BBN-T—(Verizon Technology Organization)

Houston, Texas
E911 Location Technology Field Trial

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June 4–June 14, 2001

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Figure 38: Scatter plot for Scenario S4, Location 2 (CDMA)

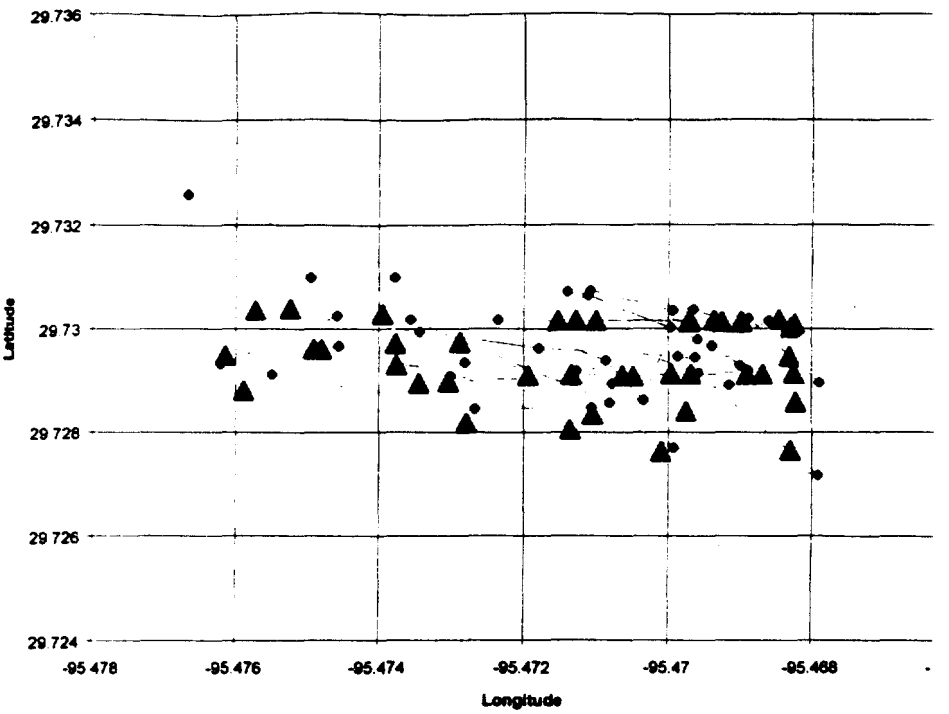

Figure 39: Scatter plot for Scenario S4, Location 3 (CDMA)

Scenario S7—Residential house, brick, upper floor—indoor, stationary (CDMA Summary)

Location 1	Broad Oaks Park, unnumbered two-storey house on corner of Woodway Drive and West Broad Oaks
Location 2	306 Bunker Hill Road
Location 3	Chateaux Dijon, 5331 Beverly Hill, Apt 22A
Fixes	122
67% error	46 m
95% error	74 m

Figure 40: Broad Oaks Park, unnumbered two-storey house on corner of Woodway Drive and West Broad Oaks

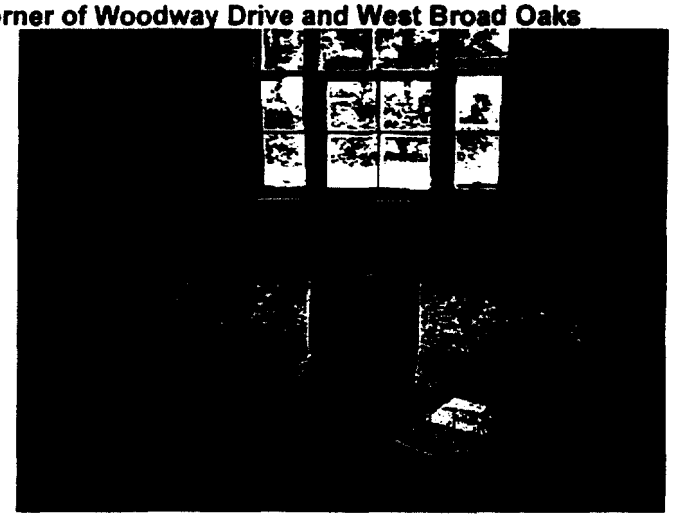

Figure 41: Broad Oaks Park, unnumbered two-storey house on corner of Woodway Drive and West Broad Oaks

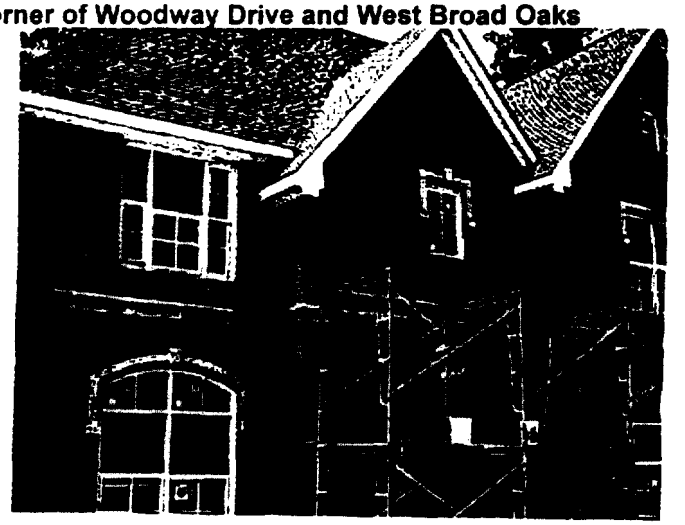

Figure 42: Broad Oaks Park, unnumbered two-storey house on corner of Woodway Drive and West Broad Oaks

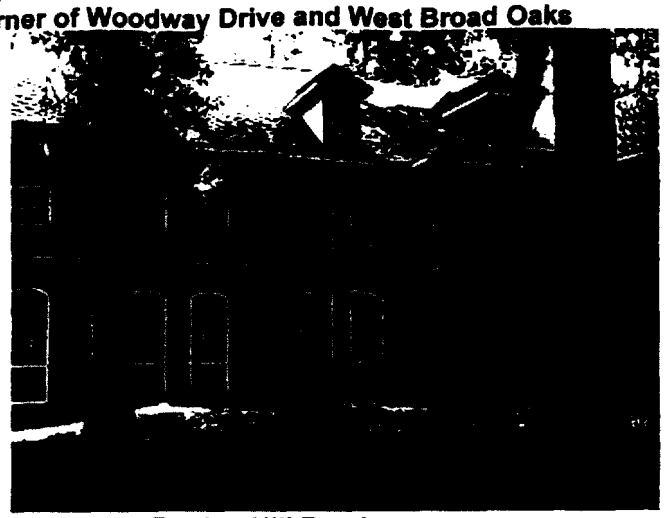

Figure 43: 306 Bunker Hill Road

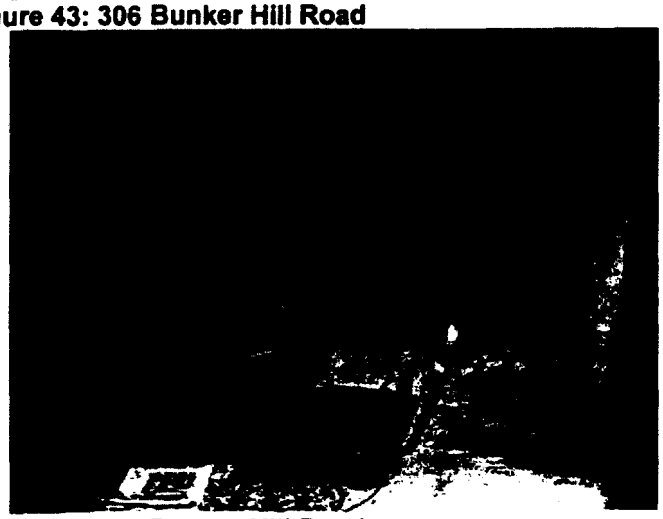

Figure 44: 306 Bunker Hill Road

Figure 45: Chateaux Dijon, 5331 Beverly Hill, Apt 22A

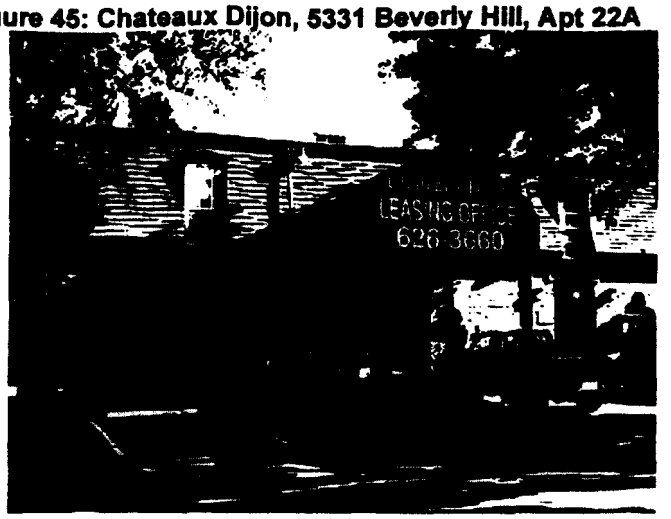

Figure 46: Chateaux Dijon, 5331 Beverly Hill, Apt 22A

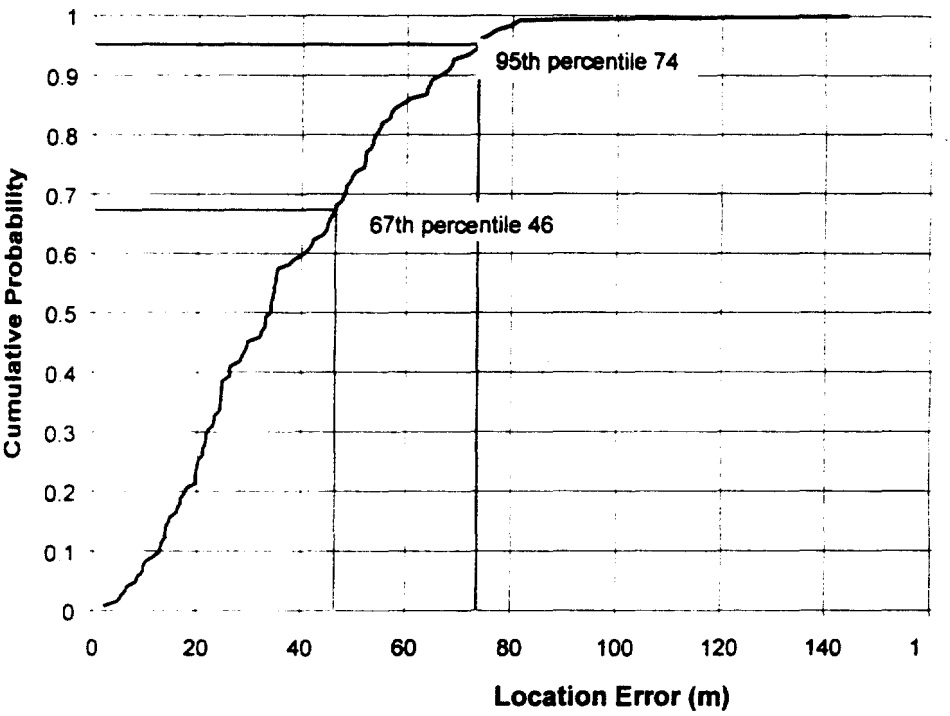

Figure 47: Cumulative Distribution Function for S7 (CDMA)

