

CAMP

Vehicle Safety Communications 3

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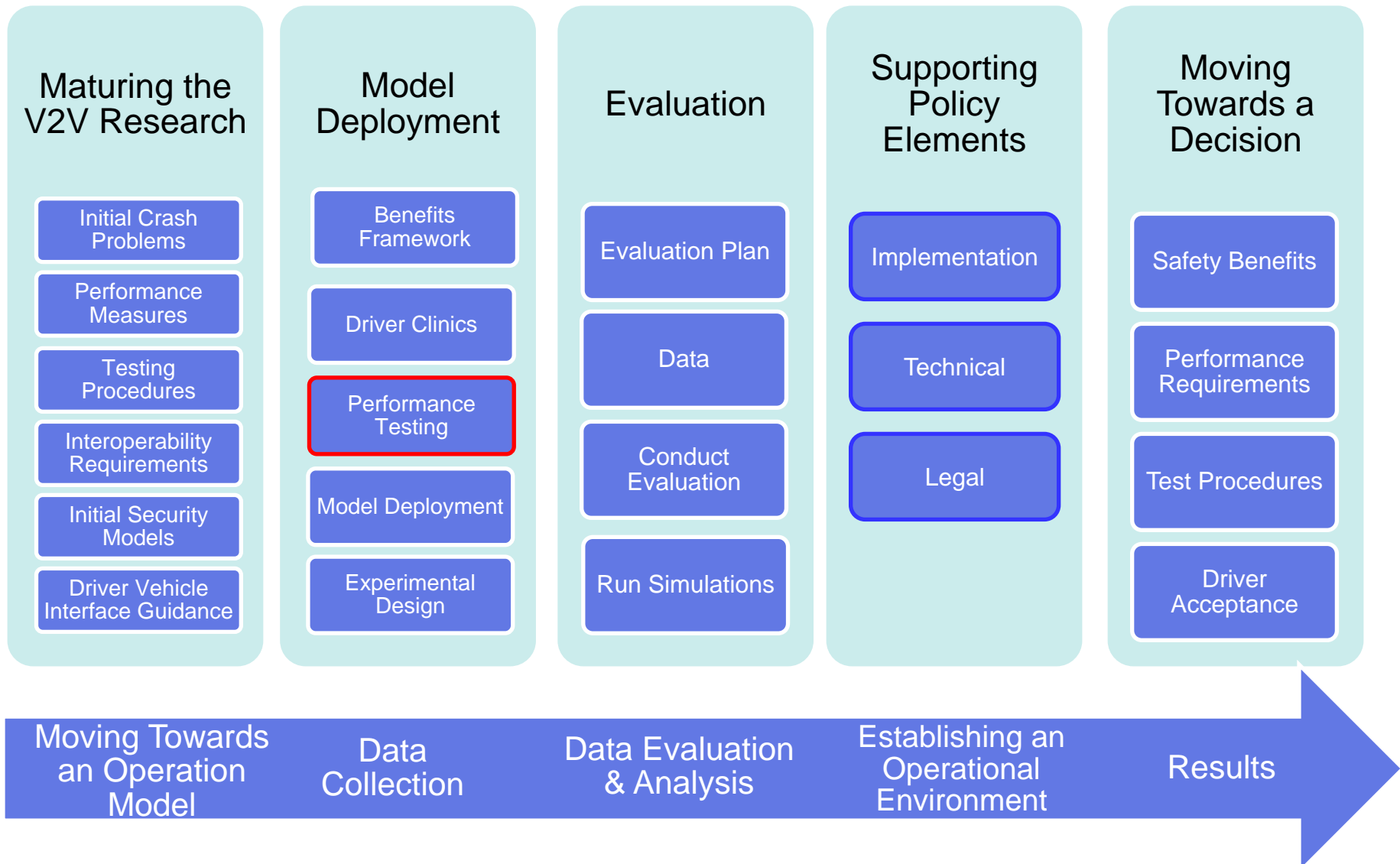
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Intelligent Transportation Systems

Connected Vehicle
V2V Safety Systems Performance
25 Sep 2012

V2V Safety Framework



Systems Performance Testing

Overview

Main Testing Concept

- **Motivation:** Collaborative System Requirements
 - Stakeholder Consensus
 - Some Minimum Performance To be Required (transmitter)
- **Scope:**
 - Assess performance and reliability
 - 5.9 GHz DSRC communications
 - GPS-based positioning
 - Diverse geographic locations
 - Environmental Conditions

Important Subsystems To Evaluate

- Positioning
 - Based on Global Navigation Satellite Systems (GNSS)
 - assisted by integrated sensors (vehicle bus)
 - wheel speed only in integrated vehicles
 - Relative Positioning Performance for V2V
 - absolute performance needed for V2I and performance guarantees
- Communications
 - DSRC
 - Range and Link Quality (Power, Antenna, Line-of-Sight)
 - (Network Scalability)
- Applications
 - Pre-competitive implementations help shape protocols

Previous System-Level Tests (2009)

1. Absolute Positioning Performance Evaluation

Table 7-1: Data Collection Summary

Category	Time collected	%
Deep Urban	1:39:54	3.7%
Major Urban Thruway	9:50:03	21.8%
Major Rural Thruway	8:40:09	19.2%
Major Road	8:10:40	18.1%
Local Road	6:30:48	14.4%
Interstate/Freeway	9:04:51	20.1%
Mountains	1:08:32	2.5%
Total	45:04:57	

2. Real-Time Kinematic (RTK) Navigation

- i. More over-the-air information (pseudorange)
- ii. Accuracy comparable to non-RTK transmissions for some correction-enabled receivers (WAAS)

3. Cross-channel interference Evaluation

4. Range, Power, Packet Error Rate Evaluation

Testing during DACs - Overview

Types of tests:

1. Open-road testing

- 8 hrs, 8 vehicles
- 6 locations



2. Targeted testing challenging locations

3. Closed-road testing closed track - refined warning timing

(Intersection Movement Assist, Do-not-pass Warning)

Performance Metrics

1. Positioning fix quality and availability, positioning errors
2. Communications error rates, signal strength, packet gap
3. Application-level target lane classification

