Proposition of internship/thesis subject

Title : A two-levels dynamic road traffic model at a regional scale (France/Italy)

Field : Transportation planning, traffic management, traffic flow models

M1 Internship at Univ. Gustave Eiffel: COSYS-GRETTIA lab
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M2 Internship at Univ. Bologna then Thesis Co-funded 50/50 (October 2021 or 2022):

- University of Bologna-DICAM
- University Gustave Eiffel-COSYS

In this co-tutelle thesis we propose a two-levels approach to address the issue of modeling dynamic road traffic at a very large scale. The spatial extent of Ile-de-France (Paris and its suburb) is about 130kmx160km (Figure 1), with a wide network of 37,500 km of road with various geometry. Therefore the method need to be setup first at a middle scale: Bologna city and its surroundings would be the opportunity both to address the problem in a progressive way and to share best practice between transportation authorities of the two cities.

Transportation planning in Ile-de-France involves several organizations, representatives of different transportation modes: public transit (bus, subway, railway managed by public companies), bicycle/pedestrian ways (managed by local authorities), and motorized highway trips (personal cars, taxis, light and heavy goods vehicles). The latter constitutes the road traffic we are interested in. It is modeled by the DRIEA organization, which is in charge of the road infrastructure: it develops a strategic software called MODUS (Modèle de Déplacements Urbains et Suburbains). As in almost all metropolitan planning organizations around the world, it is a static model: it represents key time periods of the day (AM peak, Inter peak and PM peak) calibrated on a base year (2014).

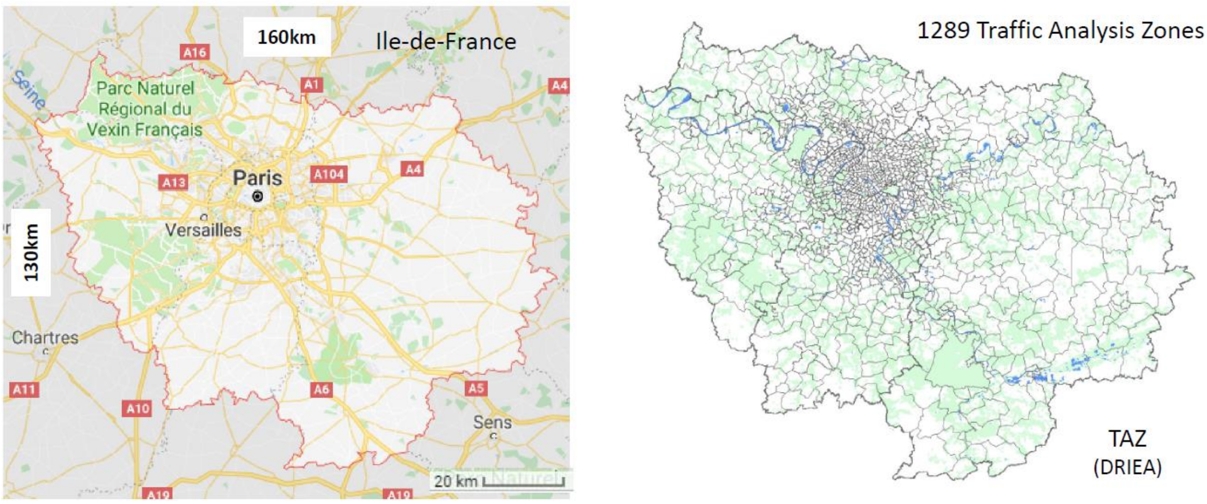

Figure 1 For transportation planning purposes, Ile-de-France region (Paris and its suburb) is divided into 1289 Traffic Analysis Zones (TAZ). It includes 12 millions people involved each day in a total of 14 millions trips (public transportation and road traffic).

MODUS is a 4 steps model: Trip Generation, Trip Distribution, Mode Choice and Route Assignment. The region is divided into 1289 traffic analysis zone (Figure 1). Each zone is made of a significant unit of inhabitants, typically 2000 to 5000 people, based on census block information. Socio-economic data are gathered on each TAZ: household demographics such as number of vehicles or bus cards, ages, incomes; employment and infrastructure within the zone. This information is used to model the demand: Generate the emitted and attracted trips within the zone, Distribute them by matching origins with destinations and estimate the proportion of trips by a particular mode. Each TAZ being an Origin and a Destination, this travel demand is summed-up in a matrix of 1289x1289 OD pairs. This travel demand is then assigned to the infrastructure (the road network supply) by allocating trips between each OD to one or several routes (for a given mode).