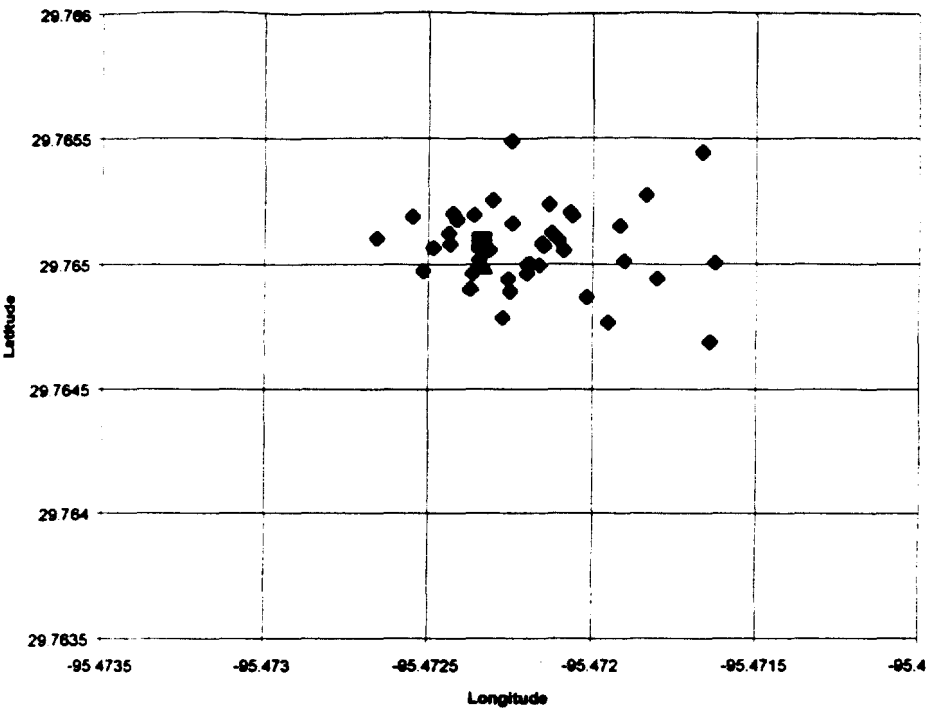

Figure 48: Scatter plot for Scenario S7, Location 1 (CDMA)

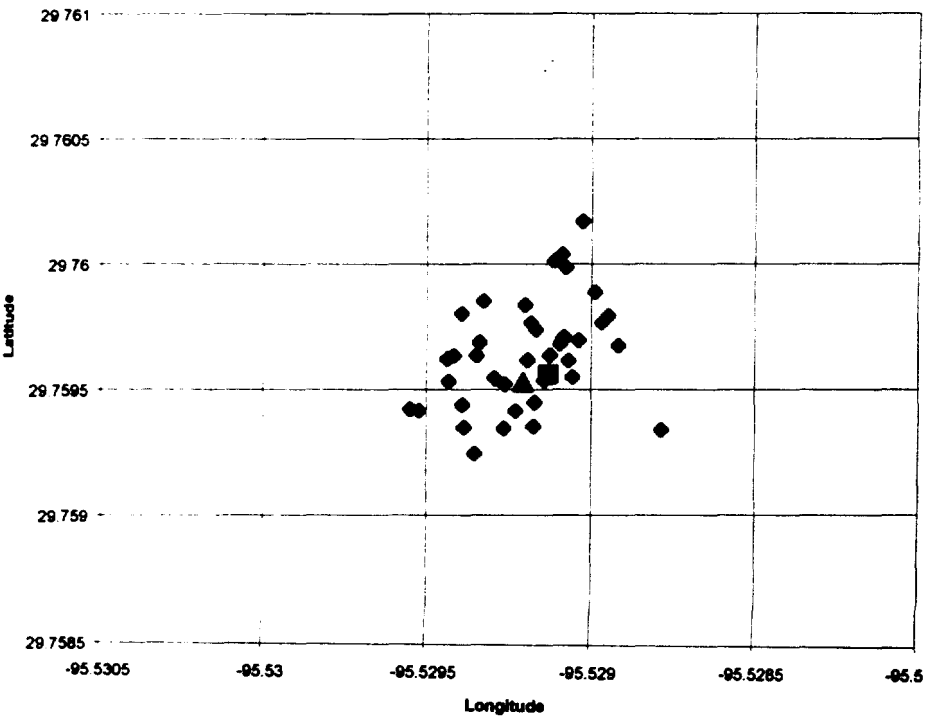

Figure 49: Scatter plot for Scenario S7, Location 2 (CDMA)

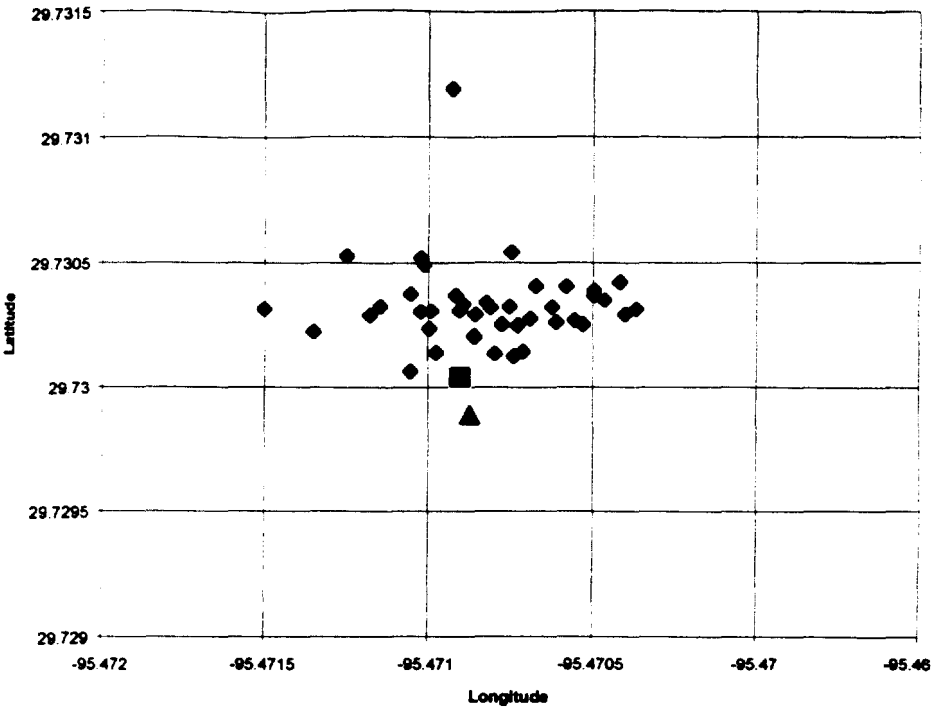

Figure 50: Scatter plot for Scenario S7, Location 3 (CDMA)

Scenario S12—Parking garage, middle floor—inside car, stationary (CDMA Summary)

Location 1	Northern Trust Bank parking, 10000 Memorial Drive; floor two of four-floor garage
Location 2	Behind 9800 Richmond
Location 3	Chase Bank Parking, 5177 Richmond; floor two of six-floor garage
Fixes	119
67% error	49 m
95% error	91 m

Figure 51: Northern Trust Bank parking, 10000 Memorial Drive; floor two of four-floor garage

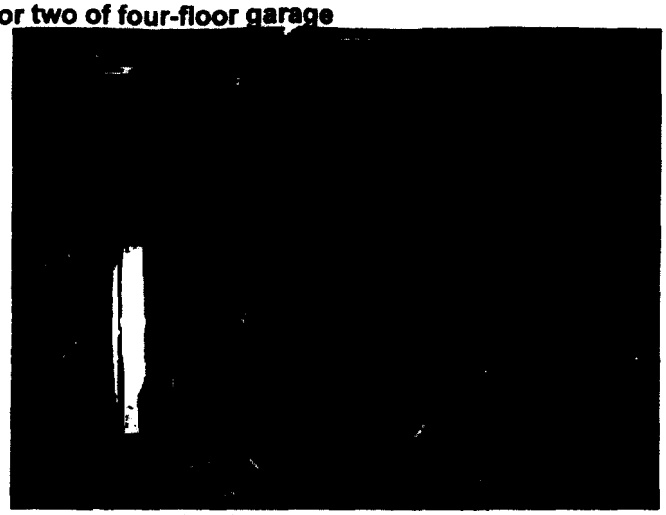

Figure 52: Behind 9800 Richmond

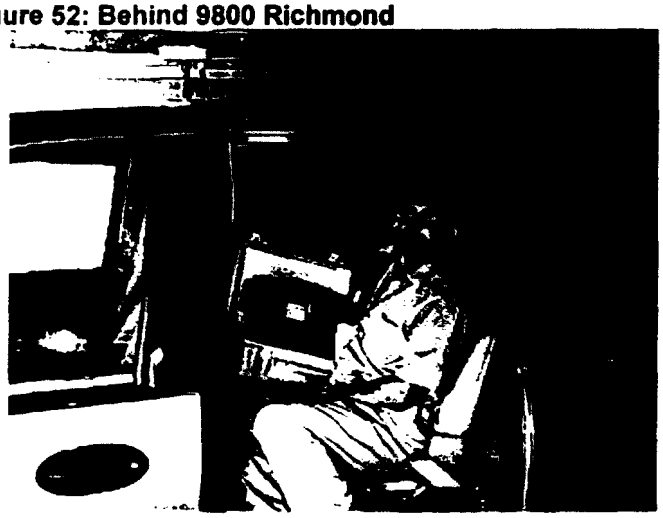

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Figure 53: Chase Bank Parking, 5177 Richmond; floor two of six-floor garage

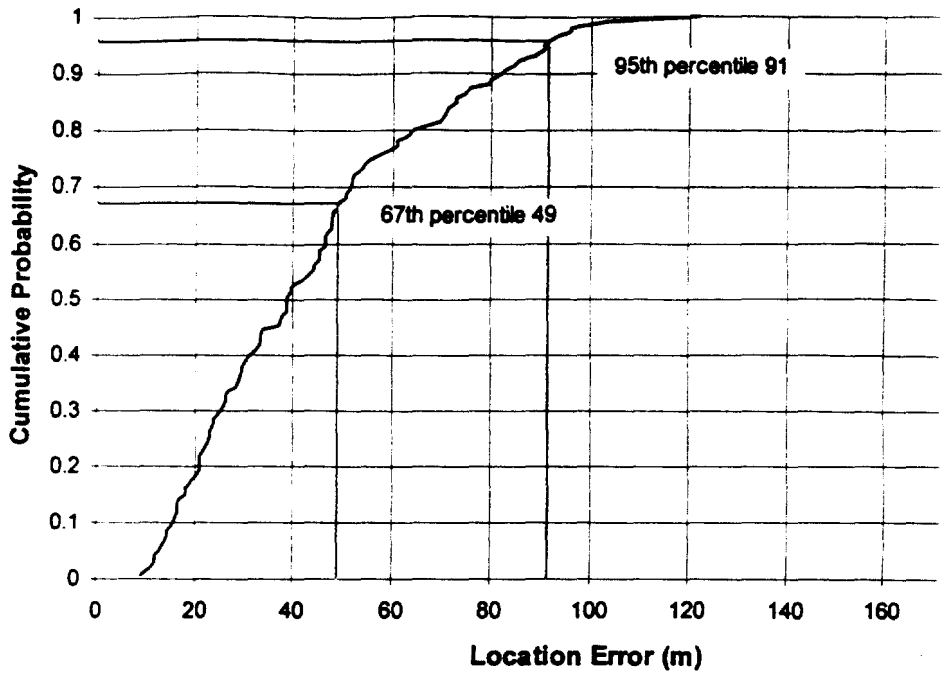

Figure 54: Cumulative Distribution Function for S12 (CDMA)

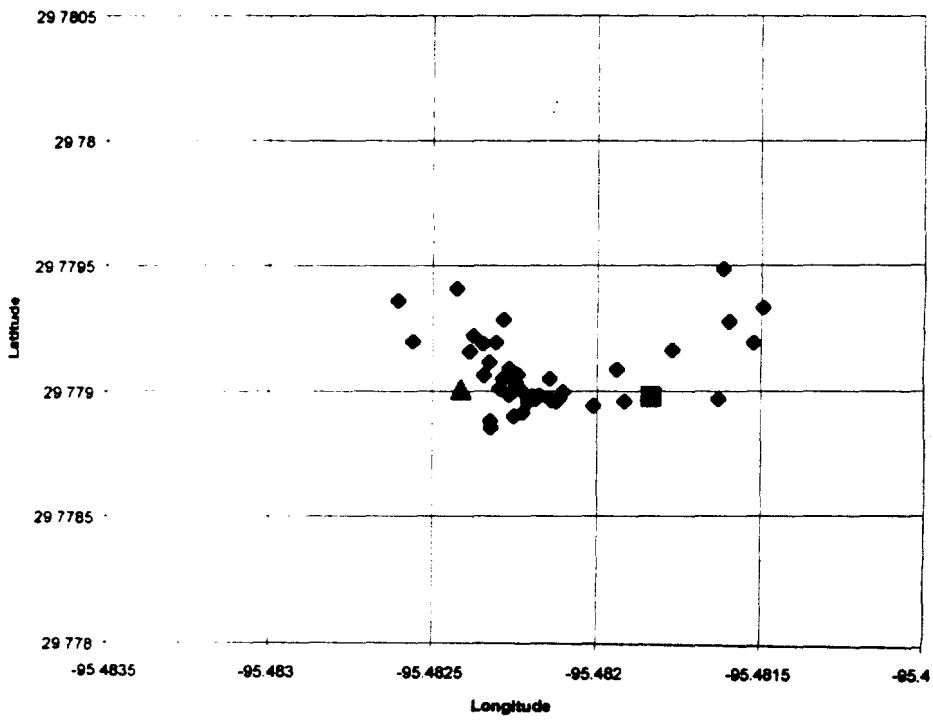

Figure 55: Scatter plot for Scenario S12, Location 1 (CDMA)

