Effects of Loop Detector Position on the Macroscopic Fundamental Diagram

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Introduction

➢ This study aimed to investigate two distinguished MFD biases induced by the nature of loop detectors

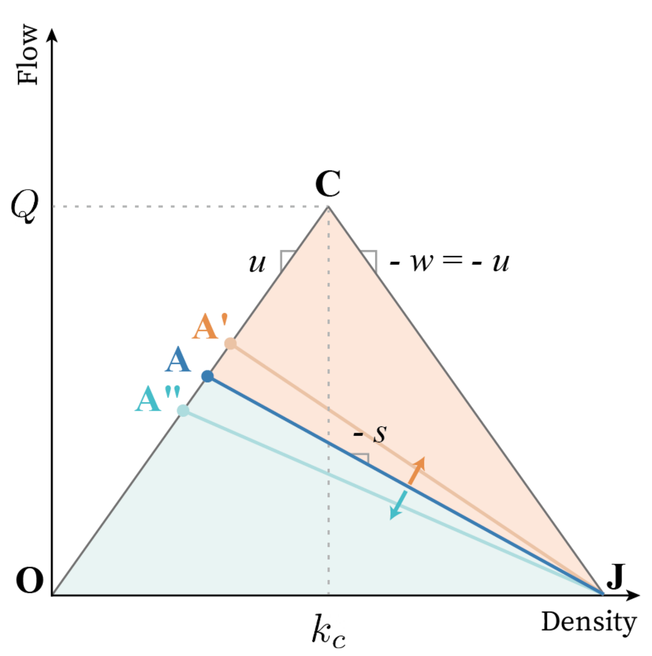
- LD bias: the bias between the link MFD and loop detector (LD)-MFD
- Subset bias: the bias between position-based subsets of LD-MFD

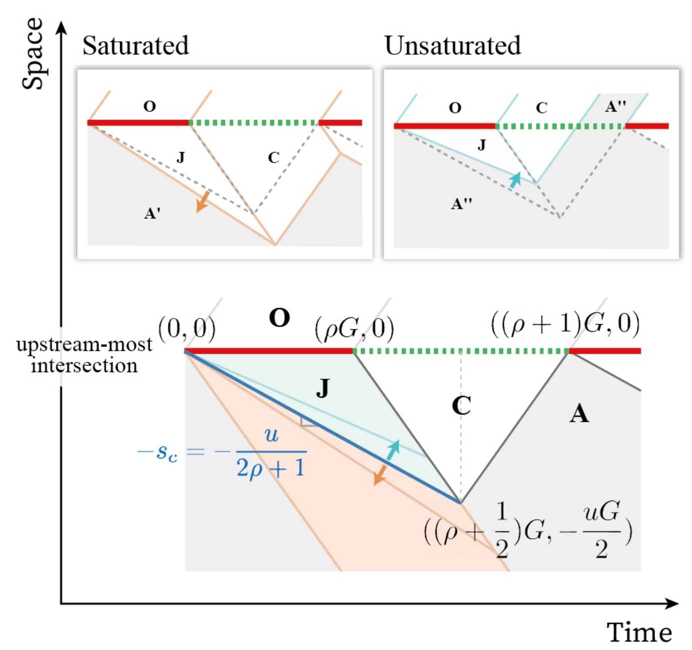
➢ Objectives

- Analytically investigate the condition and the extent of the LD-bias and subset bias occurrence in a corridor.
- Empirically analyze the characteristics of loop detector position that generate subset bias.
- Simulate the impact of different network topology on the biases.

