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Volume Delay Function Review

RTM Stakeholders Meeting – October 28, 2019

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Agenda

- Literature Review
- Process
- Exploratory Analysis Results
- Findings

Introduction

- Volume-Delay Functions (VDF) maps link-level relationship between vehicle demand and travel time in the auto assignment module
- Due to past data limitation, the current RTM VDFs
  - Have not been validated against a comprehensive set of observed data
- This review uses newly available data sources to
  - Compare the performance of current VDF parameters
  - Compare the performance of standard alternative VDF forms (equations)
    - BPR, Akcelik, Modified Davidson, Conical

Literature Review

Literature Review

Stevens, Barkley, Miller 2

ABSTRACT

Volume delay functions (VDFs) estimate travel speed based on volume, free flow speed, and capacity and help planners examine how route selection, mode choice, fuel economy, and other elements of transportation performance are affected by congestion. Although VDF calibration has garnered interest, determining why agencies should improve VDFs has received less attention. Using 2 years of observations at 8 interstate locations, the researchers quantified how site-specific data improve the accuracy of the Bureau of Public Roads (BPR), Akcelik, and conical VDFs and how this accuracy affects planning.

The results showed that using site-specific data to calibrate VDFs (compared to taking parameters and variables from the literature) improved mean absolute percent error by an average value of 20 percentage points and reduced the root mean squared error by 46%, from 16.7 to 9.0 mph. However, the impact of such site-specific data on accuracy varied by VDF: it was greatest for the BPR VDF (improved error by 8.6 mph relative to taking values from the literature) but less for the conical VDF (reducing erro… VDF selection depends on the availability of local da… but given a specific level of available local data, a sig… identified. Two case studies from the literature show… the literature can, at least for the particular sketch pla… forecast fuel economy by 1.8%-14.0% and change fo… percentage points.

Keywords: Travel Demand Forecasting, Trip Assignm… Functions

TRB 2017 Annual Meeting

Development of Speed Model… Improving Travel Forecastin… Highway Performance Evalu…

Final Report

Project No. BDK83 Task Work Order N…

by

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December 2013

Bottleneck and Queuing Analysis

Calibrating Volume–Delay Functions of Travel Demand Models

Leta F. Huntsinger and Nagui M. Rouphail

This paper discusses the link performance functions used in travel demand models with a focus on the strengths and weaknesses of the most commonly used volume–delay functions. These include the Bureau of Public Roads function, the conical delay function, *Highway Capacity Manual* procedures, and the Akcelik function. Improvements to the volume–delay functions used in travel demand models are of particular importance in light of the increased emphasis on reliable speed outputs to support air quality initiatives, improved accessibility measures for various submodels, and the desire to evaluate a broader range of policy issues. One of the key challenges that analysts face in the development of locally calibrated volume–delay functions is how best to represent the regime in which the volume—or, more aptly stated, the demand—exceeds capacity, a regime that cannot be directly observed, even though it is required for highway assignment. This paper explores the use of freeway detector data along with bottleneck and queue analysis as a relatively straightforward approach for estimating demand beyond capacity for fitting locally calibrated volume–delay functions. The results of this study show that bottleneck analysis and queue length estimation are effective means of accomplishing this goal, providing a valuable tool for improving models with locally collected data.

A travel demand model is a series of mathematical models that forecast travel demand for an urban area given a specified set of land use and transportation system inputs. A typical model consists of four basic steps: (*a*) trip generation, (*b*) trip distribution, (*c*) mode choice, and (*d*) highway and transit trip assignment. During the highway trip assignment stage, volume–delay functions (VDFs) are used to account for the effects of congestion on the highway network. These functions use link attributes such as capacity, free-flow speed, and travel demand to estimate speeds under congested conditions. Highway assignment calibration has historically focused on the comparison of link trips with traffic counts, with little emphasis being placed on the resulting speeds, which was an acceptable approach for earlier applications. However, reasonable speed outputs are a growing concern as travel demand models are increasingly used for a broader range of applications and policy testing. Reasonable speeds are necessary for air quality analysis, to achieve consistency in modeling practices through the use of accessibility measures and feedback loops, and because of the increased emphasis on the analysis of nontraditional solutions to capacity problems through travel demand management (*1*).

Even with the increased emphasis on estimation of reliable speeds from the model, it appears from the literature that common practice is to use one of the standard functions readily available in the travel demand modeling software. A recent exchange on the Travel Model Improvement Program listserv focused on this topic. This discus…

MOTIVATION

LIMITATIONS

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Transportation Research Record: Journal of the Transportation Research Board, No. 2255, Transportation Research Board of the National Academies, Washington, D.C., 2011, pp. 117–124.
DOI: 10.3141/2255-13

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Hindawi
Journal of Advanced Transportation
Volume 2017, Article ID 4629792, 10 pages
https://doi.org/10.1155/2017/4629792

WILEY Hindawi

Research Article

Estimating Macroscopic Volume Delay Functions with the Traffic Density Derived from Measured Speeds and Flows

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Received 25 July 2016; Revised 12 January 2017; Accepted 5 February 2017; Published 26 February 2017

Academic Editor: Alexandre G. De Barros

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This paper proposes a new method to estimate the macroscopic volume delay function (VDF) from the point speed-flow measures. Contrary to typical VDF estimation methods it allows estimating speeds also for hypercritical traffic conditions, when both speeds and flow drop due to congestion (high density of traffic flow). We employ the well-known hydrodynamic relation of fundamental diagram to derive the so-called quasi-density from measured time-mean speeds and flows. This allows formulating the VDF estimation problem with a speed being monotonically decreasing function of quasi-density with a shape resembling the typical VDF like BPR. This way we can use the actually observed speeds and propose the macroscopic VDF realistically reproducing actual speeds also for hypercritical conditions. The proposed method is illustrated with half-year measurements from the induction loop system in city of Warsaw, which measured traffic flows and instantaneous speeds of over 5 million vehicles. Although the proposed method does not overcome the fundamental limitations of static macroscopic traffic models, which cannot represent dynamic traffic phenomena like queue, spillback, wave propagation, capacity drop, and so forth, we managed to improve the VDF goodness-of-fit from R^2 of 27% to 72% most importantly also for hypercritical conditions. Thanks to this traffic congestion in macroscopic traffic models can be reproduced more realistically in line with empirical observations.

1. Introduction

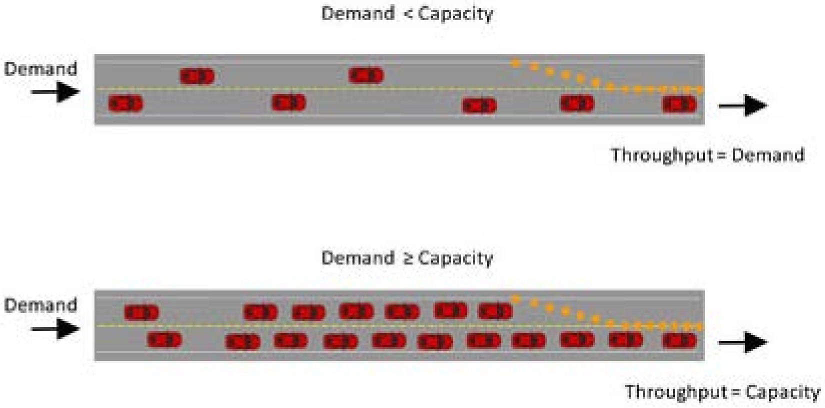
In this paper we will solve the estimation problem where traffic speed is a function of the traffic flow, generically expressed as $v = f(q)$ and further called volume delay function (VDF) or link-congestion function. The solution of the problem is a function which reproduces traffic speeds observed in field measurements. The VDF is commonly applied in static macroscopic traffic assignment to describe the resultant link travel times, as a function of flow (result of assignment) and capacity and free-flow travel time (constant parameters of the link). The purposes of this function are to reproduce congestion effects in the macroscopic model and to serve as an objective function in the assignment problem where the travel times are minimized [1]. The VDF is usually formulated in an easily integrable and differentiable form, since the assignment algorithm searches for the solution by using the integrals of VDF [2]. Unlike the physical representations of the traffic flow, the VDF allows the flow to exceed the capacity (which is by definition impossible within the traffic flow definitions). As a result, the flow volumes used in macroscopic assignment (and in turn in VDF) are not strictly related to the physically measured flows. The macroscopic flow (as we will denote it) is treated more like a demand flow which becomes delayed if it exceeds capacity. We will exploit this distinction in the proposed method.

