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Comparative Analysis of Empirical Capacities between Freeways with Different Types of High-Occupancy Vehicle (HOV) Access Control

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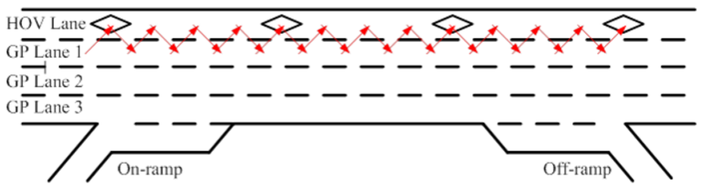
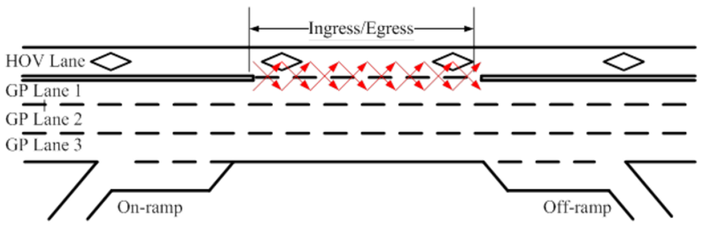
Introduction

It is generally accepted that HOV facilities can increase the passenger-carrying capability of roadway networks by providing incentives for travelers to carpool or use transit services. Such traveling mode shift may essentially help metropolitan areas address their needs for improved mobility and productivity, while also being sensitive to environmental issues and quality of life.

Compared with any other state in U.S., California has the most extensive network of HOV facilities which consist of two major types of access control: continuous-access vs. limited-access ***[Figure 1]***. The goal of this study is to set up a framework to compare the mobility performance (e.g., capacity) of different HOV facilities (see ***[Table 1]*** for the list) in the statistical context, which is useful for the planning, design and operation of HOV facilities.



(a) Continuous-access HOV facility



(b) Limited-access HOV facility

Figure 1. Two major types of HOV facilities in California.

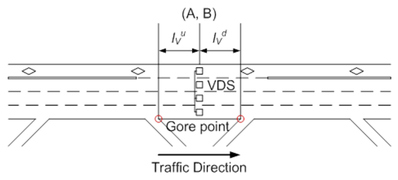
Table 1. List of HOV Facilities within the Scope of this Study

HOV Type	Corridor	District	County	Study Boundary*		Length** (mile)	No. of VDS Covered
				Start	End		
Continuous-access	I-80 W/E	4	ALA	5.3	15.3	10.0	49
	US-101 N/S	4	SCL	367.3	401.8	34.5	114
	I-680 N/S	4	CC	31.4	43.3	11.9	66
	I-880 N	4	ALA	10.5	30.3	19.8	38
	I-215 N/S	8	RIV	29.2	37.4	8.2	23
	SR-22 W/E	12	ORA	1.5	13.5	12.0	137
	SR-55 N/S	12	ORA	12.0	18.0	6.0	41
Limited-access	SR-14 N/S	7	LA	0.0	18.5	18.5	32
	I-105 W/E	7	LA	1.2	16.9	15.7	134
	I-210 E	7	LA	24.8	39.9	15.1	43
	I-405 S	7	LA	36.7	46.0	9.3	45
	I-10 W/E	8	SBD	47.3	57.3	10.0	70
	SR-60 W/E	8	RIV/SBD	30.8	56.8	26.0	93
	SR-71 N/S	8	SBD	5.3	13.2	7.9	38
	SR-91 W/E	8	RIV	37.3	59.0	21.7	135
	I-210 W/E	8	SBD	52.5	67.4	14.9	74
	I-5N/S	12	ORA	79.2	101.2	22	183
	I-405 N/S	12	ORA	0.0	24.0	24	224
	SR-55 N	12	ORA	6.0	12.0	6	34
	SR-57 S	12	ORA	0.5	12.0	11.5	52
Total	35	—	—	—	—	548.3	1625

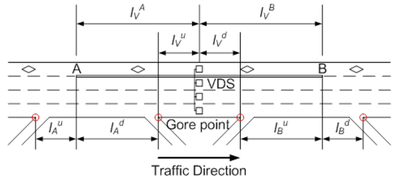
* Using absolute post-mile
** For each directional corridor

Data Sources and Processing

- **Major Data Sources**
  1. PeMS for VDS-based operational performance (e.g., capacity); and
  2. HSIS for geometric feature extraction (***[Figure 2 & Table 2]***)
- **Capacity Estimation Methods**
  1. PeMS (i.e., maximum 5-min sustainable flow over 15 min); and
  2. Max-flow (i.e., maximum 5-min flow)
- **Data Preprocessing**
  1. Erroneous data sample identification (***[Figure 3]***)
  2. Problematic data sample cleaning: imputation, correction and removal
  3. Pearson product-moment correlation analysis (linear)



(a) VDS within ingress/egress area

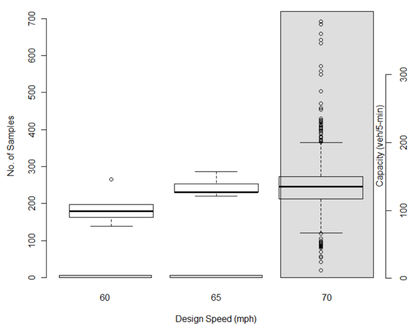


(a) VDS within barrier

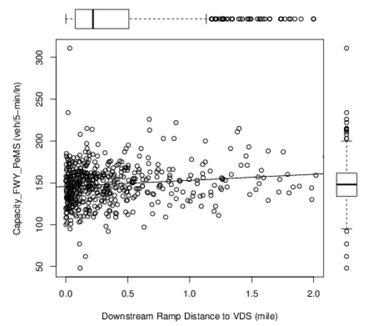
Figure 2. Illustration of geometric information related to VDS location.