Analytical Corridor Approximation

➢ To analyze LD bias and subset bias, we assume a homogeneous corridor that obeys a symmetric triangular fundamental diagram (FD)





➢ Three types of time-space diagrams under saturated condition

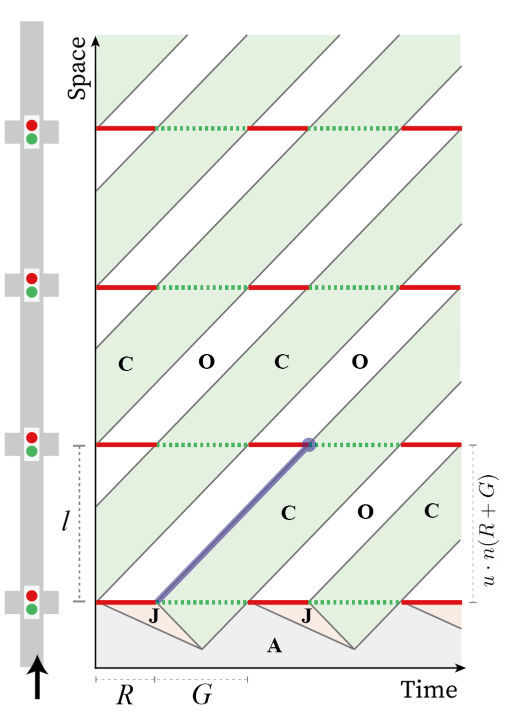
❖ Case 1: No queues $\lambda = 2n(\rho+1)$

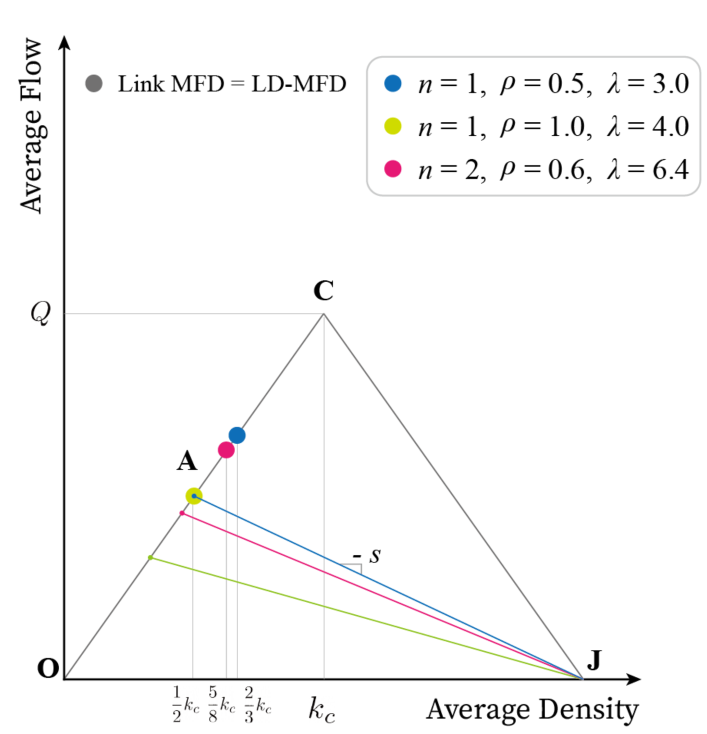
MFD: $\frac{1}{1+\rho}k_c$

- No LD bias
- No subset bias

Note that average flow of MFD is identical in all cases with $\frac{1}{1+\rho}Q$

Where, n is a ceiling of time in unit of cycle length for 1st vehicle in green arrives at next intersection, $\lambda = \frac{\ell G}{2u}$, $\rho = \frac{R}{G}$





❖ Case 2: Jam exists & Finite Voids $2n(\rho+1) < \lambda \le 2n(\rho+1)+2$

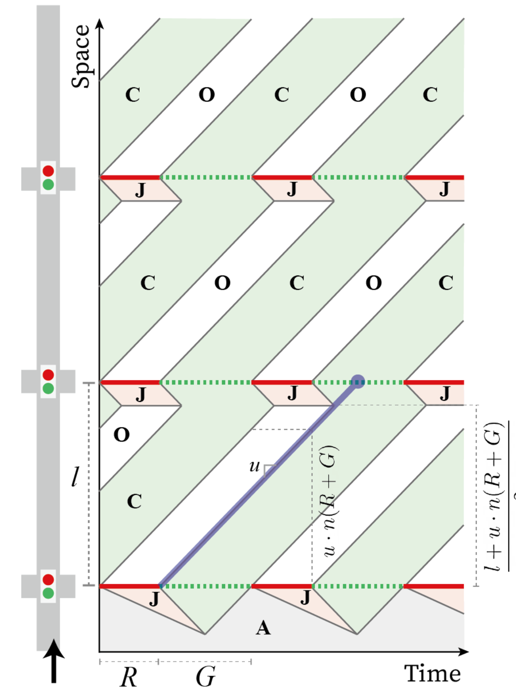
Link MFD: $\left(1-\frac{2\rho n}{\lambda}\right)k_c$

