Exploring Macroscopic Fundamental Diagrams for the Transportation Network in Central London

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1 Introduction

The existence of urban Macroscopic Fundamental Diagrams (MFDs) has been a topic of long-standing interest for researchers and practitioners due to their many applications in active traffic and demand management [1, 4, 5, 8]. In the past, several studies have developed analytical approximations of MFDs [2, 3], while others have investigated their characteristics using simulation or real traffic data from different urban transportation systems [1, 4, 5, 6, 7, 8].

The purpose of this study is to explore spatio-temporal factors that may affect the shape of MFDs developed for the transportation network in central London (Figure 1a). Automatic Number Plate Recognition (ANPR) cameras are used to obtain speed data, while SCOOT detectors provide proxy measurements for traffic flow and occupancy (Figure 1b). Five specific objectives have been defined towards this:

a) To estimate relationships amongst speed, flow and occupancy.
b) To examine the existence and form of MFDs.
c) To identify differences between MFDs developed for weekdays and weekend days.
d) To investigate the influence of the specific data collection mechanisms on estimated MFDs.

e) To determine the spatial heterogeneity of the study area by developing MFDs for three sub-regions of London: (Figure 1b): the Congestion Charging Zone (CCZ); the Ring Road (RR), and the Western Extension Zone[1] (WEZ).

[1] The WEZ was part removed from CCZ on 4 January 2011.

