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The role of trip lengths in control strategies and Macroscopic Fundamental Diagram traffic models

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1 Introduction

2 Aggregated traffic models were introduced by Godfrey (1969) and later revisited by
3 Daganzo (2007) and Geroliminis & Daganzo (2008). These traffic models require
4 the partition of the city network (see e.g., Saeedmanesh & Geroliminis, 2016, 2017,
5 Lopez et al., 2017, Casadei et al., 2018) into regions, where the traffic conditions are
6 approximately homogeneous. Such partition defines the regional network. In each
7 region, the traffic states are measured through the vehicles' accumulation $n(t)$ and
8 are regulated by a Macroscopic Fundamental Diagram (MFD). The MFD reflects
9 the relationship between the average circulating flow of vehicles and the average
10 density in the region.

11 The regional network definition brings new challenges. Figure 1 depicts the
12 challenge of scaling up trips to the regional network. The green and blue trips follow
13 a sequence of links in the city network, with a fixed length. The green and blue
14 trips cross a different sequence of regions, following the city network partitioning.
15 The ordered sequence of crossed regions by a trip is called regional path. The green
16 and blue trips describe different travel distances inside each region, as highlighted
17 in the gray region. Therefore, regional paths are characterized by distributions
18 of trip lengths, containing information of the plausible travel distances in the city

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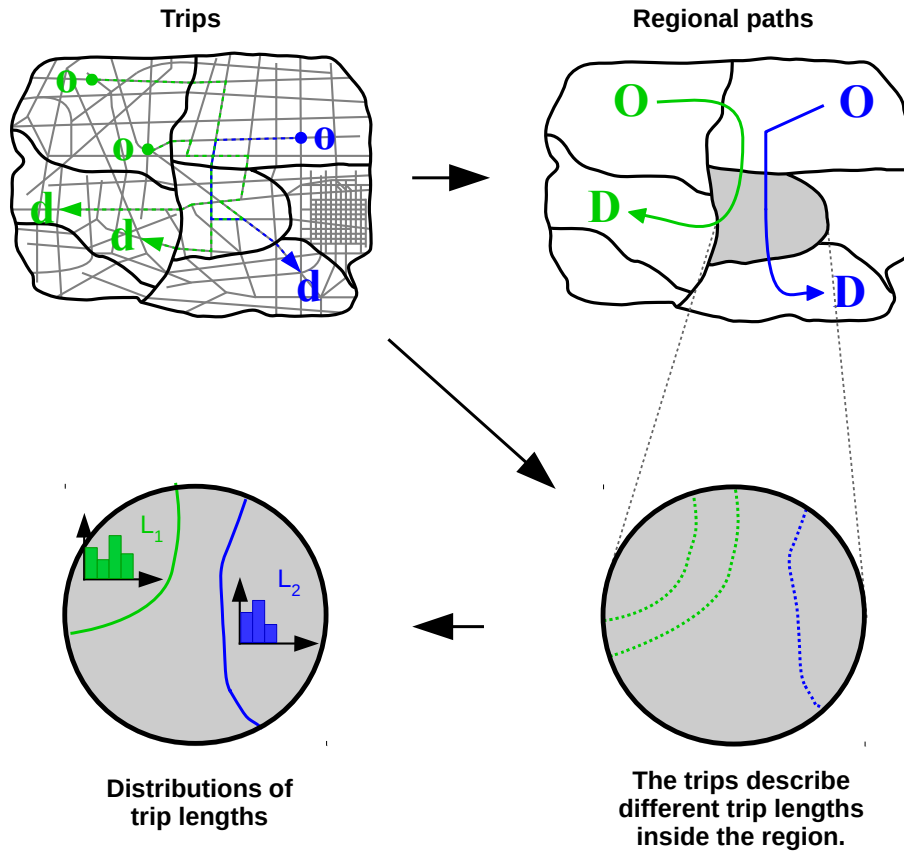


Fig. 1 – The scale up of trips into regional paths, that are characterized by trip length distributions.

1 network. Batista et al. (2018) and Batista et al. (in prep.) propose a methodological
2 framework to calculate trip length distributions based on a set of trips and different
3 levels of information from the regional network. The first level calculates trip length
4 distributions considering the travel distances of all trips crossing one region. This
5 assigns a common trip length distribution for all regional paths that cross the same
6 region, independently of their Origin and Destination (OD). We refer to this level as
7 $M_{standard}$. The most detailed level only considers the trips that define the same
8 regional path. This allows to derive different trip lengths for all regional paths that
9 cross the same region. We refer to this level as $M_{reference}$. The authors show that
10 $M_{standard}$ is not able to capture the trip lengths variability of all regional paths
11 crossing the same region. Moreover, they also show that the calibration of the trip
12 lengths clearly influences the modeled traffic dynamics inside the regions.