Locations 1-6: Trip Overview Totals

Approximate Totals Per Vehicle Per Group

Group A

CATEGORY	PLANNED TIME *	TIME COLLECTED	TIME (%)	DISTANCE (MILES)	DISTANCE (%)
Deep Urban	1:39:54	2:02:34	3.76%	30.56	1.17%
Major Rural Thruway	9:50:03	14:28:07	26.63%	826.83	31.68%
Major Urban Thruway	8:40:09	8:16:24	15.23%	419.22	16.06%
Major Road	8:10:40	9:24:31	17.31%	308.80	11.83%
Local Road	6:30:48	6:36:01	12.15%	152.93	5.86%
Interstate/Freeway	9:04:51	8:18:10	15.28%	597.84	22.91%
Mountains	1:08:32	5:14:33	9.65%	273.69	10.49%
Grand Total	45:04:57	54:20:20	100.00%	2609.85	100.00%

Group B

CATEGORY	PLANNED TIME *	TIME COLLECTED	TIME (%)	DISTANCE (MILES)	DISTANCE (%)
Deep Urban	1:39:54	1:39:30	3.14%	19.18	0.85%
Major Rural Thruway	9:50:03	13:14:32	25.05%	739.01	32.84%
Major Urban Thruway	8:40:09	9:16:49	17.56%	399.69	17.76%
Major Road	8:10:40	7:54:05	14.95%	189.75	8.43%
Local Road	6:30:48	5:50:18	11.05%	63.70	2.83%
Interstate/Freeway	9:04:51	9:41:42	18.34%	565.54	25.13%
Mountains	1:08:32	5:14:33	9.92%	273.69	12.16%
Grand Total	45:04:57	52:51:29	100.00%	2250.55	100.00%

* Distribution similar to Average driven

Communications Performance

Open Road Communications Conditions and Metrics

Testing Conditions

- Line-of-sight obstructions
- Weather

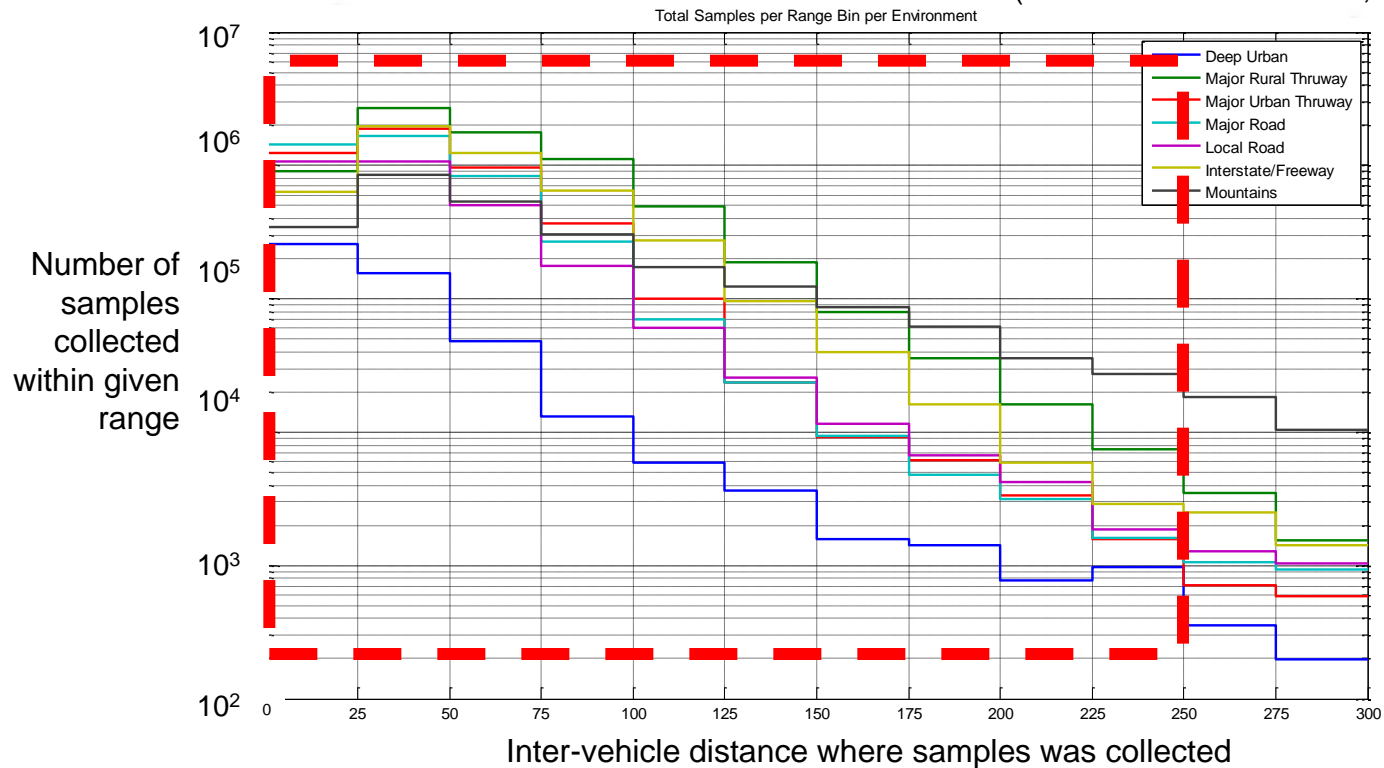
Metrics

- Received Power
- Packet Error Rate
- Inter-arrival times (Inter-Packet Gap)
- Evaluate across various inter-vehicle distances