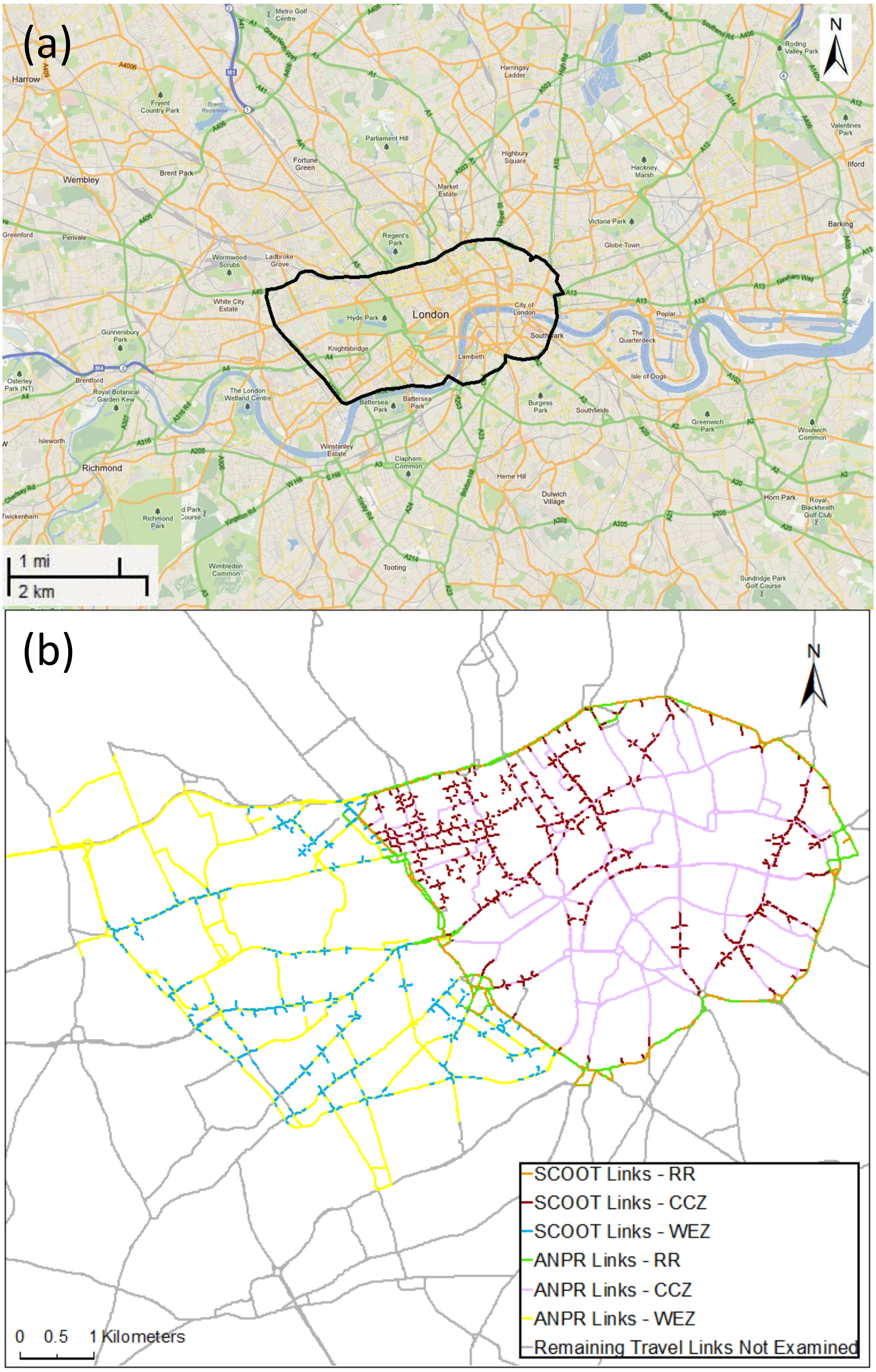

Figure 1. ANPR travel links and SCOOT links per study area.

2 Study Data

The study data cover the central part of London for the full week 4-10 July 2011[2]. Table 1 presents the main characteristics of the ANPR and the SCOOT links used. Within this area, the ANPR links do not coincide with the SCOOT ones, and are typically 3-4 times longer.

Table 1. Characteristics of ANPR and SCOOT links per study area.

	CCZ	RR	WEZ	Total
Number of ANPR Links	150	62	134	346
Avg. Length of ANPR Links (km)	1.3	1.2	1.6	1.4
St. Dev. Length of ANPR Links (km)	0.6	0.6	1.0	0.8
Total Length of ANPR Links (km)	200.3	73.2	210.8	484.3
Number of SCOOT Links	636	241	366	1243
Number of SCOOT Detectors [a]	714	349	425	1488
Avg. Length of SCOOT Links (m)	54	62	59	57
St. Dev. Length of SCOOT Links (m)	18	31	20	22
Total Length of SCOOT Links (km)	34.3	15.0	21.7	71.0

[a] Some SCOOT links include more than one detector.

2.1 ANPR Cameras – Speed

A typical configuration of this system includes two ANPR cameras per link: one located on the entry node and the second on the exit node of the link. The cameras scan, read and record the number plate of each vehicle that passes, recording the time of detection. The exit records are matched against the entry ones, and if a match is found, then the travel time is estimated as the difference between the times of detection. Average link travel time data are calculated as a simple average of individual vehicle travel times over successive 5-minute intervals. The end result is macroscopic speeds estimated as average speeds for the ANPR links.

2.2 SCOOT Detectors – Flow & Occupancy

"SCOOT flow" represents the flow as it is modelled to arrive at the stop-line. It is originally measured in link profile units (LPU) per 5 minutes, and is converted to vehicles per hour with a link-dependent conversion factor[3].

The proxy of SCOOT for occupancy is based on the concept of a four-second "congested" interval throughout which a detector is occupied by a vehicle. Specifically,

[2] The time period between 24:00 and 01:05 was not analysed due to missing SCOOT data.
[3] SCOOT flows are analysed and shown for 5-minute intervals, although they are expressed as flows in vehicles/hour.

SCOOT occupancy is expressed as a percentage of all four-second intervals, within a 5-minute period examined, that are congested.

3 Methodological Considerations

A sensitivity analysis is undertaken to investigate the impact of SCOOT links' length on the MFDs (Figure 5). The original SCOOT data set is divided into three subsets based on the frequency distribution (0.33 and 0.66 percentiles) of their length (*L*):

1. L < 48.2m - 414 SCOOT links
2. 48.2m < L < 61.7m - 414 SCOOT links
3. L > 61.7m - 415 SCOOT links

The results of the analysis are presented in the following section.