The VDF shall reproduce both travel times and traffic flows realistically. Usually, the focus is to reproduce the actually observed flow pattern in the network, and it is well known that travel times in macroscopic model are a rough approximation neglecting fundamental traffic phenomena (such as bottlenecks, spillbacks, capacity drop, and gridlocks) which can be handled with dynamic traffic flow models [3]. The relationship between travel delay and flow volume used

Literature Review | Topics

- Derive Demand for Uninterrupted Flow Facilities
- Categorization of Facility Type
- Free-Flow Speed (FFS) and Capacities
- Low Volume Data Sampling

Literature Review | Derive Demand for Uninterrupted Flow Facilities

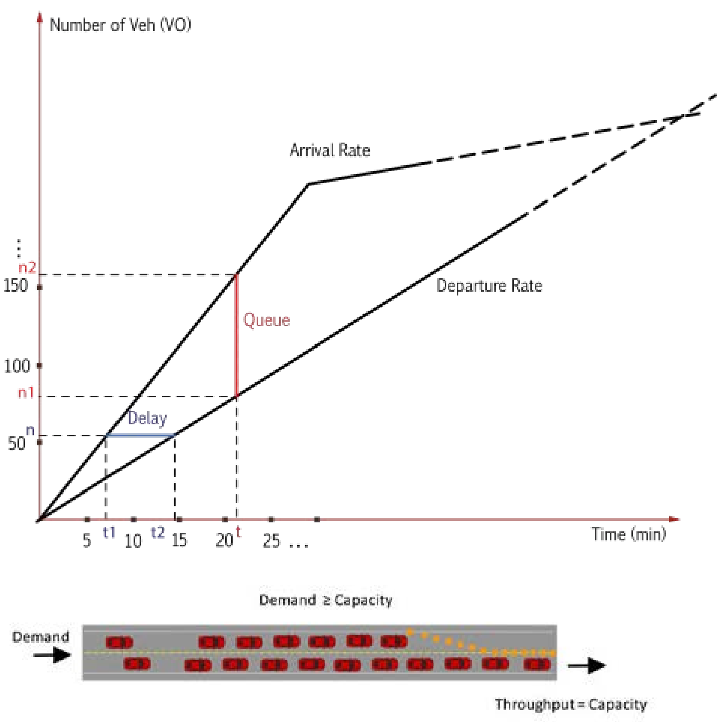


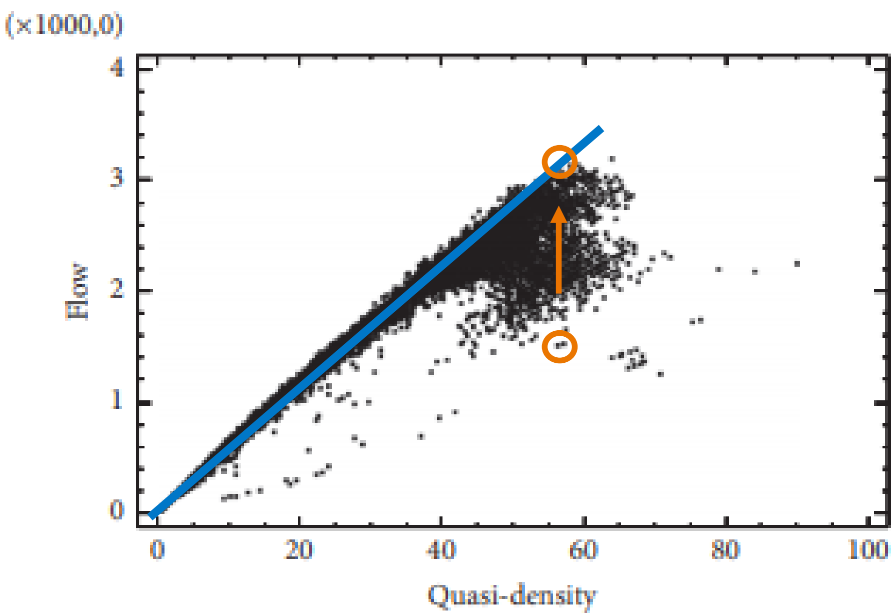
Challenge: Determine demand when it exceeds capacity

- Demand is the volume that would traverse the corridor without any capacity limitations
- Many past studies did not propose credible solutions
- 2 Methods to derive demand from processed volumes:
    1. True demand derived from queuing theory
    2. Estimated demand based on density ratio

Literature Review | Derive Demand for Uninterrupted Flow Facilities

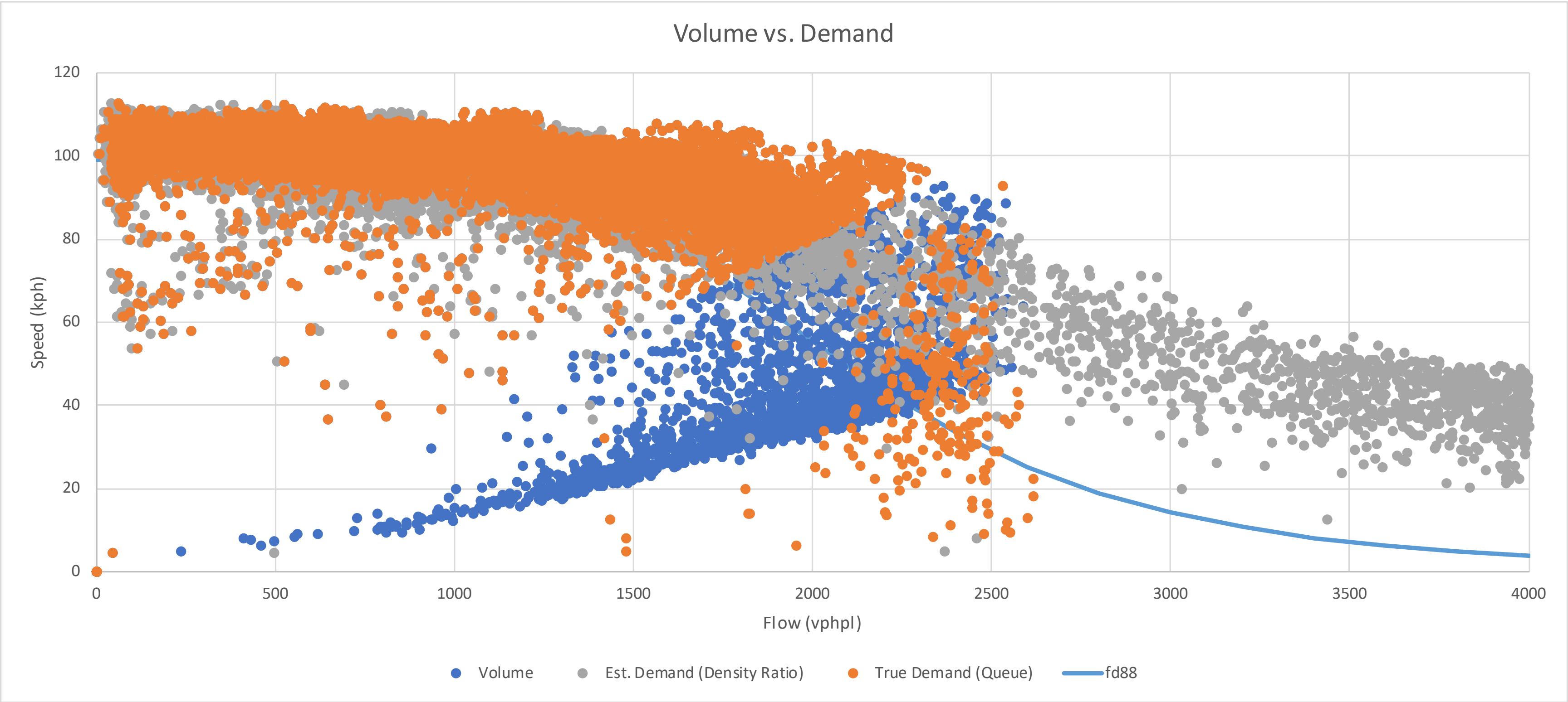
1. True demand derived from queuing theory
2. Estimated demand based on density ratio





$$n_2 = Queue + n_1$$

Literature Review | Derive Demand for Uninterrupted Flow Facilities



- Verdict
  1. True demand derived from queuing theory – most ideal, used whenever possible
  2. Estimated demand based on density ratio – less ideal, only in cases when (1) is not possible