Static models are useful for long term planning but they fail at modelling congestions hotspots because they are based on 4 hours average behavior: to finely assess traffic flows on road networks and its evolution through a day, a dynamic traffic model is required. Nowadays, most of the metropolis around the world are building their own dynamic model and trying to use it in production [1], but the task is complex because of the scale of these cities and the size of the road network (

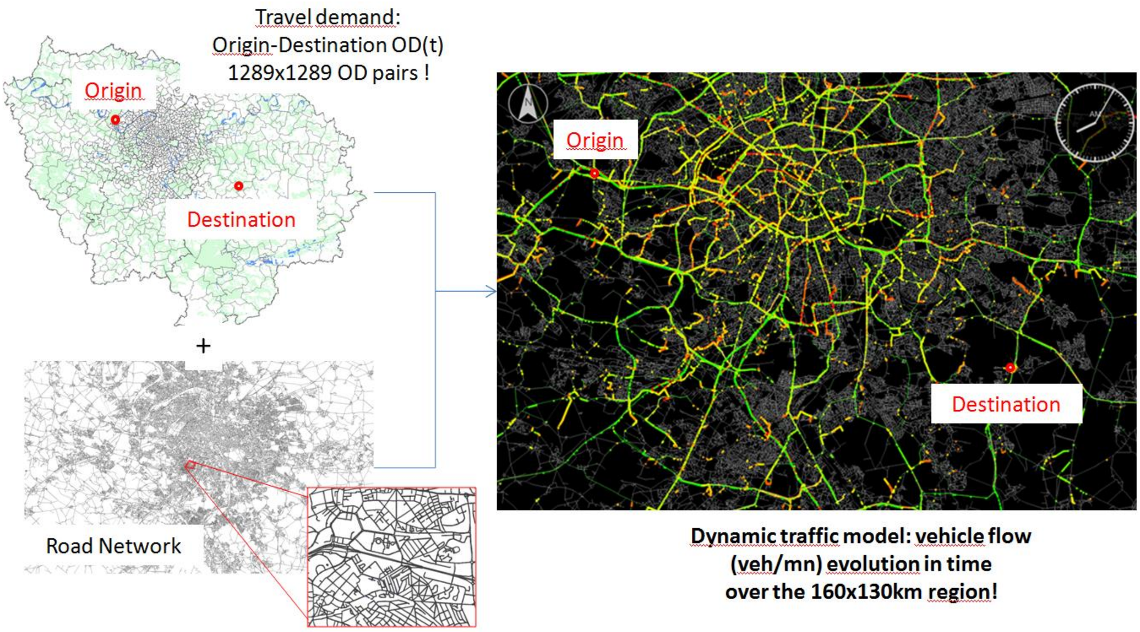

Figure 2).

