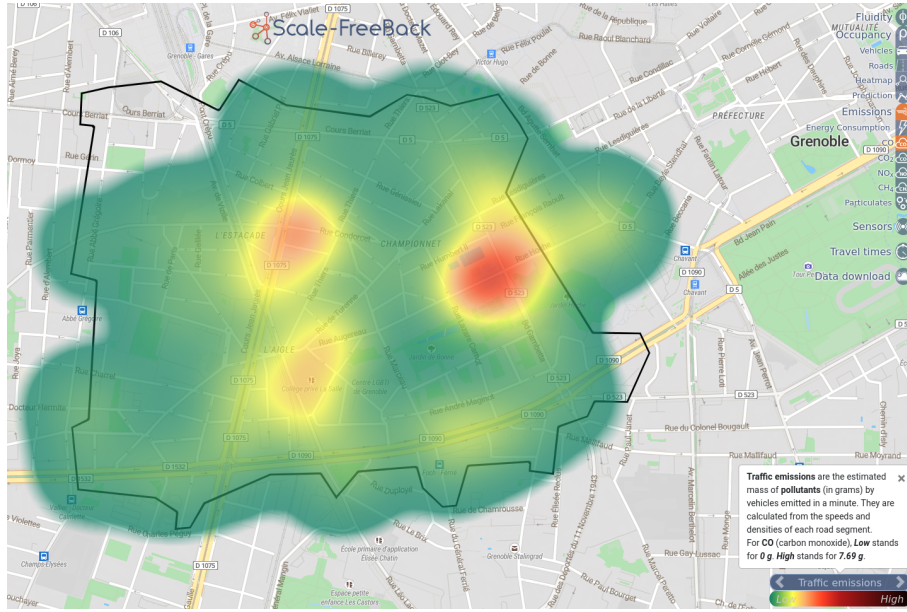


Figure 5: Emission heatmap for carbon dioxide (CO₂).

5.4 Sensors interface

By clicking in the *Sensors* button, the user can then select between the options *Floating Car Data*, *Induction loops*, or *Dual-beam radars*. The first option will show the same visualization as for the *Fluidity* case described above. The last two options will show on the map the location of the sensors of the chosen technology. By clicking on one of these locations, a panel on the left will open, as shown in Fig. 6 for the case of a microwave radar sensor.

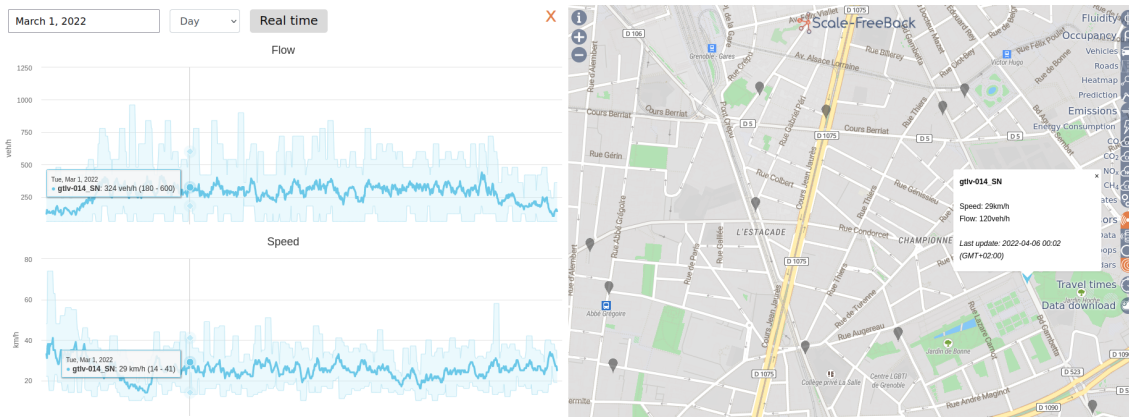


Figure 6: Flow and speed data provided by one microwave radar sensor.

The left panel contains the time series of the data provided by the sensor for the selected day.

Similarly, as in Fig. 3, the data is averaged over a 10-minute moving window, and the envelope shows the maximum and minimum values during the aggregation period. Multiple sensors can be selected and visualized simultaneously.

5.5 Travel times interface

If the user clicks on the *Travel times* button, a panel on the left will open, as shown in Fig. 7. The right panel shows the geographical location of the pre-defined origin/destination regions. The left panel shows a diagram representing the travel time values between each pair, where the color of each line depends on the origin, and its width is proportional to the travel time. By moving the mouse over the diagram, a line is highlighted and a text box shows the corresponding travel time value.

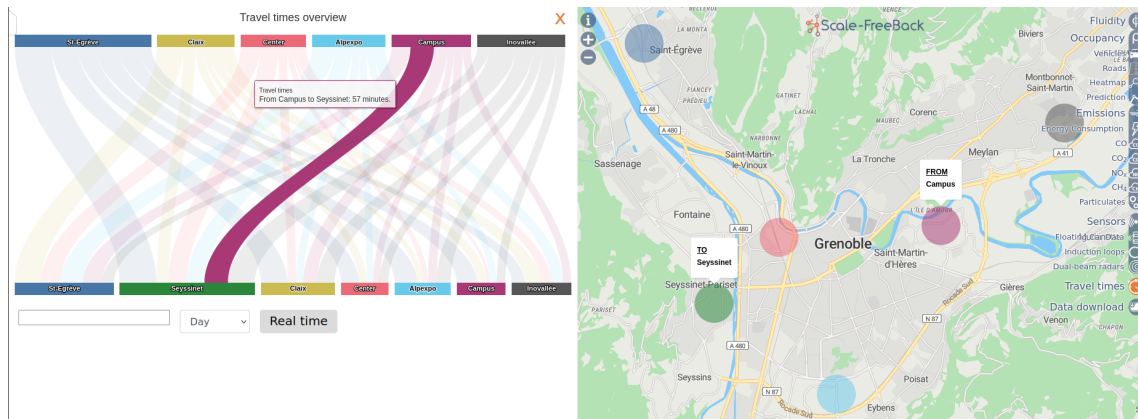


Figure 7: Interface for visualizing the travel time between two regions.

6 Conclusion and perspectives

In this paper, we presented the main structure and functionality of the GTL-Ville experimental platform. The main objective of this platform is to use real-time urban traffic data from heterogeneous data sources, to calculate and provide useful macroscopic indicators that describe and predict the spatial and temporal distribution of the traffic flow in the case of the Grenoble urban area. Furthermore, the calculated traffic indicators are also used to estimate vehicle emissions of different pollutants, which is of great importance for the assessment of air quality and greenhouse gases.

The platform uses different visualization styles for the proposed indicators, which help the general user to understand the distribution and effect of traffic more intuitively. Such visualizations include the estimation of actual vehicle positions, two-dimensional heatmaps using Gaussian kernels, and origin-estimation graph diagrams.

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