Literature Review | Categorization of Facility Type

- Facility Type Categories
  - Facility Type

Freeway	Highway	HOV Lanes	Arterial	Collector	Local

  - Facility Type and Area Type

Freeway			Highway			HOV Lanes	Arterial	Collector	Local
Urban	Resid.	Rural	Urban	Resid.	Rural				

  - Facility Type and Posted Speed

Freeway			Highway			HOV Lanes			Arterial			Collector			Local		
70	80	90	60	70	80	70	80	90	50	60	70	40	50	60	30	40	50

- Verdict
  - Categorization by Facility Type and Posted Speed

Literature Review | Free-Flow Speed (FFS) and Capacities (CAP)

- Free-Flow Speed and Capacities:

1. Current RTM posted speed and rounded capacities for each directional link (site)

   @posted_speed = 50 kph, vdf 35 = 600 vphpl
   @posted_speed = 40 kph, vdf 45 = 800 vphpl
   @posted_speed = 70 kph, vdf 45 = 800 vphpl
   @posted_speed = 30 kph, vdf 25 = 400 vphpl

2. Group Derived FFS and CAP – derive FFS and CAP for each Facility-Speed category

   FFS = 58 kph, CAP = 627 vphpl
   FFS = 58 kph, CAP = 627 vphpl
   FFS = 58 kph, CAP = 627 vphpl
   FFS = 46 kph, CAP = 542 vphpl

3. Site Derived FFS and CAP – derive FFS and CAP for each directional link (site)

   FFS = 62 kph, CAP = 478 vphpl
   FFS = 74 kph, CAP = 795 vphpl
   FFS = 56 kph, CAP = 947 vphpl
   FFS = 46 kph, CAP = 542 vphpl

- Verdict
  - They are all performed to better understand results

Literature Review | Low Volume Data Sampling

- Low flows and near free-flow speeds are common outside the four peak hours of a weekday (~90% of all 15-min intervals)
- Greater emphasis should be placed on high v/c region
  - High v/c region is harder to get accurate
  - To accurately represent speed and travel times during the peak hours
- Low volume data sampling
  - Equal number of data points for each of the 4 v/c intervals (0.00-0.19, 0.20-0.39, 0.40-0.59, 0.60-0.79)
  - One-half of all data points have v/c < 0.8, one-half of all data points have v/c >= 0.8
- Verdict
  - Low volume data sampling is used during analysis

Process

Process | Data Source

- Uninterrupted
  - BCMOTI Permanent Count Stations
  - Highway 1 Detectors (TI Corp)
- Interrupted
  - Screenline
  - Vancouver
  - Surrey

Process | Data Assembling

- Uninterrupted – Speed & Flow information together (101M rows)
  - BCMOTI Permanent Count Stations
    - 2017 Classified Counts with Speed by Speed Bins
  - Highway 1 Detectors (TI Corp)
    - 2017 Classified Counts with Average and 85th Percentile Speed
- Interrupted – Travel Time & Flow information separate (136M rows)
  - Screenline, Vancouver
    - 2017 Traffic Counts
    - 2017 Google Maps API Travel Times
  - Surrey
    - 2018 Traffic Counts
    - 2018 Oct-Nov Google Maps API Travel Times

Process | GIS Matching

- Uninterrupted – Speed & Flow information together
  - BCMOTI Permanent Count Stations
    - Site and Channels (lane) matching Emme Link
  - Highway 1 Detectors (TI Corp)
    - Site and Channels (lane) matching Emme Link
- Interrupted – Travel Time & Flow information separate
  - Screenline, Vancouver
    1. Traffic Count locations matching Travel Times network
    2. Traffic Count locations matching Emme Link
  - Surrey
    1. Traffic Count locations matching Travel Times network
    2. Traffic Count locations matching Emme Link

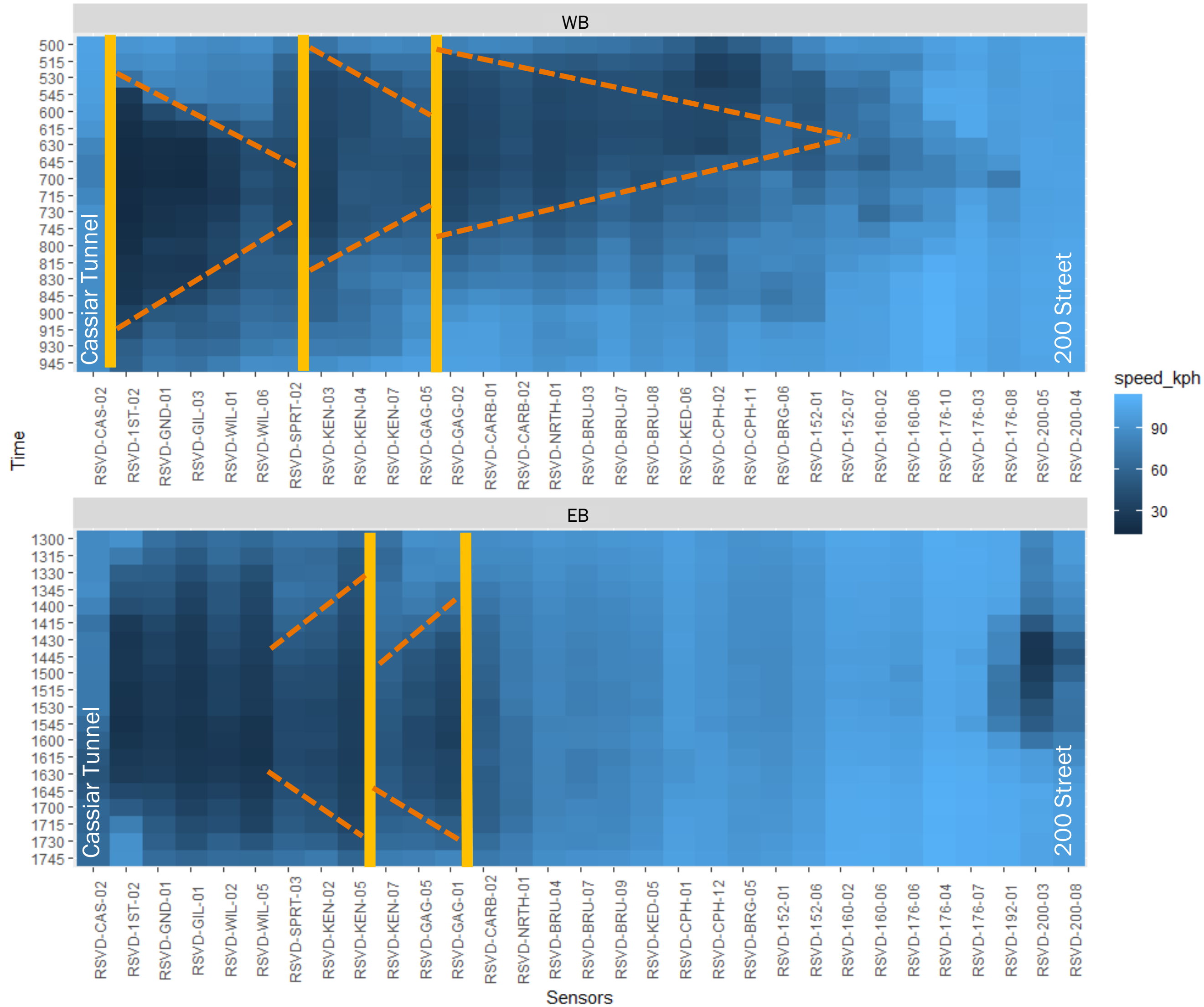
Process | Develop FFS and CAP

- Convert time-mean-speed (TMS) to space-mean-speed (SMS)
- Convert Volumes to Passenger-Car-Equivalents (PCEs)
- Calculate FFS as 85th percentile speed
- Calculate CAP as 99th percentile flow
- Calculate Critical Density (Density at Capacity)