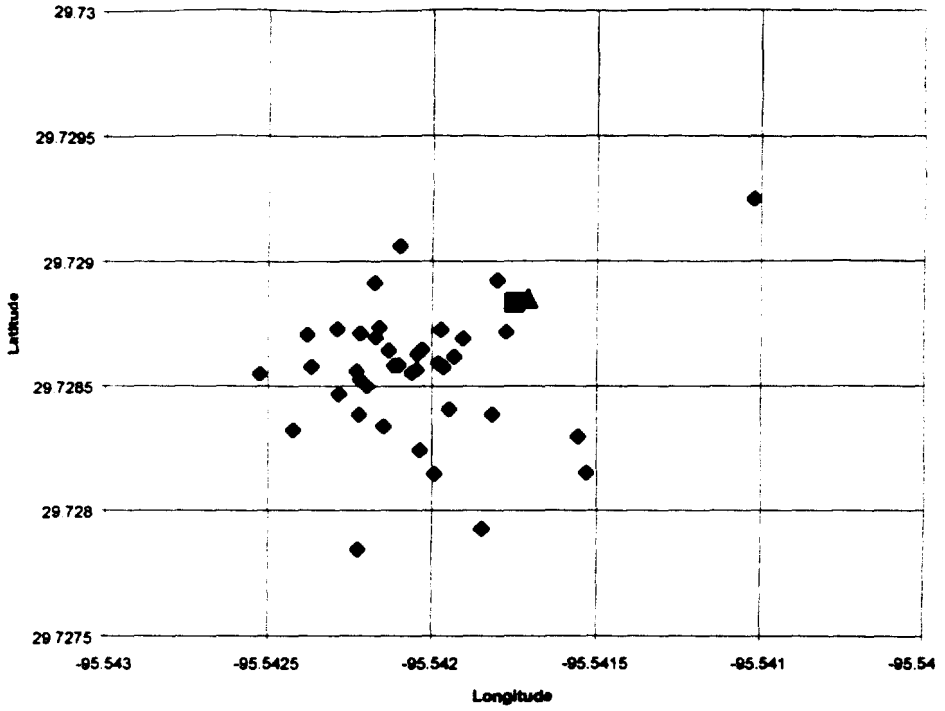

Figure 56: Scatter plot for Scenario S12, Location 2 (CDMA)

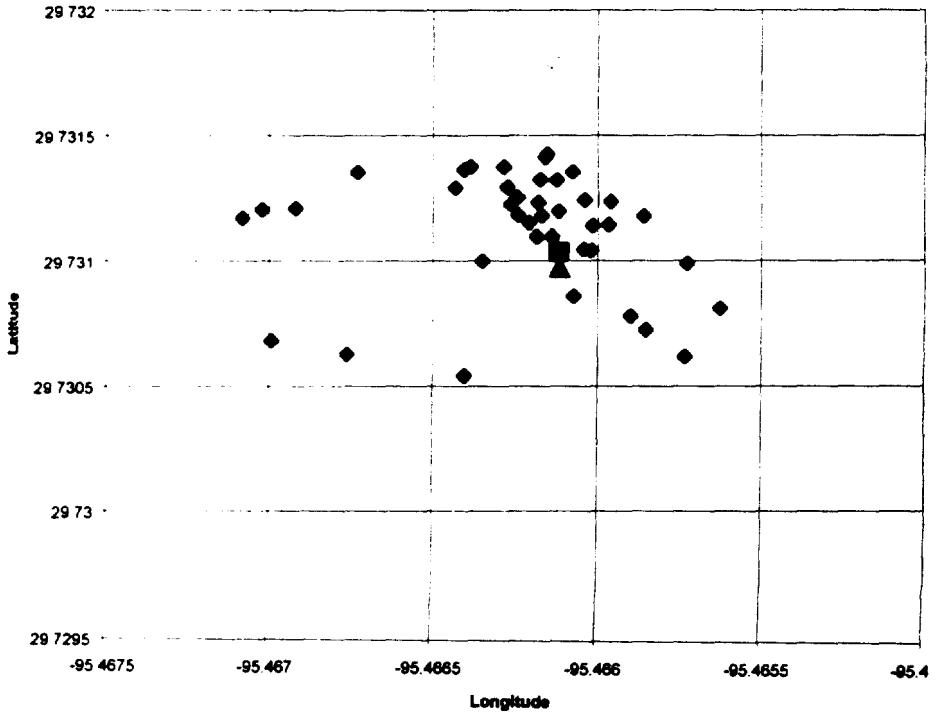

Figure 57: Scatter plot for Scenario S12, Location 3 (CDMA)

Scenario S13—Parking garage, middle floor—outside car, stationary (CDMA Summary)

Location 1	Northern Trust Bank parking, 10000 Memorial Drive; floor two of four-floor garage
Location 2	Behind 9800 Richmond
Location 3	Chase Bank Parking, 5177 Richmond; floor two of six-floor garage
Fixes	123
67% error	51 m
95% error	97 m

Figure 58: Northern Trust Bank parking, 10000 Memorial Drive; floor two of four-floor garage

Figure 59: Behind 9800 Richmond

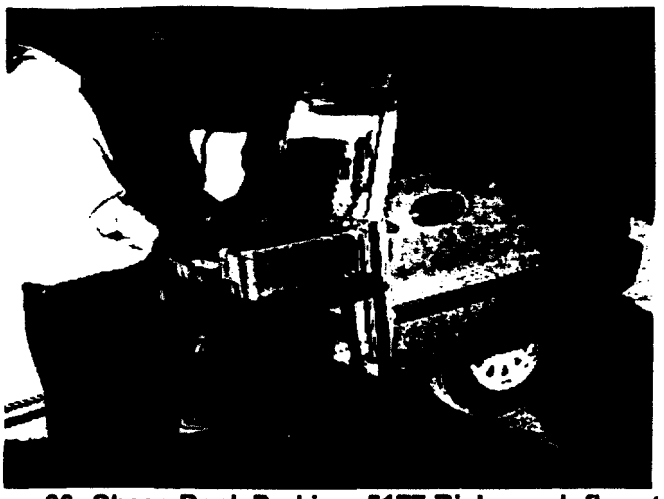

Figure 60: Chase Bank Parking, 5177 Richmond; floor two of six-floor garage

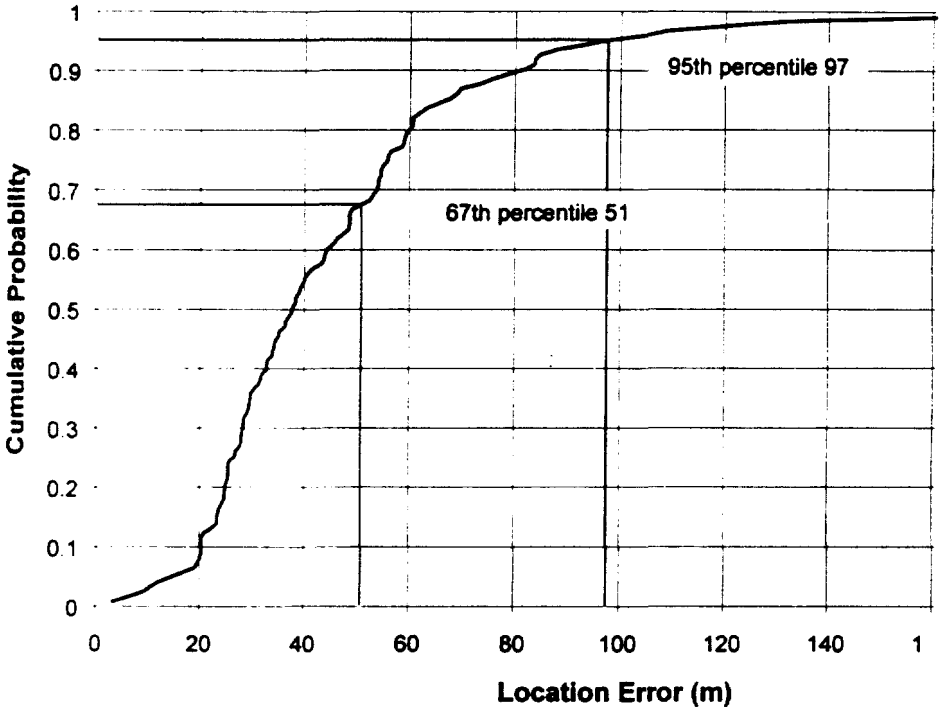

Figure 61: Cumulative Distribution Function for S13 (CDMA)

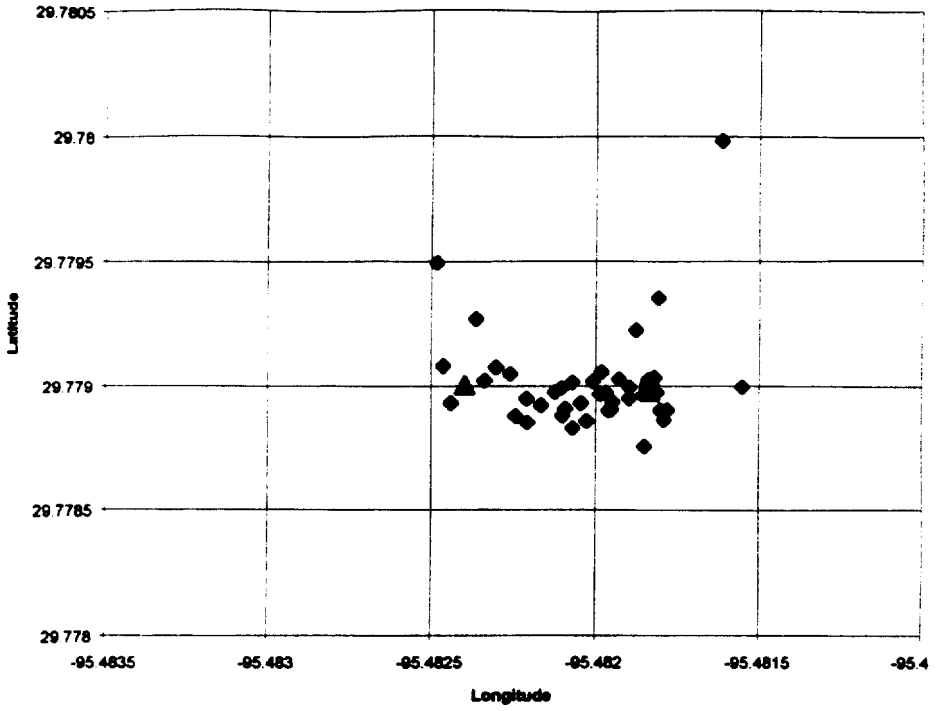

Figure 62: Scatter plot for Scenario S13, Location 1 (CDMA)

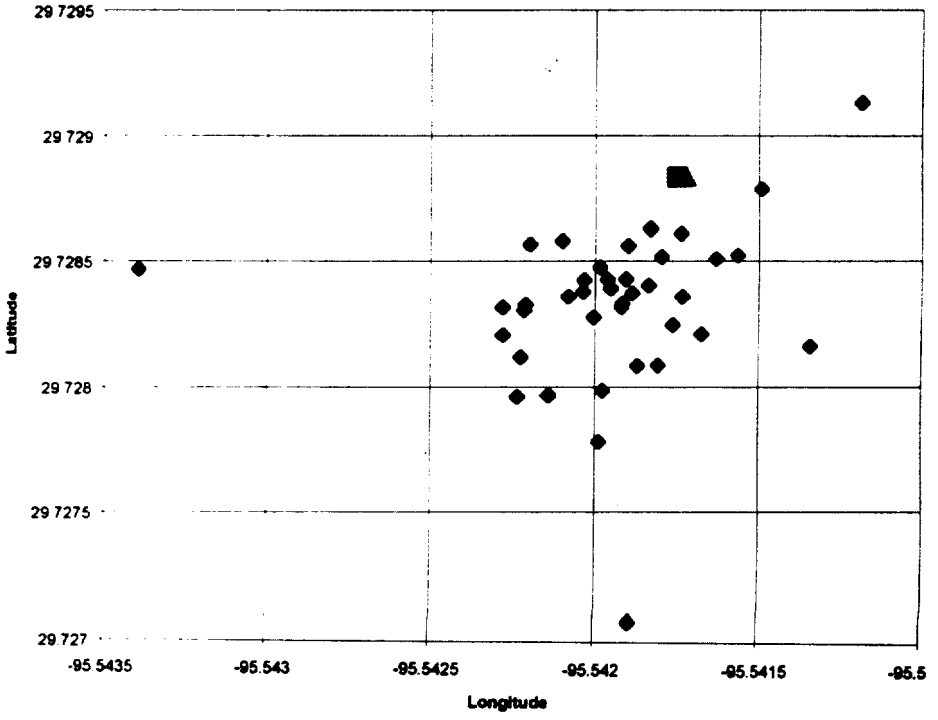

Figure 63: Scatter plot for Scenario S13, Location 2 (CDMA)