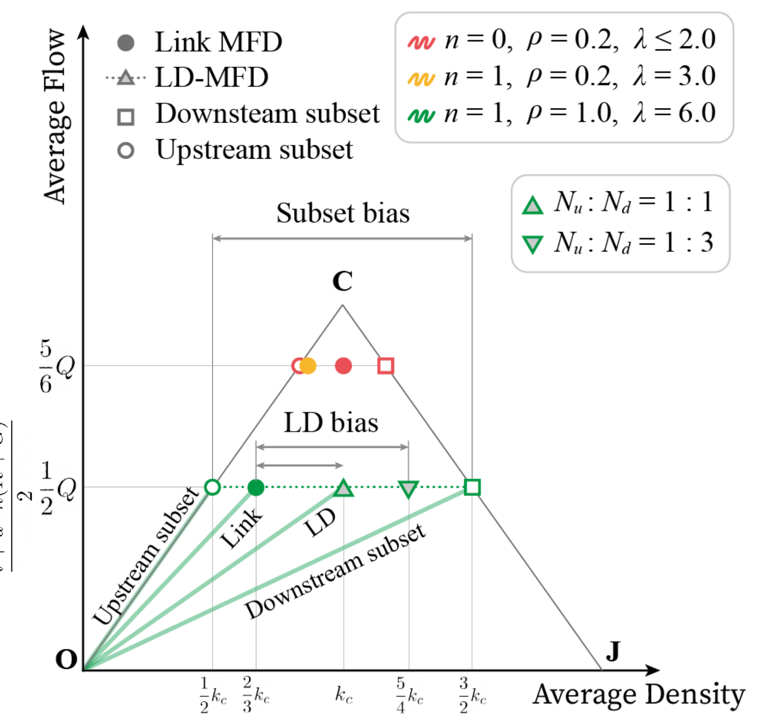
LD-MFD: $\frac{1}{1+\rho}\left(1+\frac{2\rho\cdot N_d}{N_u+N_d}\right)k_c$

Downstr. subset: $\frac{1+2\rho}{1+\rho}k_c$

Upstream subset: $\frac{1}{1+\rho}k_c$

Subset bias: $\frac{2\rho}{1+\rho}k_c$





❖ Case 3: Jam exists & Infinite Voids $2n(\rho+1)+2 < \lambda \le 2(n+1)(\rho+1)$