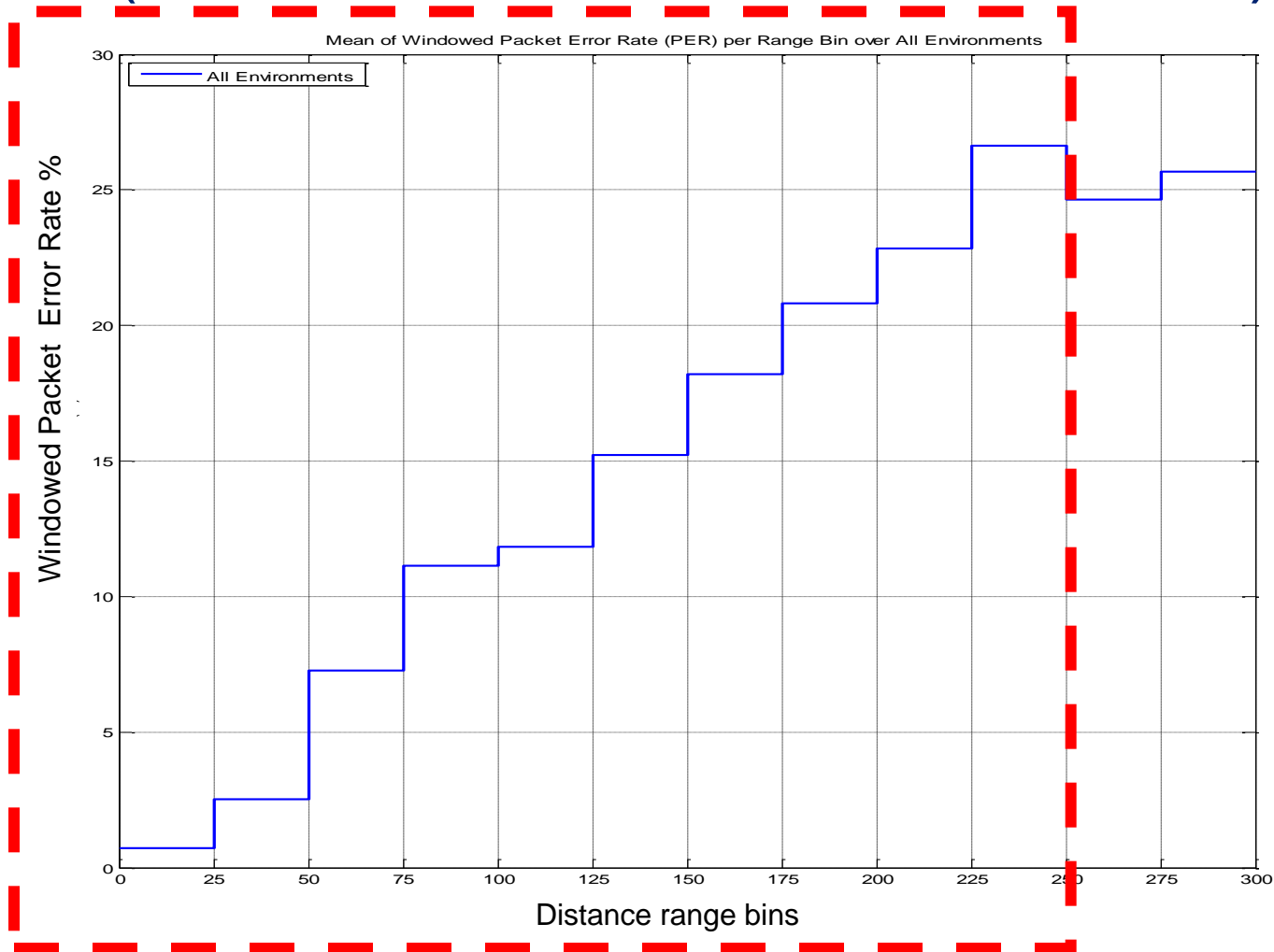
Range Statistics (used for Communications Performance)



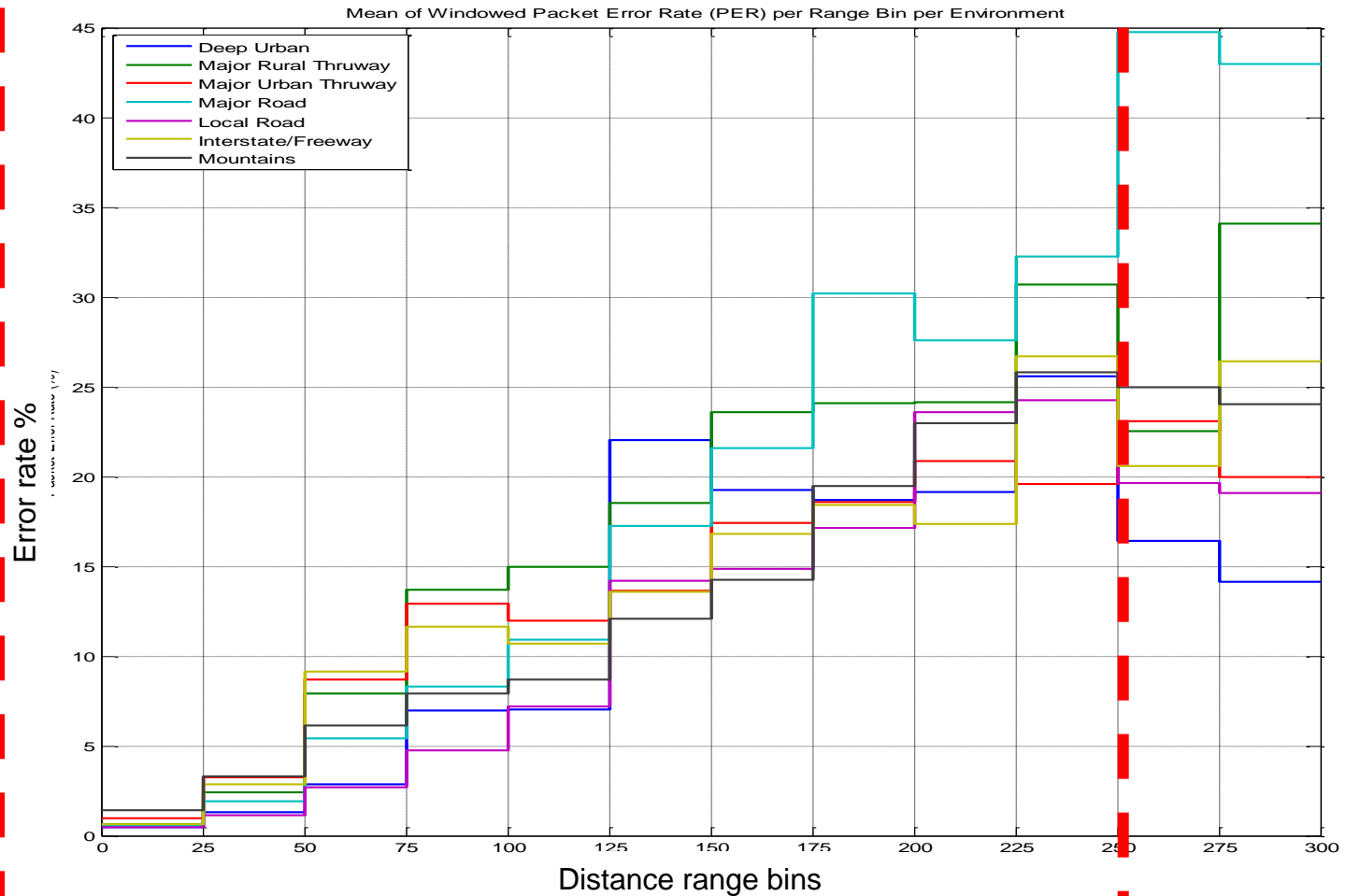
(Data from All the Clinics, all vehicle pairs/links)



