Modeling local flow restriction at boundaries in multi-reservoir systems: An hybrid approach

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Extended abstract submitted for presentation at the hEART 2018 7th Symposium
Sept. 5–7, 2018, Athens, Greece

Word count: 1274 words (excluding the references)
March 15, 2018

Extended abstract

Since the early works of Daganzo (2007), Geroliminis & Daganzo (2007), using the Macroscopic Fundamental Diagram (MFD) to simulate traffic states at a city scale has gained more and more interest in the literature. Numerous studies (see e.g., Kouvelas *et al.*, 2017, Sirmatel & Geroliminis, 2017, Yang *et al.*, 2017, Zhong *et al.*, 2017) notably used MFD-based simulation to design promising traffic control frameworks for large-scale networks, where such networks are considered split in several homogeneous reservoirs with well-defined MFD. However, there is still a lack in understanding flow exchanges and limitations at the reservoir boundaries in multi-reservoir systems. More precisely, we identify three research questions which need to be investigated: (i) how to define dynamically the maximum available flow that can enter a reservoir, both for under- and over-saturated conditions? (ii) how to scale up link-level information from the real network to account for local capacity reductions (that may be due to incidents, change in green times, temporarily closure of a major arterial, etc)? (iii) how to manage flow merging and diverging when different demand flows are distinguished (by their origins, destinations, or regional paths)?

All these questions currently received incomplete answers in the literature. The first one refers to what is sometimes called the "entry supply function" of the reservoir. Its existence has been shown by Geroliminis & Daganzo (2007) through a simulation study. Then, other authors like Hajiahmadi *et al.* (2013), Knoop & Hoogendoorn (2014), Lentzakis *et al.* (2016), Mariotte & Leclercq (2018) adopted an entry supply function with a shape based on the Cell Transmission Model of Daganzo (1994). Recently, Kim *et al.* (2018) explored flow exchanges between reservoirs with results from a micro-simulation, and proposed a different shape for this function. Nevertheless, only inflow and outflow shares were tested with network loading scenarios, but the proposed entry supply function was not implemented in an MFD-based simulation. Most of the time, the second question is addressed by studying the corresponding impact on the MFD itself, like in Kim & Yeo (2017). Integrating link-level capacity directly into the modeling of flow exchanges was investigated by Kim *et al.* (2018) for fixed settings of the network supply (road configuration and signal timings). This idea was already mentioned in the modeling approach of Knoop & Hoogendoorn (2014). Mariotte & Leclercq (2016) analyzed the effect of heterogeneous supply distributions at the reservoir border, and proposed to modify both the MFD shape and the flow restriction in the reservoir dynamics to account for this link-level heterogeneity. Their approach shows promising results, but can be hardly generalized for more complex networks and requires a lot of calibrations. Finally, the third problem about merging is often solved by using pro-rata merges (see e.g., Geroliminis, 2009, Knoop & Hoogendoorn, 2014, Yildirimoglu & Geroliminis, 2014, Ramezani *et al.*, 2015), or less often fair merges (see e.g., Zhong *et al.*, 2018). However, Mariotte & Leclercq (2018) recently found that incorporating constraints on production into the merging scheme potentially leads to a different flow allocation. In this case, the inflow share at entry would also depend on the reservoir inner dynamics (i.e. evolution of each partial accumulation) and the different trip lengths inside the reservoir. More importantly, the same authors showed that flow exchanges in multi-reservoir systems also depend on constraints on flow diverging at the exit of each reservoir. Nevertheless, all these results still needs to be validated with simulated or real data.

In this study, we thus want to further investigate these three questions by proposing an original hybrid modeling approach of multi-reservoir systems based on the work of Mariotte & Leclercq (2018). Our framework will be then validated with micro-simulation on a grid network. The idea behind our hybrid approach is to discretize the border between two adjacent reservoirs into several connection nodes. These nodes can either correspond to physical link connections (like a bridge or a major arterial), or represent an aggregation of different link connections. The flows in a reservoir are thus distinguished by their entry and exit connection nodes. This idea is extending the concept of macroscopic route or regional path, first introduced in Yildirimoglu & Geroliminis (2014), which consists in assigning users on a succession of reservoirs to travel from their origin to destination. The principle is the same as Dynamic Traffic Assignment on link paths in a microscopic network. It allows to study regional re-routing at the city scale, and it also ensures a better representation of the trip lengths traveled by the users. The reader can refer to Batista *et al.* (2018) for a more detailed description of the methods to aggregate link-level traveled distances into reservoir-level trip lengths. Therefore here, we propose to define a regional path as a succession of connection nodes. This means that two regional paths may have an identical succession of reservoirs but differ through the connection nodes they used at the reservoir borders, as illustrated in figure 1. This framework allows a more refined representation of the trip lengths inside a reservoir. This can contribute to answering our second research question. About traffic flow modeling, the traffic dynamics are the same as in the framework of a reservoir with multiple trip lengths, first presented in Geroliminis (2009, 2015) for the accumulation-based model, and further extended to highly congested cases for both accumulation- and trip-based models by Mariotte & Leclercq (2018). In this perspective, the merge and diverge scheme introduced by the latter authors will be included in our new approach, and will shed some light on our third research question. As for the first question, different shapes of the entry supply function based on the previously mentioned works will be tested against the results from the micro-simulation.