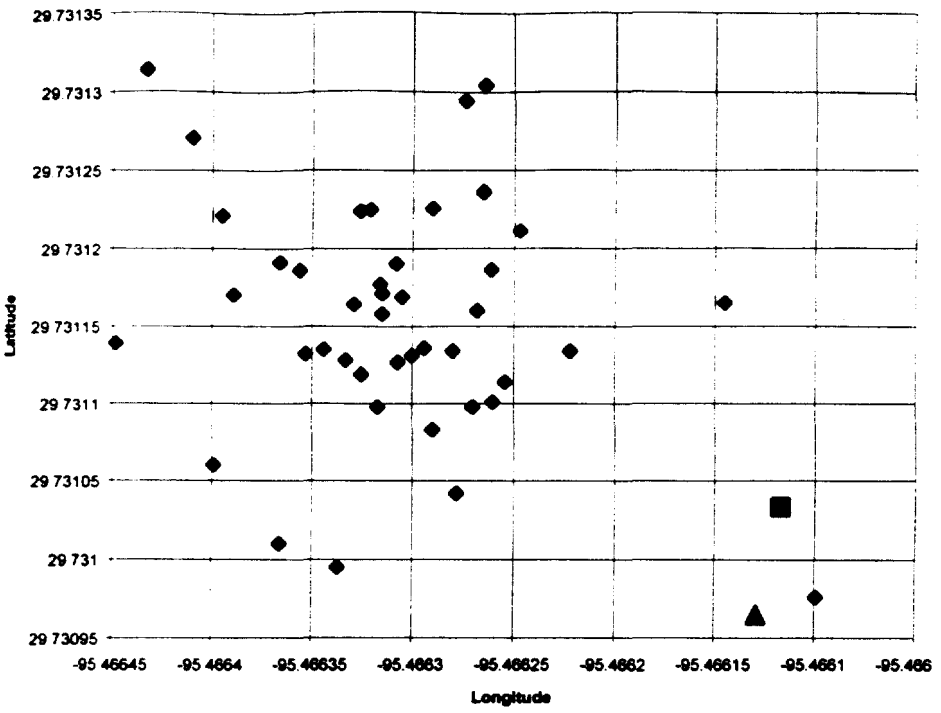

Figure 64: Scatter plot for Scenario S13, Location 3 (CDMA)

Scenario S14—Shopping plaza—outdoor, stationary (CDMA Summary)

Location 1	In Walgreen shopping plaza, 510 Chimney Rock
Location 2	In Thai Gourmet shopping plaza, 6324 Richmond Avenue
Location 3	In Bombay Brasserie shopping plaza, 5160 Richmond at Sage
Fixes	121
67% error	96 m
95% error	134 m

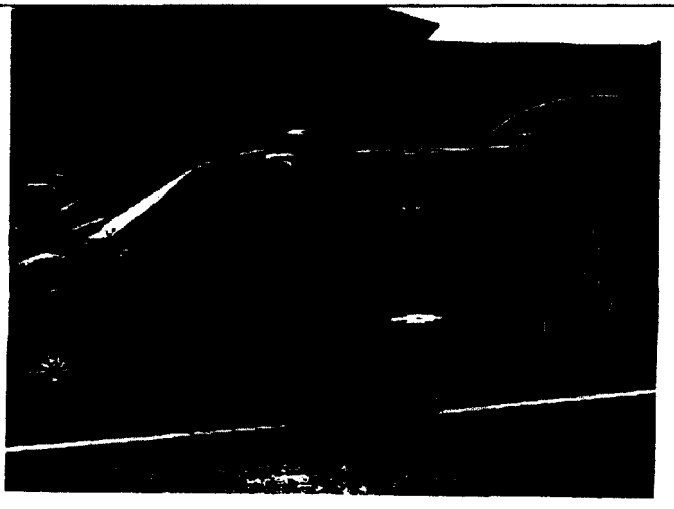

Figure 65: In Walgreen shopping plaza, 510 Chimney Rock

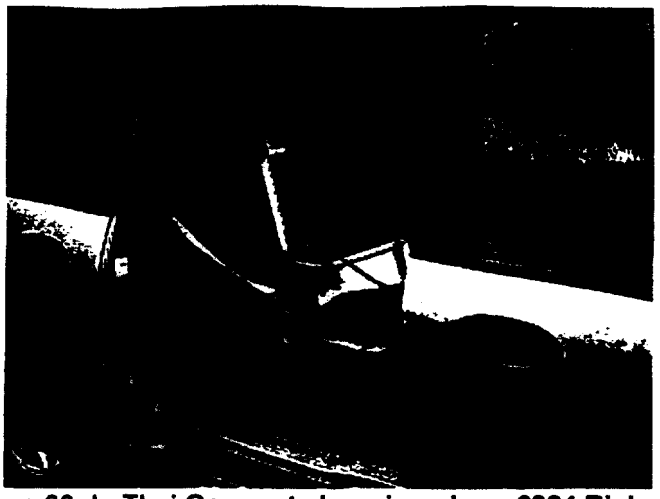

Figure 66: In Thai Gourmet shopping plaza, 6324 Richmond Avenue

Figure 67: In Bombay Brasserie shopping plaza, 5160 Richmond at Sage

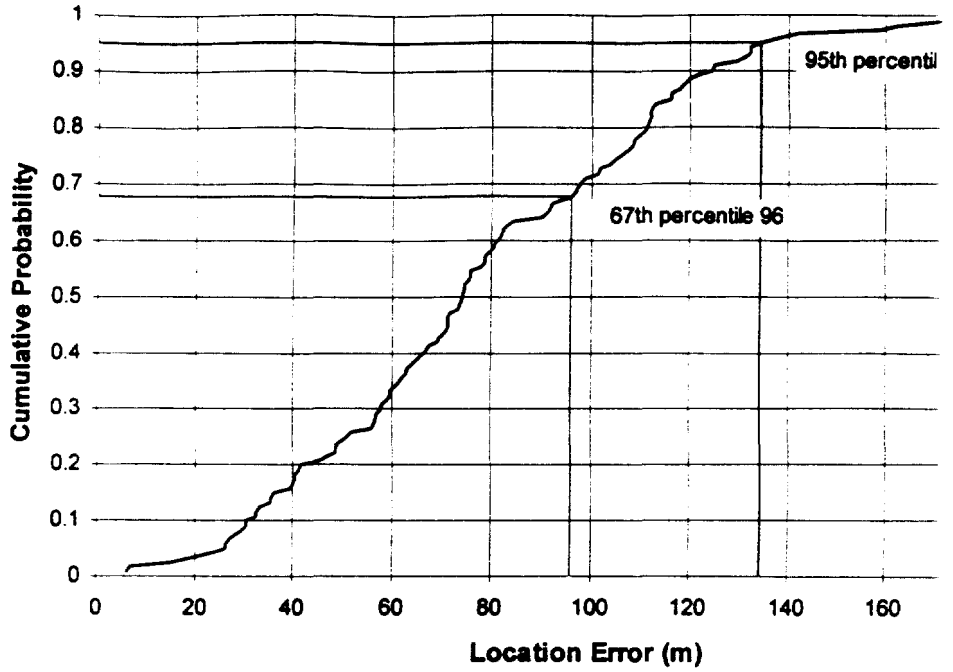

Figure 68: Cumulative Distribution Function for S14 (CDMA)

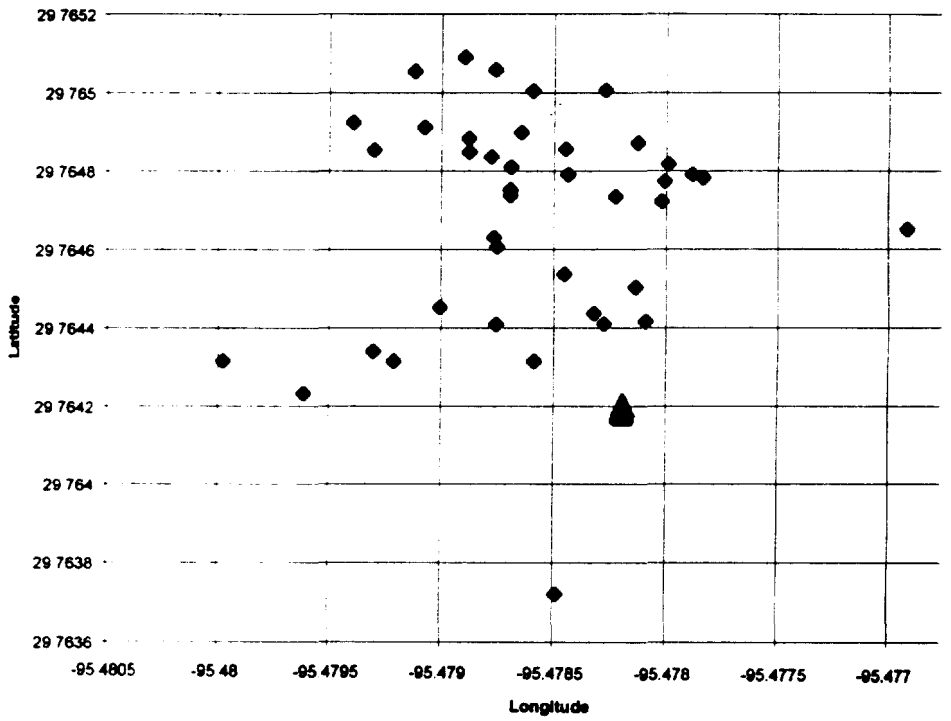

Figure 69: Scatter plot for Scenario S14, Location 1 (CDMA)

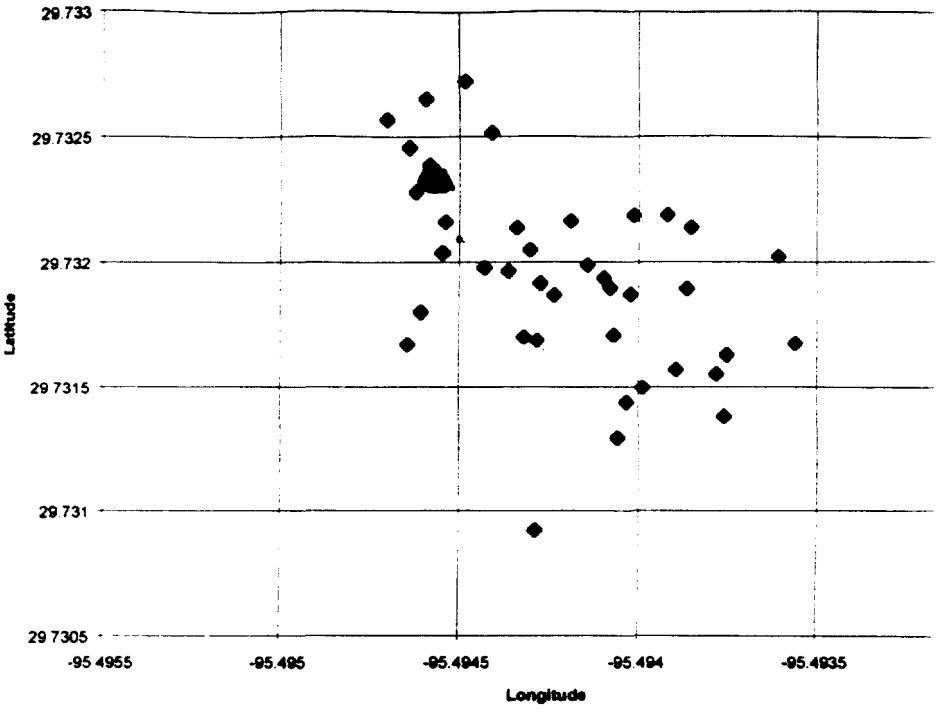

Figure 70: Scatter plot for Scenario S14, Location 2 (CDMA)