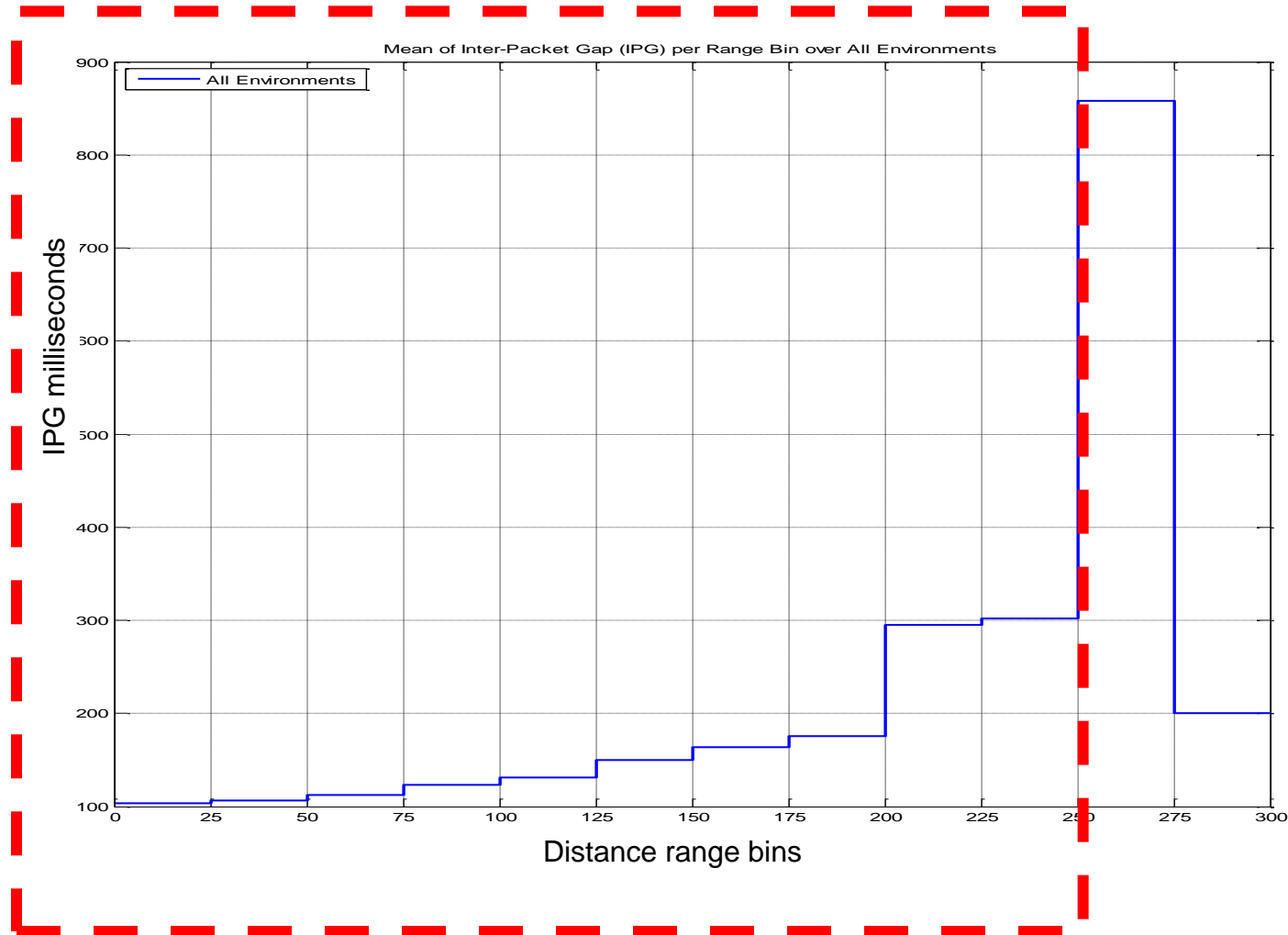
Communications Performance (Mean Packet Error Rate overall)



Communications Performance (Mean Packet Error Rate per environment)



Communications Performance (Inter-packet-gap @ 10Hz / overall)