13 Up to now, most of the MFD applications have been designed to test control
14 algorithms or design perimeter control strategies. Daganzo (2007), Keyvan-
15 Ekbatani et al. (2012) and Ekbatani et al. (2013) tested perimeter control strategies
16 for a one region network, where all vehicles were assigned a common average travel
17 distance. Some theoretical studies (see e.g., Haddad, 2017, Zhong et al., 2017, Yang

1 et al., 2018) focused on the outflow-MFD application, where all vehicles were as-
 2 signed the same trip length. Aboudolas & Geroliminis (2013) and Kouvelas et al.
 3 (2017) tested perimeter control strategies in real city networks, but an average trip
 4 length for all regions was also considered.

5 Research contribution

6 In this paper, we propose to investigate the role of the trip lengths calibration
 7 for perimeter control strategies. The goal is to quantify the effects of improper
 8 assumptions on the travel distances in the regions on Model Predictive Control
 9 (MPC) based control strategies. In this extended abstract, we discuss some initial
 10 and preliminary results obtained by a Proportional-Integral (PI) gating control
 11 scheme on a real network.

12 Test scenario and methodological framework

13 The test network is depicted in Figure 2 (a). It includes the 3rd and 6th districts of
 14 Lyon and the city of Villeurbanne (France). The network has 3127 nodes and 3363
 15 links and is divided into seven regions. Figure 2 (b) depicts the MFD functions.
 16 They were calculated by assuming a bi-parabolic shape to fit microscopic simulation
 17 data obtained from Symuvia (Leclercq, 2007).

18 The calculation of the trip lengths and regional paths are based on a virtual
 19 trips set in the city network. To gather this set, we randomly sample 3 million
 20 origin and destination nodes in the city network and calculate the shortest-path in
 21 distance between each of them. To obtain the regional paths, we filter all trips by
 22 the specific sequence of regions they cross. For each regional OD pair, the regional
 23 paths are ranked according to the number of trips they have associated. For our case
 24 study, we consider three OD pairs: 1-7; 4-2; and 6-4. To define the regional choice
 25 set for each OD pair, we gather the two regional paths with the largest number of
 26 trips associated. We calculate the trip lengths distributions following the $M_{standard}$
 27 and $M_{reference}$ described in the Introduction (see also Batista et al., 2018, in prep.,
 28 , for more details). The regional paths and demand assignment coefficients are
 29 listed in Table 1. The average trip lengths calculated by $M_{standard}$ and $M_{reference}$
 30 are listed in Table 2. The demand scenarios for the three OD pairs are shown in
 31 Figure 2 (c). The traffic states are simulated through an accumulation-based MFD
 32 model (Daganzo, 2007, Geroliminis & Daganzo, 2008), for a total simulation period
 33 of $T = 20000$ seconds.

34 Our goal is to control the maximum vehicles' accumulation in region 3 (i.e.
 35 $(n_3(t))$). For this purpose, we designed a gating control composed by three PI
 36 controllers with an anti-windup scheme to track the desired set-point, i.e. $(n_3(t))$.
 37 Figure 3 depicts the PI-based gating control scheme that is implemented. The
 38 inflows of regional paths 1 – 3 – 5 – 7 ($I_{3,1}^1$), 4 – 3 – 2 ($I_{3,2}$) and 6 – 5 – 3 – 4 ($I_{3,3}$)
 39 are manipulated by the PI controller before entering region 3. The new inflows are
 40 $u_{3,1}(t)$, $u_{3,2}(t)$ and $u_{3,3}(t)$. The manipulation by the controller is done such that
 41 $n_3(t)$ is maintained at the set-point. The outflows ($o_{3,1}$, $o_{3,2}$, $o_{3,3}$) will continue to the
 42 next regions in the sequence of the corresponding regional paths. In this example,

¹The first subscript refers to the region that is being controlled. The second subscript refers to the regional paths will cross region 3.