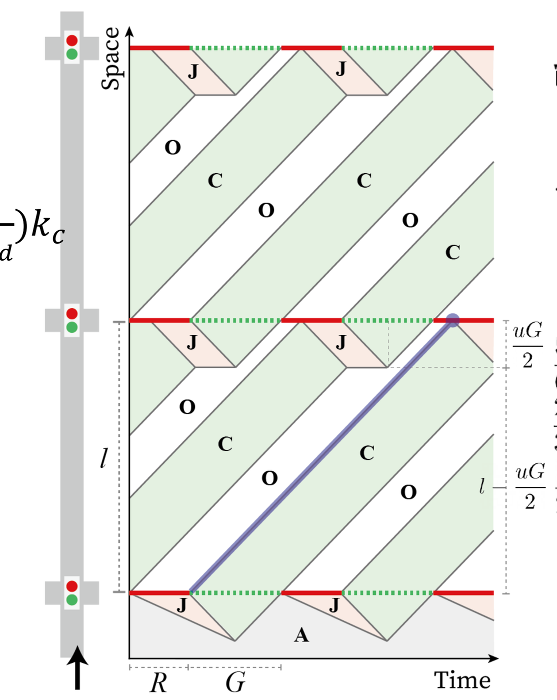
Link MFD: $\frac{2(n+1)}{\lambda}k_c$

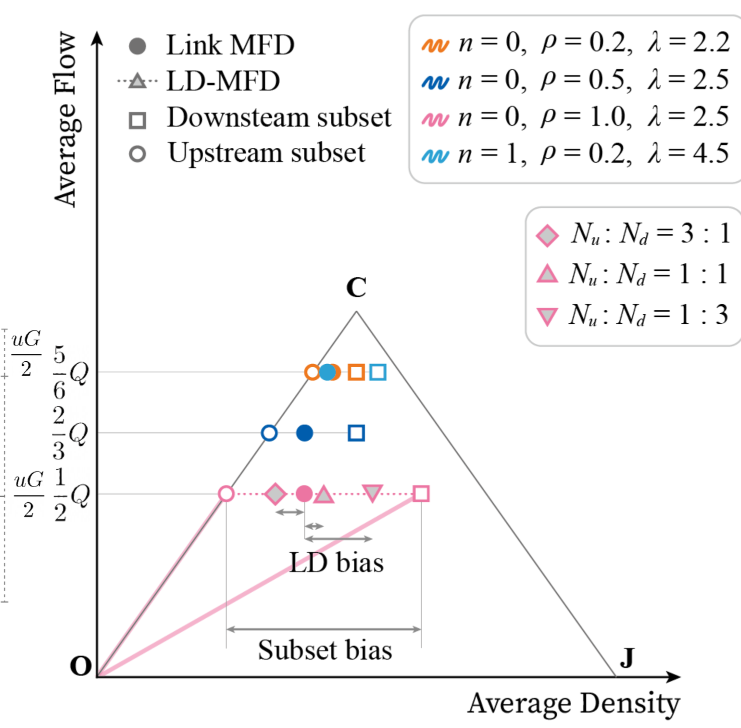
LD-MFD: $\left(\frac{1}{1+\rho}+\left(n+1-\frac{\lambda}{2(1+\rho)}\right)\frac{2N_d}{N_u+N_d}\right)k_c$

Downstr. subset: $\left(\frac{1-\lambda}{1+\rho}+2(n+1)\right)k_c$

Upstream subset: $\frac{1}{1+\rho}k_c$

Subset bias: $\left(2(n+1)-\frac{\lambda}{1+\rho}\right)k_c$



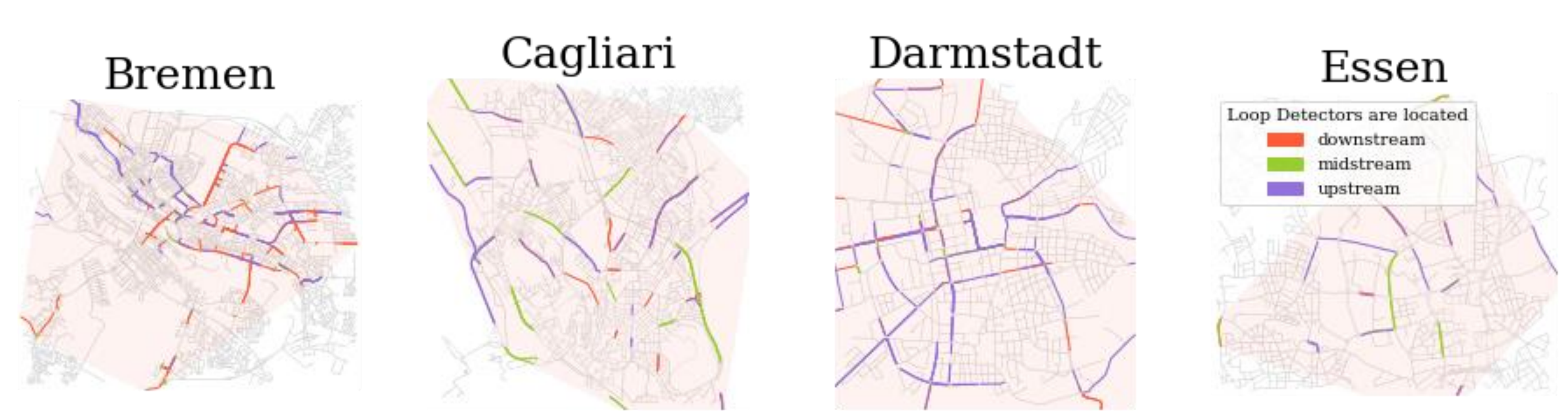


- Subset bias = Range to which LD-MFDs can exist = Max amount of LD bias
- Subset bias is inevitable unless the traffic signal system:
  - (i) is perfect that never forms queue (Case1)
  - (ii) has negligibly small red time under Case 2
  - (iii) satisfies diminutive $2(n+1)-\lambda/((1+\rho))$ under Case 3

