Applying Traffic Flow Theory in Assessing Detector Performance

NWTC 2024, March 5th, 2024

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Funded by

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Oregon Department of Transportation

Oregon State University

Motivation

- Current methods of detector health monitoring commonly do not capture:
  - Latency issues
    - Detector ‘sticks’ temporarily, holding the call longer than it should
    - Detector drops call early
  - Shifting traffic patterns, and vehicles are not passing over detection zone
  - Detector flickering (i.e. spotty detection) below threshold of erratic count
  - Erratic detector performance (detector fails for several minutes, then operates normally before failing again)

Project Objectives

- *Develop a reliable and robust method of determining poor performance of a traffic detector based solely on historical data and traffic flow theory.*
- *It is proposed that this method will work at isolated signalized intersections, using data only from that intersection's detectors for evaluation.*
- *Additionally, a system design of this method will be developed to assist ODOT with implementation of the method.*

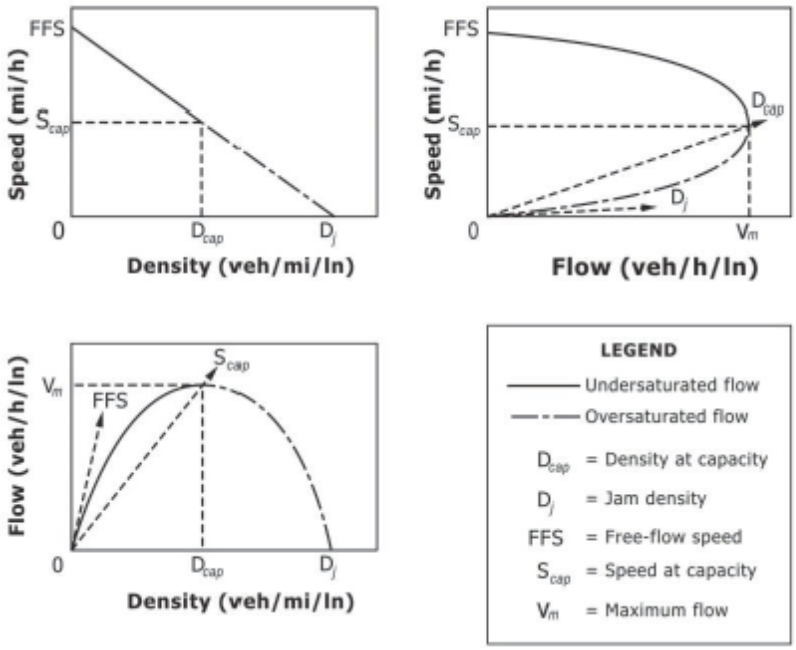
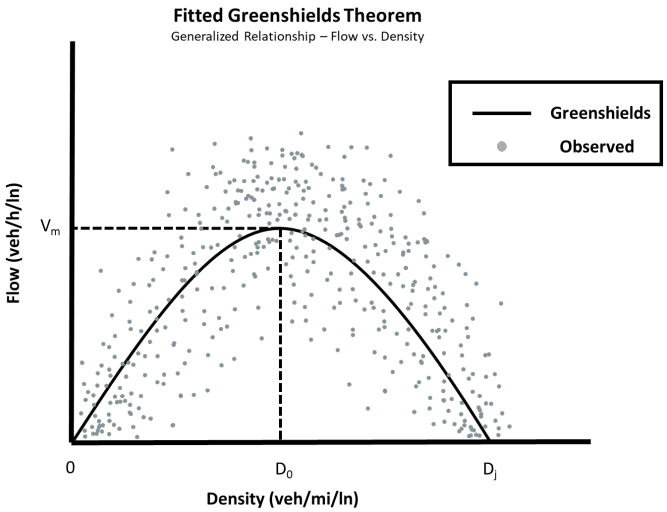
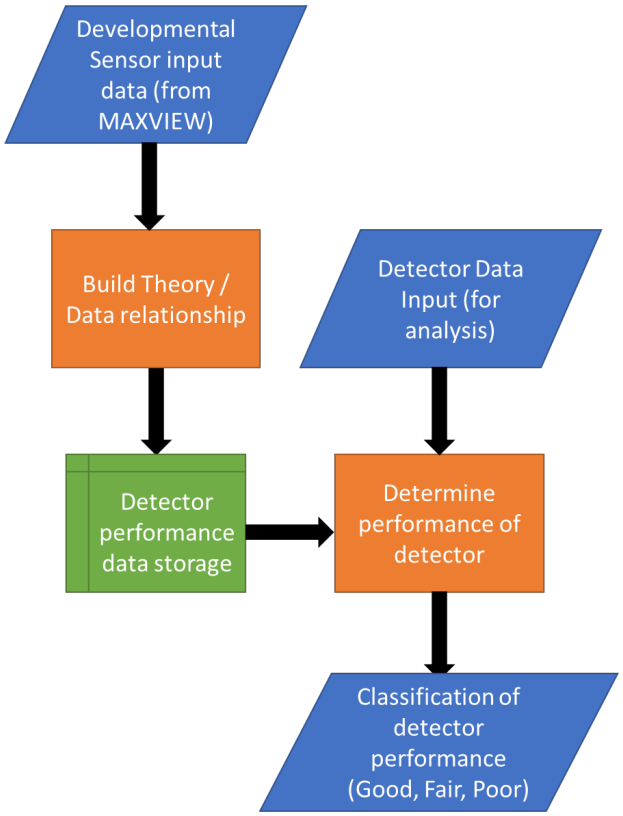


Exhibit 4-2
Generalized Relationships Among Speed, Density, and Flow Rate on Uninterrupted-Flow Facilities

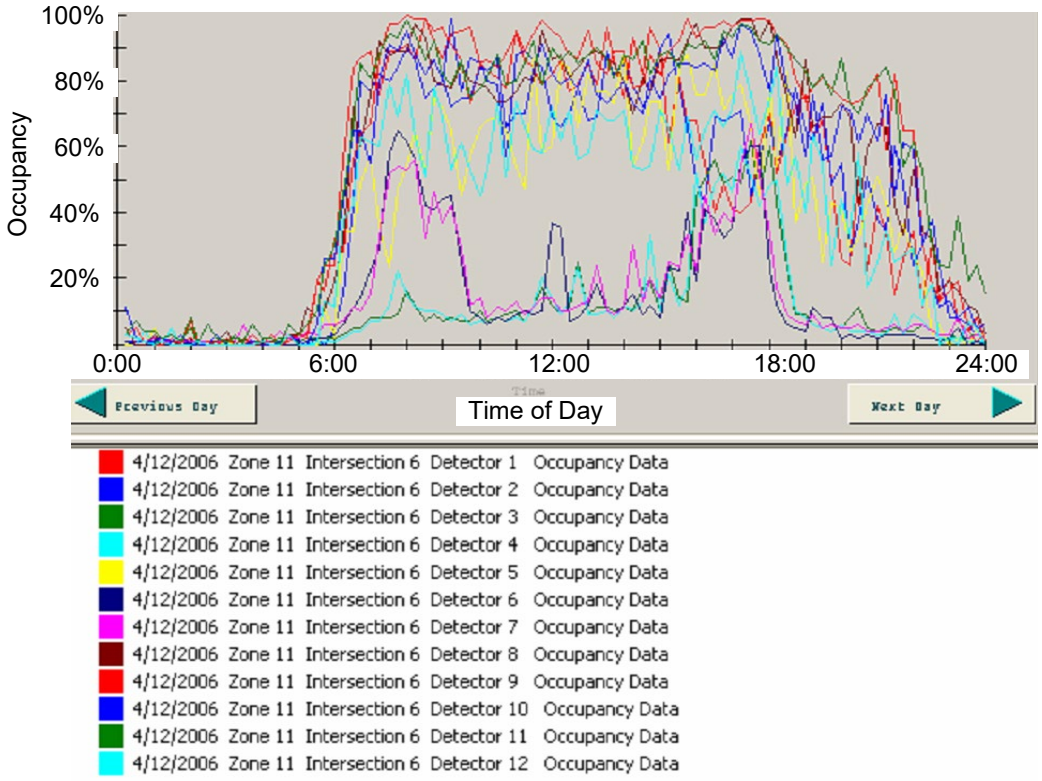
Research Approach

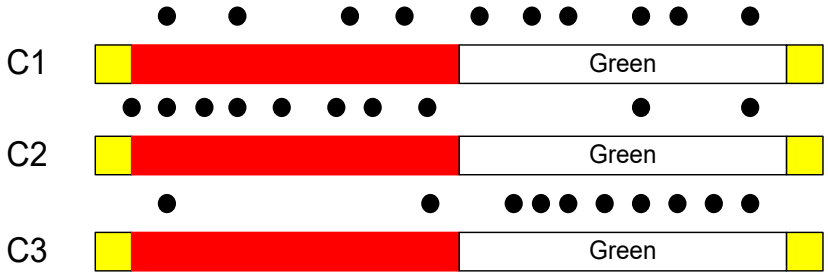
- Generalized Process:
  - Collect data from representative sites
  - Approximate uninterrupted flow from event-based data
  - Develop mathematical relationships for empirical data (Volume vs. Density curve)
  - Develop Volume vs. Density prediction model from empirical data
  - Develop performance datasets for algorithm comparisons





Importance of Event Based High Resolution Data (Building blocks of ATSPM





Percent Arrival on Green

60%

20%

80%

Average = 53.33%

Site Identification

- Rudimentary check of detection performance
  - Are we seeing activations?
  - Do they take the expected shape?
  - Are they within a plausible range?

9: OR34_1-5SB Histograms 8-3-2020

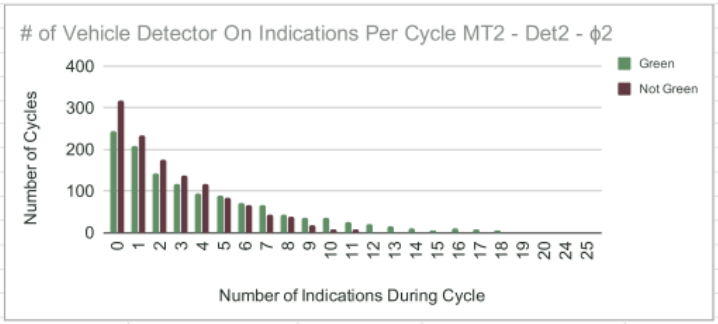
MT2 - Det2 - ϕ2

max	25
mode	0
# of mode	243
Outliers	None

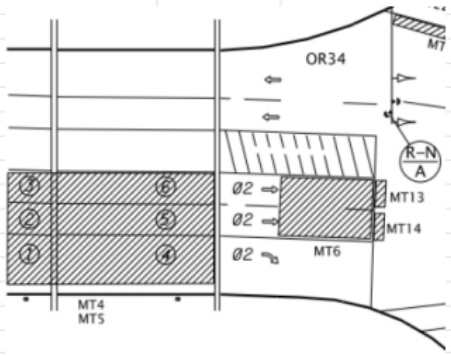
Totals	
0	243
1	208
2	143
3	117
4	94
5	89
6	71
7	66
8	44
9	36
10	35
11	26
12	20
13	15
14	11
15	6
16	10
17	7
18	4
19	1
20	1
24	1
25	1

max	18
mode	0
# of mode	318
Outliers	None

Totals	
0	318
1	233
2	175
3	137
4	118
5	85
6	66
7	42
8	38
9	18
10	7
11	8
12	1
16	1
17	1
18	1