Preliminary results from the development of our hybrid framework shows that a single reservoir with multiple entry and exit connection nodes is able to reproduce macroscopic phenomena highlighted in Mariotte & Leclercq (2016), like a global outflow decrease due to local supply reductions at the reservoir exit. Such a phenomenon was impossible to simulate with the classical single reservoir model as inflows and outflows are homogenized along the whole border of the reservoir. The grid network designed to test our modeling approach is presented in figure 2. It consists in a single reservoir represented by a 4-by-12 one-way road network, and crossed by two regional paths. Such a configuration ensures that the two macroscopic trips O1-D1 and O2-D2 have different average lengths inside the reservoir, and that users traveling on each trip will interact in the middle of the network through the shared links of their microscopic trips (link paths). Thus, this case study will allow us to observe the inflow share between the two entries O1 and O2 when one or both the regional paths are congested, and then validate or infringe our merging and diverging hypotheses. Congestion will be generated either by adding internal trips within the network (which origins and destinations are set at the inner nodes), or by limiting the link outflow through the exits D1 or D2. The new hybrid approach with connection nodes will be tested by aggregating microscopic nodes at macroscopic entries and exits. For instance, the macroscopic entry O1 could be divided in two connection nodes, each of them encompassing two microscopic nodes. The same will be done with O2, D1 and D2, as depicted in figure 3. All the results cannot be presented here as our investigations are still part of an ongoing work.

Keywords: Hybrid modeling, Macroscopic Fundamental Diagram, multi-reservoir systems, flow exchanges, local network heterogeneities

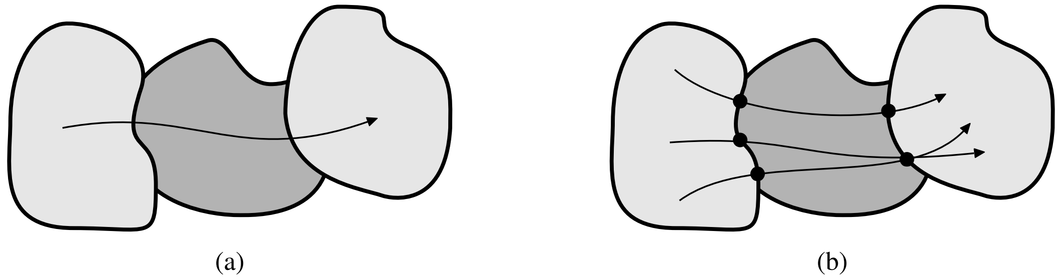

FIG. 1 – (a) *Classical regional path as the succession of the reservoirs, and* (b) *new regional paths based on the border connection nodes*

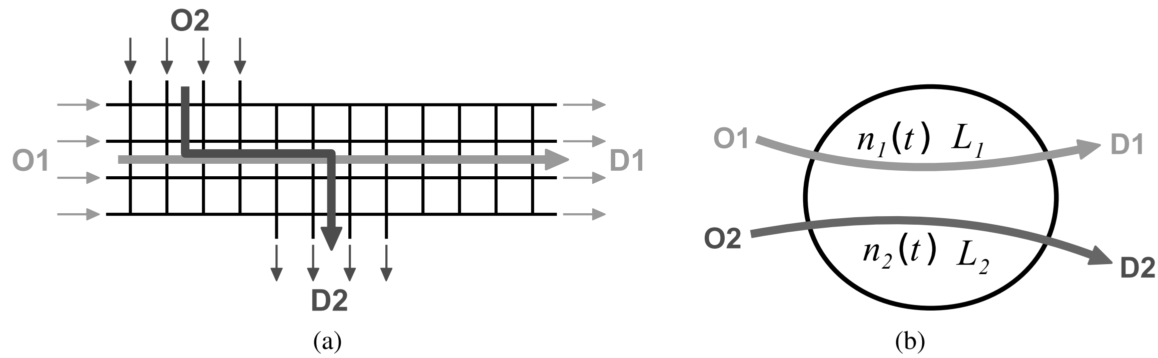

FIG. 2 – (a) *Configuration of the grid network with two regional origins O1, O2, and destinations D1, D2, and* (b) *single reservoir modeling with the two regional paths O1-D1 and O2-D2*

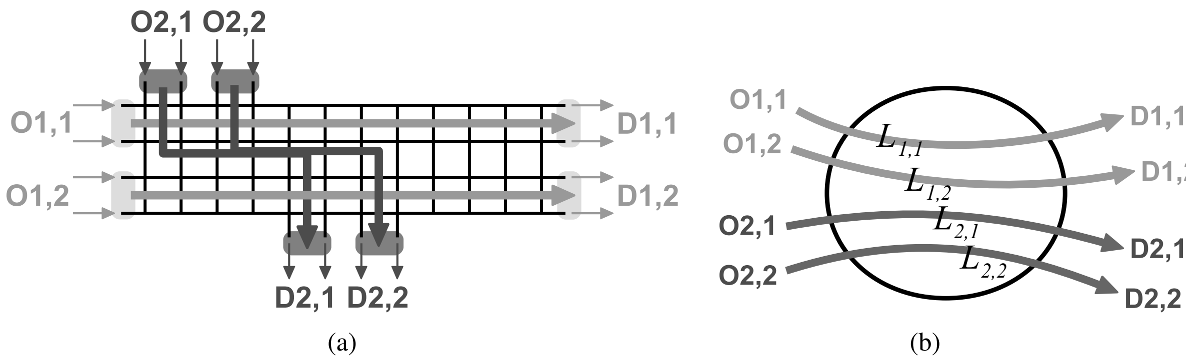

FIG. 3 – (a) *Same grid network with example of connection nodes O1,1, O1,2, O2,1, O2,2 at entry and D1,1, D1,2, D2,1, D2,2 at exit, and* (b) *single reservoir modeling with examples of the corresponding regional paths*

Acknowledgement

This project has received funding from the European Research Council (ERC) under the European Union's Horizon 2020 research and innovation programme (grant agreement No 646592 – MAGnUM project).

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