Process | Develop Demand

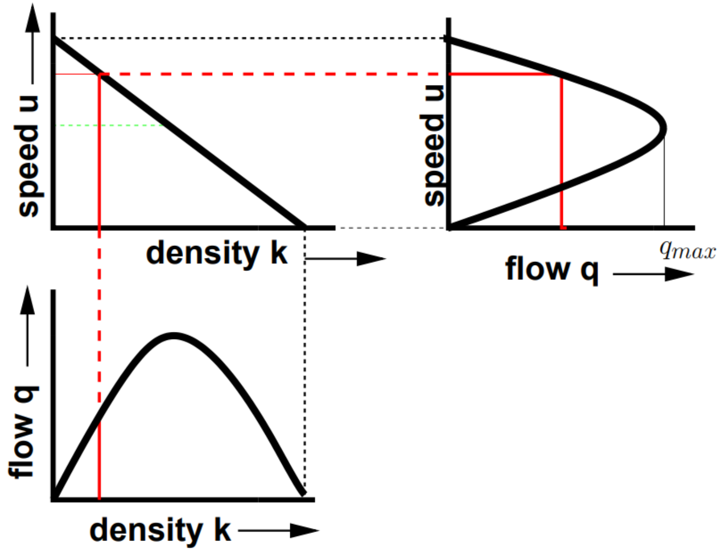
- True demand
  - Highway 1 bottleneck identification
  - Derive queues from densities at upstream detectors
  - Add queues to throughput at bottleneck

Process | Develop Demand



Process | Exploratory Analysis

- For each Facility-Speed Category
  - Low Volume Data Sampling
  - Create the 3 Fundamental Diagrams



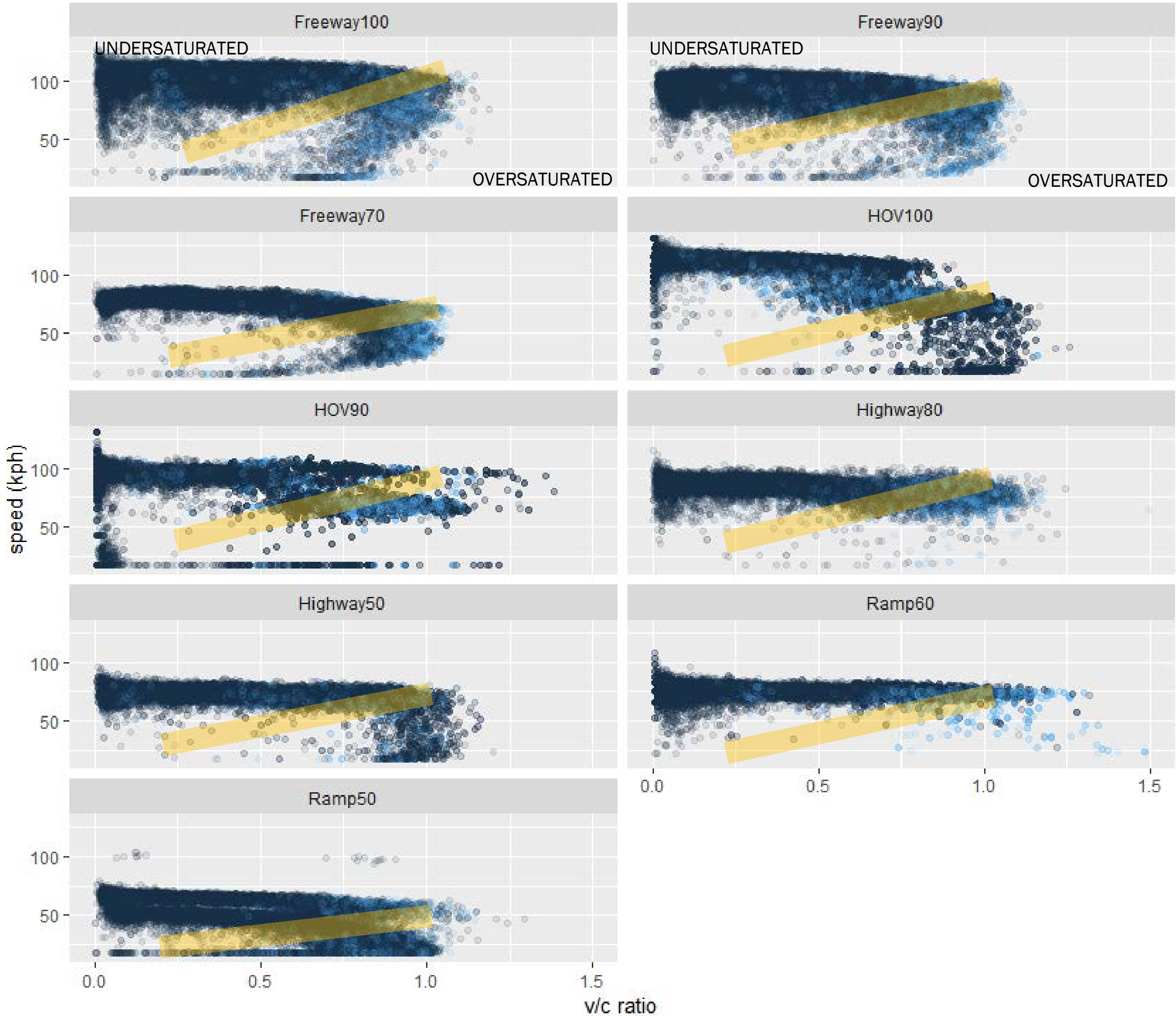
$$Flow = Density * Speed$$
$$q = ku$$

  - Examine data versus RTM VDFs, and standard alternative VDFs
  - Calculate R^2 and RMSE for data versus RTM VDFs, and standard alternative VDFs

Exploratory Analysis Results

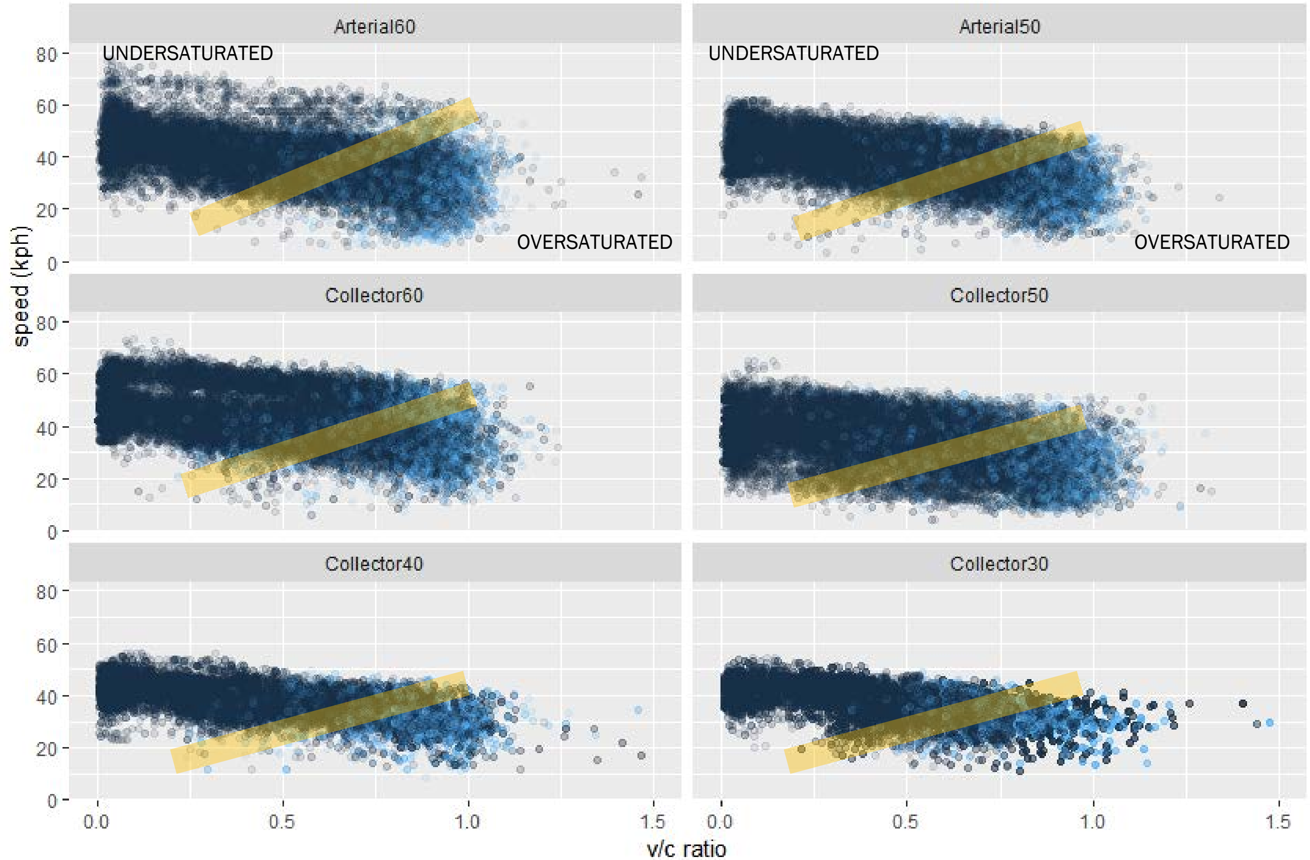
Exploratory Analysis Results | Speed-Flow Diagram Uninterrupted Facility