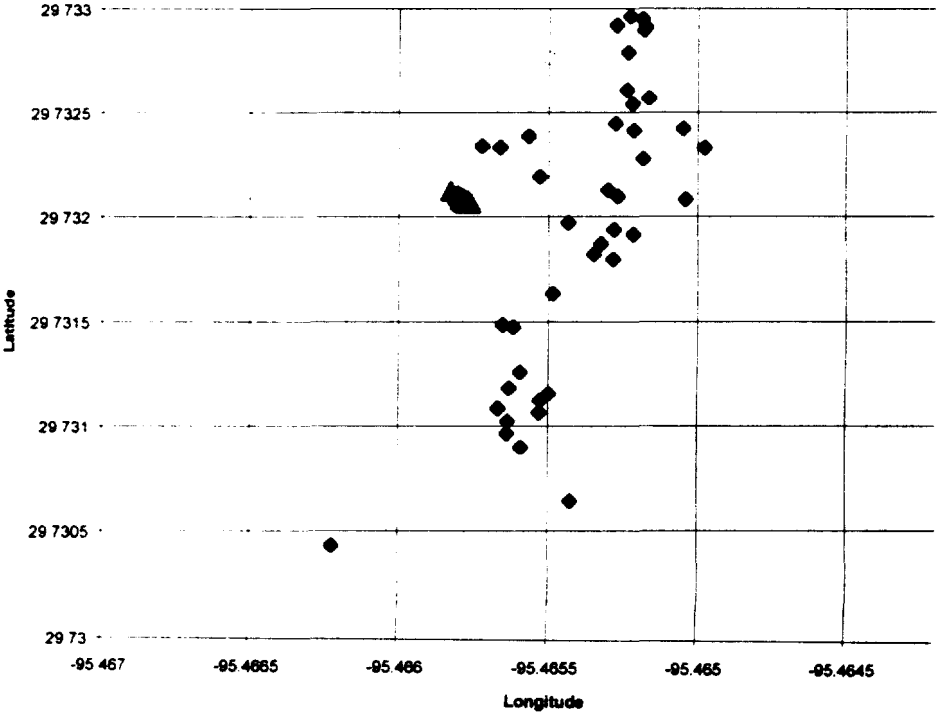

Figure 71: Scatter plot for Scenario S14, Location 3 (CDMA)

Scenario S15—Shopping plaza—indoor, stationary
(CDMA Summary)

Location 1	Quizno's Subs in Walgreen shopping plaza, 510 Chimney Rock
Location 2	In Thai Gourmet, 6324 Richmond Avenue
Location 3	In Bombay Brasserie, 5160 Richmond at Sage
Fixes	120
67% error	143 m
95% error	174 m

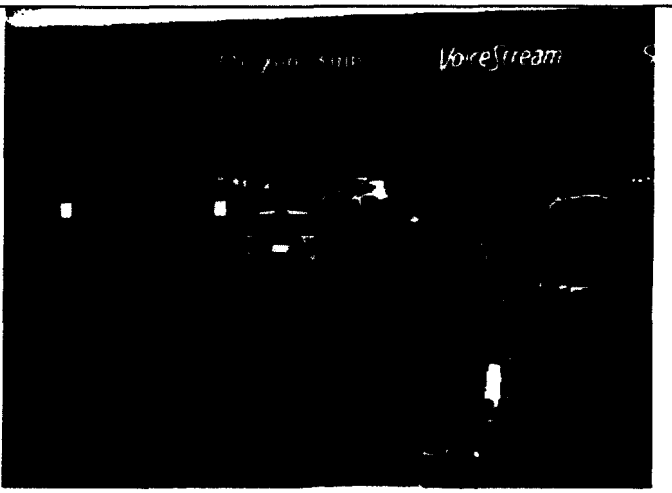

Figure 72: Quizno's Subs in Walgreen shopping plaza, 510 Chimney Rock

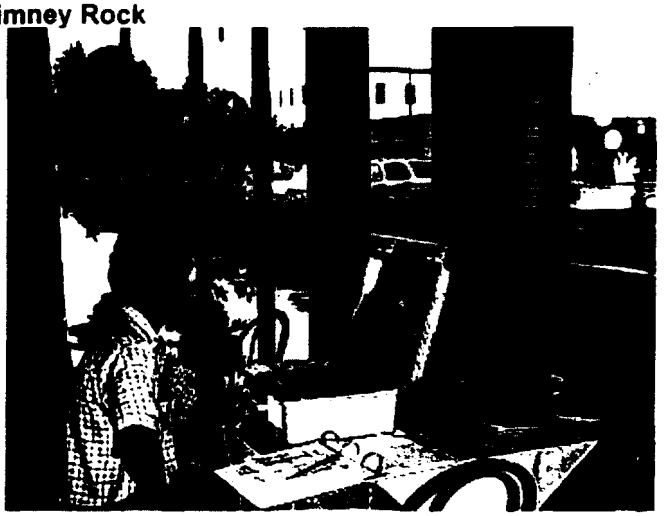

Figure 73: In Thai Gourmet, 6324 Richmond Avenue

Figure 74: Bombay Brasserie, 5160 Richmond at Sage

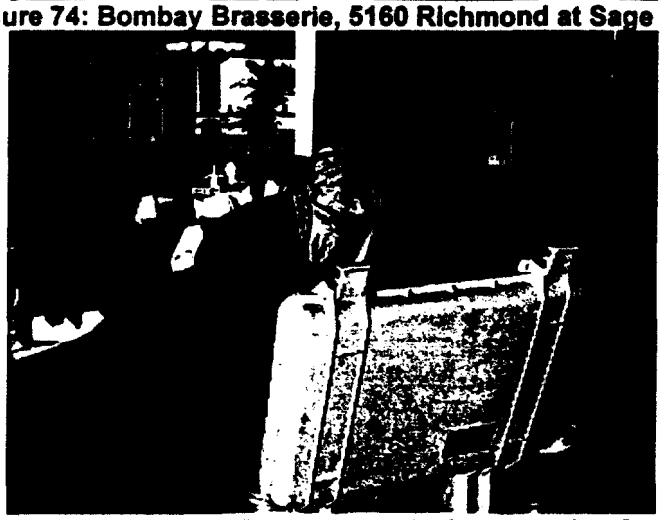

Figure 75: In Bombay Brasserie, 5160 Richmond at Sage

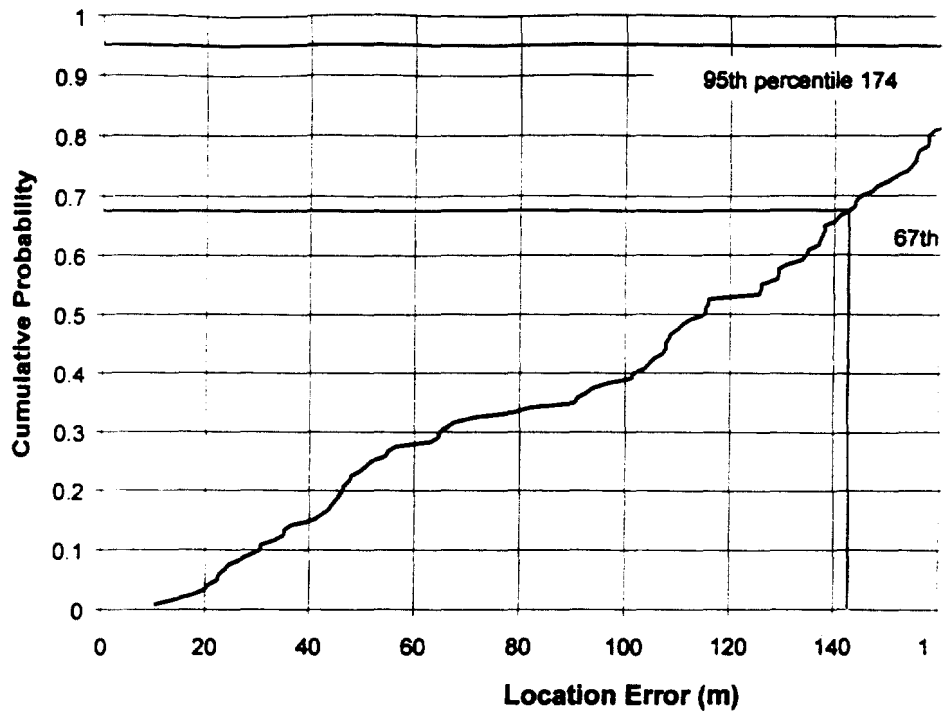

Figure 76: Cumulative Distribution Function for S15 (CDMA)

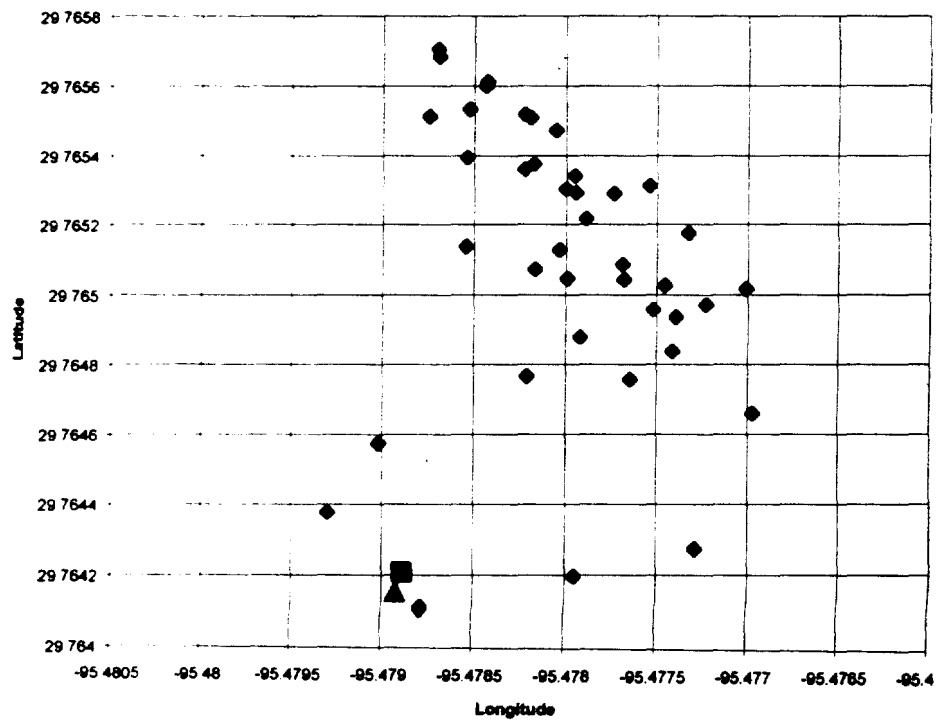

Figure 77: Scatter plot for Scenario S15, Location 1 (CDMA)

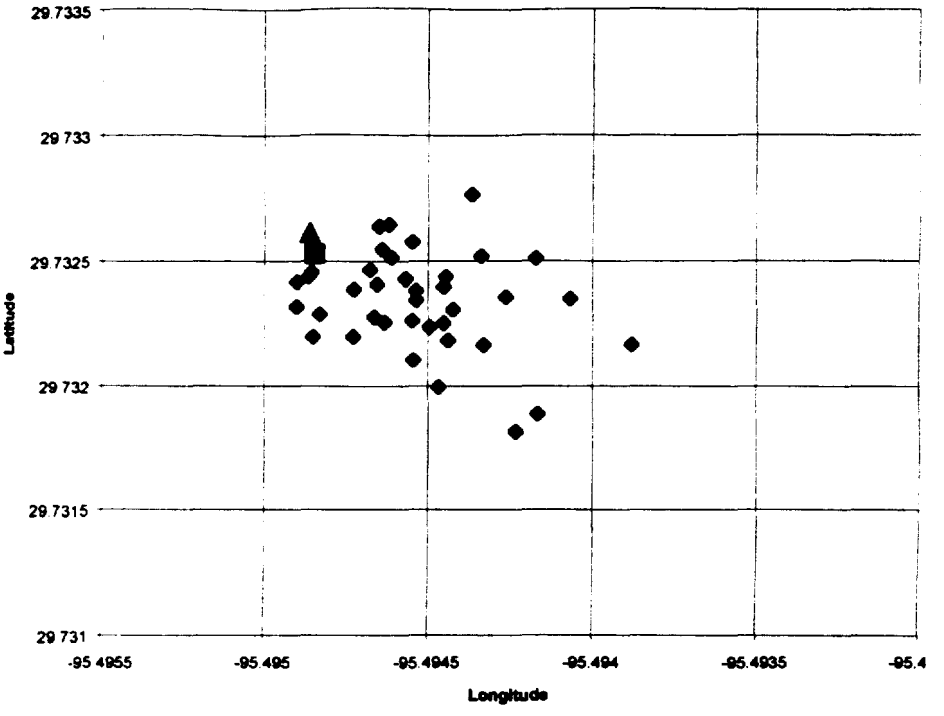

Figure 78: Scatter plot for Scenario S15, Location 2 (CDMA)