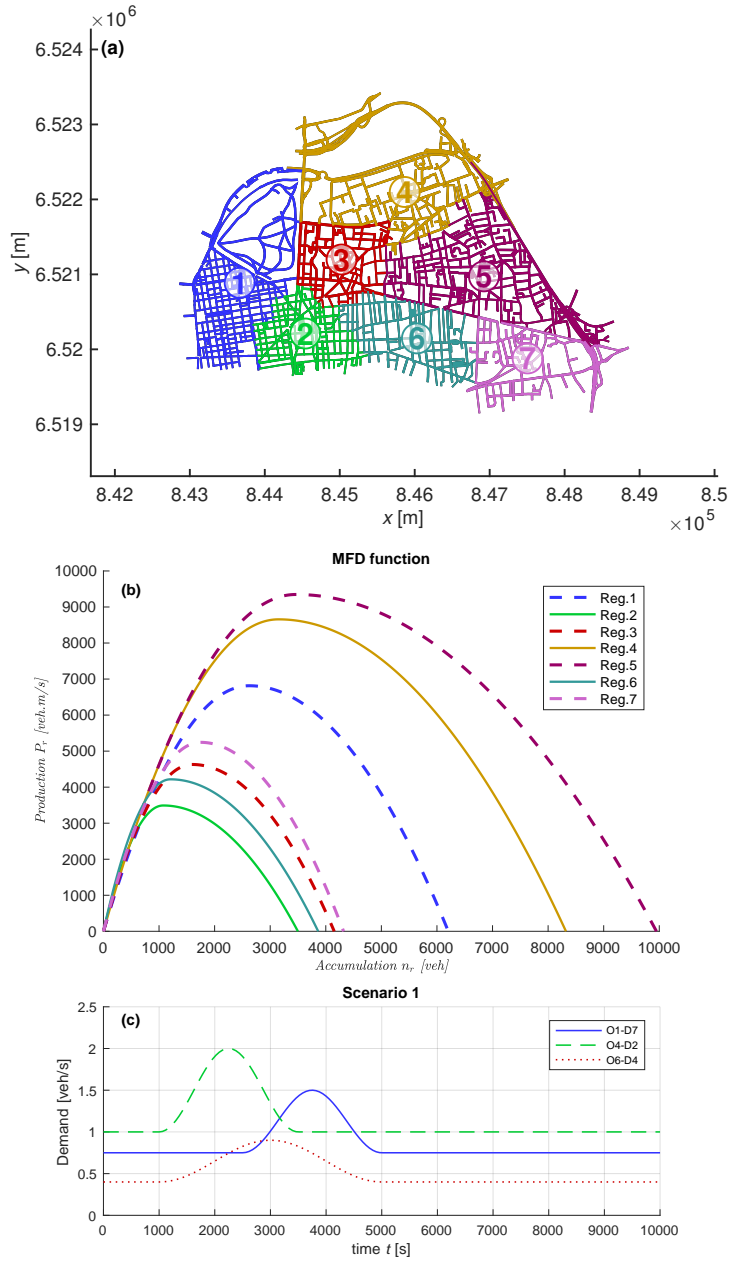


Fig. 2 – (a) Villeurbanne and the 3^d and 6th districts of Lyon (France) traffic network, divided into seven regions. (b) MFD function of each region. (c) Demand scenarios.

O	D	Regional path	Assignment coefficient
1	7	1-2-6-7	0.15
		1-3-5-7	0.85
4	2	4-1-2	0.25
		4-3-2	0.75
6	4	4-3-2	0.00
		6-5-3-4	1.00

Tab. 1 – Regional paths and the assignment coefficients used for this study.

Method	Regional path	Region						
		1	2	3	4	5	6	7
Standard	1-2-6-7	987	649	~	~	~	694	926
	1-3-5-7	987	~	880	~	1042	~	926
	4-1-2	987	649	~	1347	~	~	~
	4-3-2	~	649	880	1347	~	~	~
	6-5-3-4	~	~	880	1347	1042	694	~
Reference	1-2-6-7	788	1121	~	~	~	1424	676
	1-3-5-7	927	~	1297	~	1032	~	1142
	4-1-2	2761	335	~	2227	~	~	~
	4-3-2	~	708	1049	1191	~	~	~
	6-5-3-4	~	~	458	733	861	584	~

Tab. 2 – Average trip lengths (m) calculated by the methods $M_{standard}$ and $M_{reference}$.

1 we assume that the set of regional paths and trip lengths remain unchanged. In
2 the full paper, we will consider the vehicles' re-routing due to the control effects on
3 the travel times and time-dependent trip lengths. The proportional ($k_p = 1$) and
4 integral ($k_i = 0.05$) gains of the PI controller are obtained using trial and error
5 methods.