- Consistent with Fundamental Diagram



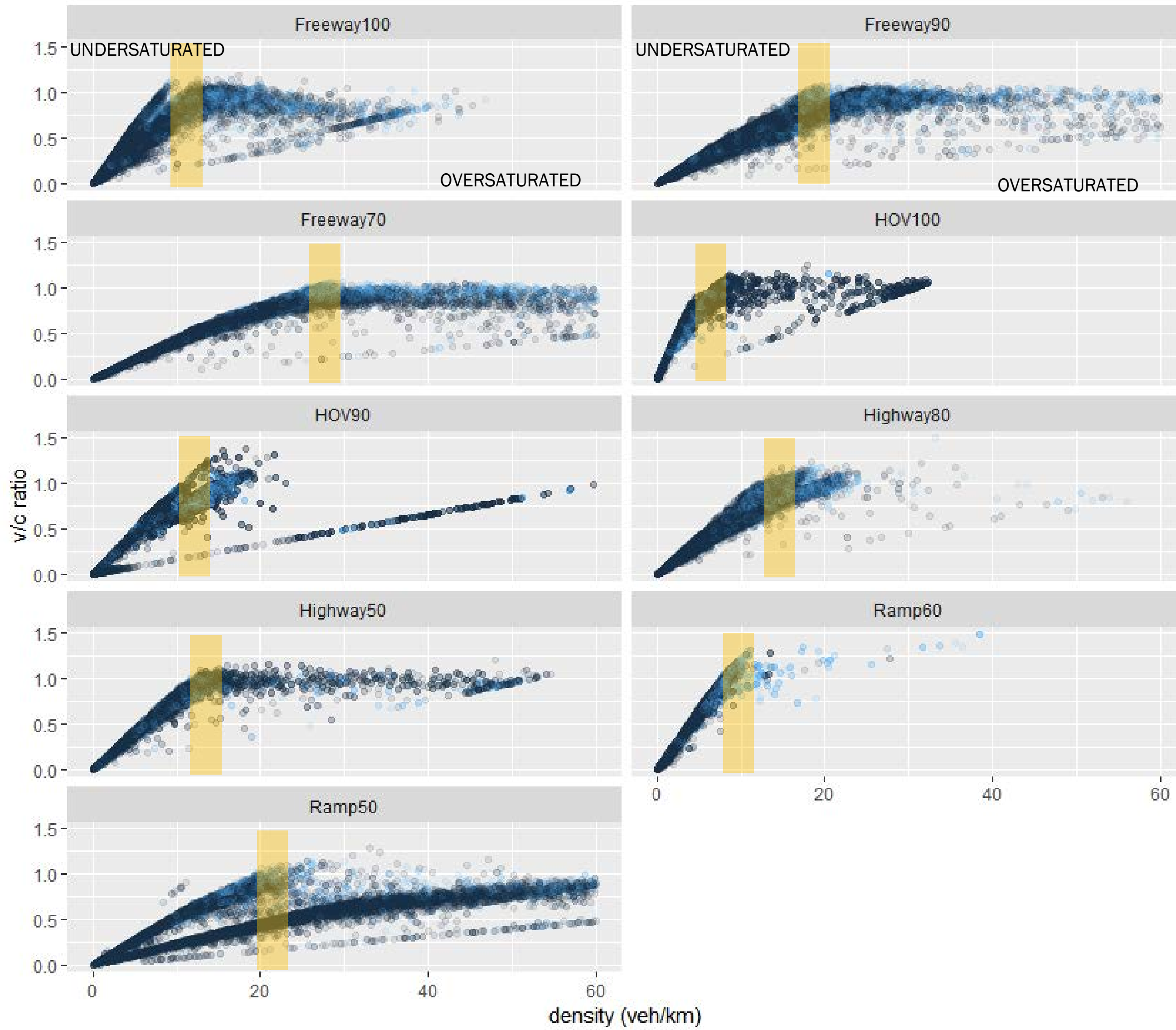
Exploratory Analysis Results | Speed-Flow Diagram Interrupted Facility

- Inconsistent with Fundamental Diagram
- Data Points Scattered and Trend Down (Incur Signal Delays)



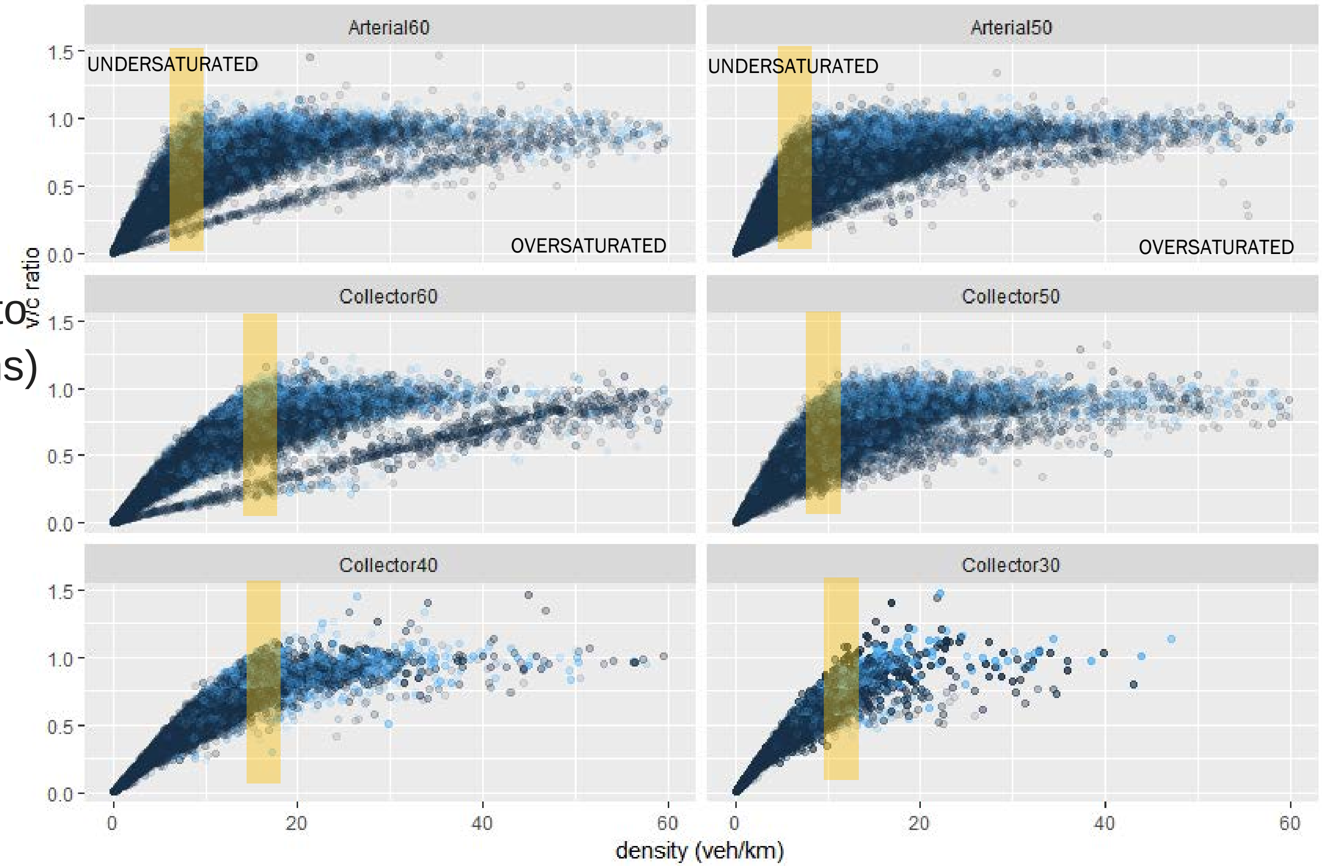
Exploratory Analysis Results | Flow-Density Diagram Uninterrupted Facility