4 Results and Discussion

Figures 2a, 2b and 2c illustrate the time series of speed, flow and occupancy respectively. It can be clearly observed that the single-peak weekend patterns differ substantially from the flatter weekday trends. As one might expect, weekday speeds decrease and flows increase from 06:00 to 19:00, remaining stable during this period. Occupancy exhibits greater variation over time and days. Note that Thursday has high occupancy values from 11:00 to 20:00, but there is no corresponding deviation in speed and flow trends.

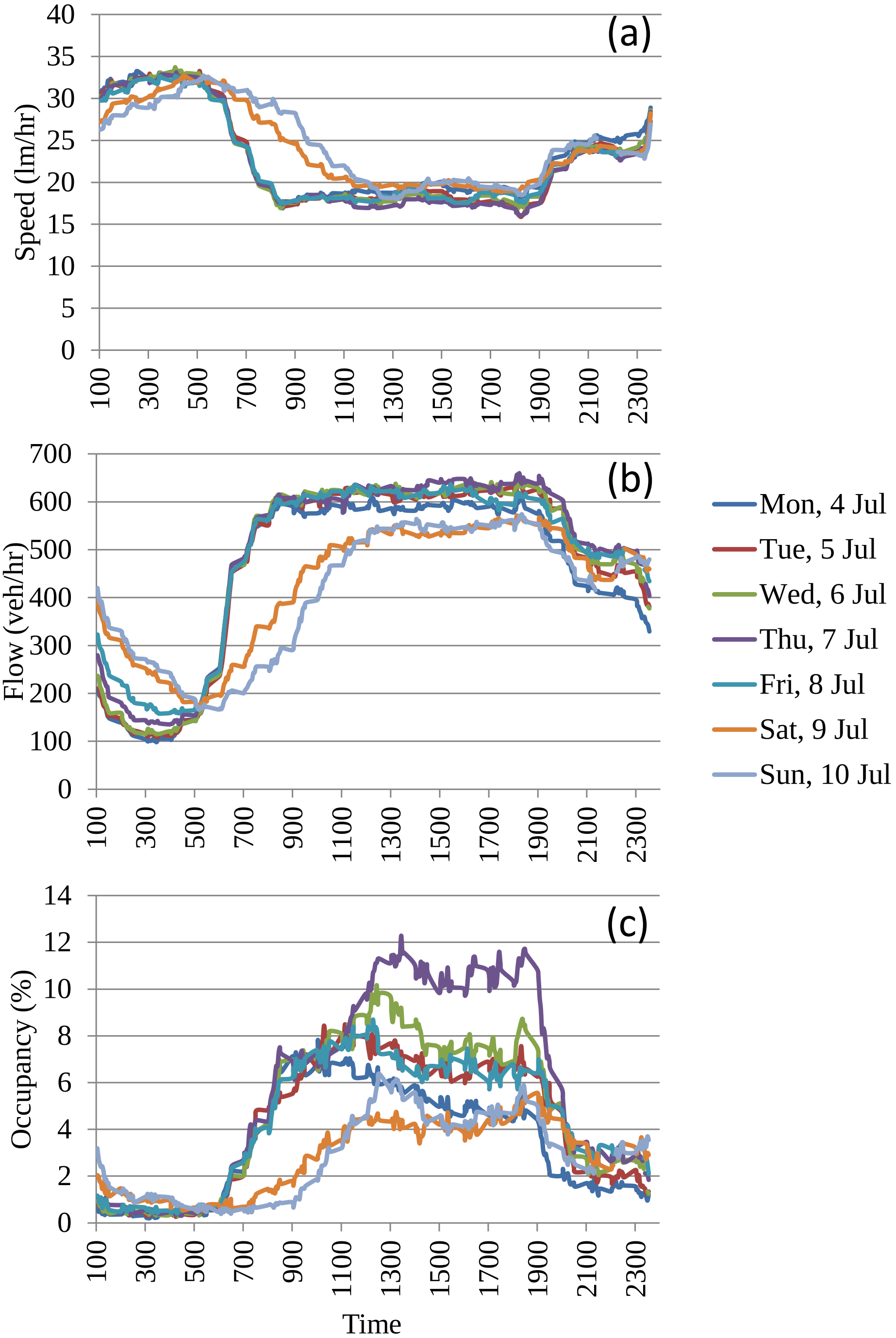

Figure 2. Daily patterns for the entire study area: (a) speed; (b) flow; and (c) occupancy.