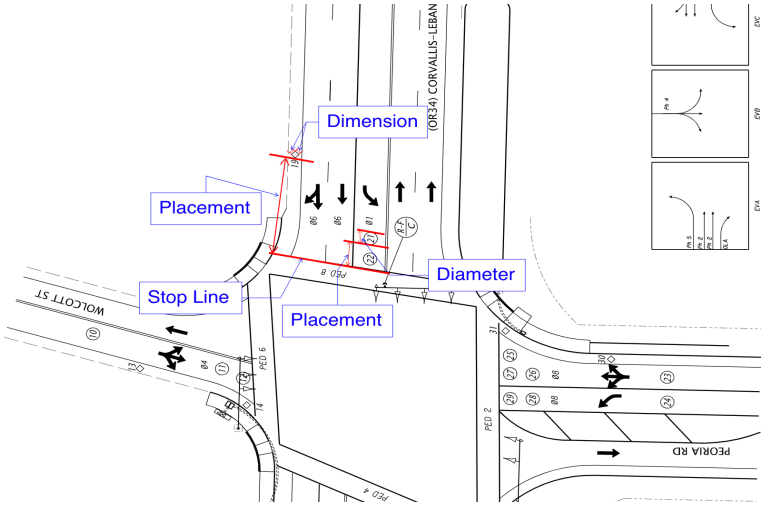


81 Repeats
0
0%
82 Repeats
0
0%
Total Rows
16484



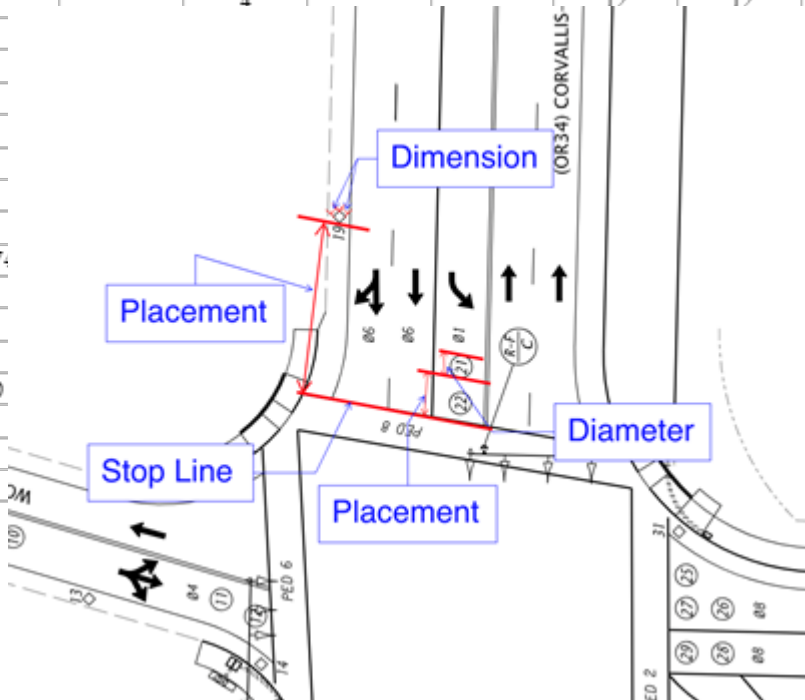
Site Verification

- Log site characteristics
- Record operations with drones
  - Drone Video Log Transcription
- Process and reduce event log data
- Validate detectors
  - Comparing drone video logs to event logs
  - Number of activations
  - Detector on duration
- Outcome
  - List of provided detectors that passed the performance metrics, for use in algorithm development



Log Site Characteristics

Intersection	Urban / Rural	Detector	Technology	Approach	Approach Speed	Location	Distance To Stop Bar (ft)			Size (ft)		Lane Usage and Width		
							1st Det	2nd Det	3rd Det	Length	Width	Left	Thru	Right
OR22 @ I-5	HWY Ramp	1	Loop	EB	50	Advanced	365			6			12	
OR22 @ I-5	HWY Ramp	2	Loop	EB	50	Advanced	365			6			12	
OR22 @ I-5	HWY Ramp	4-6	Loop	EB	50	Advanced	164	168	168	6			12	
OR22 @ I-5	HWY Ramp	7	Loop	SB	45	Advanced	130			6		12		
OR22 @ I-5	HWY Ramp	8	Loop	SB	45	Advanced	129			6		12		
OR22 @ I-5	HWY Ramp	9-10	Loop	SB	45	Advanced	57.5	57.5		6		12		
OR22 @ I-5	HWY Ramp	17-18	Loop	WB	50	Advanced	202.5	202.5		6			12	
OR34 @ I-5	Rural	2	Loop	EB	40	Advanced	377.7			4.0833			12	
OR34 @ I-5	Rural	7	Loop	SB	30	Advanced	128			4				12
OR34 @ I-5	Rural	8	Loop	SB	30	Advanced	130			4			12	12
OR34 @ I-5	Rural	9	Loop	SB	30	Advanced	132							
OR34 @ I-5	Rural	13	Radar	EB	40	Stop Bar	0							
OR34 @ I-5	Rural	14	Radar	EB	40	Stop Bar	0							
OR34 @ I-5	Rural	23	Radar	SB	30	Stop Bar	12							
OR34 @ I-5	Rural	25	Radar	SB	30	Stop Bar	12							
OR34 @ I-5	Rural	27	Radar	WB	40	Stop Bar	11							
OR34 @ I-5	Rural	28	Radar	WB	40	Stop Bar	11							
OR34 @ Peoria	Rural	3-4	Loop	EB	55	Advanced	174	17-						
OR34 @ Peoria	Rural	10	Loop	SB	25	Advanced	70							
OR34 @ Peoria	Rural	16	Loop	WB	55	Advanced	379							
OR34 @ Peoria	Rural	20	Loop	WB	55	Advanced	69							
OR34 @ Peoria	Rural	21-22	Loop	WB	55	Stop Bar	9	0						
OR34 @ Peoria	Rural	23	Loop	NB	45	Advanced	79							
OR34 @ Peoria	Rural	24	Loop	NB	45	Advanced	79							
US20 @ 15th	Rural	1	Loop	EB	45	Advanced	319.8							



Drone Video Recordings and Video Log Transcription

Site	US20@15th St
Date	11/20/2020
Direction	NB

Video	Vehicle	Time*											Traffic Signal Status**			Comment(s)
		Arrival	Depart	Calculation									Red	Yellow	Green	
				Arrival (Degree)				Depart (Degree)				Duration (Decimal) (second)				
				h	m	s	sss	h	m	s	sss					
NB #17-19	Detector	19														
	1	13:07:02	13:07:03	13	7	2	6	13	7	3	4	0.93	x			
	2	13:07:29	13:07:30	13	7	29	10	13	7	30	27	1.57	x			
	3	13:08:47	13:08:48	13	8	47	23	13	8	48	21	0.93	x			
	4	13:08:59	13:09:00	13	8	59	21	13	9	0	25	1.13	x			
	5	13:10:19	13:10:20	13	10	19	10	13	10	20	12	1.07	x			
	6	13:10:41	13:10:42	13	10	41	7	13	10	42	8	1.03	x			

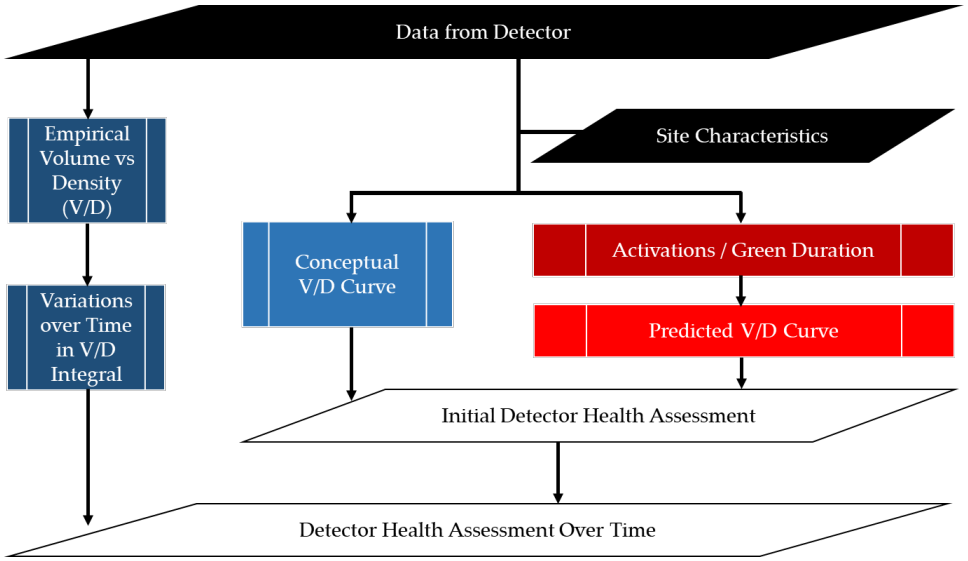
Detector Verification Outcome Overview

Usable Detectors from Each Study Intersection

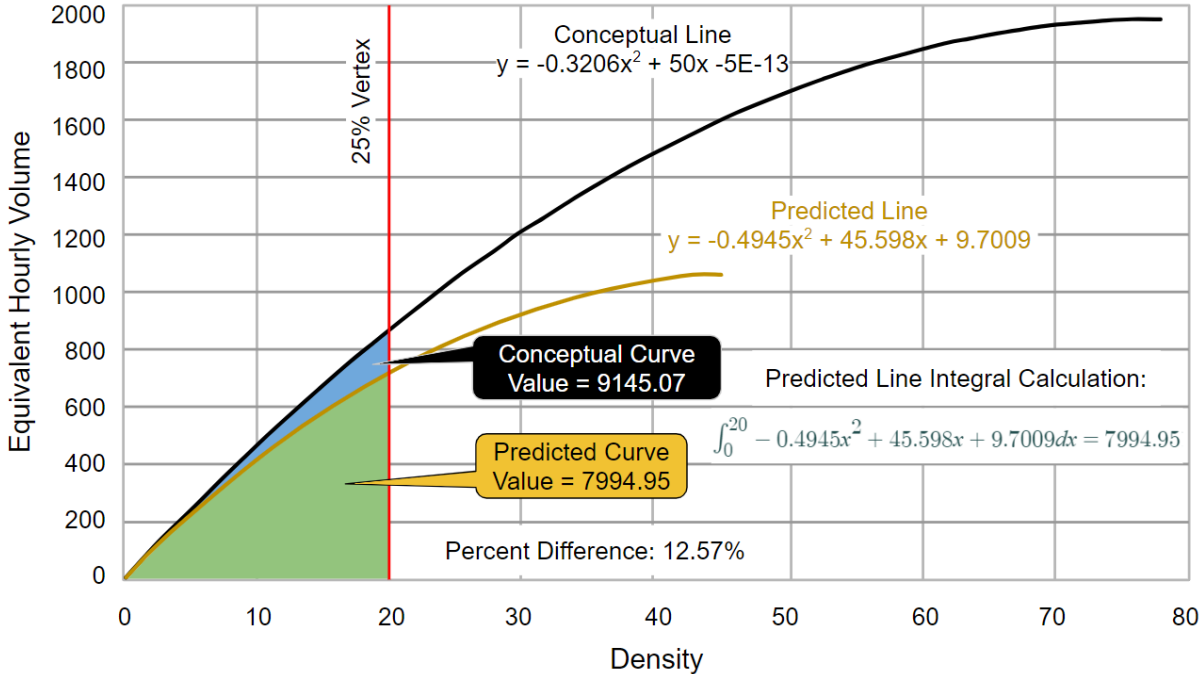
Intersection	Det#	MT#		Lanes	Location
OR22 at I-5	1	2	Loop	1	Advanced
	2	3		1	Advanced
	4-6	5		3	Advanced
	7	8		1	Advanced
	8	9		1	Advanced
	9-10	10		2	Advanced
	17-18	18		2	Advanced
OR34 at I-5	2	2	Loop	1	Advanced
	7	8		1	Advanced
	8	9		1	Advanced
	9	12		1	Advanced
	13	13	Radar	1	Stop Bar
	14	14		1	Stop Bar
	23	23		1	Stop Bar
	25	25		1	Stop Bar
	27	27		1	Stop Bar
	28	28		1	Stop Bar
OR34 at Peoria	3-4	6	Loop	2	Advanced
	10	7		1	Advanced
	16	17		1	Advanced
	20	1		1	Advanced
	21-22	13		1	Stop Bar
	23	22		1	Advanced
	24	23		1	Advanced
US20 at 15th	1	2	Loop	1	Advanced
	2	3		1	Advanced
	3	15		1	Advanced
	4-5	27		1	Stop Bar
	8	8		1	Advanced
	9-10	9		1	Stop Bar
	13	1		1	Advanced
	15	16		1	Advanced
	19	22		1	Advanced
US26 at Meinig	4	8	Loop	1	Advanced
	5-6	9		1	Stop Bar
	7	21		1	Advanced
US101 at 22nd	3-4	4	Loop	1	Stop Bar
	5-6	5		1	Stop Bar
	7	15		1	Advanced
	8-9	27		1	Stop Bar
	17-18	18		1	Stop Bar
	19-20	19		1	Stop Bar
	21	1		1	Advanced
	24	22		1	Advanced
	25-26	23		1	Stop Bar

- 79 detection zones underwent comparative analysis (70 inductive loop and 9 radar).
- 39 inductive loop and 6 radar zones passed the analysis