Open Road Positioning Conditions and Metrics

Testing Conditions

1. Environments affecting signal reception:



2. Geographical, seasonal, and time-of-day variety



Metrics

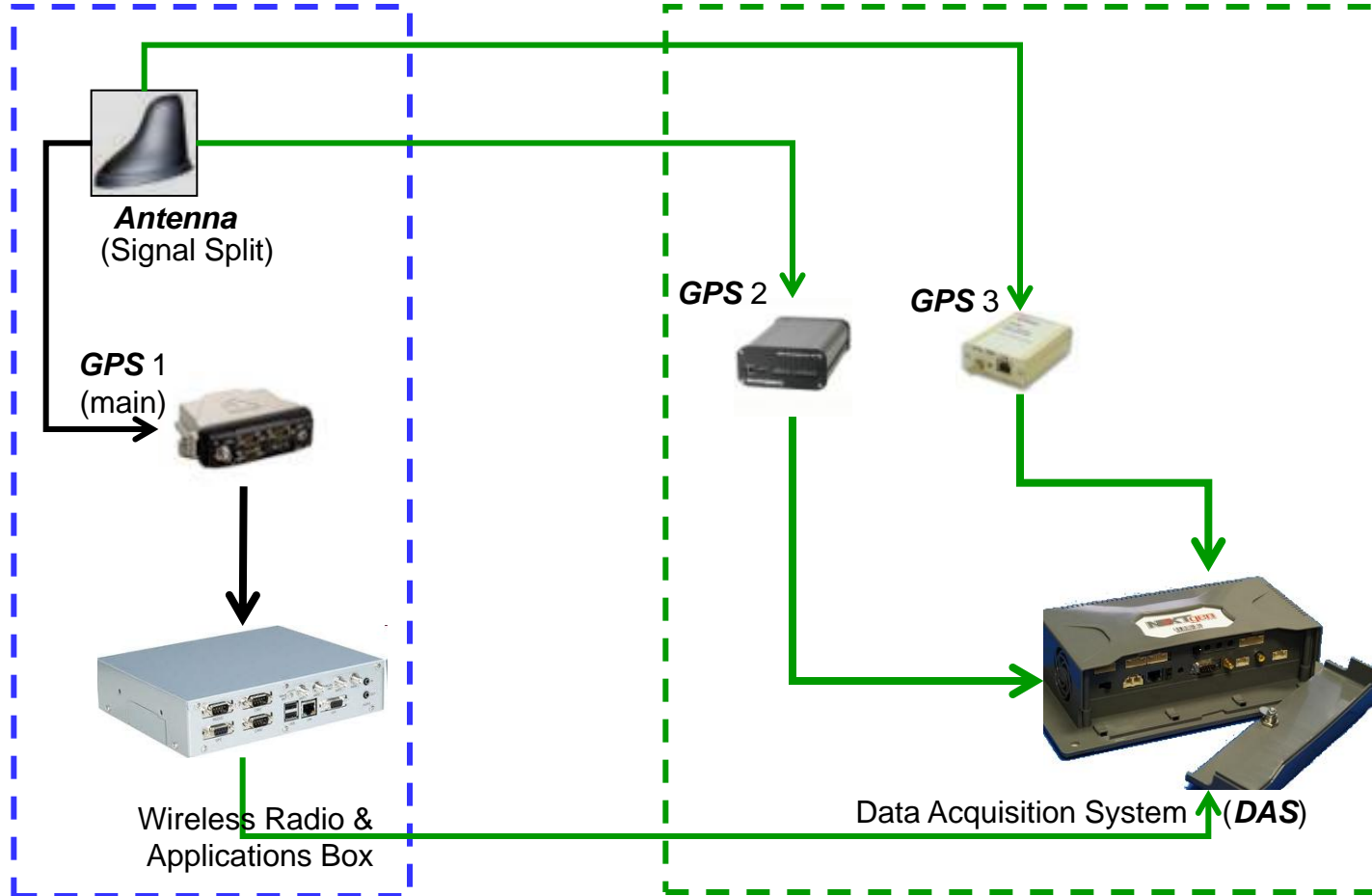
- Positioning Fix **availability** and constellation use
- Signal **reliability** and relative positioning **accuracy**

Five (5) different GPS receivers giving numerous combinations

Positioning Equipment Configuration

Standard Clinics Configuration

Additional Test Vehicle Equipment



Positioning Fix Availability

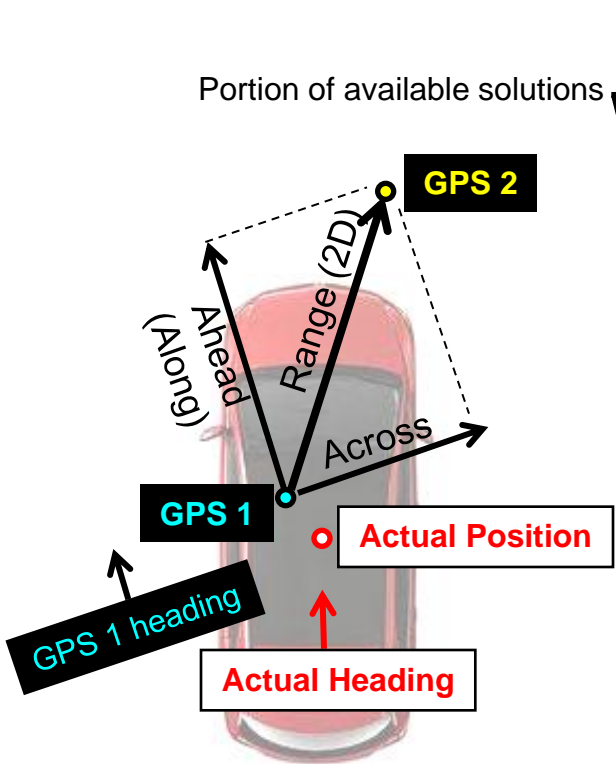
Data from All the Clinics, all vehicles,
Rounded to nearest 1%

Receiver	Solution Availability (% of the time)	
	Deep Urban	All Environments
† SG ₁	77	97
† SG ₀	82	99
† SG ₂	94	88
* AG ₃	98	100
* AG ₂	99	100
* AG ₁	98	100

† **Survey-Grade (SG)** receivers designed for **high SNR, selectivity**,
SG₂ better at lower speeds