- Consistent with Fundamental Diagram



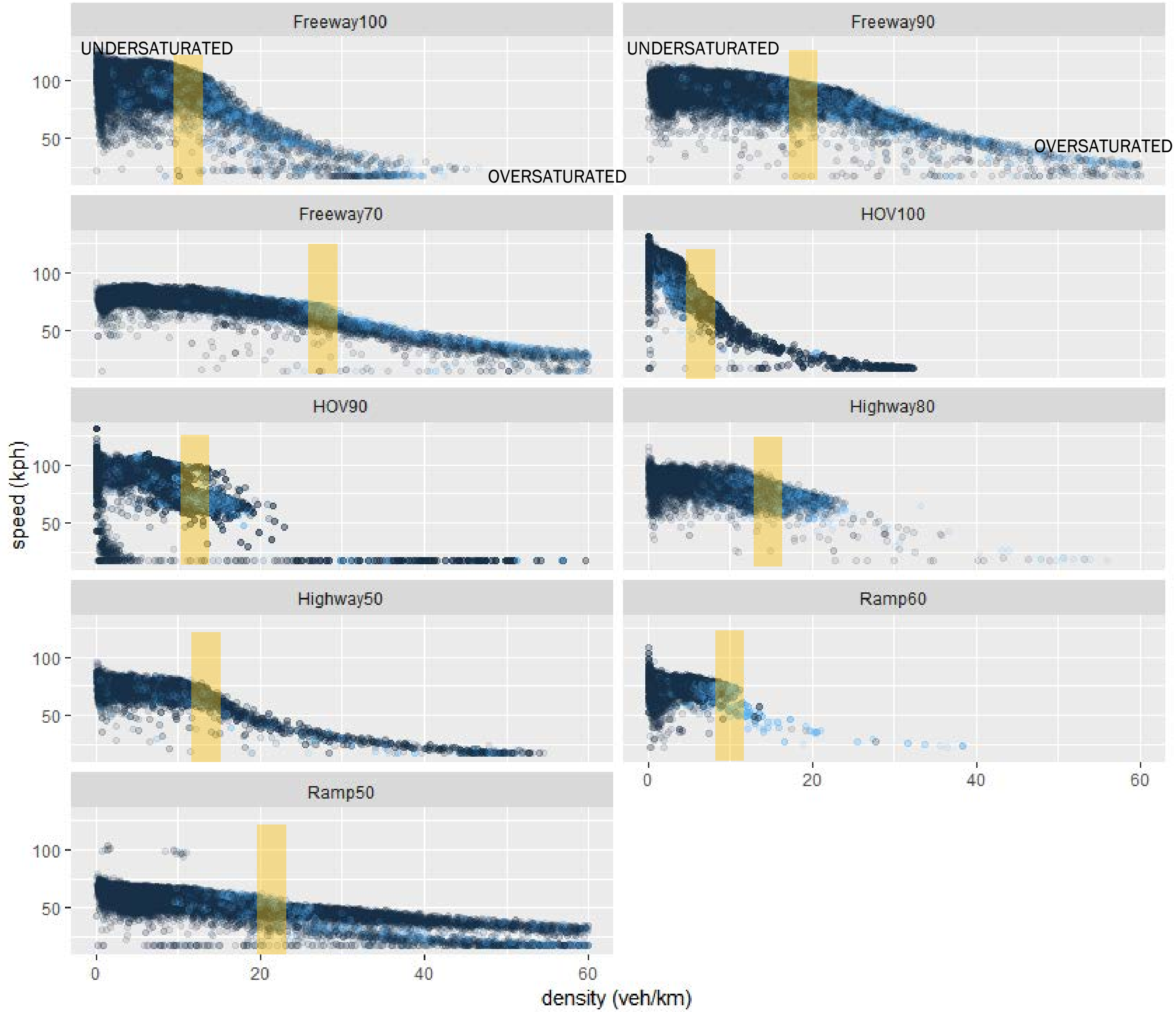
Exploratory Analysis Results | Flow-Density Diagram Interrupted Facility

- Inconsistent with Fundamental Diagram
- Data Points More Spread Out (Due to Signal Interruptions)



Exploratory Analysis Results | Speed-Density Diagram Uninterrupted Facility

- Consistent with Fundamental Diagram



Exploratory Analysis Results | Speed-Density Diagram Interrupted Facility

- Inconsistent with Fundamental Diagram
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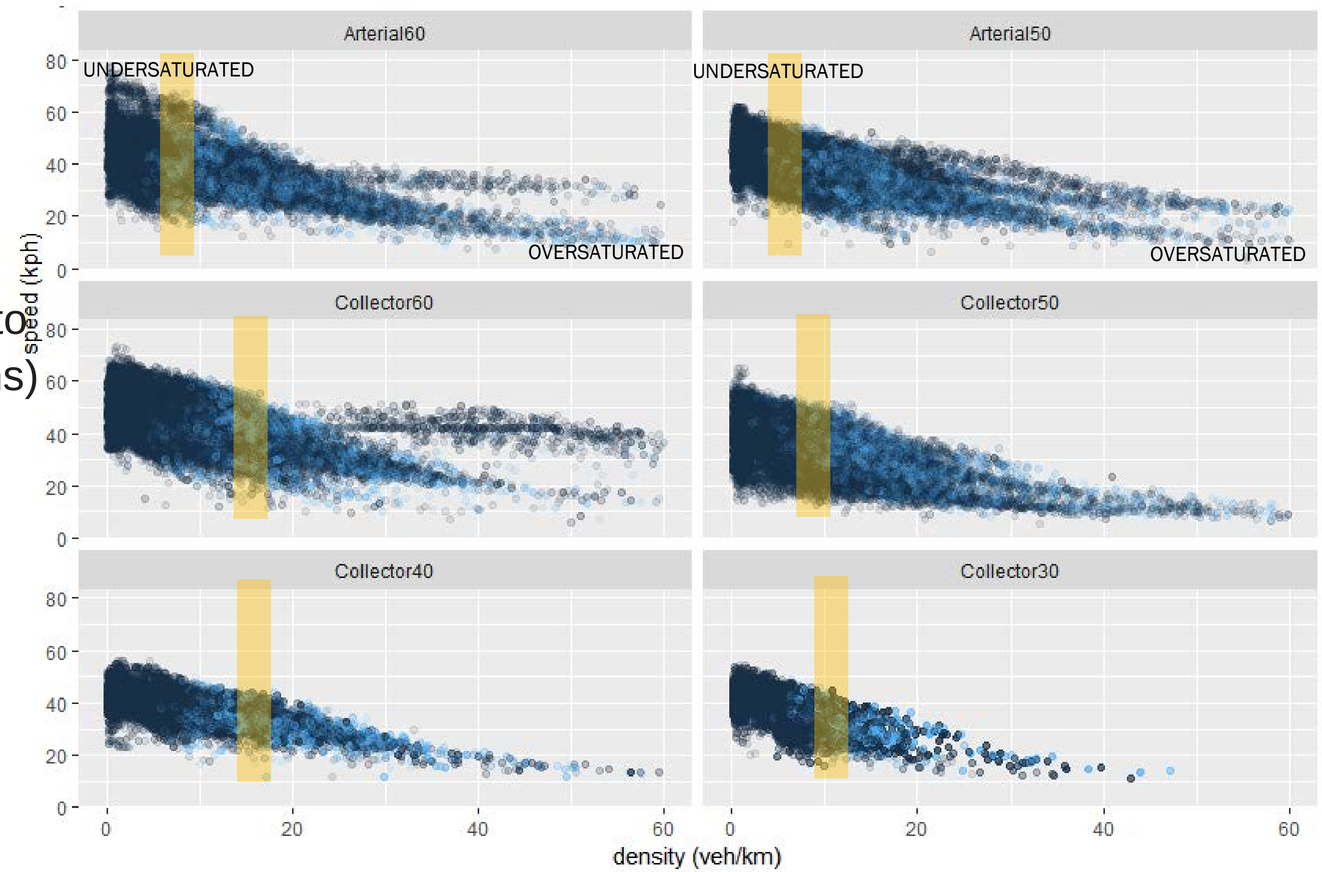