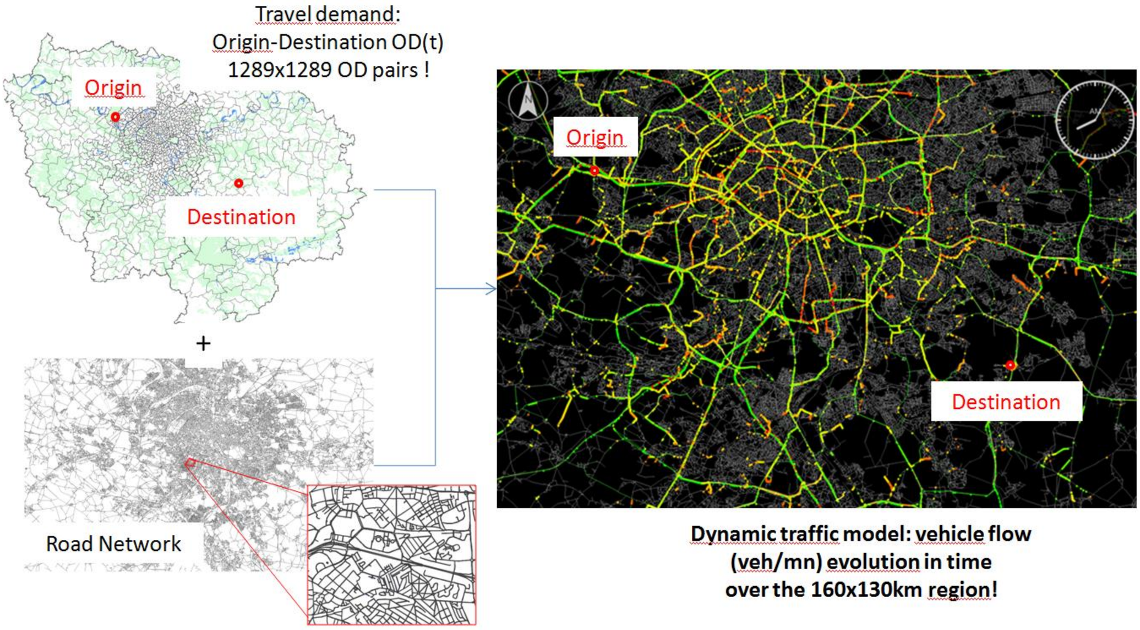

Figure 2 A dynamic traffic model requires: a travel demand sampled over short slices of time, and an urban road network with dynamic characteristics such as capacity constraints.

Indeed, dynamic traffic models are only efficient at small scale, typically a corridor with a few intersections or a block of less than one kilometer. In this case, the road network is only a few kilometers at best, and it becomes possible to accurately build fundamental diagram of all the roads implied, and even calibrate the model to fit vehicles counts measured on the ground. The fundamental diagram links the flow (veh/h) and density (veh/km) of a road during free flow and congestion phases: it is necessary to characterize the dynamic behavior of a road or links of the road (in static models roads are only modeled by arbitrary volume-delay functions). Measuring vehicles flow and building fundamental diagrams takes a lot of qualified manpower. This work is usually done by modelling consultants from firms that have the hardware and the technical skills required to understand the very large number of parameters appearing in the software used (usually Aimsun or Vissim, using disaggregated model of the traffic: microscopic for small scale or mesoscopic else).

Dynamic models are longer to build compared to static models because they are sensitive to supply and demand inputs, and they can easily lead to gridlock or oversaturation [2]. Any discrepancy in the model output or errors in the links and nodes of the network can be spot easily and fixed at this scale by a modelling engineer.

At larger scale, errors tend to accumulate over time. The infrastructure supply is too wide to be characterized link by link: there are almost 600k links in the Ile-de-France road network, for which basics information are known or reported (speed limit, capacity, geometry), but building an accurate fundamental diagram would require a decade lasting load of work. Networks errors can be hard to detect. Achieving a good level of convergence would require several network corrections and running a series of time-consuming calibration steps. A monolithic approach applying a dynamic model over the whole region at once, fed by a time-dependent 1289x1289 OD matrix and a huge network would rapidly lead to gridlocks everywhere and pockets of unrealistic queues, congestion and travel times [2].

The idea of this thesis is to exploit the capabilities of dynamic models at small scales, and extend it to a large scale: dynamic models are applied independently over a patchwork of cells called macrozones, from which the major regional flows can be computed. These regional flows are then injected in the macrozone as part of the travel demand. Inside a macrozone, there is then two components: the regional flows used a boundary inputs, and the travel demand of travelers staying inside the macrozone. A macrozone is large enough to contain several OD centroids but small enough to have an efficient dynamic model. Figure 3 shows an example of partition of Ile-de-France into several macrozones.