General Form of Comparative Process



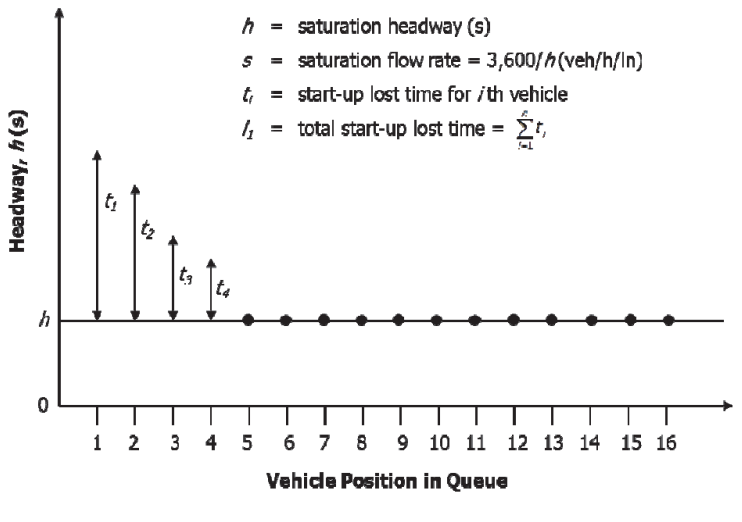
$$\left|\frac{\textit{Predicted Integral} - \textit{Conceptual Integral}}{\textit{Conceptual Integral}}\right| = \textit{Percent Difference}$$

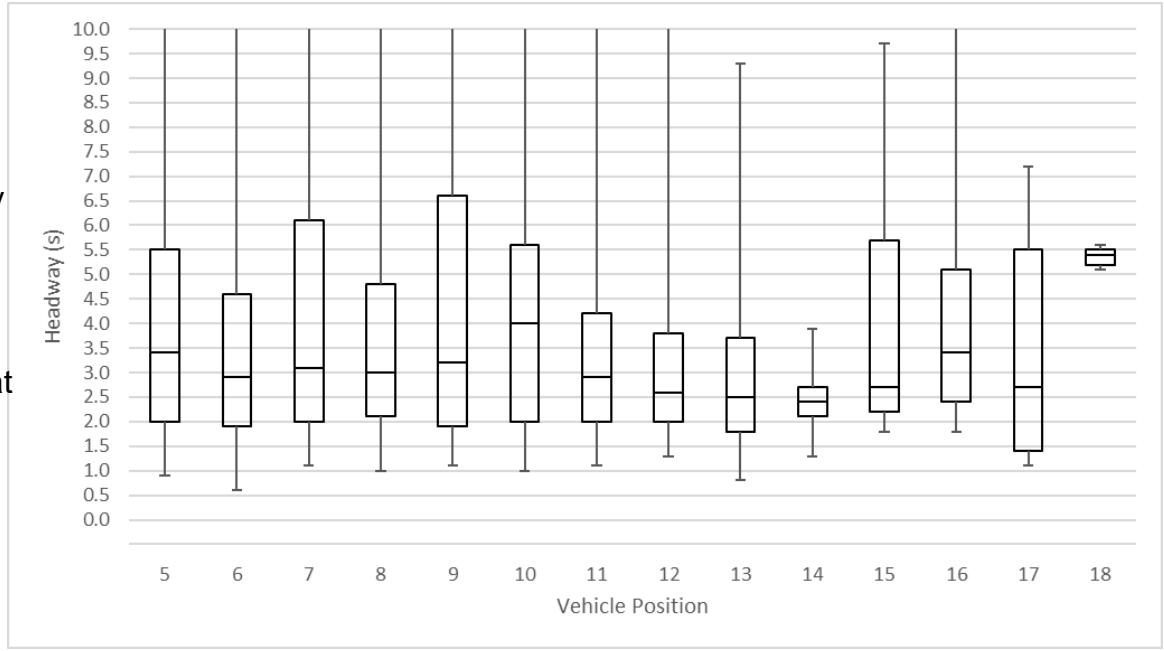


Approximation of Uninterrupted Flow

- Peak Period Selection
  - High volume desired
  - Tu, Wed, Thu: 6a-9a; 4p-7p
- Start-Up Lost Time
  - Remove first four activations
- Saturated Headway
  - Various approaches attempted
    - Remove top quartile
    - Remove points that are more than 2x or 3x median
    - Remove activations detected during the last six seconds of green
    - Remove all data if first headway over 8 seconds
  - In the end, limited headways to those at or below 3.0s
    - Common value for gap setting at signalized intersections
    - Easy from a calculation standpoint

Exhibit 4-8
Concept of Saturation Flow Rate and Lost Time





Calculation of Equivalent Hourly Volume (EHV) and Density

- EHV = surrogate for volume
  - Volume for one green duration scaled to an hourly volume

$$EHV = {}^{3600}/_{(3600 \times 24 \times C)(A)}$$

Where:
EHV = Equivalent Hourly Volume
C = Cycle Duration
A = Number of Filtered Activations per Green Duration

- Density
  - Approximated from Occupancy

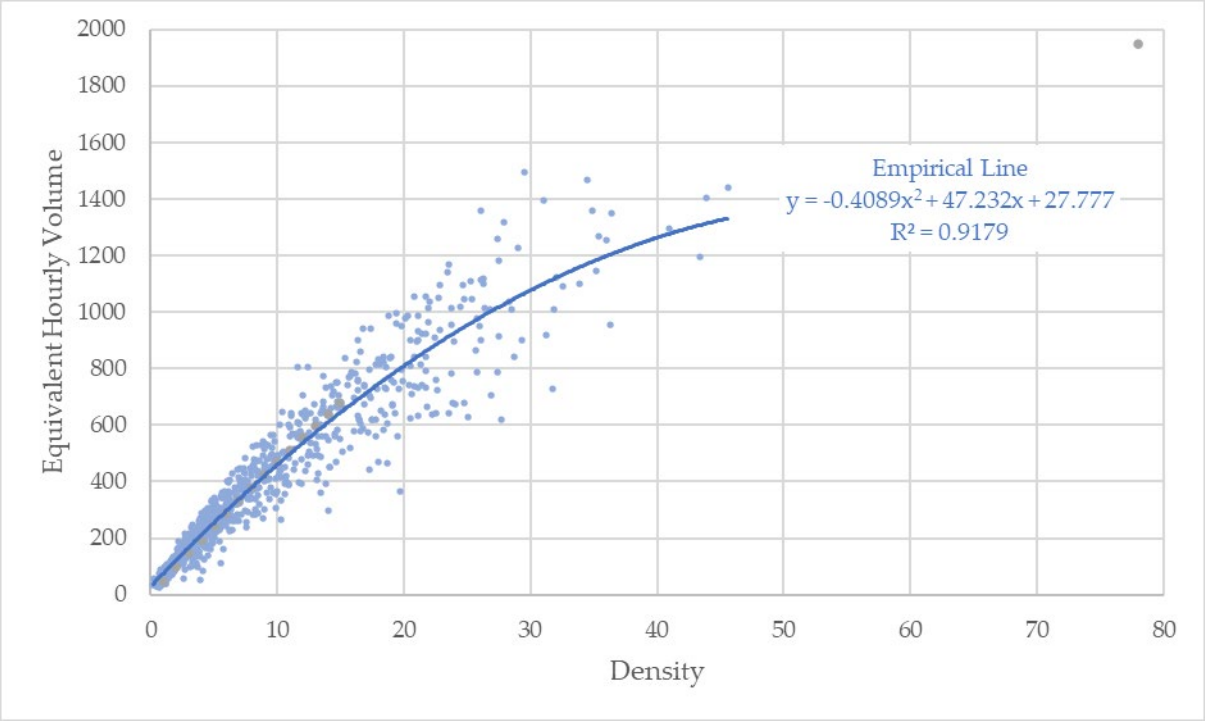
$$D = {}^{O \times 5280}/_{(L_{Veh} + L_{Det})}$$

Where:
D = Density
O = Occupancy
L_{Veh} = Average Vehicle Length
L_{Det} = Detector Length

$$Occupancy = \frac{Filtered\ Detector\ On\ During\ Green\ \ Duration}{Green\ Duration}$$

Plot Data Points and Generate Empirical Curve

- Plot values of EHV and Density for one week of data (18 hours); 50 points/week required to plot
- Generate second order trendline



Calculation Conceptual Volume vs. Density Curve

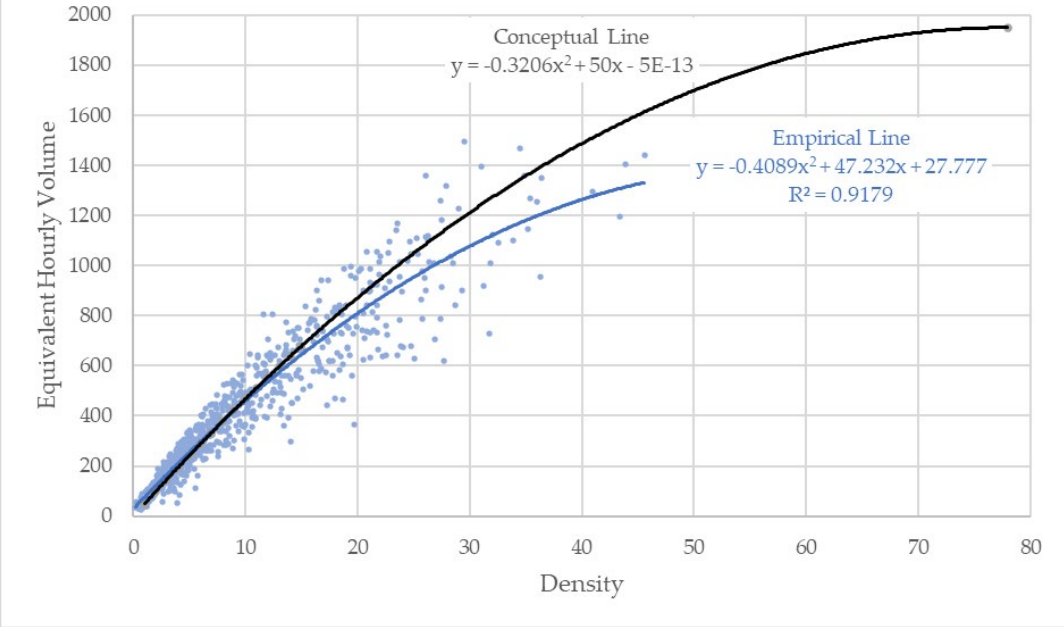
- Vertex of Conceptual curve calculated directly from Greenshields relationship

$$S_O = \frac{1}{2}\ Speed\ Limit$$

$$Maximum\ Volume = V_{MAX} = {}^{3600}/_{Average\ Headway}$$

$$Optimum\ Density = D_O = {}^{V_{MAX}}/_{S_O}$$

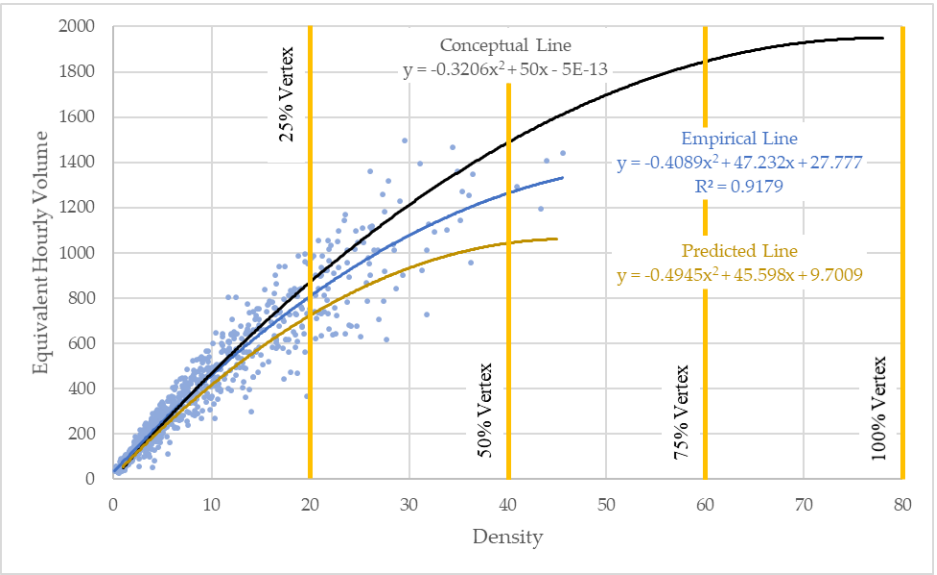
- Create quadratic line with vertex and origin