Table 2. List of Explanatory Variables in Regression

i	x_i	Unit
0	Intercept	—
1	HOV access type indicator (0 – continuous, 1 – limited)	
2	Distance between VDS and Point A	mi
3	Distance between VDS and Point B	mi
4	Number of Lanes	—
5	Outer shoulder width	ft
6	Average width per lane	ft
7	Inner shoulder width	ft
8	Type indicator of upstream ramp w.r.t. VDS (0 – off, 1 – on)	—
9	Distance to upstream ramp w.r.t. VDS	mi
10	Type indicator of downstream ramp w.r.t. VDS (0 – off, 1 – on)	—
11	Distance to downstream ramp w.r.t. VDS	mi
12	District indicator of District 7	—
13	District indicator of District 8	
14	District indicator of District 12	
15	Truck proportion at capacity	—
16	VDS occupancy at capacity	—



(a) Combined histogram and box-plot



(b) Combined scatter plot and box-plot

Figure 3. Example tools for exploratory data analysis (EDA)

Regression Models and Results

- **Multiple Linear Regression or MLR** (***[Table 3]***)

$$y_i = \sum_k \beta_k \cdot x_{i,k} + \varepsilon_i$$

- **Robust Multiple Linear Regression or R-MLR** (***[Table 3]***)

$$f_H(e) = \begin{cases} e^2/2, & |e| \le k \\ k|e| - k^2/2, & |e| > k \end{cases}, \text{ and } \omega_H(e) = \begin{cases} 1, & |e| \le k \\ k/|e|, & |e| > k \end{cases}$$

- **Linear Mixed Effect (LME) Model** (***[Table 4]***)

$$y(i,j) = \sum_k \beta_k \cdot x_k(i,j) + \sum_k b_k(i) \cdot z_k(i,j) + \varepsilon(i,j)$$

Table 3. Regression Coefficients for Overall Capacity in MLR and R-MLR Analysis

*i**	MLR				R-MLR	
	PeMS		Max-flow		PeMS	Max-flow
	β_i	P-Value	β_i	P-Value	β_i	β_i
0	-49.31	0.594	**-271.50**	0.039	-41.00	**-238.88**
1	**48.58**	0.008	**94.69**	3.0E-04	**48.45**	**88.04**
2	1.89	0.829	0.85	0.946	-1.75	5.80
3	7.26	0.420	16.77	0.192	-1.30	12.51
4	**121.32**	< 2E-16	**162.86**	< 2E-16	**123.17**	**153.53**
5	3.10	0.431	11.01	0.051	2.81	13.08
6	2.97	0.542	0.52	0.940	2.40	0.21
7	**-3.68**	0.006	**-3.90**	0.040	**-3.16**	**-4.37**
8	-0.68	0.949	15.22	0.310	-2.72	7.89
9	0.78	0.827	-2.38	0.638	-2.68	-3.80
10	-15.79	0.117	-6.14	0.669	-15.48	-7.99
11	3.27	0.318	1.69	0.718	3.98	4.86
12	-30.15	0.195	**-114.99**	6.0E-04	-27.29	**-115.60**
13	**-49.59**	0.028	**-111.78**	5.3E-04	**-45.12**	**-106.87**
14	**110.46**	1.3E-09	**280.96**	< 2E-16	**106.16**	**282.04**
15	-96.67	0.445	-161.51	0.370	-68.14	-207.62
16	**710.14**	7.6E-10	**1177.38**	9.2E-12	**686.87**	**1226.85**
Degree of Freedom	513		513		513	513
Residual Standard Error	102.2		145.8		90.40	102.4
Multiple R-Squared	0.725		0.790		—	—
Adjusted R-Squared	0.717		0.784		—	—
F-Statistic P-Value	< 2.2E-16		< 2.2E-16		—	—

Variables in bold-face are statistically significant at 5% α-level
* *Refer to Table 2 for the description of each index i*

Table 4. Regression Coefficients for LME Model on Overall Capacity (District Effect)

Effect Type	*i*	x_i	PeMS Method		Max-flow Method	
			Estimate	t-Value	Estimate	t-Value
Random Effects*	**0**	**Intercept for D4 data**	-52.92	—	-273.98	—
		Intercept for D7 data	-80.65	—	-386.47	—
		Intercept for D8 data	-99.97	—	-383.82	—
		Intercept for D12 data	56.31	—	6.00	—
Fixed Effects	**1**	**HOV access type**	**47.97**	2.660	**94.18**	3.638
	…	…	…	…	…	…

* *ANOVA shows variance between Districts is statistically significant (see our paper for details)*

Conclusions and Future Work

- A statistical framework is developed to compare the mobility performance of different types of HOV facilities, which can be applied to other similar analyses for managed lanes.
- Three linear regression models indicate that a freeway segment with limited-access HOV lane would have higher overall capacity than that of a continuous-access HOV lane, given that everything else being identical.
- District effects are statistically significant for HOV facility capacity in California.
- An on-going project is to develop and evaluate an alternative HOV facility type, called partially limited access HOV lane, by formulating into a dynamic multi-commodity traffic assignment problem based on the Link-Node Cell Transmission Model (LNCTM).

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