Empirical Data Analysis

➢ Existence of LD bias and subset bias in empirical data from UTD-19

➢ The distribution of loop detector positions varies by city: e.g,



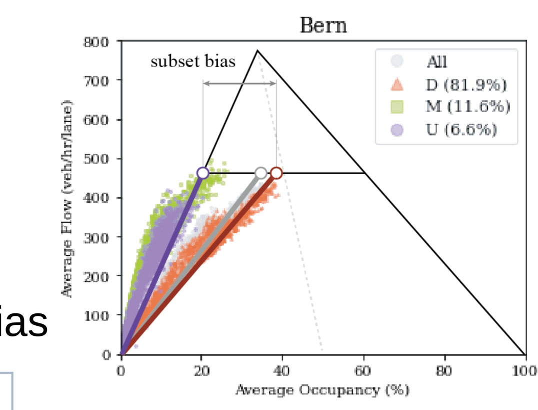
➢ Position-based subsets of MFD

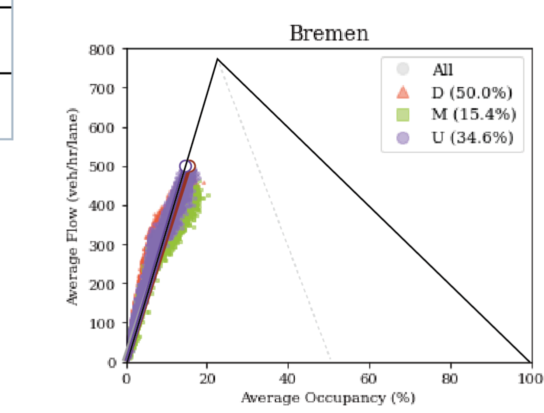
- Different slopes vs. Same slope
- Subset bias is not always extant
- Cities with no subset bias = no LD-bias

➢ Logistic regression – find variables to explain subset bias

Variables	Coeff.	Std.Err	p-val.
Mean of Relative Position	-0.087	0.042	0.040
Std. Dev. of Relative Position	0.170	0.075	0.023

- Rel. Pos. = distance to downstream signal ÷ link length
- Odds ratio: $e^{-0.087}$= 0.92 and $e^{0.170}$ = 1.19
- If LDs are mostly located downstream and have a large variation, subset MFDs are more likely to have different free-flow branch slope