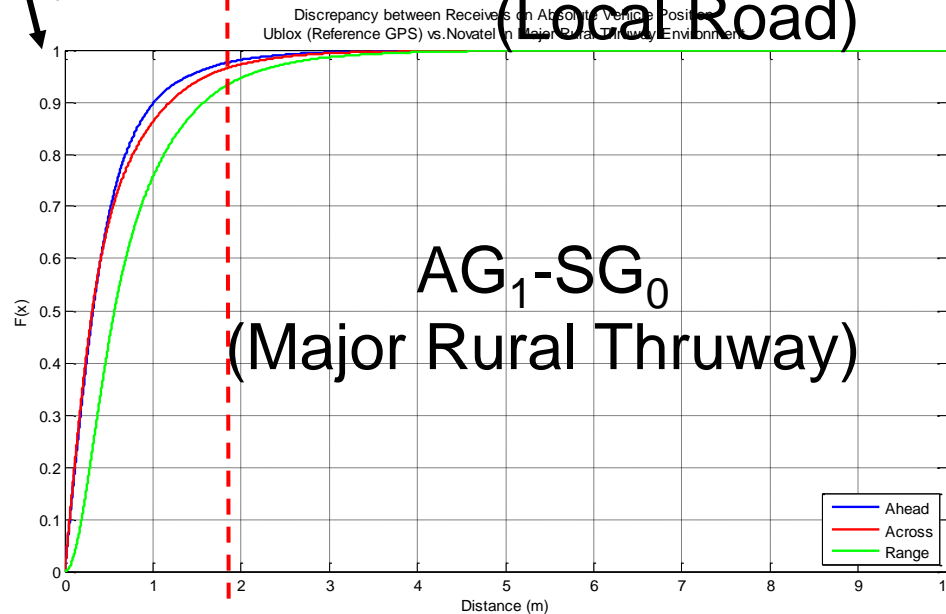
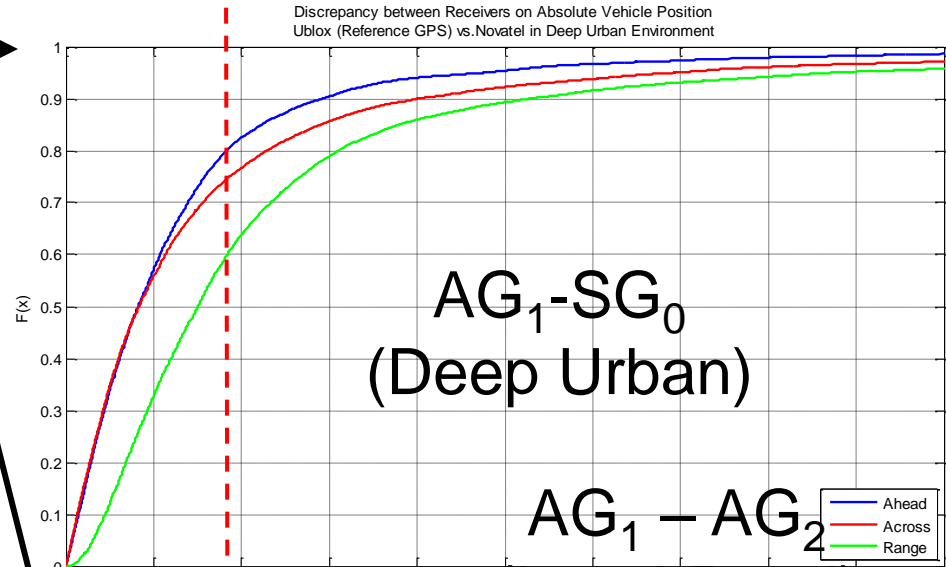
* **Automotive-Grade (AG)** receivers designed for **high availability in challenging environments**

Single Vehicle Position Discrepancy when reported by 2 GPS units



Half Lane Width

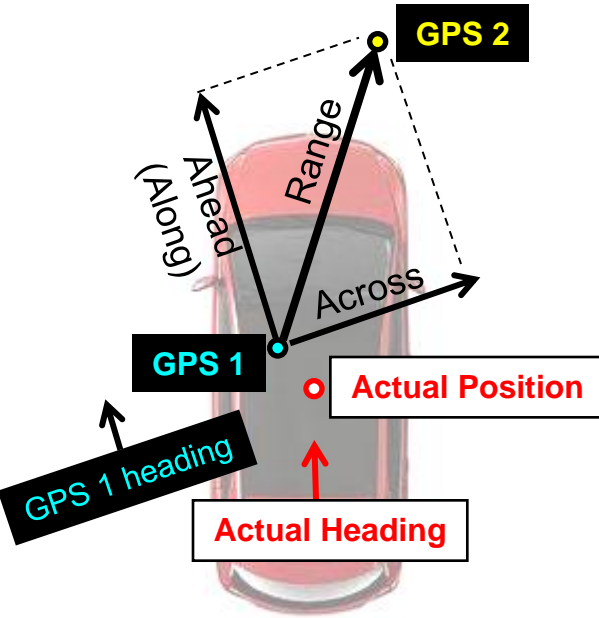
Portion of available solutions



Receiver Discrepancies:

- Across Error
- Ahead (Along) Error
- Range (2D) Error

Single Vehicle Position Discrepancy when reported by 2 GPS units†



% of time **AG₁** is within **1.8m** (Across Path):

Rcv/Env	Deep Urban	Mountain	Major Urban Thruway	Interstate Freeway	Major Road	Local Road	Major Rural Thruway
AG ₃	41	61	61	71	52	46	64
AG ₂	56	70	81	76	81	81	86
AG ₂	44	72	82	90	87	81	87
SG ₁	67	79	84	81	84	88	91
SG ₃ *	64	-	83	61	91	92	91
SG ₀	74	87	95	97	96	91	96

% of time **AG₁** is within **5m** (Across Path):