Exploratory Analysis Results | Standard Alternative VDF

BPR

$$u = \frac{u_0}{\left[1.0 + \alpha (x)^\beta\right]}$$

- (Bureau of Public Roads) 1960s
- based on parabolic speed-volume

Conical

$$u = \frac{u_0}{\left[2 + \sqrt{\beta^2 (1-x)^2 + \alpha^2} - \beta (1-x) - \alpha\right]}$$

$$\text{where, } \alpha = \frac{\beta - 0.5}{\beta - 1} \quad \text{and} \quad \beta > 1$$

- Heinz Spiess (INRO) 1990
- based on hyperbolic volume-delay

Modified Davidson

$$u = \begin{cases} \dfrac{u_0}{1 + \dfrac{Jx}{(1-x)}}, & \text{for } x \le \mu \quad (i) \\[2ex] \dfrac{u_0}{1 + \dfrac{J\mu}{(1-\mu)} + \dfrac{J(x-\mu)}{(1-\mu)^2}}, & \text{for } x > \mu \quad (ii) \end{cases}$$

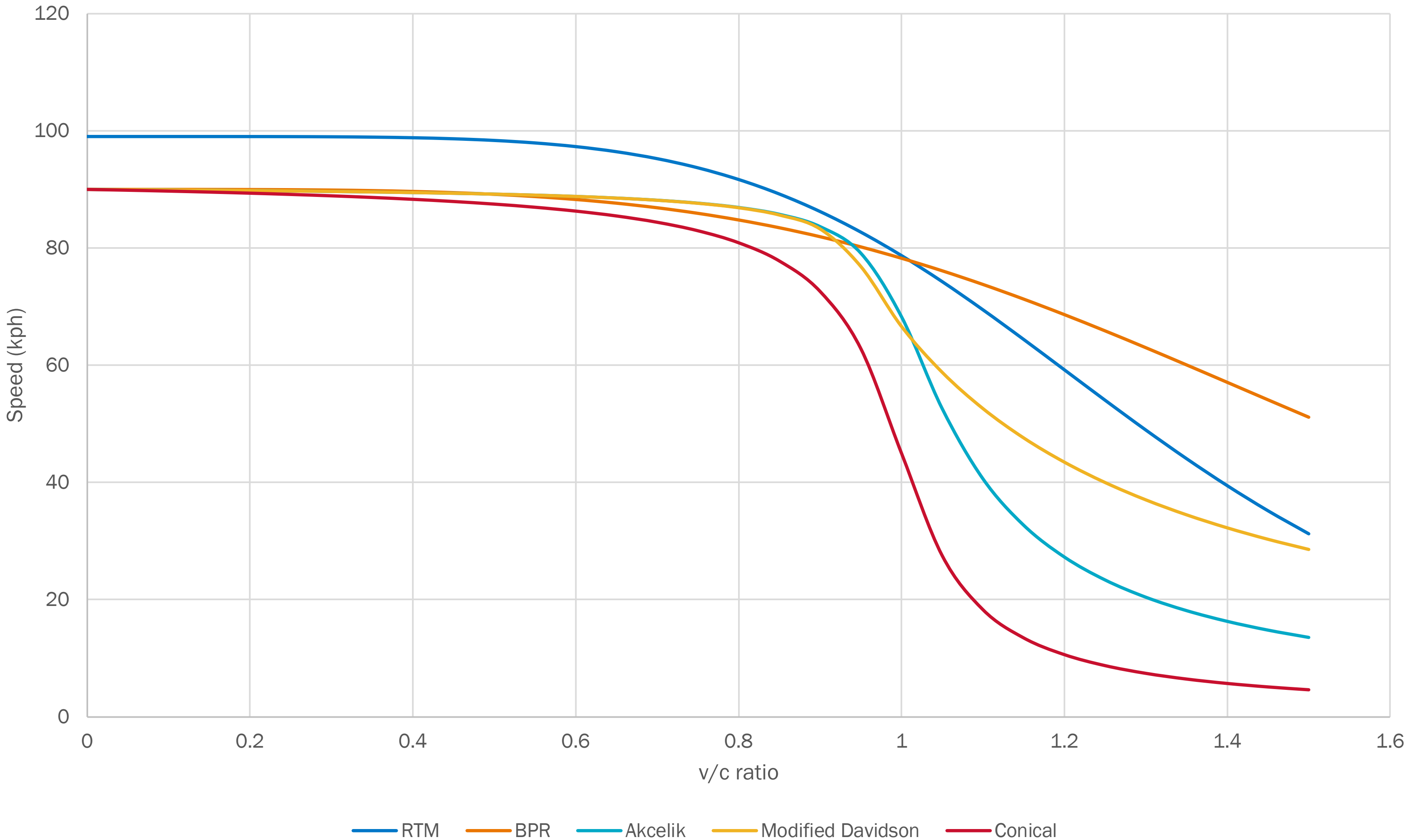
- Tisato (Australian Road Research) 1991
- based on steady-state stochastic queuing theory
- ***J*** is associated with land use or area type

Akcelik

$$u = \frac{u_0}{\left(1 + 0.25 u_0 \left[(x-1) + \sqrt{(x-1)^2 + 8\tau \frac{x}{u_0 c}}\right]\right)}$$

- Rahmi Akcelik (Sidra) 1991
- τ is associated with signal coordination

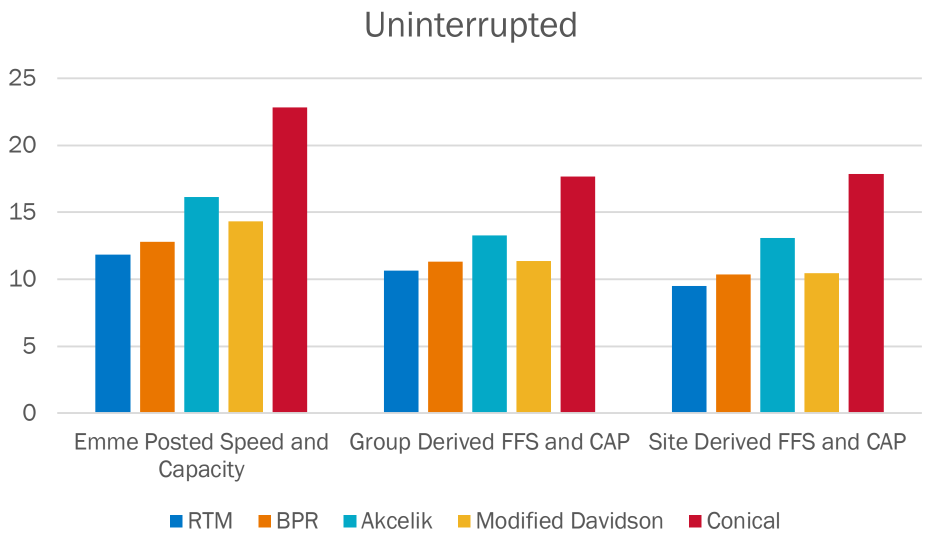
Exploratory Analysis Results | Standard Alternative VDF