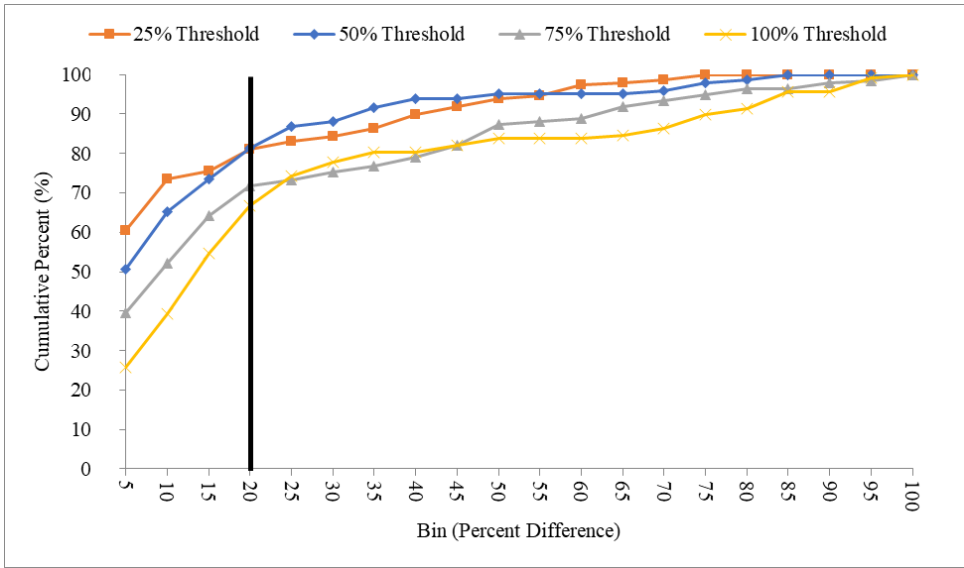


Develop Performance Datasets for Algorithm Comparisons

- Empirical Performance Dataset (EPD)
  - Using filtered dataset, develop set of percent difference values for each detector (50+ pts per week, $r^2 > 0.7$, -*a* coefficient, positive integral)
  - Processed four weeks data to yield six percent difference values (interested in week-to-week variability)
    - Week 2 compared to Week 1
    - Week 3 compared to Week 1
    - Week 4 compared to Week 1
    - Week 3 compared to Week 2
    - Week 4 compared to Week 2

	25%	50%	75%	100%
Mean	10.64	13.51	24.54	142.55
Std Dev	16.69	24.81	36.36	386.77





Develop Volume vs. Density Prediction Model from Empirical Data

- Predict *a*, *b*, and *c* coefficients ($ax^2 + bx + c$) of Volume vs. Density curve based upon site characteristics

	a			*b*			*c*		
Predictor Variable	**Beta**	**Std. Error**	**p-value**	**Beta**	**Std. Error**	**p-value**	**Beta**	**Std. Error**	**p-value**
(intercept)	0.629	0.338	0.066	6.337	8.624	0.464	-10.341	27.478	0.707
Tech Loop	-0.267	0.136	0.052	3.773	3.472	0.280	9.171	11.062	0.409
Detect Advance	-0.180	0.100	0.074	6.754	2.542	0.009	21.385	8.098	0.010
Single Lane	-0.171	0.120	0.157	4.700	3.062	0.128	-29.725	9.758	0.003
Activations	-0.001	<0.001	0.022	0.064	0.007	<0.001	-0.047	0.024	0.051
Indications	-0.008	0.006	0.162	-0.136	0.145	0.348	1.458	0.461	0.002
Model Summary									
Adjusted R^2			0.172			0.661			0.154

- Number of activations/hour is all activations during green (unfiltered), averaged for the week
- Number of green indications/hour is averaged for the week

$$\hat{y}_a = 0.629 - 0.267\left(x_{tech_{loop}}\right) - 0.180\left(x_{detect_{adv}}\right) - 0.171\left(x_{lane_{single}}\right) - 0.001\left(x_{wk_{act\,hour}}\right) - 0.008\left(x_{wk\_grn\,hr}\right)$$

$$\hat{y}_b = 6.337 + 3.773\left(x_{tech\_loop}\right) + 6.754\left(x_{detect\_adv}\right) + 4.700\left(x_{lane\_single}\right) + 0.064\left(x_{wk\_act\,hour}\right) - 0.136\left(x_{wk\_grn\,hr}\right)$$

$$\hat{y}_c = -10.341 + 9.171\left(x_{tech\_loop}\right) + 21.385\left(x_{detect\_adv}\right) - 29.725\left(x_{lane\_single}\right) - 0.047\left(x_{wk\_act\,hour}\right) + 1.458\left(x_{wk\_grn\,hr}\right)$$

Where:

$\hat{y}_a, \hat{y}_b, \hat{y}_c$ equals the predicted values of a, b, and c

x_{tech_loop} equals the presence of a loop detector (binary)

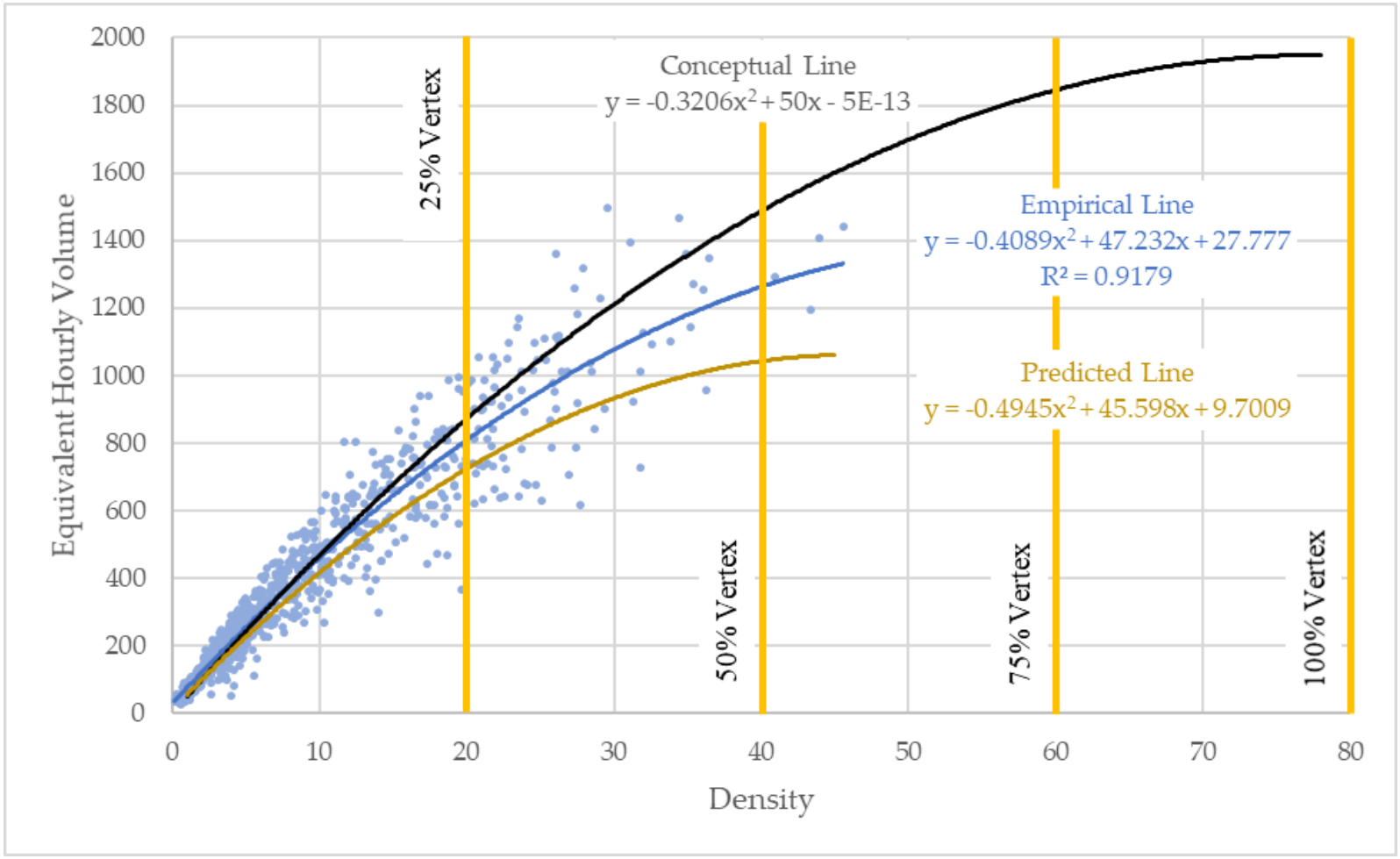
x_{detect_adv} equals the presence of advanced detector technology (binary)

x_{lane_single} equals site location within a single lane roadway (binary)

$x_{wk\_act\,hour}$ equals the number of activations per hour (continuous)

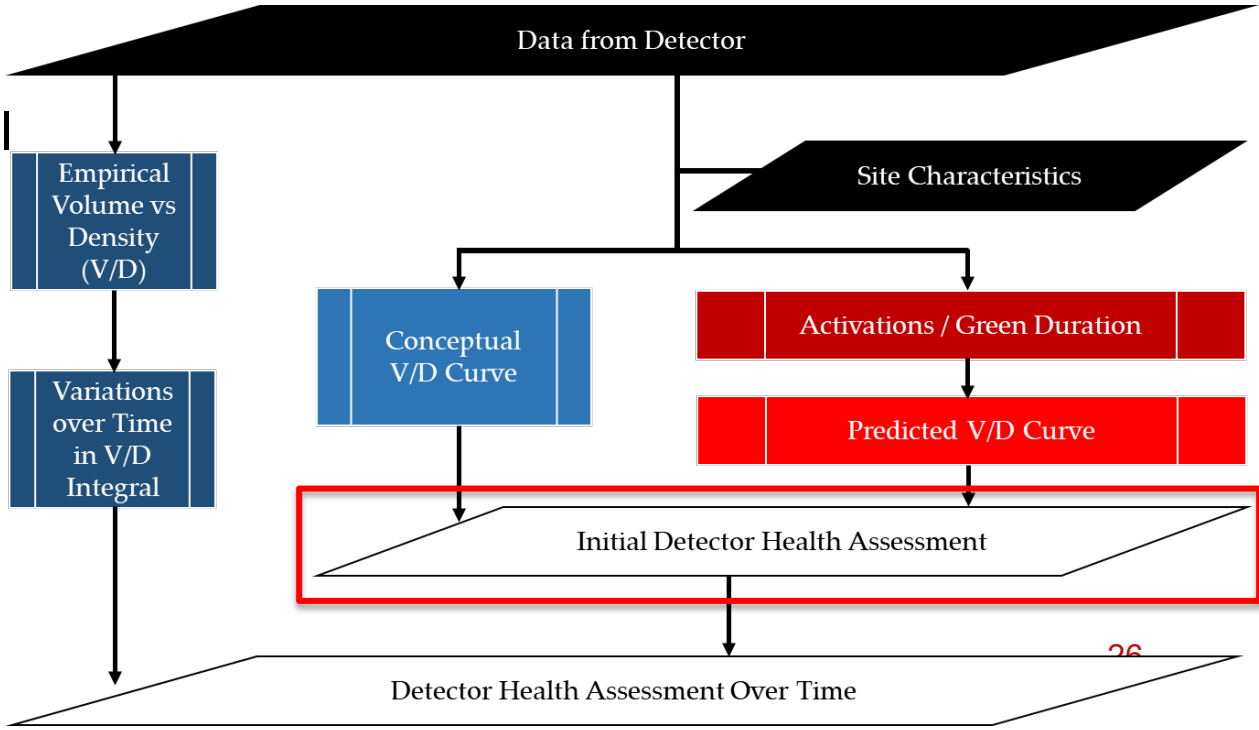
$x_{wk\_grn\,hr}$ equals the number of indications per hour (continuous)

Developed lines for comparison



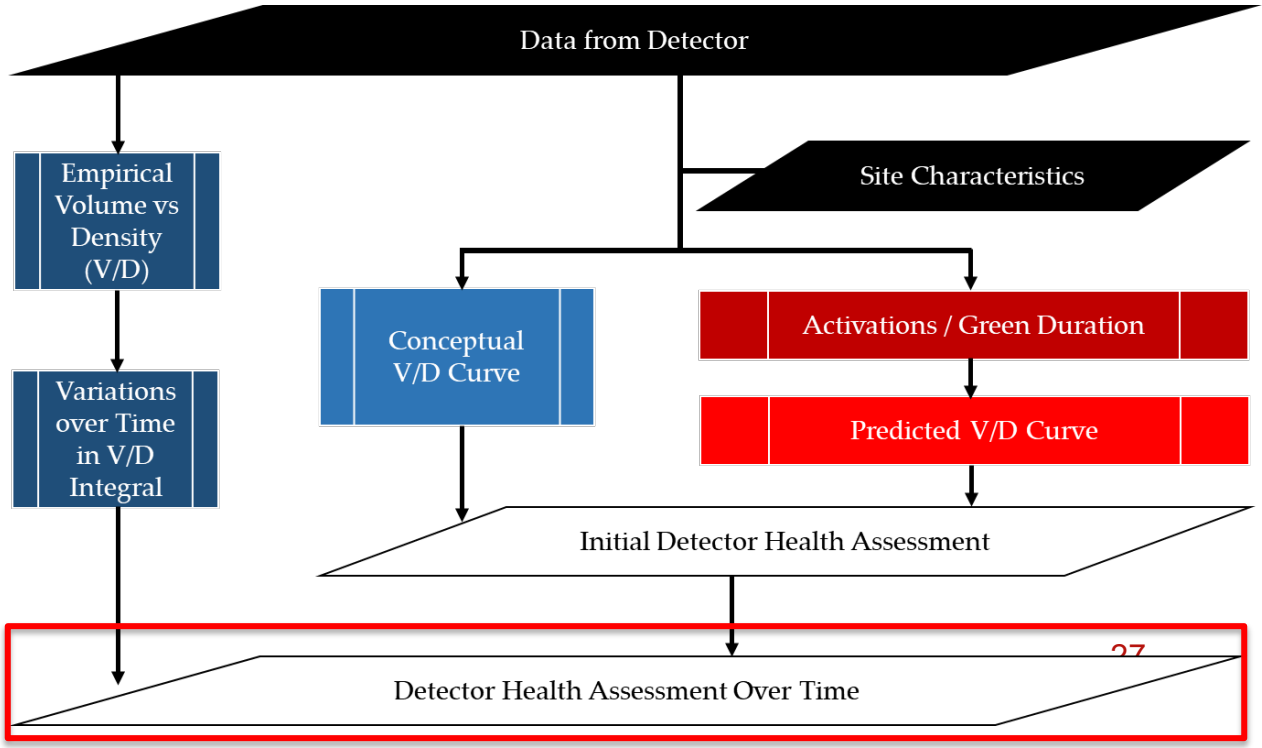
Algorithm: Initial Detector Health Assessment