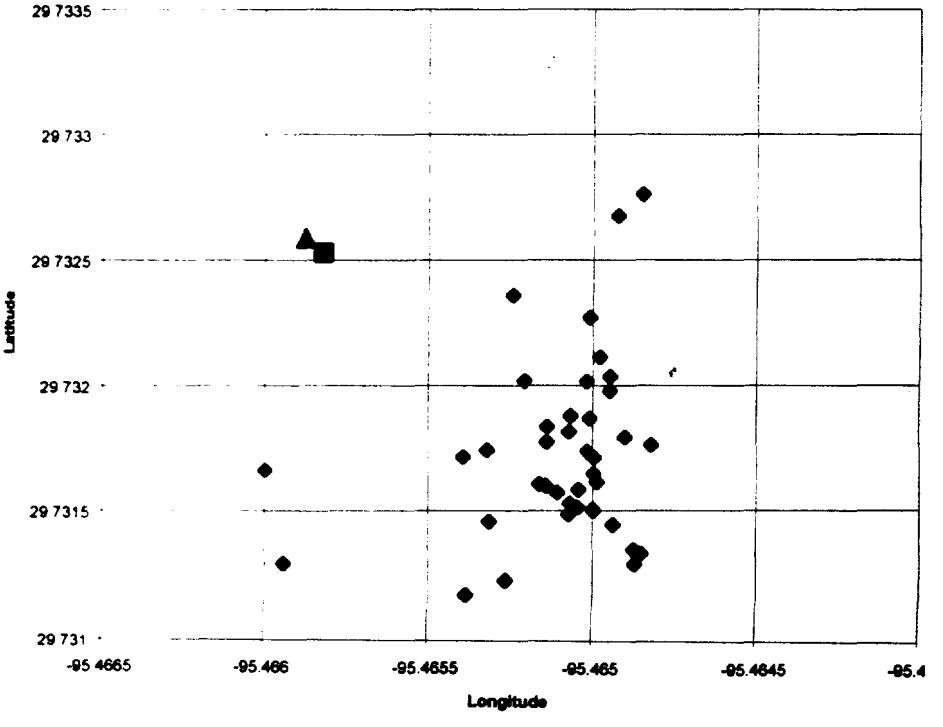

Figure 79: Scatter plot for Scenario S15, Location 3 (CDMA)

Scenario H1—Highway—Inside car, heavy traffic
(CDMA Summary)

Location 1	On I-10 between I-610 and State Loop 8
Location 2	On State Loop 8 between I-10 and Westpark Dr
Location 3	On I-610 between I-10 and Richmond Avenue
Fixes	93
67% error	144 m
95% error	354 m

Figure 80: On I-10 between I-610 and State Loop 8

Figure 81: On I-10 between I-610 and State Loop 8

Figure 82: On I-10 between I-610 and State Loop 8

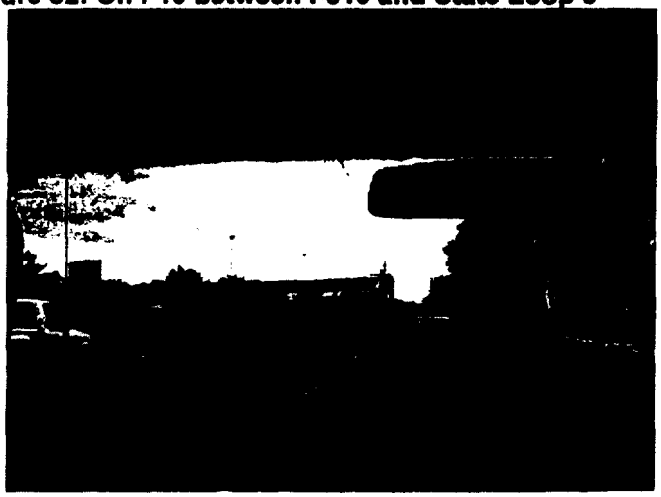

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Figure 83: On State Loop 8 between I-10 and Westpark Dr

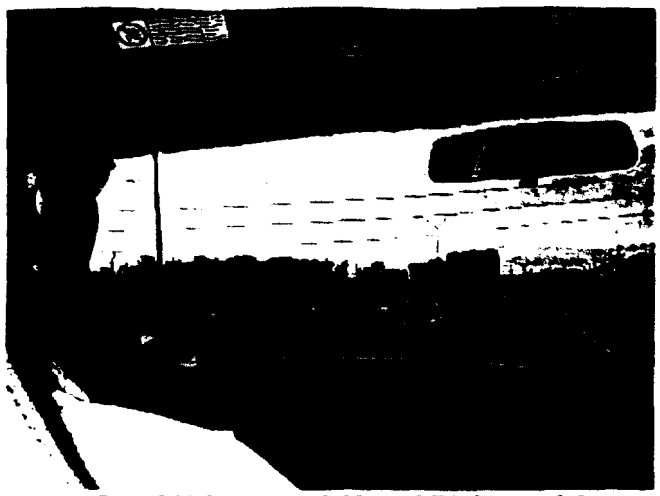

Figure 84: On I-610 between I-10 and Richmond Avenue

Figure 85: On I-610 between I-10 and Richmond Avenue

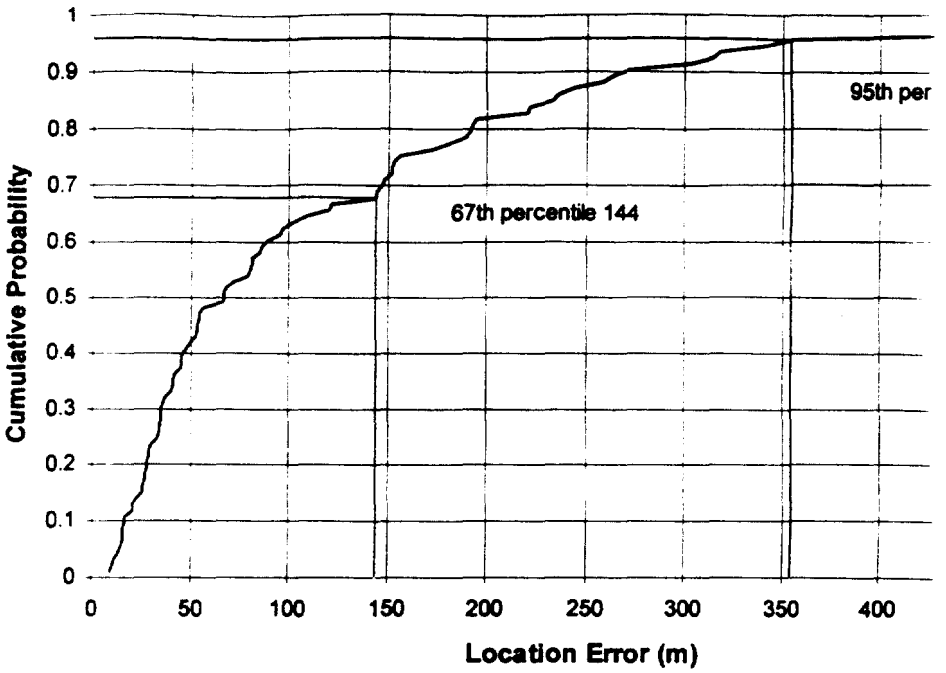

Figure 86: Cumulative Distribution Function for H1 (CDMA)

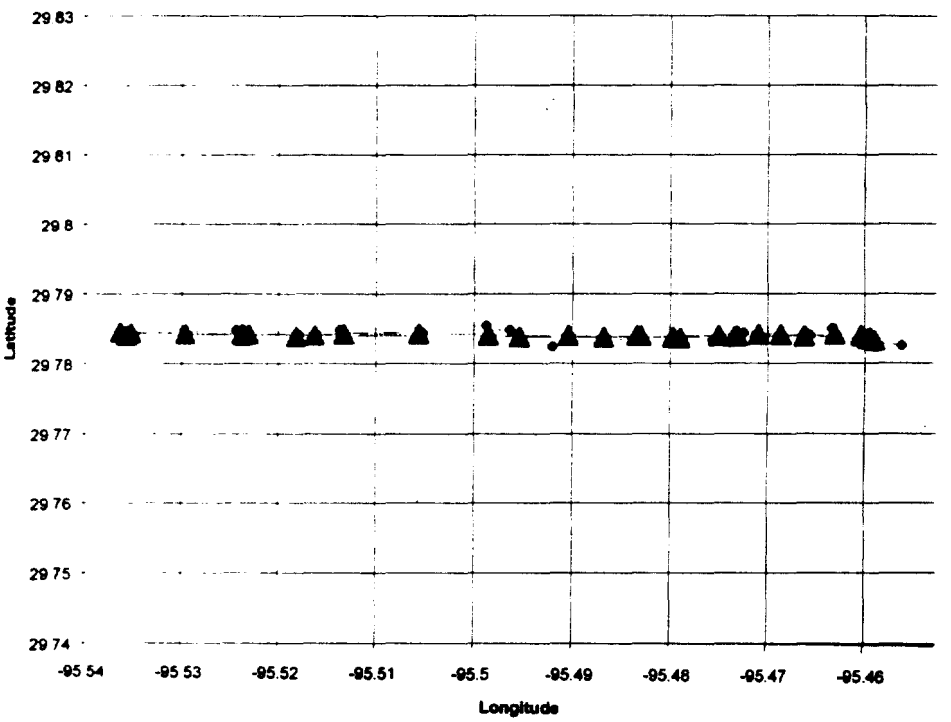

Figure 87: Scatter plot for Scenario H1, Location 1 (CDMA)

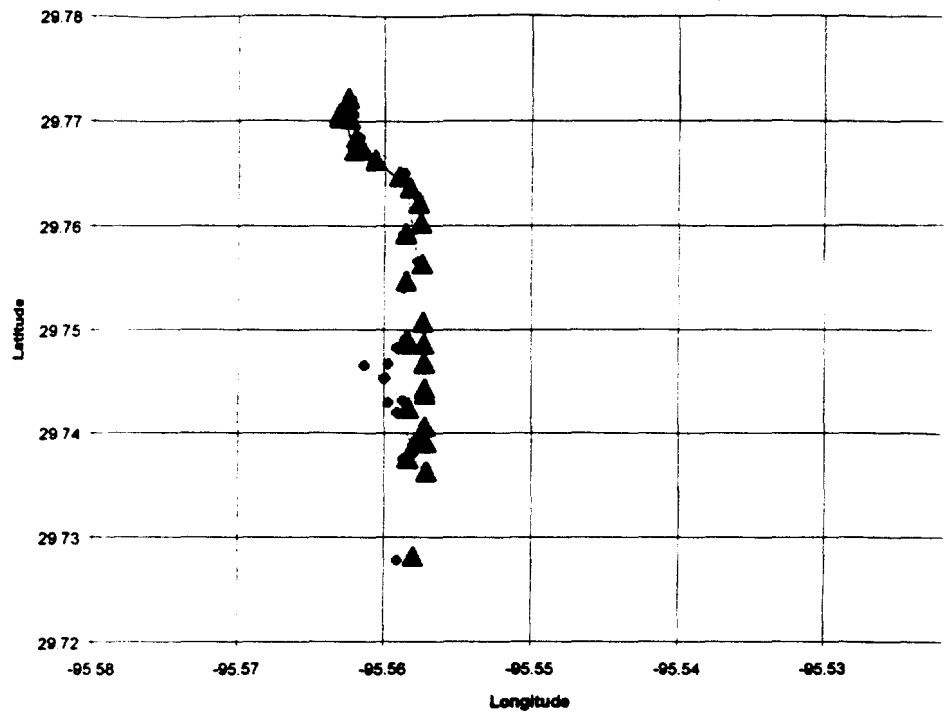

Figure 88: Scatter plot for Scenario H1, Location 2 (CDMA)