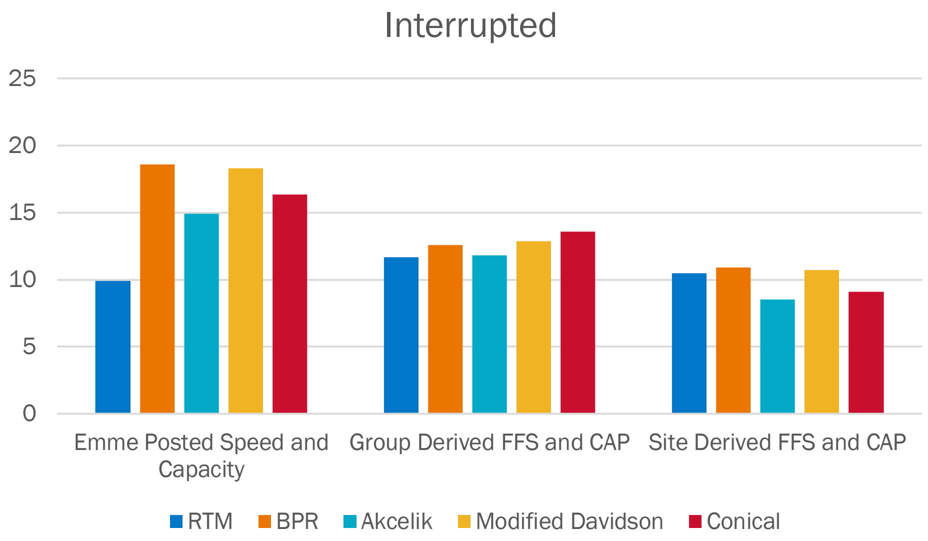


Exploratory Analysis Results | RMSE

Uninterrupted / Interrupted			Uninterrupted											Interrupted								
Facility Type			HOV		Freeway				Highway		Ramp		Blended	Arterial				Collector				Blended
Posted Speed (kph)			100	90	100	70	80	90	50	80	50	60		50	60	70	80	30	40	50	60	
Demand Treatment			DR	DR	DR	DR	QT	QT	DR	DR	DR	DR										
1. Emme Posted Speed and Capacity	R2	RTM	0.77	0.55	0.59	0.77	0.54	0.43	0.71	0.50	0.53	0.32	0.52	0.30	0.31	0.71	0.65	0.27	0.30	0.36	0.37	0.37
		BPR	0.73	0.51	0.57	0.49	0.52	0.44	0.70	0.50	0.30	0.53	0.50	0.22	0.17	0.38	0.60	0.17	0.26	0.12	0.12	0.21
		Akcelik	0.76	0.49	0.58	0.47	0.54	0.30	0.69	0.44	0.42	0.44	0.45	0.19	0.16	0.47	0.51	0.26	0.26	0.09	0.11	0.19
		Modified Davidson	0.75	0.47	0.58	0.49	0.54	0.38	0.72	0.46	0.47	0.44	0.48	0.10	0.08	0.26	0.28	0.15	0.16	0.05	0.05	0.10
		Conical	0.75	0.49	0.52	0.51	0.52	0.41	0.76	0.43	0.55	0.33	0.47	0.12	0.10	0.29	0.36	0.17	0.19	0.07	0.06	0.12
	RMSE	RTM	18	17	13	18	15	11	16	7	13	27	12	11	11	7	11	14	9	9	9	10
		BPR	15	14	11	15	20	14	21	8	16	18	13	15	22	20	29	9	7	19	19	19
		Akcelik	16	14	15	16	22	18	21	12	14	21	16	12	19	12	24	11	6	15	16	15
		Modified Davidson	15	14	12	15	21	16	21	11	13	19	14	15	22	19	30	10	7	18	19	18
		Conical	19	15	22	19	31	24	22	20	14	25	23	13	19	16	25	13	8	17	18	16
2. Grouped Derived FFS and CAP	R2	RTM	0.77	0.55	0.59	0.49	0.55	0.59	0.71	0.51	0.54	0.27	0.57	0.17	0.20	0.37	0.65	0.22	0.29	0.34	0.10	0.26
		BPR	0.73	0.51	0.57	0.73	0.53	0.59	0.70	0.51	0.30	0.53	0.56	0.08	0.11	0.01	0.60	0.15	0.25	0.28	0.02	0.16
		Akcelik	0.76	0.50	0.58	0.47	0.53	0.48	0.71	0.44	0.44	0.41	0.51	0.07	0.09	0.00	0.50	0.21	0.25	0.23	0.01	0.14
		Modified Davidson	0.75	0.47	0.58	0.75	0.54	0.54	0.72	0.46	0.47	0.44	0.54	0.05	0.06	0.00	0.31	0.11	0.18	0.21	0.01	0.11
		Conical	0.75	0.49	0.52	0.75	0.53	0.57	0.76	0.44	0.55	0.33	0.53	0.06	0.08	0.00	0.37	0.13	0.20	0.19	0.01	0.11
	RMSE	RTM	21	18	12	21	9	9	10	7	13	19	11	12	13	10	16	7	8	10	12	12
		BPR	23	19	12	23	11	11	11	6	18	5	11	12	13	15	16	10	9	11	14	13
		Akcelik	21	18	16	21	10	12	10	11	15	11	13	12	12	15	13	8	7	10	15	12
		Modified Davidson	21	20	13	21	10	10	10	9	15	8	11	13	13	16	16	10	9	11	15	13
		Conical	22	18	21	22	14	16	9	18	14	15	18	14	14	19	13	11	10	11	16	14
3. Site Derived FFS and CAP	R2	RTM	0.77	0.55	0.80	0.77	0.55	0.46	0.71	0.51	0.73	0.27	0.60	0.43	0.41	0.68	0.65	0.34	0.39	0.58	0.57	0.50
		BPR	0.73	0.51	0.81	0.59	0.53	0.44	0.70	0.51	0.69	0.53	0.59	0.48	0.42	0.62	0.60	0.22	0.31	0.67	0.57	0.53
		Akcelik	0.76	0.50	0.73	0.51	0.53	0.38	0.71	0.44	0.68	0.41	0.53	0.49	0.45	0.69	0.50	0.33	0.36	0.64	0.62	0.54
		Modified Davidson	0.75	0.47	0.78	0.54	0.54	0.45	0.72	0.47	0.75	0.44	0.57	0.43	0.38	0.58	0.31	0.18	0.24	0.61	0.54	0.47
		Conical	0.75	0.49	0.66	0.53	0.53	0.48	0.76	0.44	0.73	0.33	0.54	0.40	0.38	0.58	0.37	0.20	0.26	0.55	0.50	0.45
	RMSE	RTM	21	18	9	11	9	10	10	7	10	19	10	11	12	9	16	8	7	9	9	10
		BPR	23	19	9	23	11	12	11	6	15	5	10	11	12	11	16	9	9	9	11	11
		Akcelik	21	18	14	13	10	14	10	11	13	11	13	9	10	7	13	7	6	7	8	8
		Modified Davidson	21	20	10	12	10	11	10	9	12	8	10	11	12	11	16	9	9	9	10	11
		Conical	22	18	19	22	14	18	9	18	12	15	18	9	10	8	13	9	8	8	9	9

Exploratory Analysis Results | RMSE





Findings

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- True demand based on queuing theory has a much more solid foundation
- For this study, the categorization of facility-speed is preferred
- Three ways to assume FFS and capacities are all performed
- Low volume data sampling is effective in placing greater emphasis on high v/c region
- Without calibrating VDF parameters using fitted models, the current RTM VDFs seem to outperform other standard VDF functions

Thank You