- Two comparison points:
  - Compare integrated percent difference between predicted vs. conceptual line against Predicted Performance Dataset
  - Compare percent differences between four weeks of empirical data against Empirical Performance Dataset

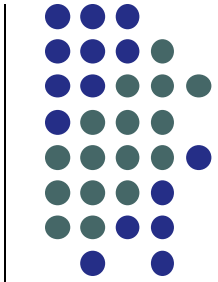


Algorithm: Detector Health Assessment Over Time

- Plot percent difference values over time
  - Compute integral percent differences from empirical data in rolling four-week increments
  - Plot calculated differences on a control chart; compare with PPD
  - Adjust control chart limits over time



Limitations and Future Work



- Algorithm was developed with a finite number of detectors, and as such, dataset might not be a universally representative sample of ODOT system
- Long term testing and validation not conducted due to time constraints
- Investigate different control chart limits as system is deployed
- Develop percent difference datasets for detectors of various technologies and configurations
  - Can allow for tighter control chart limits

Thank You.
Questions/Discussion?

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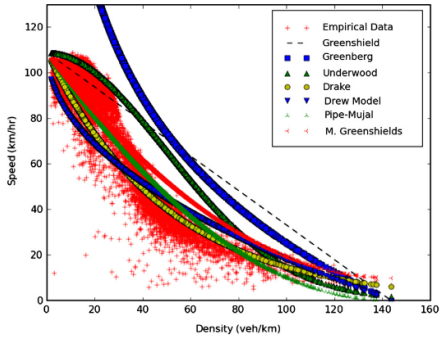
Full Project Report:
ODOT SPR837 “Automated Identification of Traffic Detector Malfunctions”
https://www.oregon.gov/odot/Programs/ResearchDocuments/SPR837DetectorMalfunctionFinalReport.pdf

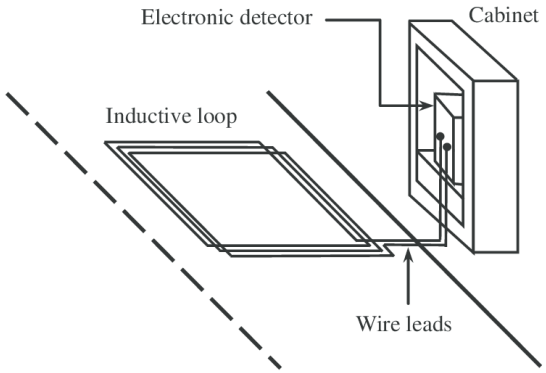
Extra

Literature Review

- Topics Covered
  - Detection Technology
  - Traffic Flow Theory and Fundamental Diagrams
  - Existing processes for monitoring detector health
- Key Points:
  - Three methods of monitoring health:
    - Traffic products and software
    - Algorithms / Post Processing
    - On-site monitoring
  - One existing project in a related area
  - Application of Fundamental Diagrams and headways to detector health untried



Real world Speed-Density plot (Wang et al., 2011)



Wire Inductive Loop Setup (Lamas et al., 2016)

Wavetronix Radar Detection (Huotari, 2015)

Site Identification and Verification

- Site verification process
  - Event-based data used to evaluate detector sufficiency
  - For each detector
    - EventID outputs, corresponding:
      - MaxTime Number (1-28)
      - Detector Number(s) (Detector Number(s) or RAD Number)
      - Phase (φ1-φ8)
    - Number of "Vehicle Detector On" indications for each green and each non-green interval in a day
      - Repeating "Vehicle Detector On' indications were reported
  - Other items
    - Varying outputs of radar zones
    - Removal of extend / delay on detection zones

Event ID	Name	Description	Parameter Description
1	Phase Begin Green	Set when either solid or flashing green indication has begun.	Phase #
8	Phase Begin Yellow Clearance	Set when phase yellow indication becomes active and clearance timer begins.	Phase #
81	Vehicle Detector Off	Vehicle detector has turned off. Detector on and off events are triggered post any detector delay/extension processing.	Vehicle detector #
82	Vehicle Detector On	Vehicle detector has turned on. Detector on and off events are triggered post any detector delay/extension processing.	Vehicle detector #

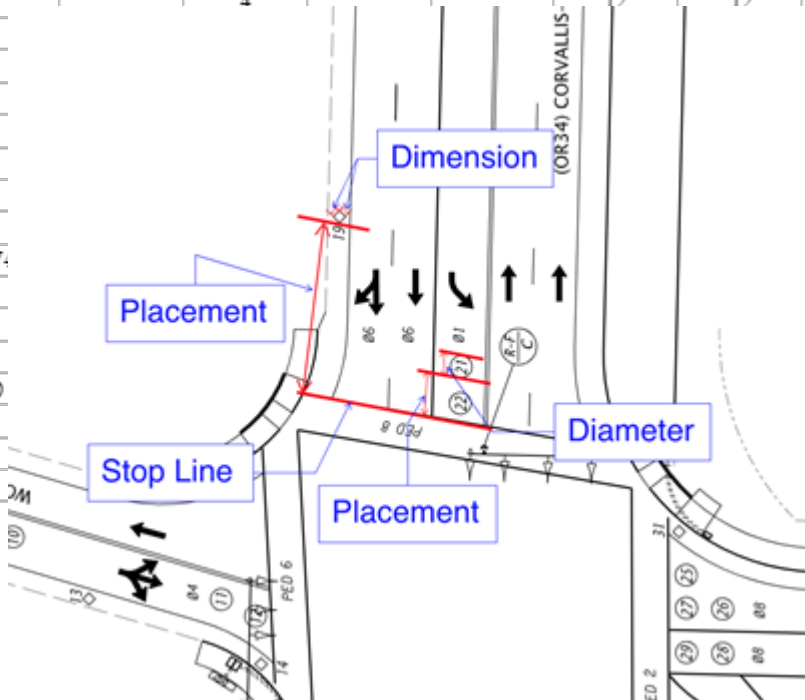
Site Identification

- Rudimentary check of detection performance
  - Are we seeing activations?
  - Do they take the expected shape?
  - Are they within a plausible range?

Number	Site	Location	Added	Deleted	Notes	Reason for Inclusion / Exclusion
1	Technology Loop	Corvallis	June 30	August 13	–	Some loops ground out
2	**US101@N22nd**	**Lincoln City**	**June 30**		**Has extend/delay on detectors (removed 8/25)**	**Has extend/delay on detectors (removed 8/25)**
3	**OR34@Peoria**	**Corvallis**	**June 30**		**Loops and radar, has extend/delay on detectors (removed 8/24)**	**Loops and radar, has extend/delay on detectors (removed 8/24)**
4	OR212@135th	Happy Valley	July 16	August 4	Replaces OR99W@Tualatin-Sherwood-RD	Too much broken data
5	OR51@16th	Independence	July 16th	August 4	–	Replaces OR34@I-5NBRamp; PreCovid data not available
6	OR99W@OR18	Dundee	June 30	August 4	–	PreCovid data not available; No detector event data
7	**OR22@I-5SBOfframp**	**Salem**	**July 16**		**Has extend/delay on detectors (removed 8/24)**	**Added as an option**
8	**US20@15th**	**Corvallis**	**August 13**		**Extend/delay on detectors removed.**	**--**
9	**OR34@I-5SBRamp**	**Albany**	**August 12**		**Has loops and radar and no stretch or delay time on loops (verified August 17)**	**--**
10	**US26@Meinig-Pioneer**	**Sandy**	**August 25**		**Delay/extend temoved from detectors**	**Replaces OR34@1-5NBRamp for something closer to Portland and isn't an on/off ramp**
–	OR99W@Tualatin-Sherwood-RD	Sherwood	June 30	July 16	–	--
–	OR34@I-5NBRamp	Albany	August 12	August 19	Has loops and radar and no stretch or delay time on loops (verified August 17)	Removing to replace with oversaturated location

Log Site Characteristics

Intersection	Urban / Rural	Detector	Technology	Approach	Approach Speed	Location	Distance To Stop Bar (ft)			Size (ft)		Lane Usage and Width		
							1st Det	2nd Det	3rd Det	Length	Width	Left	Thru	Right
OR22 @ I-5	HWY Ramp	1	Loop	EB	50	Advanced	365			6			12	
OR22 @ I-5	HWY Ramp	2	Loop	EB	50	Advanced	365			6			12	
OR22 @ I-5	HWY Ramp	4-6	Loop	EB	50	Advanced	164	168	168	6			12	
OR22 @ I-5	HWY Ramp	7	Loop	SB	45	Advanced	130			6		12		
OR22 @ I-5	HWY Ramp	8	Loop	SB	45	Advanced	129			6		12		
OR22 @ I-5	HWY Ramp	9-10	Loop	SB	45	Advanced	57.5	57.5		6		12		
OR22 @ I-5	HWY Ramp	17-18	Loop	WB	50	Advanced	202.5	202.5		6			12	
OR34 @ I-5	Rural	2	Loop	EB	40	Advanced	377.7			4.0833			12	
OR34 @ I-5	Rural	7	Loop	SB	30	Advanced	128			4				12
OR34 @ I-5	Rural	8	Loop	SB	30	Advanced	130			4			12	12
OR34 @ I-5	Rural	9	Loop	SB	30	Advanced	132							
OR34 @ I-5	Rural	13	Radar	EB	40	Stop Bar	0							
OR34 @ I-5	Rural	14	Radar	EB	40	Stop Bar	0							
OR34 @ I-5	Rural	23	Radar	SB	30	Stop Bar	12							
OR34 @ I-5	Rural	25	Radar	SB	30	Stop Bar	12							
OR34 @ I-5	Rural	27	Radar	WB	40	Stop Bar	11							
OR34 @ I-5	Rural	28	Radar	WB	40	Stop Bar	11							
OR34 @ Peoria	Rural	3-4	Loop	EB	55	Advanced	174	17-						
OR34 @ Peoria	Rural	10	Loop	SB	25	Advanced	70							
OR34 @ Peoria	Rural	16	Loop	WB	55	Advanced	379							
OR34 @ Peoria	Rural	20	Loop	WB	55	Advanced	69							
OR34 @ Peoria	Rural	21-22	Loop	WB	55	Stop Bar	9	0						
OR34 @ Peoria	Rural	23	Loop	NB	45	Advanced	79							
OR34 @ Peoria	Rural	24	Loop	NB	45	Advanced	79							
US20 @ 15th	Rural	1	Loop	EB	45	Advanced	319.8							



Drone Video Recordings and Video Log Transcription

Site	US20@15th St
Date	11/20/2020
Direction	NB

Video	Vehicle	Time*											Traffic Signal Status**			Comment(s)
		Arrival	Depart	Calculation									Red	Yellow	Green	
				Arrival (Degree)				Depart (Degree)				Duration (Decimal) (second)				
				h	m	s	sss	h	m	s	sss					
NB #17-19	Detector	19														
	1	13:07:02	13:07:03	13	7	2	6	13	7	3	4	0.93	x			
	2	13:07:29	13:07:30	13	7	29	10	13	7	30	27	1.57	x			
	3	13:08:47	13:08:48	13	8	47	23	13	8	48	21	0.93	x			
	4	13:08:59	13:09:00	13	8	59	21	13	9	0	25	1.13	x			
	5	13:10:19	13:10:20	13	10	19	10	13	10	20	12	1.07	x			
	6	13:10:41	13:10:42	13	10	41	7	13	10	42	8	1.03	x			