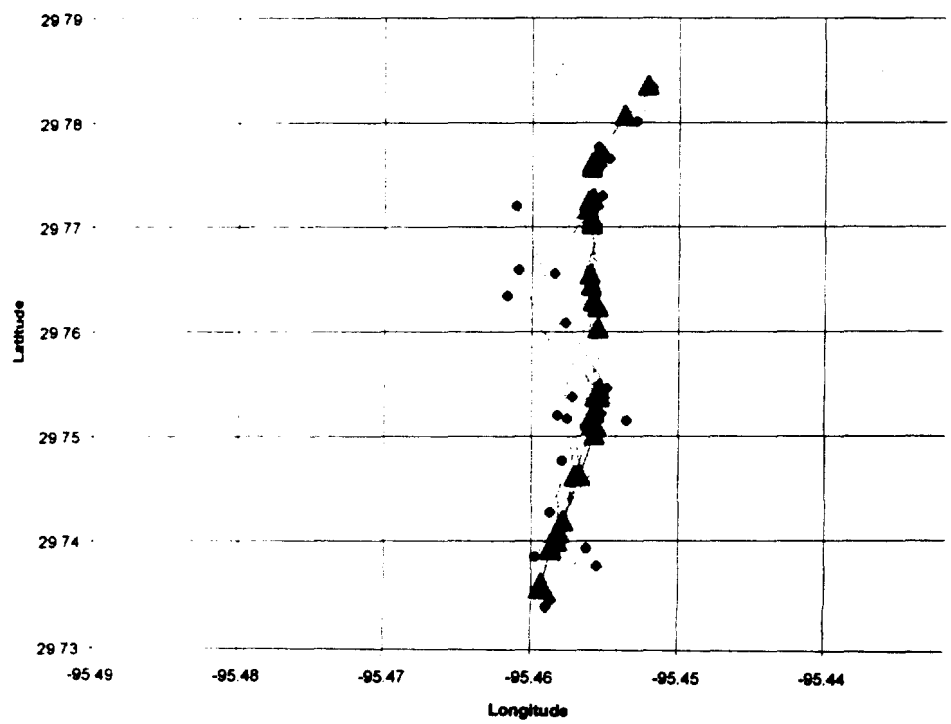

Figure 89: Scatter plot for Scenario H1, Location 3 (CDMA)

Scenario H2—Highway—Inside car, 30–40 MPH

(CDMA Summary)

Location 1	On I-10 between I-610 and State Loop 8
Location 2	On State Loop 8 between I-10 and Westpark Dr
Location 3	On I-610 between I-10 and Richmond Avenue
Fixes	95
67% error	116 m
95% error	330 m

Figure 90: On I-10 between I-610 and State Loop 8

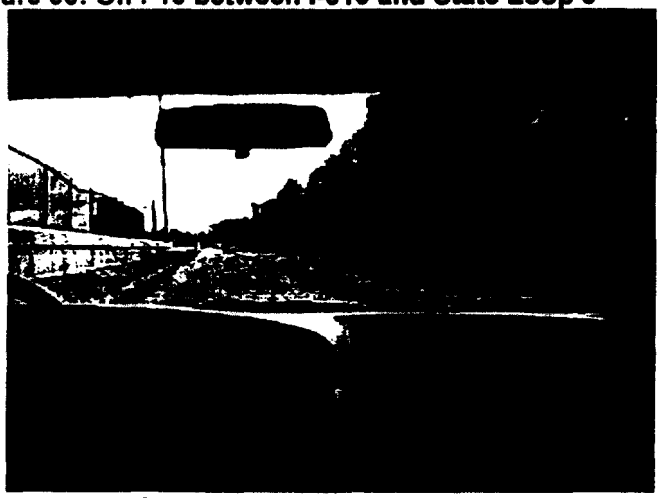

Figure 91: On State Loop 8 between I-10 and Westpark Dr

Figure 92: On I-610 between I-10 and Richmond Avenue

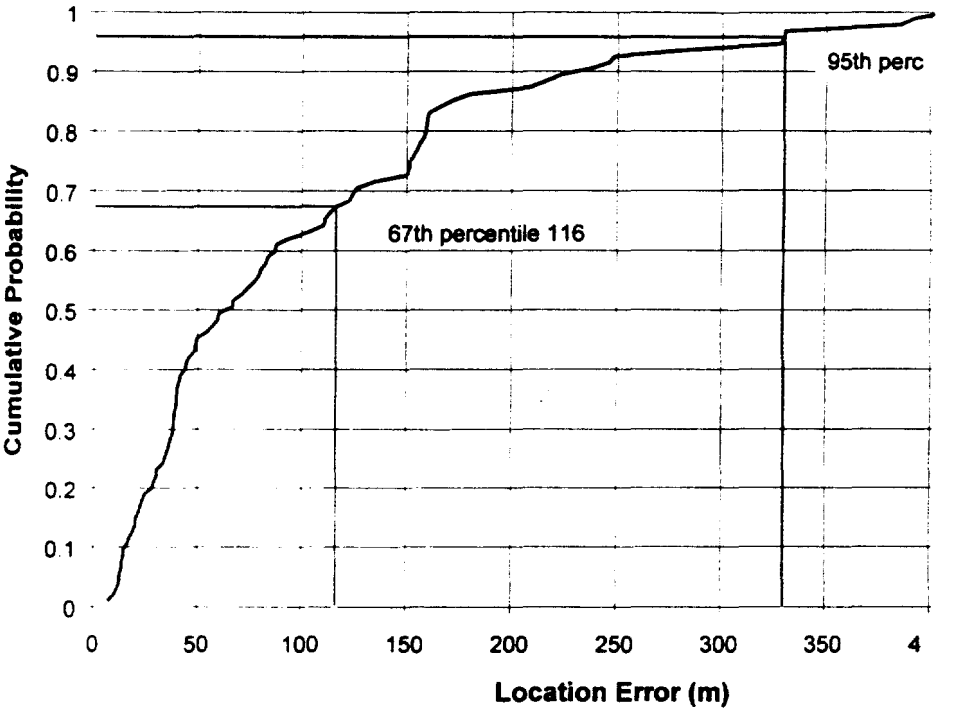

Figure 93: Cumulative Distribution Function for H2 (CDMA)

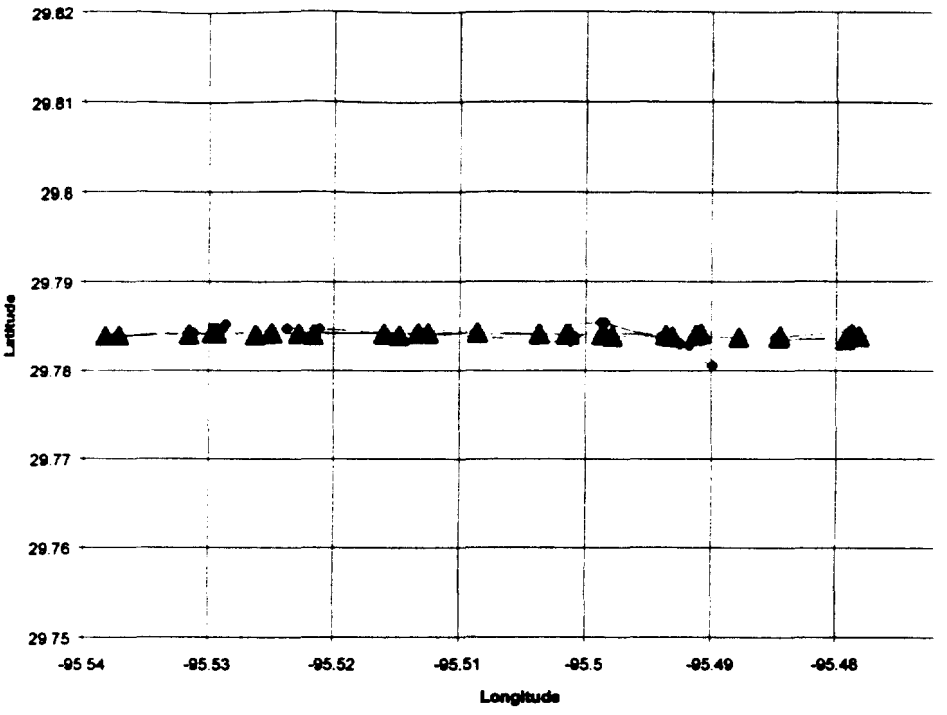

Figure 94: Scatter plot for Scenario H2, Location 1 (CDMA)

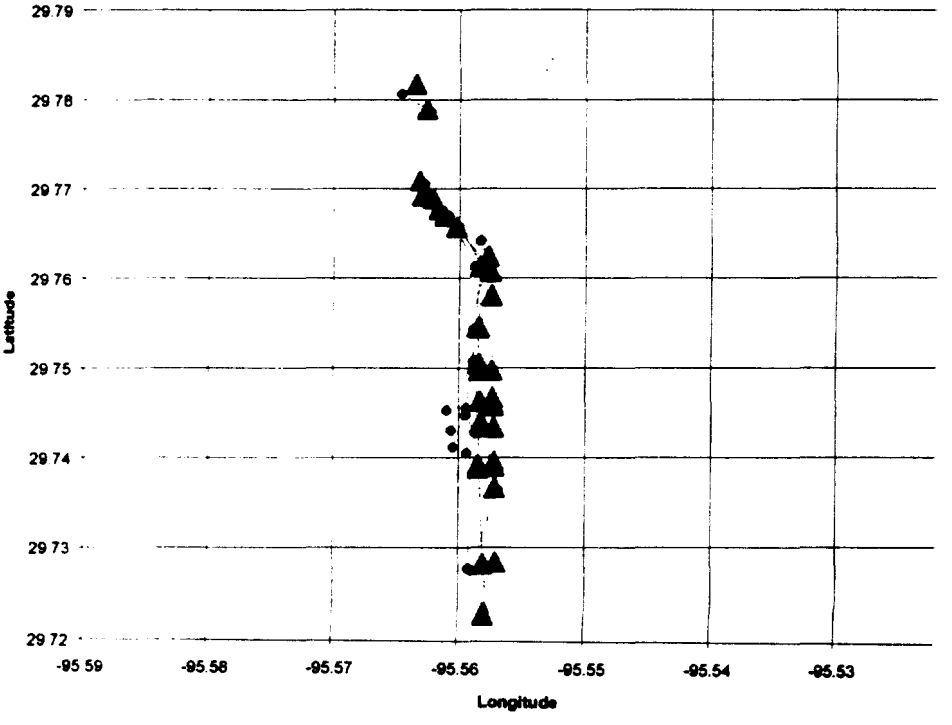

Figure 95: Scatter plot for Scenario H2, Location 2 (CDMA)

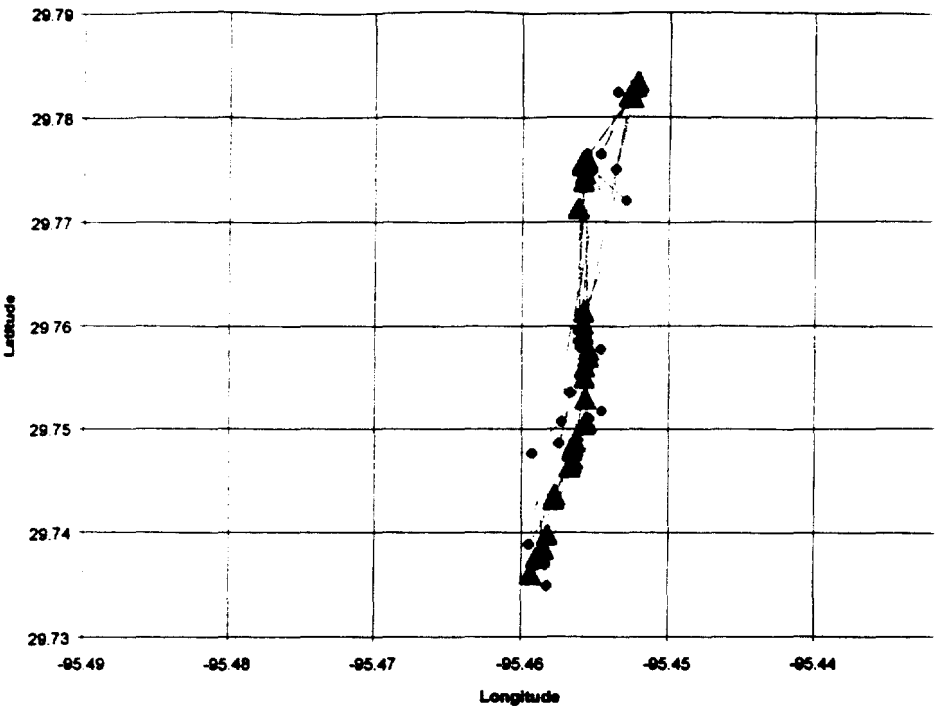

Figure 96: Scatter plot for Scenario H2, Location 3 (CDMA)