The correlation coefficients presented in Table 2 range from 0.80 to 0.98, indicating strong relationships amongst the 3 parameters, and hence providing a solid basis for the construction of the MFDs.

Table 2. Correlation coefficients per study area.

	CCZ		RR		WEZ		ALL 3 REGIONS	
	Flow	**Occup.**	**Flow**	**Occup.**	**Flow**	**Occup.**	**Flow**	**Occup.**
Occup.	0.87		0.80		0.87		0.87	
Speed	-0.97	-0.86	-0.95	-0.90	-0.98	-0.87	-0.98	-0.89

The well-defined curves, shown in Figure 3, verify the existence of MFDs for the entire study area, even though only the free-flow part is revealed. One reason behind this finding may be the use of the two SCOOT proxy variables for flow and occupancy that are expected to underestimate the real values. Another explanation may be the good network performance, partially due to the effectiveness of the CCZ. The lack of observations in the congested part, whose existence has been verified in other case studies [1, 4, 6], is investigated within the following objectives.

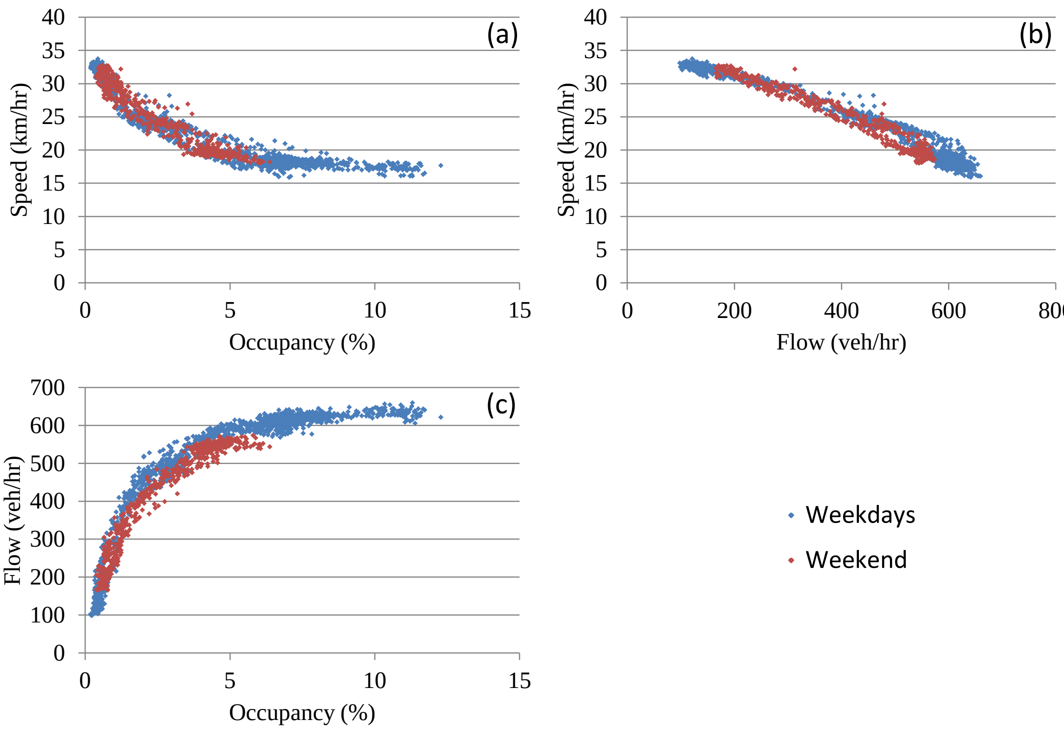

Figure 3. MFDs for the entire study area: (a) speed vs. occupancy; (b) speed vs. flow; and (c) flow vs. occupancy.