Process and Reduce Event Log Data

timestamp	eventID
6:00:09.4	8
6:00:26.4	1
6:01:20.2	8
6:01:37.2	1
6:02:07.6	8
6:02:24.6	1
6:02:36.2	82
6:02:36.9	81
6:02:44.6	8
6:03:07.9	1
6:03:32.7	82
6:03:33.4	81
6:03:33.9	8
6:03:52.9	1
6:04:26.2	82
6:04:26.9	81
6:04:38.8	82
6:04:39.6	81
6:04:54.6	8

- Processing and Reduction

Event ID	Name	Description	Parameter Description
1	Phase Begin Green	Set when either solid or flashing green indication has begun.	Phase #
8	Phase Begin Yellow Clearance	Set when phase yellow indication becomes active and clearance timer begins.	Phase #
81	Vehicle Detector Off	Vehicle detector has turned off. Detector on and off events are triggered post any detector delay/extension processing.	Vehicle detector #
82	Vehicle Detector On	Vehicle detector has turned on. Detector on and off events are triggered post any detector delay/extension processing.	Vehicle detector #

- Number of Activations
- Detector On Duration
- Cycle Duration
- Occupancy = Detector On Duration / Cycle Duration

Detector Validation

- Compare drone video logs to event logs
  - Detector On Duration
    - Compare means of each distribution

Detector On Duration: t-Test: Paired Two Sample for Means		
	Variable 1	*Variable 2*
Mean	8.025	8.325
Variance	17.0071	17.70916667
Observations	4	4
Pearson Correlation	0.969743814	
Hypothesized Mean Difference	0	
df	3	
t Stat	-0.583524346	
P(T<=t) one-tail	0.300256457	
t Critical one-tail	2.353363435	
P(T<=t) two-tail	0.600512915	
t Critical two-tail	3.182446305	

Detector Indication (minutes:seconds.00)				Detector On Duration	
Video Log		Event Log		Video Log	Event Log
On	Off	On	Off	= Off - On	= Off - On
43:29.67	43:31.13	43:30.10	43:31.70	0:00:01.46	0:00:01.60
43:32.13	43:33.27	43:32.60	43:33.80	0:00:01.14	0:00:01.20
43:37.80	43:38.67	43:38.20	43:39.10	0:00:00.87	0:00:00.90
43:44.37	43:44.90	43:44.90	43:45.40	0:00:00.53	0:00:00.50
43:46.53	43:47.10	43:47.00	43:47.60	0:00:00.57	0:00:00.60
43:59.33	43:59.90	43:59.70	44:00.40	0:00:00.57	0:00:00.70
44:07.23	44:08.40	44:07.80	44:09.00	0:00:01.17	0:00:01.20
44:12.43	45:24.77	44:12.90	45:25.40	0:01:12.34	0:01:12.50
45:28.30	45:29.60	45:28.80	45:30.30	0:00:01.30	0:00:01.50
45:31.00	45:32.23	45:31.70	45:32.80	0:00:01.23	0:00:01.10
45:34.87	45:36.03	45:35.50	45:36.70	0:00:01.16	0:00:01.20
45:47.63	45:47.93	45:48.20	45:48.50	0:00:00.30	0:00:00.30

  - Number of activations

$$\frac{Total\ Observation\ Event\ Log\ Activations - Total\ Observation\ Video\ Log\ Activations}{Total\ Observation\ Video\ Log\ Observations}$$

Detector Validation

- If either test is out of range, do not use detector for algorithm development
  - Activations, within 10%
  - Detector On Duration, statistically significant difference

Det	Activations			Detector On Duration Mean			Usable?
	Manual	Event Log	Difference	Manual	Event Log	Difference	
1	100	95	-5*	00:00.3	00:00.4	00:00.0	Y
2	105	103	-2	00:00.3	00:00.4	00:00.0	Y
3	72	72	0	00:00.3	00:00.3	00:00.05**	N
4-6	100	90	-10	00:00.4	00:00.5	00:00.1	Y
7	58	58	0	00:03.7	00:03.7	00:00.0	Y
8	75	75	0	00:02.4	00:02.6	00:00.2	Y
9-10	103	98	-5	00:03.8	00:04.9	00:01.1	Y
11-12	59	76	17*	00:09.4	00:08.0	-00:01.40	N
13-14	78	59	-19*	00:07.8	00:09.3	00:01.6	N
15	100	48	-52*	00:00.2	00:00.6	00:00.34**	N
16	100	58	-42*	00:00.3	00:00.9	00:00.59**	N
17-18	100	93	-7	00:01.0	00:01.0	00:00.1	Y
* indicates a difference of >10% between the Manually reported and Event Log activations							
** indicates Significant Difference in the Detector On Durations as reported by the t-Test							

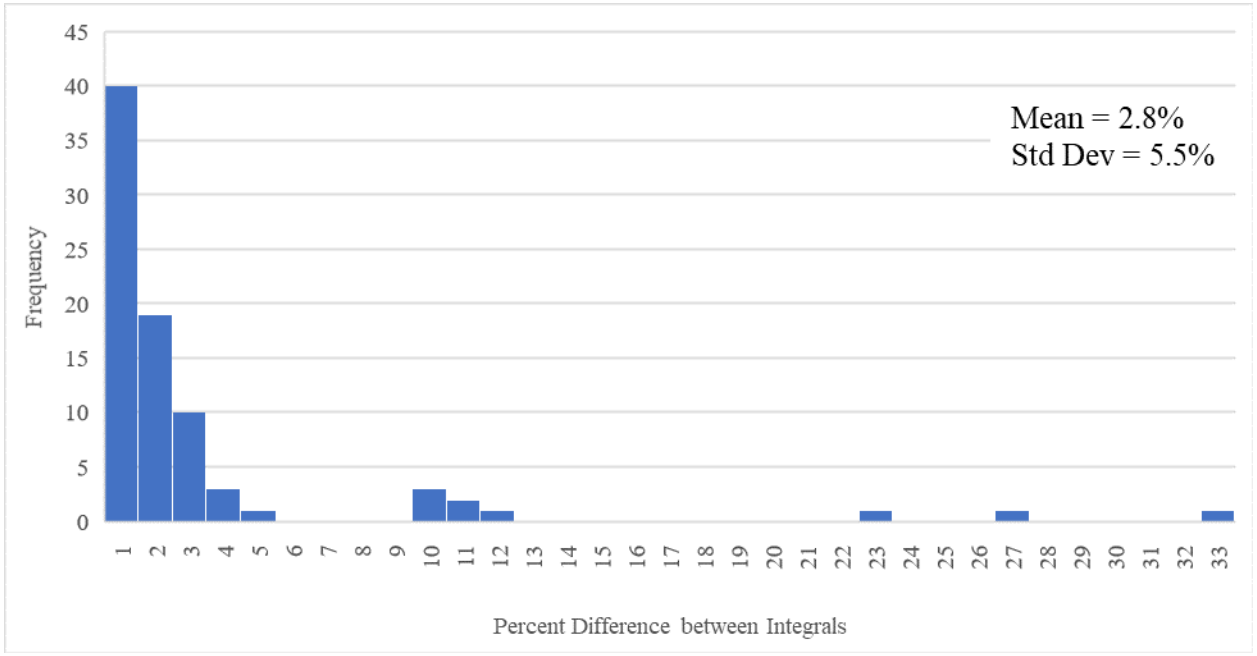
Detector Verification Outcome Overview

Usable Detectors from Each Study Intersection					
Intersection	Det#	MT#		Lanes	Location
OR22 at I-5	1	2	Loop	1	Advanced
	2	3		1	Advanced
	4-6	5		3	Advanced
	7	8		1	Advanced
	8	9		1	Advanced
	9-10	10		2	Advanced
	17-18	18		2	Advanced
OR34 at I-5	2	2	Loop	1	Advanced
	7	8		1	Advanced
	8	9		1	Advanced
	9	12		1	Advanced
	13	13	Radar	1	Stop Bar
	14	14		1	Stop Bar
	23	23		1	Stop Bar
	25	25		1	Stop Bar
	27	27		1	Stop Bar
	28	28		1	Stop Bar
OR34 at Peoria	3-4	6	Loop	2	Advanced
	10	7		1	Advanced
	16	17		1	Advanced
	20	1		1	Advanced
	21-22	13		1	Stop Bar
	23	22		1	Advanced
	24	23		1	Advanced
US20 at 15th	1	2	Loop	1	Advanced
	2	3		1	Advanced
	3	15		1	Advanced
	4-5	27		1	Stop Bar
	8	8		1	Advanced
	9-10	9		1	Stop Bar
	13	1		1	Advanced
	15	16		1	Advanced
	19	22		1	Advanced
US26 at Meinig	4	8	Loop	1	Advanced
	5-6	9		1	Stop Bar
	7	21		1	Advanced
US101 at 22nd	3-4	4	Loop	1	Stop Bar
	5-6	5		1	Stop Bar
	7	15		1	Advanced
	8-9	27		1	Stop Bar
	17-18	18		1	Stop Bar
	19-20	19		1	Stop Bar
	21	1		1	Advanced
	24	22		1	Advanced
	25-26	23		1	Stop Bar

- 79 detection zones underwent comparative analysis (70 inductive loop and 9 radar).
- 39 inductive loop and 6 radar zones passed the analysis

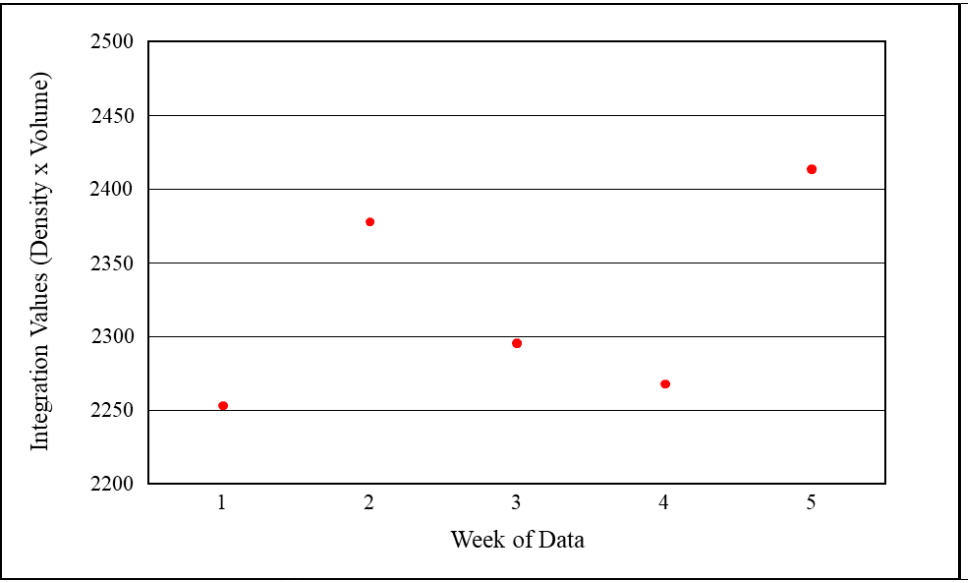
Develop Performance Datasets for Algorithm Comparisons

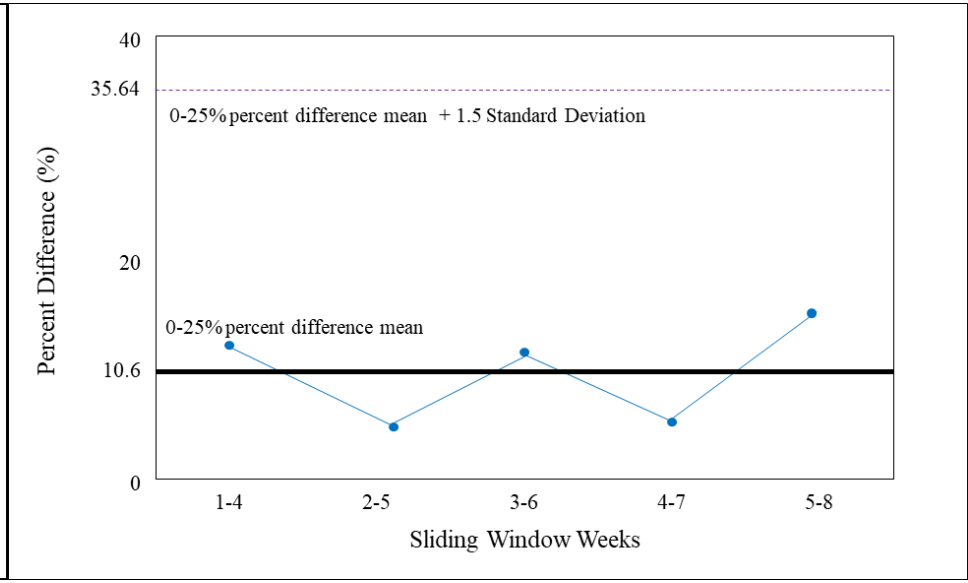
- Predicted Performance Dataset (EPD)
  - Similar process to EPD development
  - Integrated to 25% of Vertex