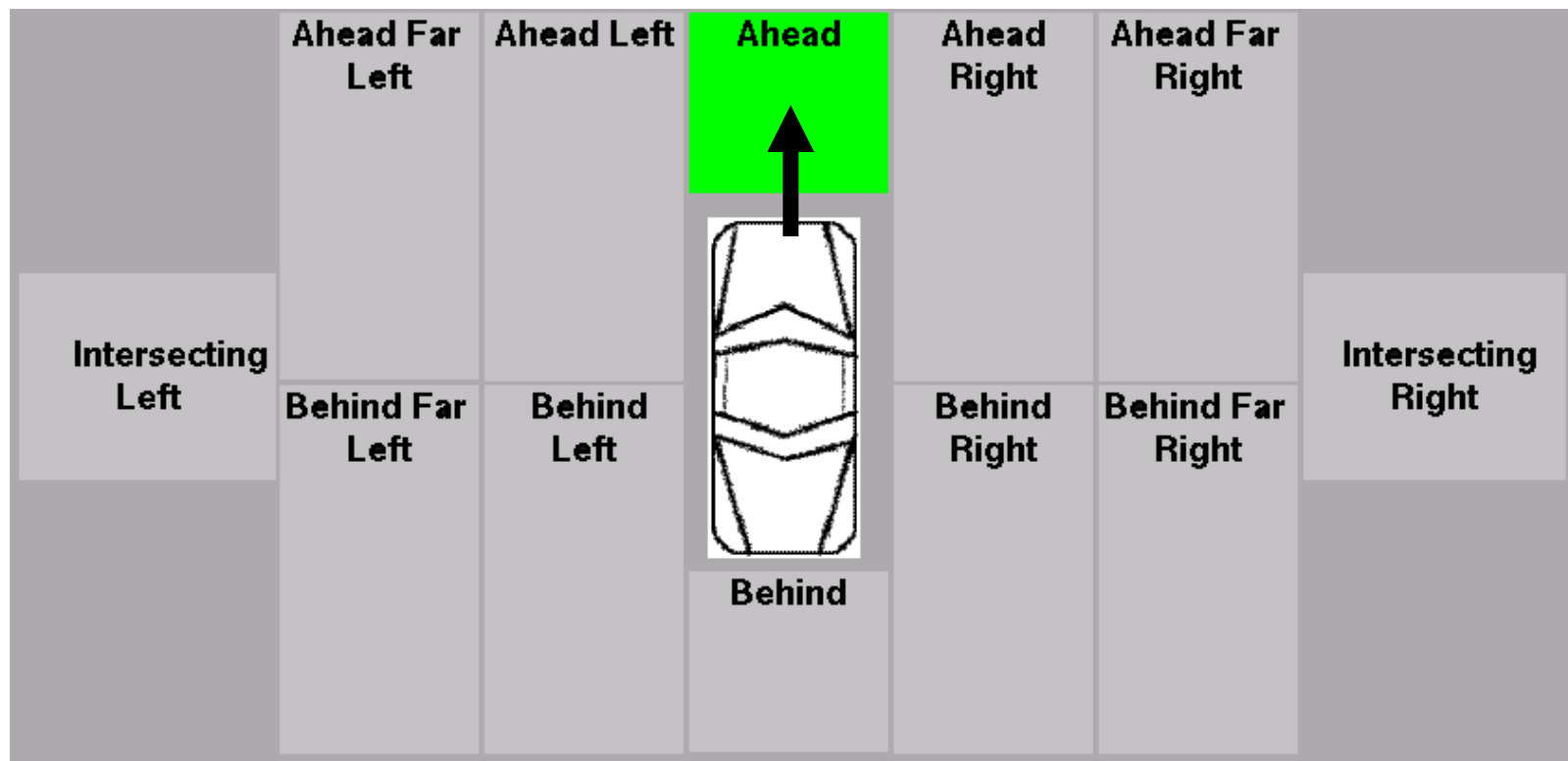
Rcv/Env	Deep Urban	Mountain	Major Urban Thruway	Interstate Freeway	Major Road	Local Road	Major Rural Thruway
AG ₃	81	95	96	99	98	90	99
AG ₂	79	96	98	98	98	97	99
AG ₂	80	97	99	100	100	98	100
SG ₁	83	99	98	99	99	98	100
SG ₃ *	88	-	99	98	99	100	99
SG ₀	92	99	100	100	100	99	100

† Rounded to 1%

* SG₃— Only used in 1st Clinic

Applications Performance

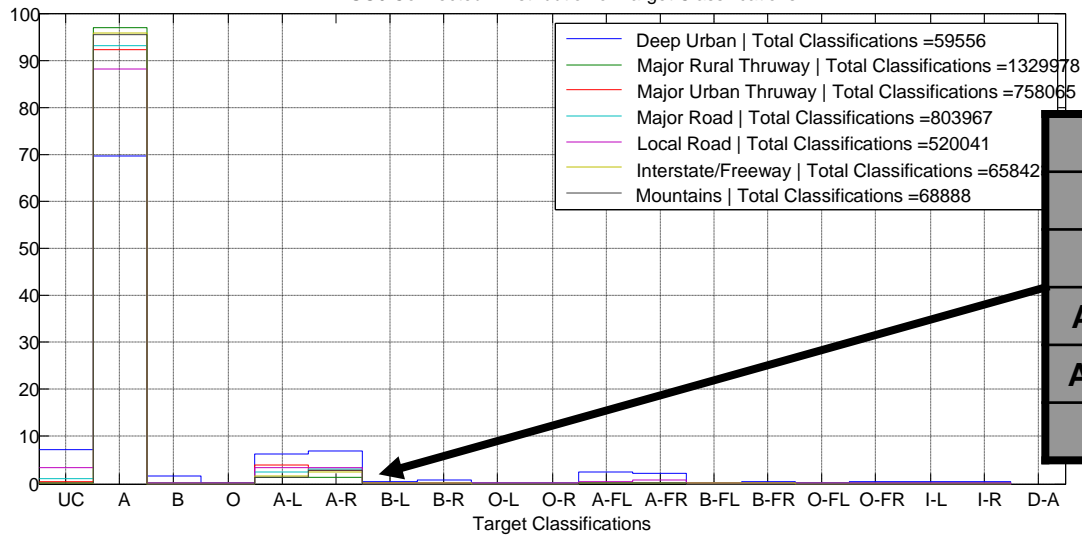
Lane classification of leading vehicles in each group.



SG₀-SG₀ Target Classification

SG0 Connected - Distribution of Target Classifications

% samples of target classification output



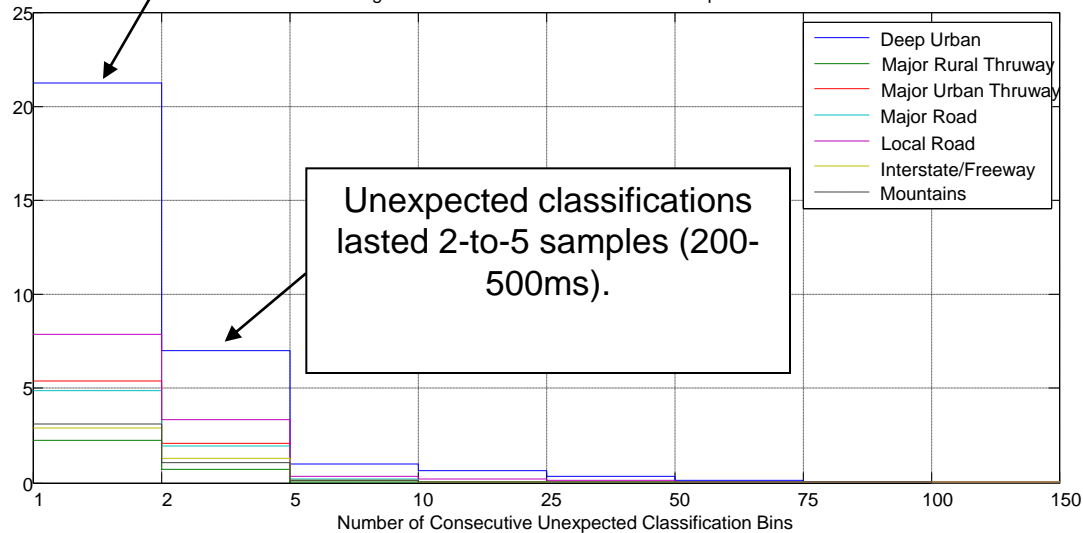
Legend

A	Ahead
A-L	Ahead Left
A-R	Ahead Right
A-F-L	Ahead Far Left
A-F-R	Ahead Far Right
UC	Unclassified