Another finding derived from Figure 3 is the distinct weekend MFDs that have significantly shorter ranges of speed, flow and occupancy than the corresponding weekday MFDs. Note that the CCZ and other parking enforcements are not applied on weekend days, affecting the effective capacity of the network and the travel demand. As a result, part of the weekend MFD (Figure 3c) lies below the weekday MFD. Similar conclusions can be drawn from Figure 4 that presents how the MFDs evolve during an average weekday (Figures 4a-4c) and weekend day (Figures 4d-4f). One may notice that the two edges of the weekday curves do not always correspond to the same time-periods as those of the weekend MFDs.

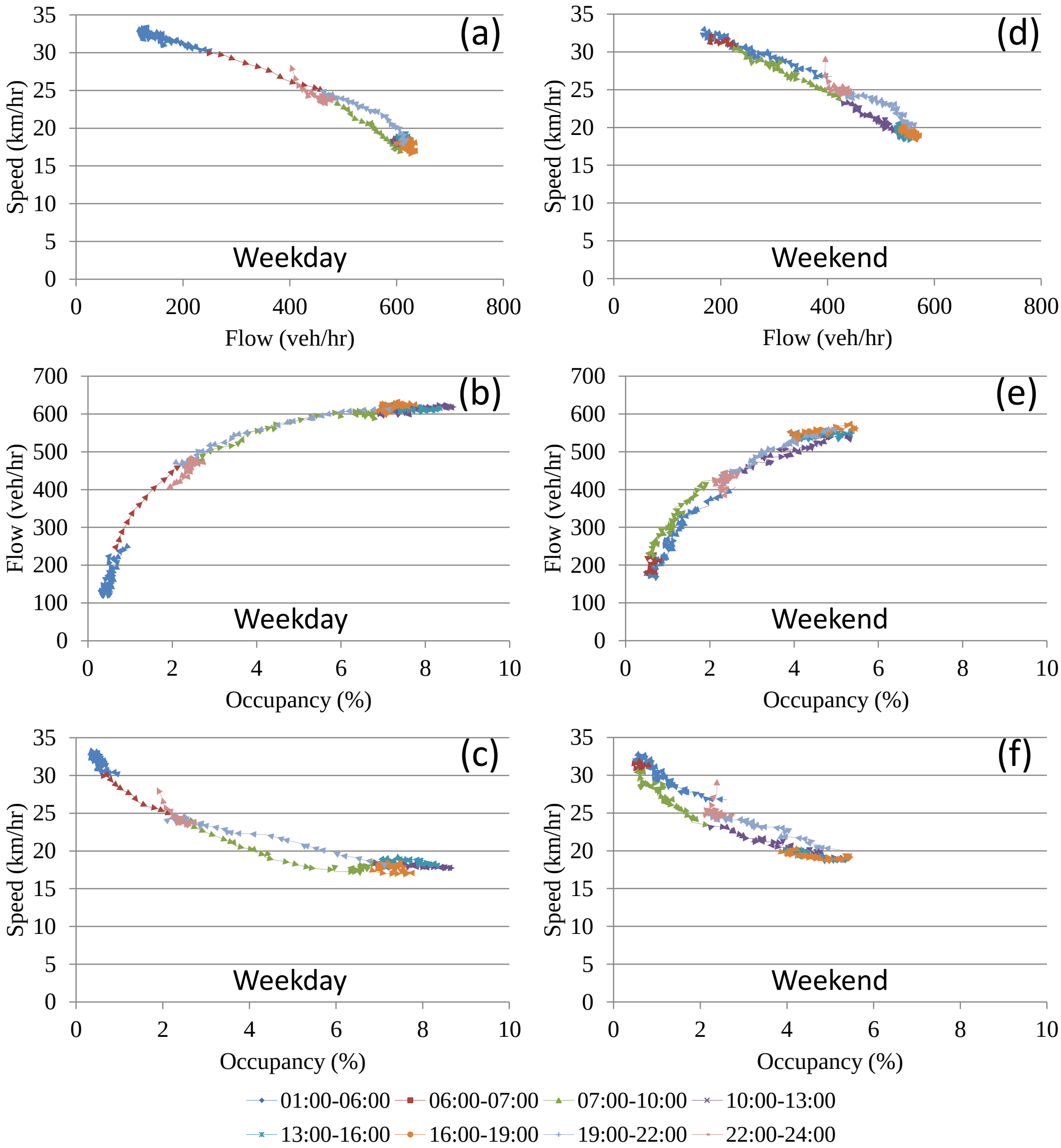

Figure 4. MFDs for the entire study area: (a) speed vs. flow - average weekday; (b) flow vs. occupancy - average weekday; (c) speed vs. occupancy - average weekday; (d) speed vs. flow - average weekend day; (e) flow vs. occupancy - average weekend day; (c) speed vs. occupancy - average weekend day.