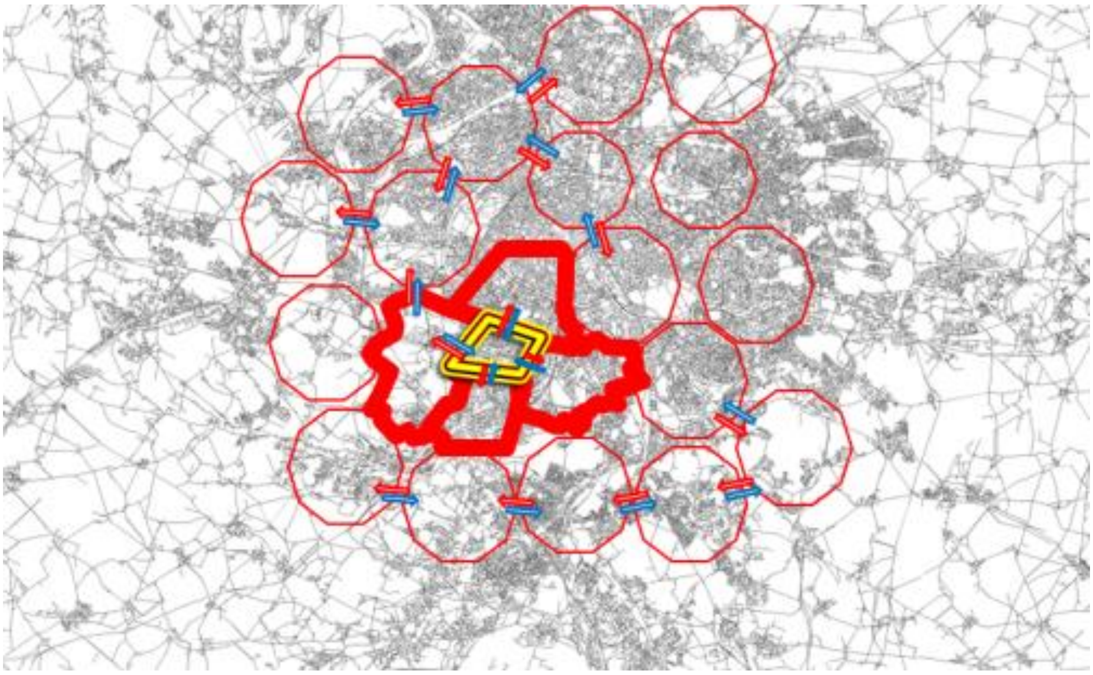

Figure 3 First level of the proposed method computes major regional flows between macrozones (illustrated by blue/red arrows). They part the region into reservoirs where the traffic conditions are approximately homogenous. The yellow macrozone groups 8 TAZ.

The spatial extent of a macrozone is defined so that it takes *dT* minutes to cross it bound to bound. The optimal time to cross dT and the partition of the region in macrozones are major questions in this thesis, we will suppose *dT*=15 minutes.

Let us focus on the yellow macrozone of Figure 3: that cell contains eight TAZs from the original 1289x1289 demand. If the travel demand is sampled every 15 minutes, there are two kind of trips to take into account during a 15 minutes window, as shown by Figure 4:

- Internal to the macrozone: origin and destination of these travelers are inside it, travel time is less than 15 minutes. This information can be collected in a 8x8 OD matrix, extracted from the large 1289x1289 OD matrix linking the TAZ.
- Travelers going out of the macrozone or coming from outside of it: as a traveler takes 15 minutes to cross this macrozone, it necessarily comes from (or goes to) one of the 4 neighbor macrozones. This travel demand is modelled by the regional flow. This information can be stored in a 4x4 matrix linking the macrozone.

The spirit of the separation of the demand into two components stems from the dynamics of vehicles: at this microscopic scale, the travel demand varies slowly and the complexity of dynamic traffic assignment will be limited. At this scale the main outcome of having dynamic flows, compared to a static assignment, is the production of a correct vision of congestions and travel time, and to take into account the progressive varation of the demand.