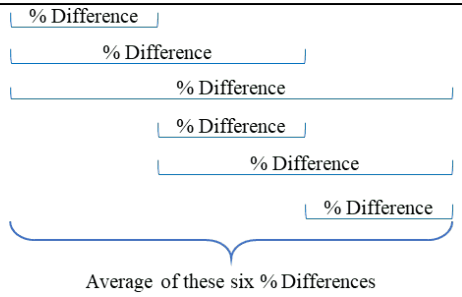


Health Assessment Over Time

- Sliding Window Technique and Control Chart
- Mean + 1.5 Std Dev from EPD





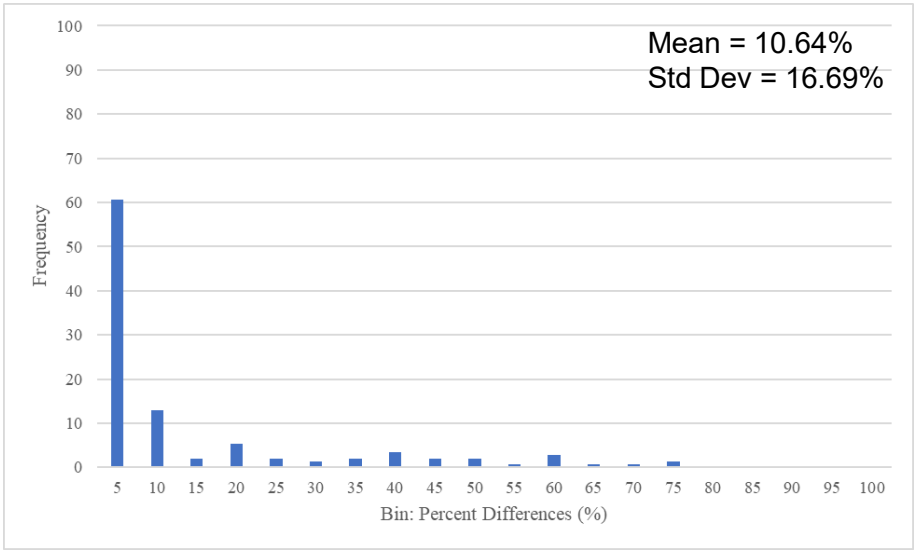


	25%	50%	75%	100%
Mean	10.64	13.51	24.54	142.55
Std Dev	16.69	24.81	36.36	386.77

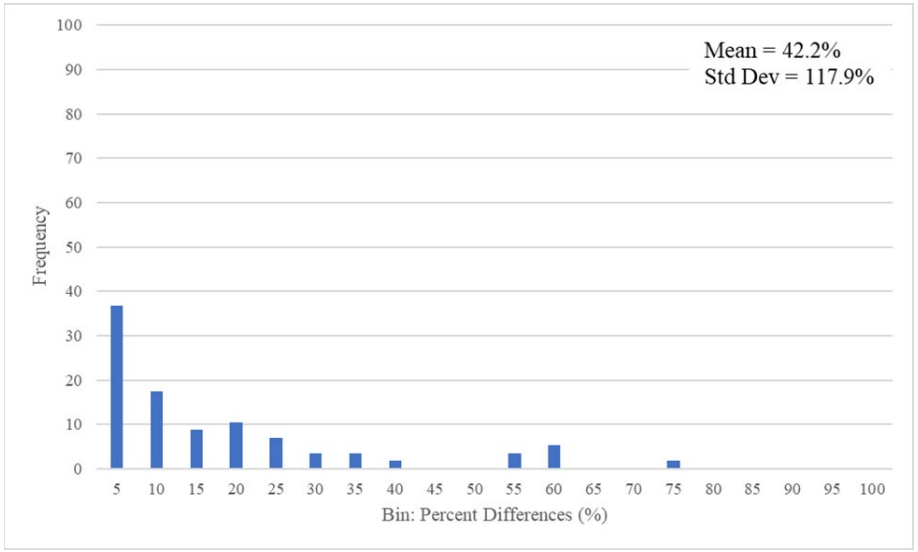
Performance Dataset Verification

Verification

- Compare validated detectors with underperforming detectors from Task 6



Validated Detectors

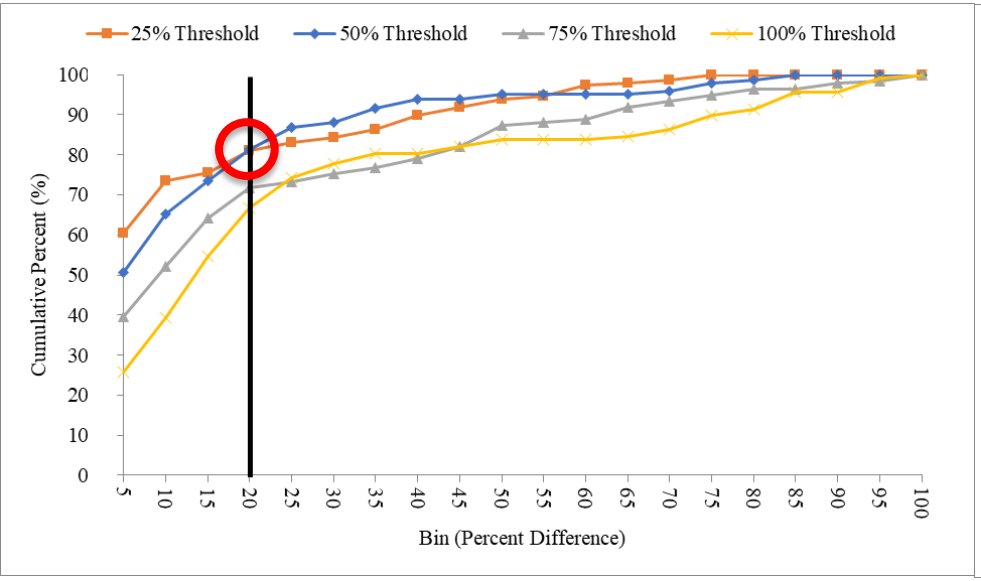


Underperforming Detectors

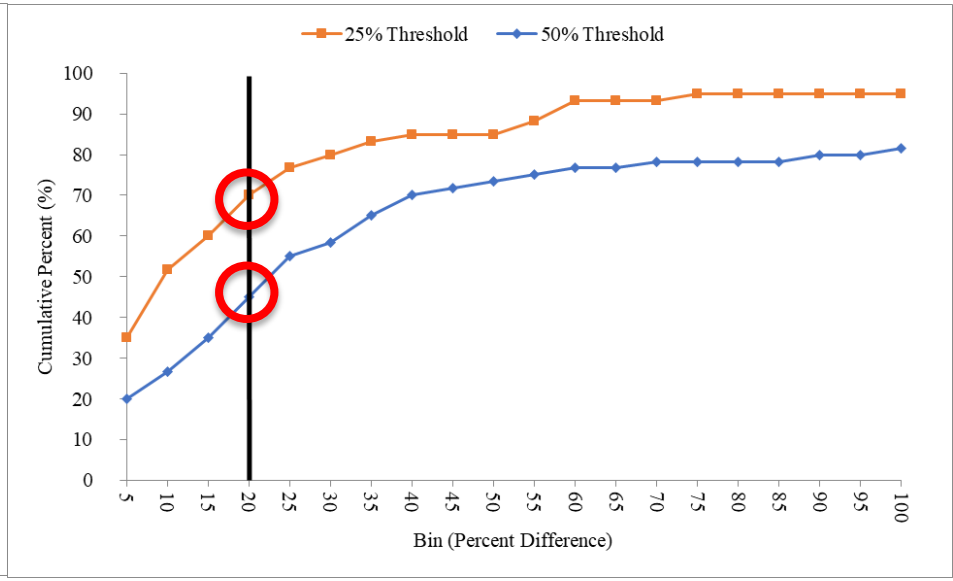
Performance Dataset Verification

Verification

- Compare validated detectors with underperforming detectors from Task 6



Validated Detectors

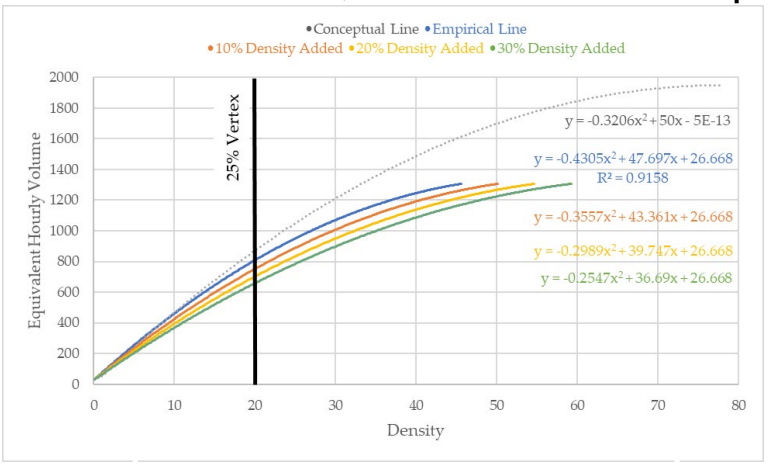


Underperforming Detectors

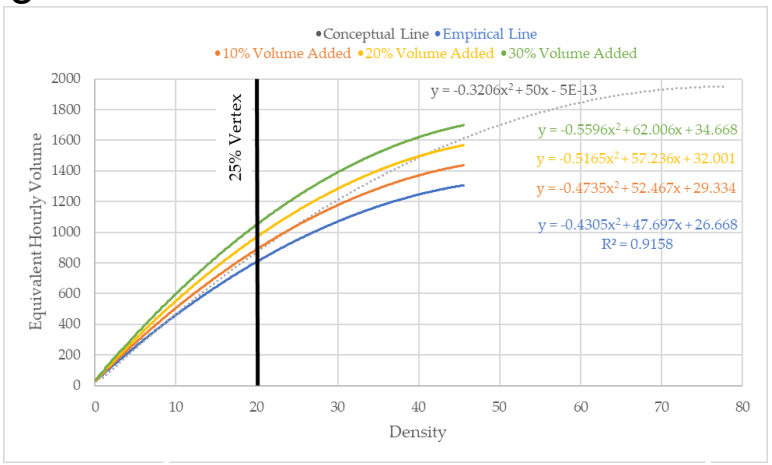
Performance Dataset Verification

Verification

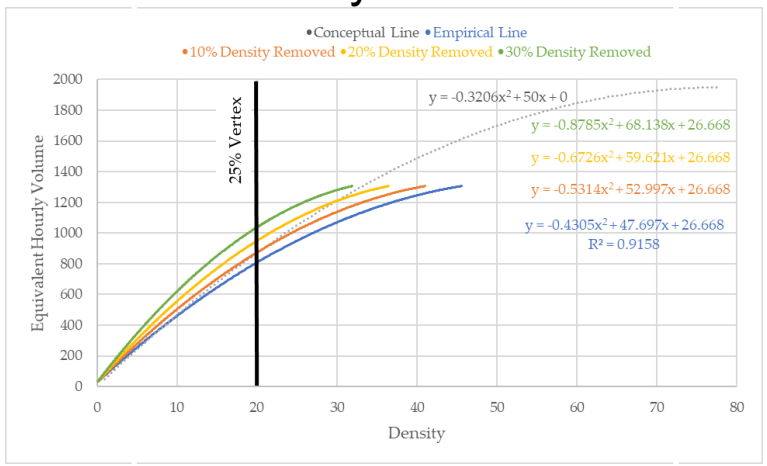
- Increase / Decrease volume and density values by 10%, 20%, and 30% and compare integral differences