The different curves illustrated in Figures 5a and 5b confirm previous research findings [6], according to which the distance of a SCOOT detector from its downstream traffic light affects the shape of the MFD. This suggests that the closer a detector to the stop-line, the more likely it will be occupied by the forming queue caused by the traffic signal. Nonetheless, the asymptotic heights of the curve indicate different capacities; a fact that will be further investigated in the full paper.

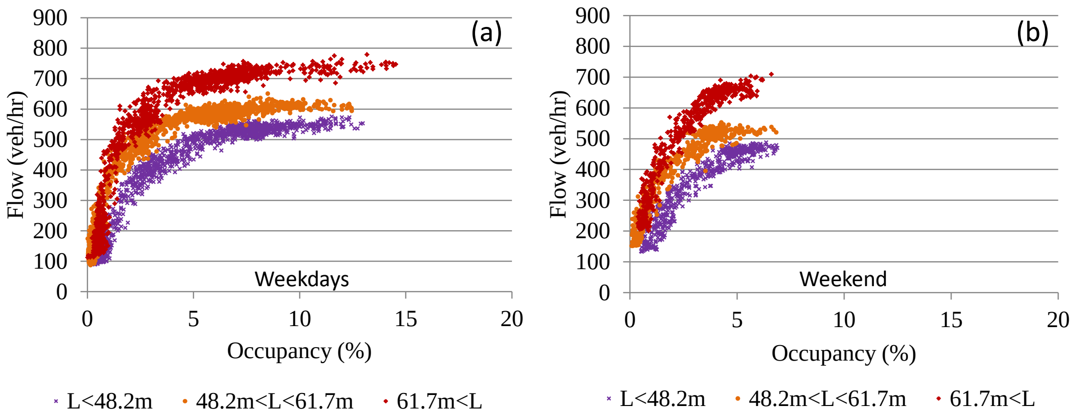

Figure 5. MFDs for the entire study area: (a) flow vs. occupancy for weekdays; and (b) flow vs. occupancy for weekend days.

Figure 6 indicates that the division of the study area into sub-regions of unique roadway and traffic characteristics produces different MFDs. Another important finding is that the congested part of the MFDs is revealed in the ring-road case, which also exhibits lower average speeds, and significantly higher flows and occupancies than the CCZ and the WEZ.