6 Preliminary results and discussion

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9 Union's Horizon 2020 research and innovation program (grant agreement No 646592 -
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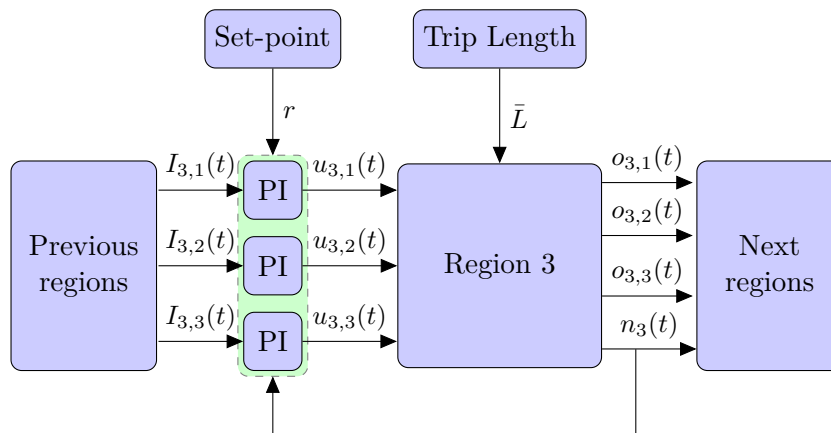


Fig. 3 – Representation of closed-loop gating control using PI controllers.

Region	TTS ($\times 10^5 [s]$)						
	Uncontrolled		Controlled				Mismatch
	M_s	M_r	PID		MPC		
M_s			M_r	M_s	M_r		
1	2.31	4.45	2.64	5.54	2.54	6.41	5.61
2	1.11	1.16	1.11	1.16	1.11	1.16	1.16
3	2.07	2.53	2.03	2.46	2.03	2.46	2.47
4	2.77	2.68	2.95	3.31	3.06	2.66	2.87
5	2.19	2.03	2.29	2.42	2.25	2.36	3.37
6	1.03	1.12	1.03	1.12	1.03	1.12	1.12
7	1.60	1.86	1.60	1.86	1.60	1.86	1.86
Total ($\times 10^6 [s]$)	1.31	1.58	1.36	1.79	1.36	1.80	1.85

Tab. 3 – Total Time Spent (TTS) in all regions.

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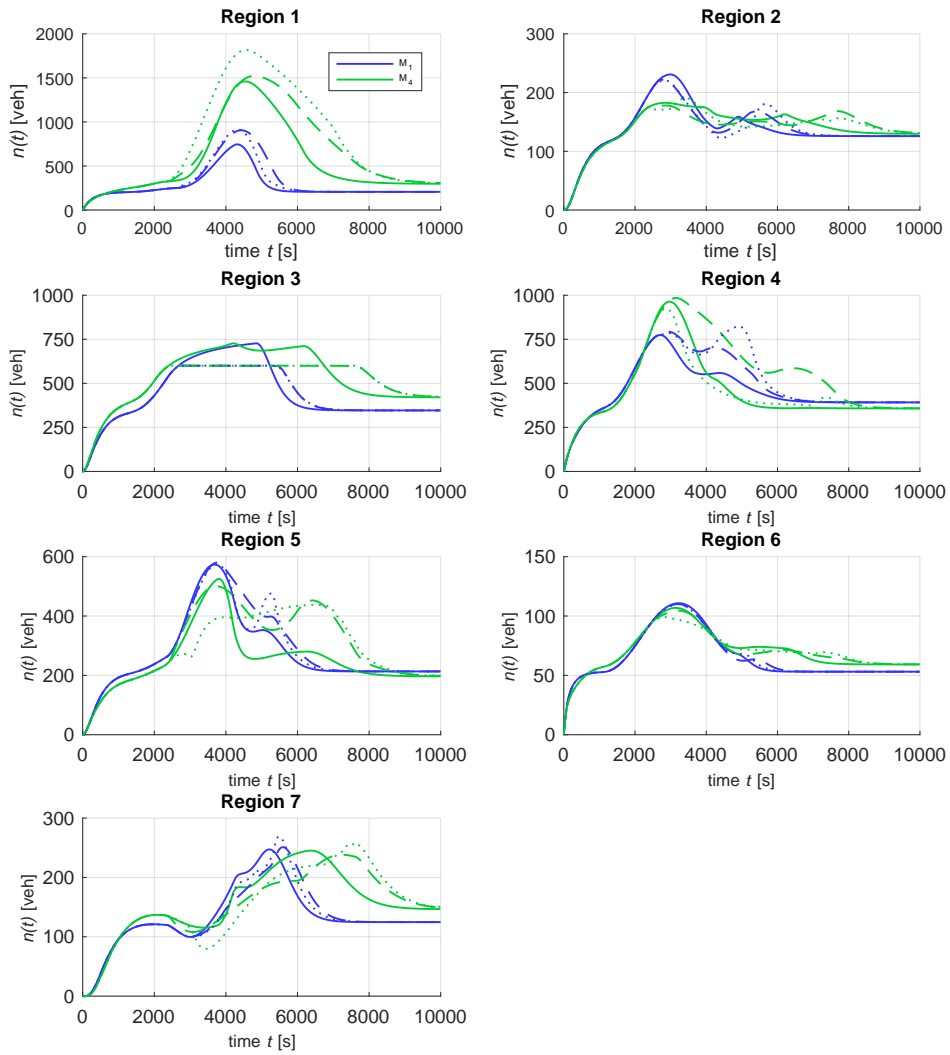