Unexpected classifications lasted one sample, 100ms (as part of total time)

% of Total Target Classifications vs. Consecutive Unexpected Classifications

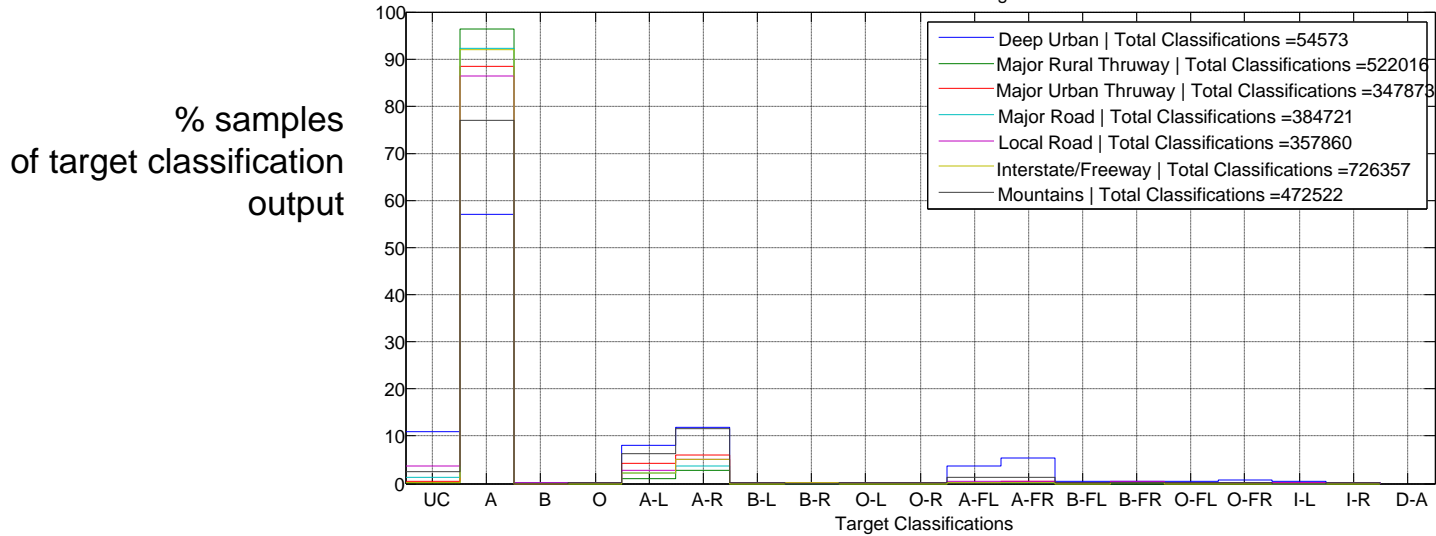
% samples of target classification output



Criteria for Data:
 GPS valid
 Above 5mph
 No Left/Right turn sig.

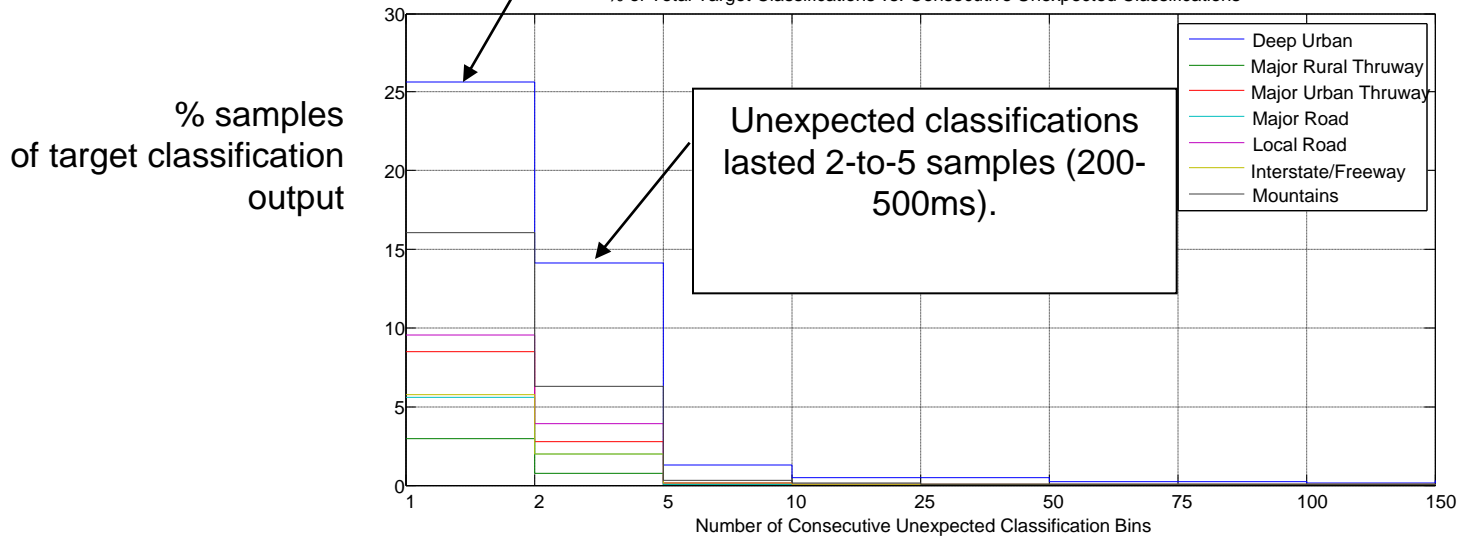
AG₁-AG₁ Target Classification

AG1 Connected - Distribution of Target Classifications



Unexpected classifications lasted one sample, 100ms (as part of total time)

% of Total Target Classifications vs. Consecutive Unexpected Classifications



Conclusions

1. **Positioning & Application** performance
 - Lane-level target classification in most environments
 - Road-level achievable in all environments
 - Deep urban most challenging
2. **Communications** performance
 - Very reliable

Upcoming Work

1. **Positioning** performance
 - Improvement of relative positioning performance
 - Relate to absolute performance
2. **Communications** performance
 - Evaluate network scalability / congested environment performance