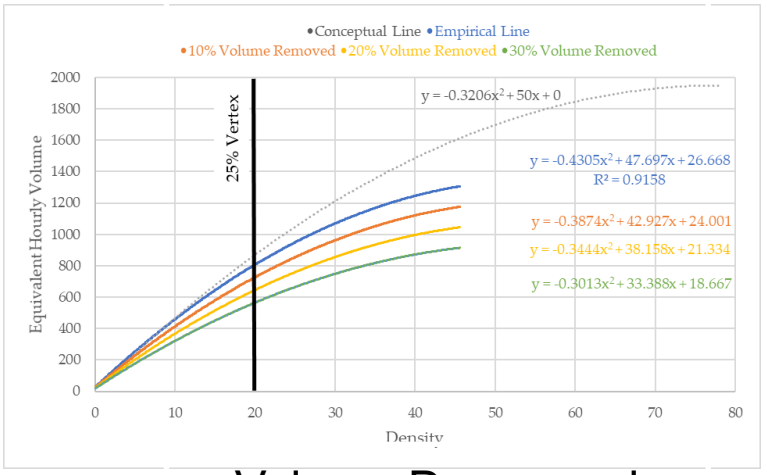
Density Increased



Volume Increased



Density Decreased



Volume Decreased

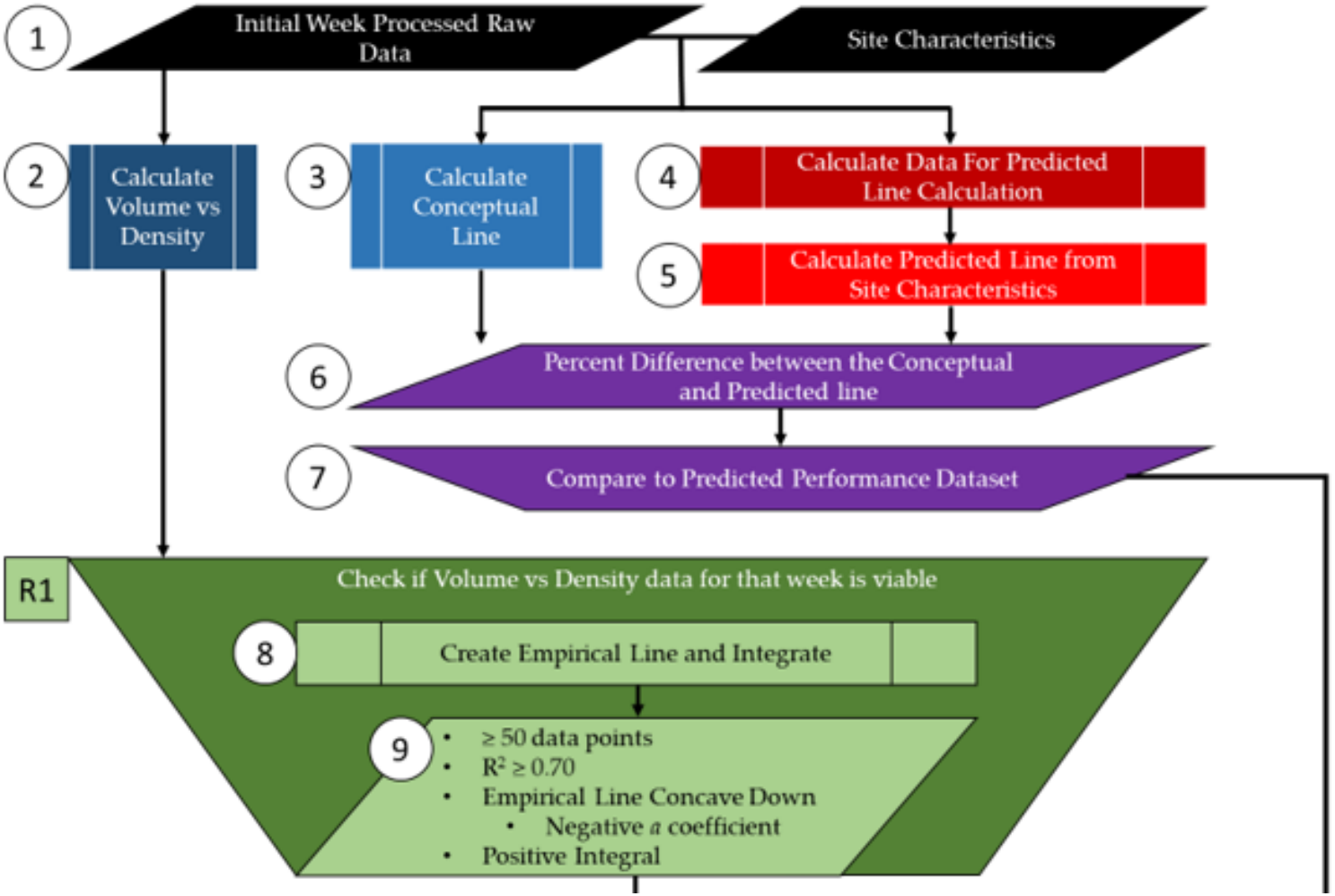
Performance Dataset Verification

Verification

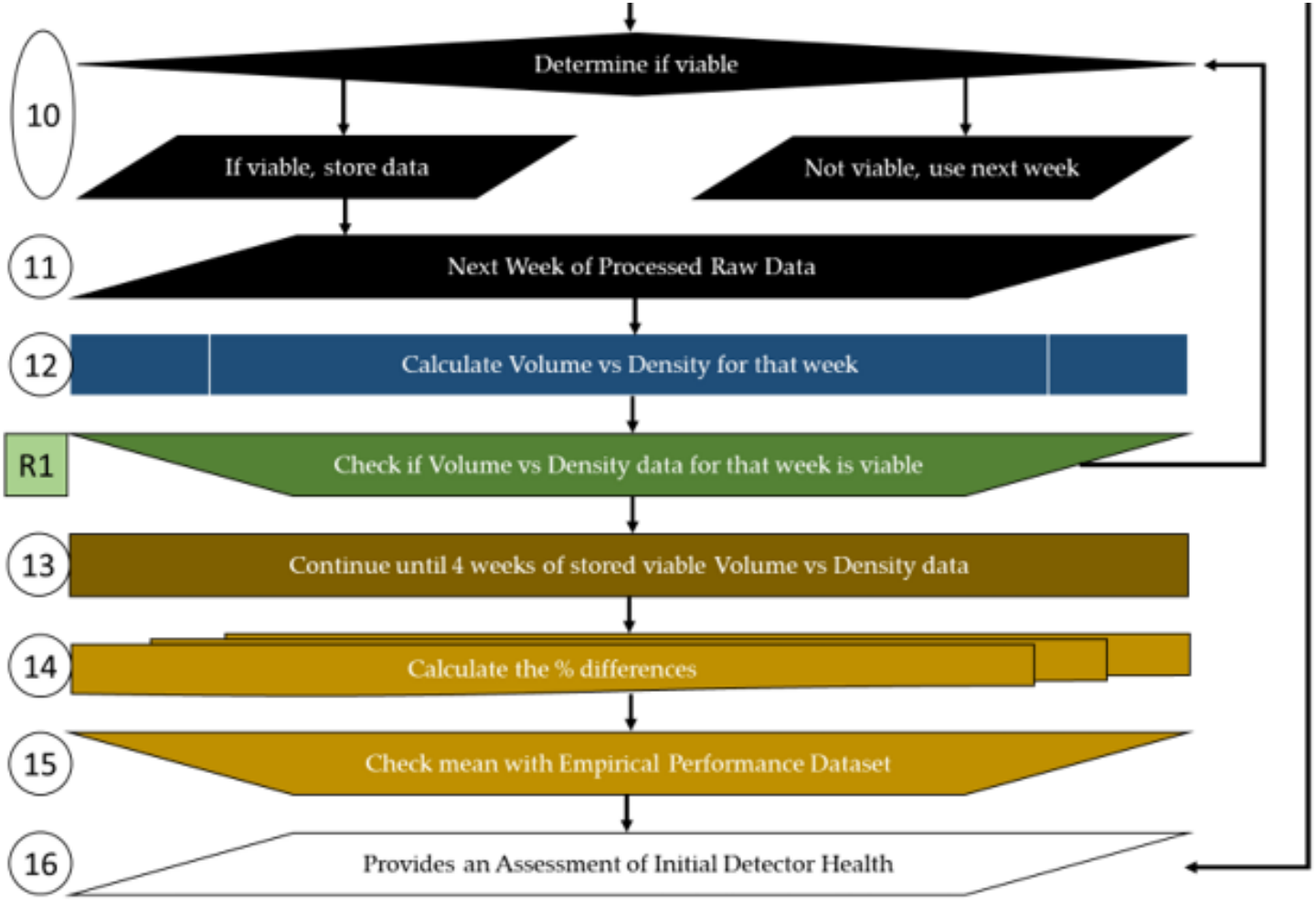
- Mean and Std Dev of the percent differences between empirical and conceptual lines for healthy detectors is 10.64% and 16.69% respectively
- Using 1.5 Std Dev from the mean, threshold of 35.68% difference indicates this may not be sensitive enough to identify most malfunctions (note this is just one detector compared)

% Difference from Conceptual Integral (Conceptual – x) / Conceptual Integral from 0 to 25% of Conceptual Vertex		
Empirical		2.2%
Density Added	10% Added	9.5%
	20% Added	15.8%
	30% Added	21.2%
Volume Added	10% Added	7.6%
	20% Added	17.4%
	30% Added	27.2%
Density Removed	10% Removed	6.5%
	20% Removed	17.0%
	30% Removed	29.7%
Volume Removed	10% Removed	12.0%
	20% Removed	21.7%
	30% Removed	31.5%

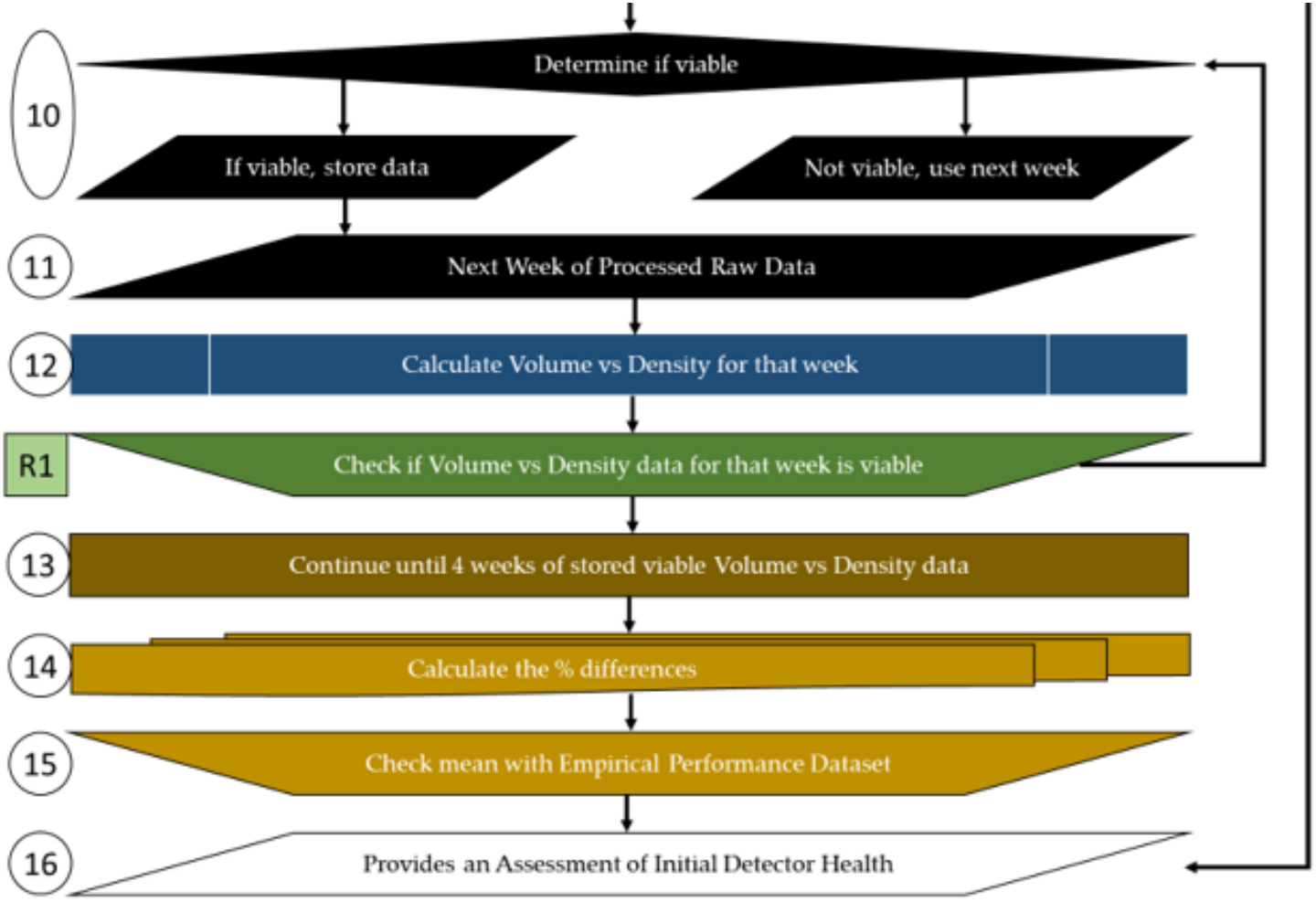
Initial Detector Health Assessment



Initial Detector Health Assessment



Initial Detector Health Assessment



Health Assessment Over Time