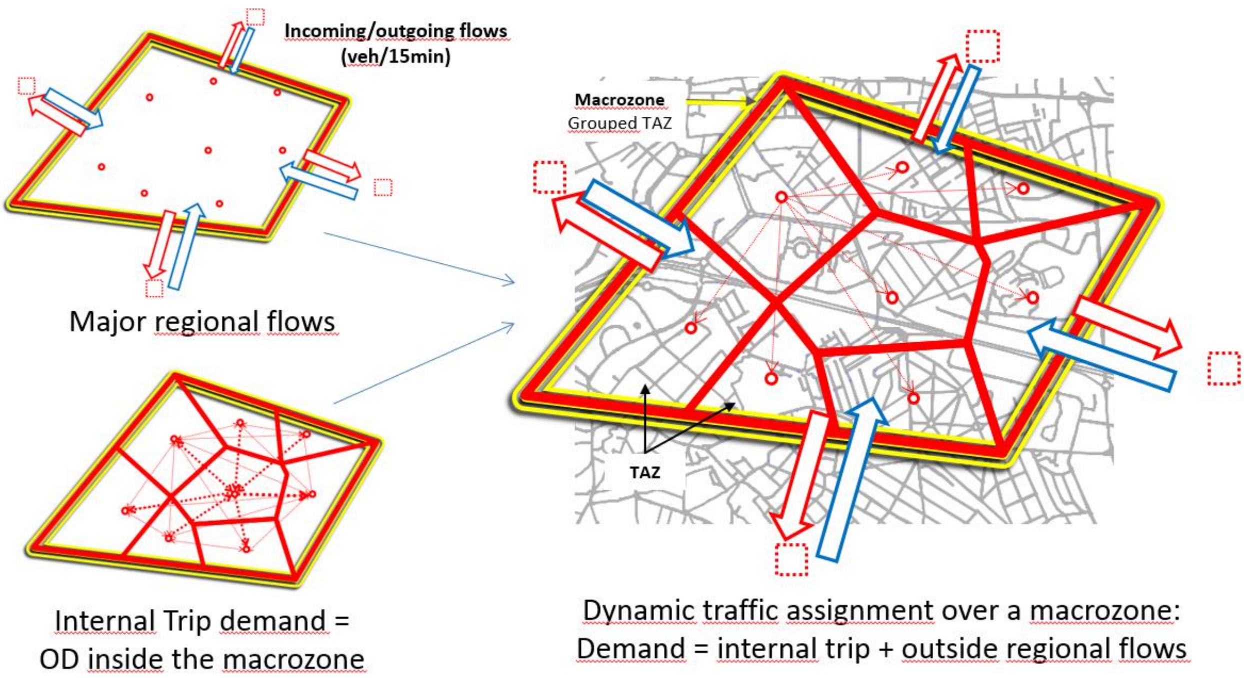

Figure 4 Inside a macrozone over a time period dT=1/4h, the travel demand is made of incoming/outgoing regional flows and internal demand.

Once the major regional flows are computed, we can then run a dynamic model with a 12x12 matrix as demand input, and a local road network as shown by Figure 5.

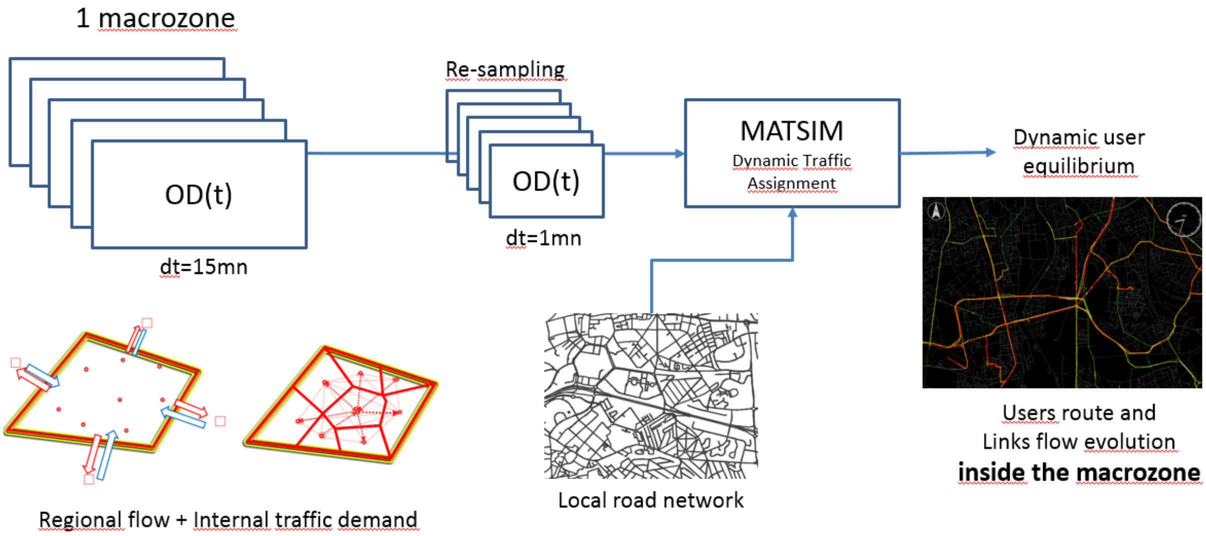

Figure 5 Application of the DTA over one macrozone grouping eight TAZ.

Two orientations can be taken to estimate the regional model:

- Experimental approach (computer science): a simplified regional model computes the major volumes by summing the output of the local traffic over each zone. Those major flows are re-injected locally to refine the road traffic flow over each macrozone independently. Then re-estimation of the regional model: iterative approach until convergence, with the advantage that dynamic traffic assignment is never performed at the regional scale (decreased complexity).

- Theoretical approach (mathematics): elaboration of regional model using an aggregated traffic flow model within a two-dimensional continuum anisotropic [3] (see the family of reservoir models such as MFD Macroscopic Fundamental Diagram). Dynamic traffic assignment is performed macroscopically with routes linking macrozones ("reservoirs"). Then usage at the local scale for boundary traffic. This approach is sequential: the regional model is estimated first by a hydrodynamic model by a set of equation that can be resolved using finite element calculus.

This division of labor into two levels addresses the issue of computing a dynamic user equilibrium at a very large scale, which requires a large amount of computation time and resources. It also reckons that dynamic traffic models can be efficient at small scale, and brings a mechanism to make dynamic model outputs of connected macrozones work together.

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