Fig. 4 – Evolution of the vehicles' accumulation $n(t)$ for all seven regions.

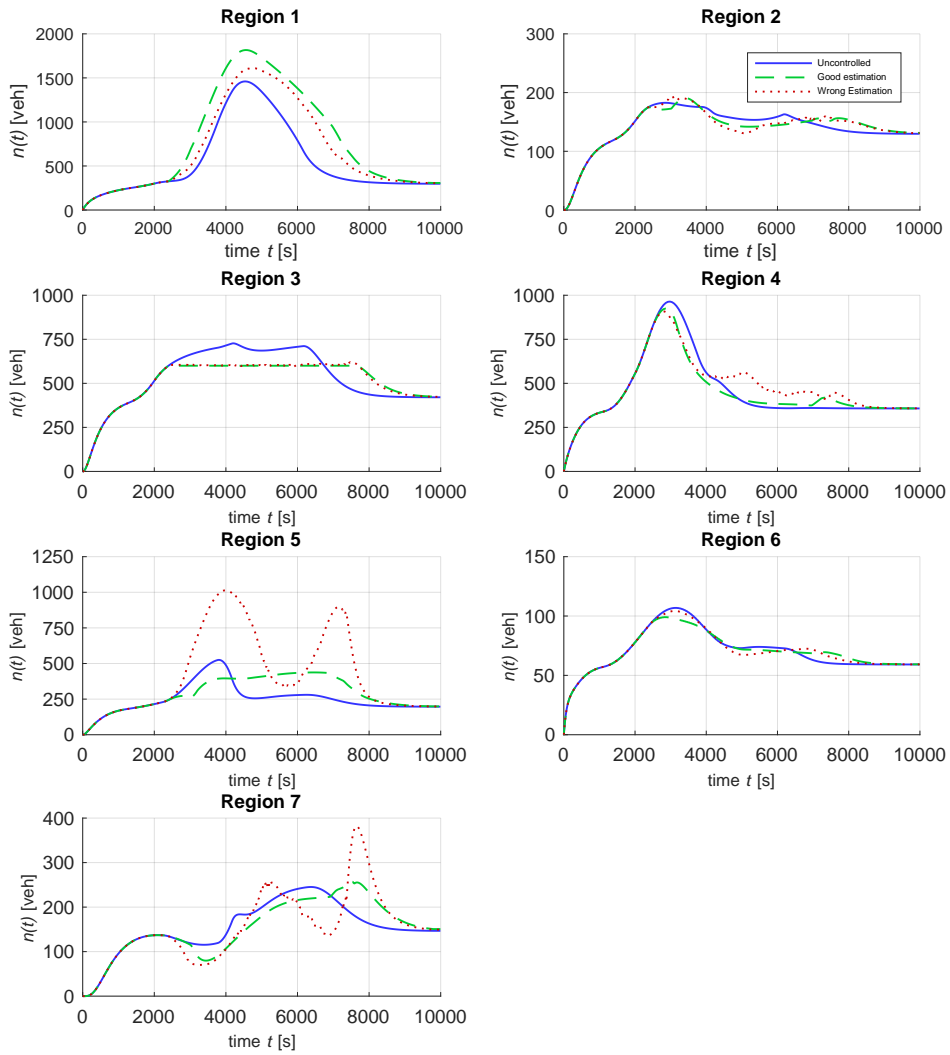


Fig. 5 – Evolution of the vehicles' accumulation $n(t)$ for all seven regions.

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