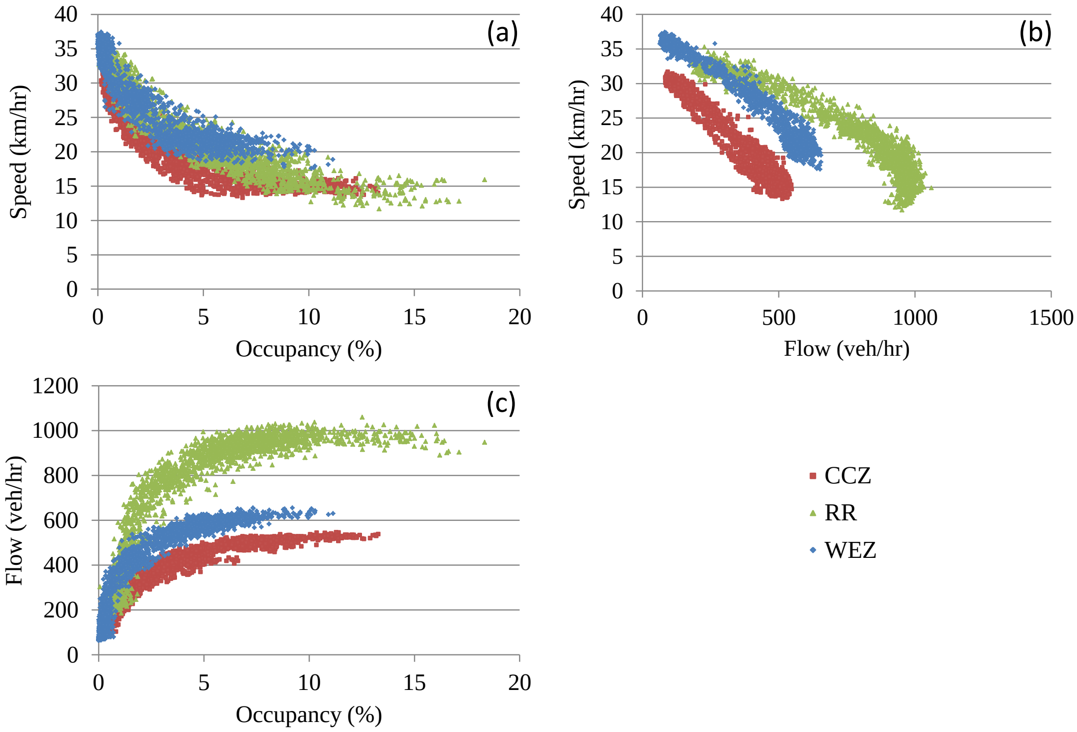

Figure 6. MFDs for CCZ, RR and WEZ: (a) speed vs. occupancy; (b) speed vs. flow; and (c) flow vs. occupancy.

The results presented in Figures 5 and 6 suggest that “SCOOT occupancy” may not be a reliable measure for occupancy. This topic will be further explored in the full paper.

5 Conclusions

The main findings of this study are:

- A clear relationship exists amongst the ANPR speed and the SCOOT flow/occupancy data.
- Well-defined curves, without exhibiting any hysteresis phenomena, exist for the examined heterogeneous network; although only the free-flow part of the MFDs is revealed.
- “Weekend” MFDs are different that those on weekdays, indicating that operational changes on the network may affect the shape of the MFD.
- The closer a detector to the stop-line, the more likely to be occupied by the forming queue caused by the traffic signal.

- A careful geographical division of a heterogeneous network based on similar roadway and traffic characteristics may result in different MFDs for each sub-region created.

References

[1] Buisson, C., and C. Ladier. Exploring the impact of the homogeneity of traffic measurements on the existence of macroscopic fundamental diagrams. *Transportation Research Record 2124*, 127–136, 2009.

[2] Daganzo, C. F., and N. Geroliminis. An Analytical Approximation for the Macroscopic Fundamental Diagram of Urban Traffic. Transportation Research Part B, 42, 771–781, 2008.

[3] Daganzo, C. F. Urban Gridlock: Macroscopic Modeling and Mitigation Approaches. Transportation Research Part B, 41(1), 49–62, 2007.

[4] Geroliminis, N., and C. F. Daganzo. Existence of Urban-Scale Macroscopic Fundamental Diagrams: Some Experimental Findings. Transportation Research Part B, 42, 759–770, 2008.

[5] Geroliminis, N., and C. F. Daganzo. Macroscopic Modeling of Traffic in Cities. Presented at 86th Annual Meeting of the Transportation Research Board, Washington, D.C., 2007.

[6] Geroliminis, N., and S. Jiu. Properties of a well-defined macroscopic fundamental diagram for urban traffic. *Transportation Research Part B*, 45(3), 605-617, 2011.

[7] Godfrey, J.W. The mechanism of a road network. *Traffic Engineering and Control* 11 (7), 323–327, 1969.

[8] Ji, Y., Daamen, W., Hoogendoorn, S., Hoogendoorn-Lanser, S., and X., Qian. Investigating the shape of the macroscopic fundamental diagram using simulation data. *Transportation Research Record 2161*, 40-48, 2010.