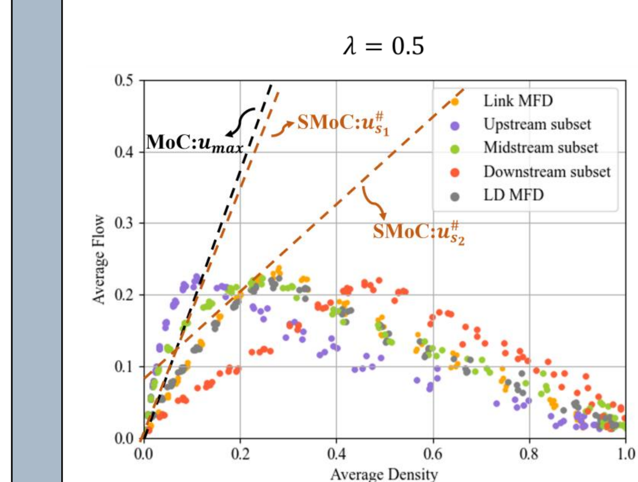


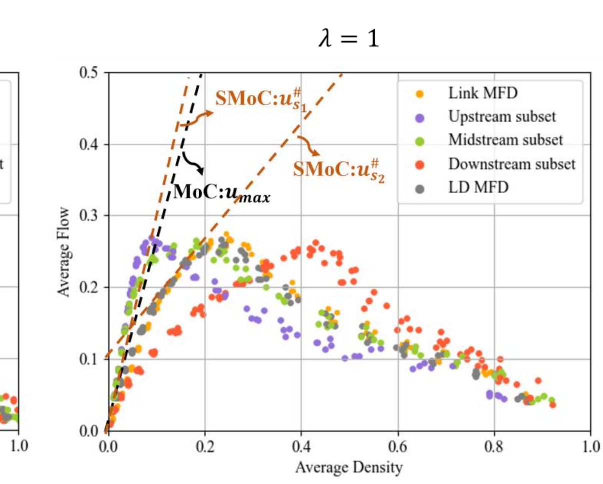
Simulation

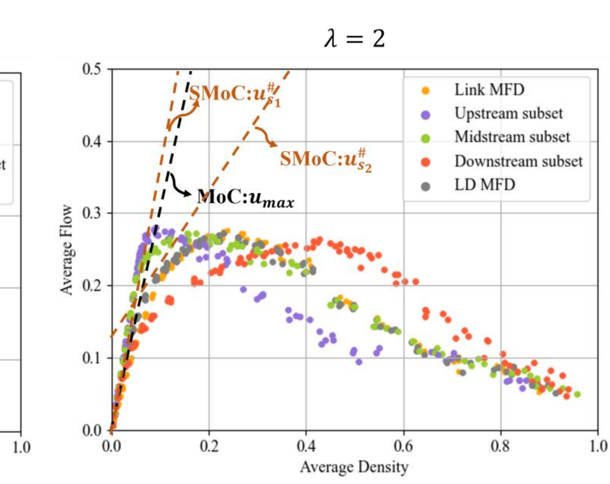
➢ Investigate the effect of network parameters λ on the subset bias

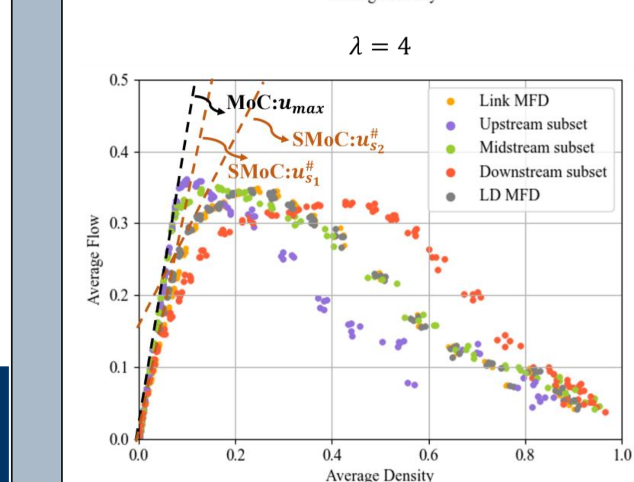
➢ SUMO, 10 × 10 grid, one lane per direction, two-phase signal

As λ increases, (1) Max. avg. flow increases (2) MFDs approach to upstream subset (3) Smaller subset bias (4) $u_{\gamma_{max}}$ approaches free-flow speed $u_f = 54$









Variables		$\lambda = 0.5$	$\lambda = 1$	$\lambda = 2$	$\lambda = 4$
MoC	γ_{max}	9	5	3	2
	$u_{\gamma_{max}}$ (km/h)	**27**	**32.04**	**38.16**	**51.84**
	$u_{\gamma_{max}}$ (normalized)	2.15	2.55	3.04	4.13
SMoC	c	1	0.5	0.25	0.125
	$u^{\#}_{s_1}$	2	2.67	3.2	3.55
	$u^{\#}_{s_2}$	0.6	0.83	1.125	1.42

Main Findings

- Analytical approach based on KW theory explained the impact of LD position under saturated condition – LD bias and subset bias
- Logistic regression model based on empirical data provided variables that are significant to the occurrence of bias
- Simulation results indicated that the network parameter λ plays a key role in the bias magnitude
- Opened the possibility of LD-MFD correction method