Scenario H3—Highway—Inside car, maximum speed limit (CDMA Summary)

Location 1	On I-10 between I-610 and State Loop 8
Location 2	On State Loop 8 between I-10 and Westpark Dr
Location 3	On I-610 between I-10 and Richmond Avenue
Fixes	116
67% error	254 m
95% error	441 m

Figure 97: On I-10 between I-610 and State Loop 8

Figure 98: On I-610 between I-10 and Richmond Avenue

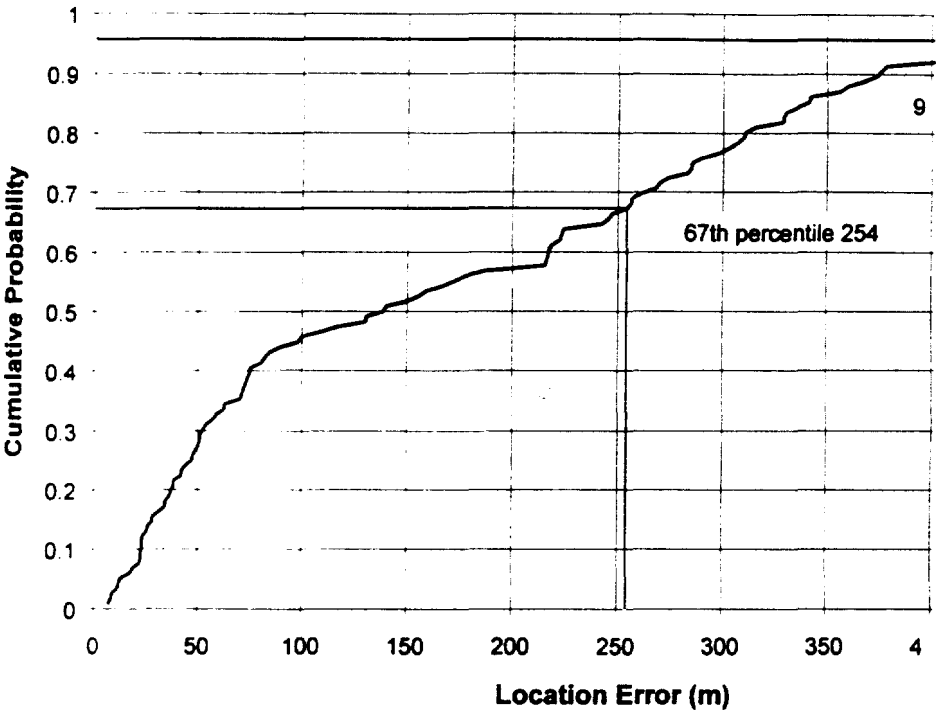

Figure 99: Cumulative Distribution Function for H3 (CDMA)

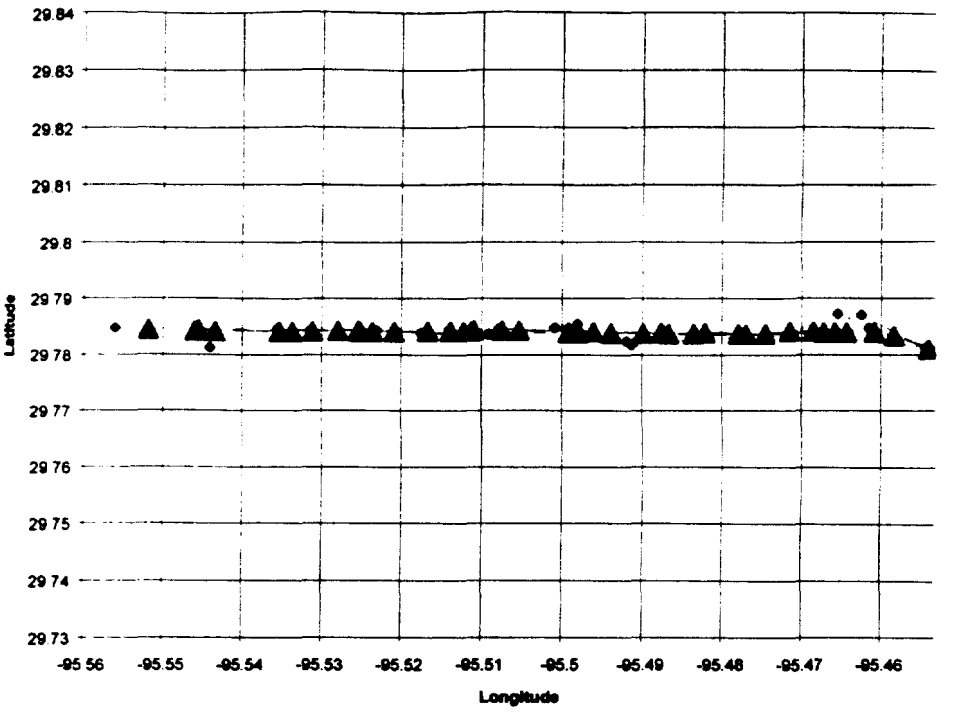

Figure 100: Scatter plot for Scenario H3, Location 1 (CDMA)

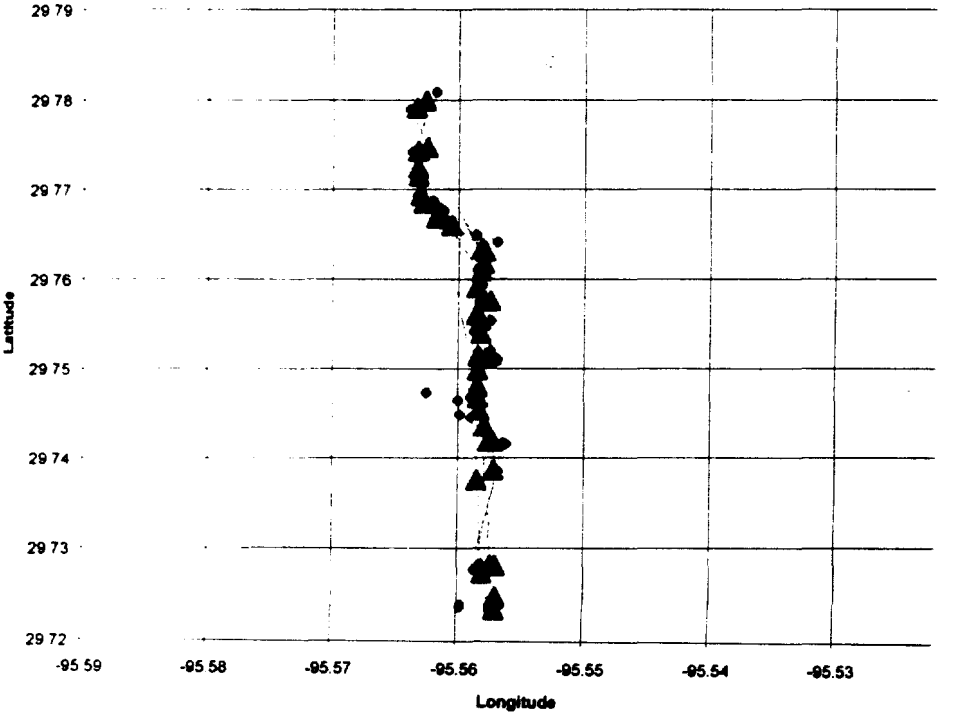

Figure 101: Scatter plot for Scenario H3, Location 2 (CDMA)

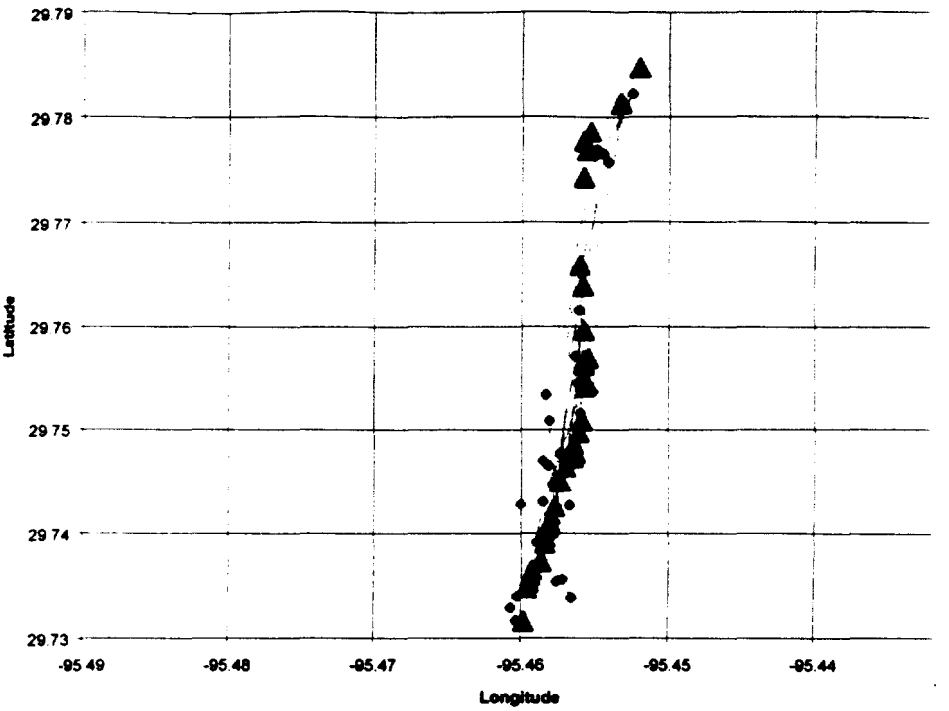

Figure 102: Scatter plot for Scenario H3, Location 3 (CDMA)

3. Summary Performance Results by Scenario

The following table summarizes the performance of E911 location testing by scenario, indicating the extent of compliance with the FCC requirements. The green entries are those percentiles below the required FCC values (100 m for the 67th percentile, 300 m for the 95th percentile); the red entries are those that exceed the limit.

VTO Accuracy Analysis by Scenario Tested Percentiles from Cumulative Distribution Function

Scenario		67% (m)	95% (m)
S1	Residential sidewalk—outdoor, stationary	63	149
S1	Residential sidewalk—outdoor, stationary, CDMA + AMPS	80	274
S2	Residential sidewalk—outdoor, walking	52	94
S3	Residential 2-lane street—inside car, stationary	78	161
S3	Residential 2-lane street—inside car, stationary, CDMA + AMPS	89	190
S4	Residential 2-lane street—inside car, 15-40 mph	59	125
S7	Residential house, brick, upper floor—indoor, stationary	46	74
S12	Parking garage, middle floor—inside car, stationary	49	91
S13	Parking garage, middle floor—outside car, stationary	51	97
S14	Shopping plaza—outdoor, stationary	96	134
S15	Shopping plaza—indoor, stationary	143	174
H1	Highway—inside car, heavy traffic	144	354
H2	Highway—inside car, 30-40 mph	116	330
H3	Highway—inside car, max speed limit	254	441

4. Aggregated Performance Results

In this section, we aggregate the test results so as to provide an overall evaluation of performance. This is done by weighting the constituent scenarios so as to reflect one model of expected usage.

Three different weighting profiles are employed. Two of the profiles, Profile 1 and Profile 2, collect the scenarios into more general classes, and give each class a weight. Within a class, all scenarios are given equal weight. The following table shows the weighting profiles

Weighting Profiles for Aggregating Scenarios

Weighting Class	Constituent Scenarios	Profile 1	Profile 2	Profile 3
Inside car, stationary	S3, S12	25%	50%	No weighting classes; all scenarios have equal weight
Inside car, moving	S4, H1, H2, H3	25%	20%	
Outdoor	S1, S2, S13, S14	25%	20%	
Indoor	S7, S10, S11, S15	25%	10%	

For two of the scenarios, S1 and S3, data was collected for AMPS calls along with CDMA calls. Within these scenarios, the data was aggregated by giving CDMA an 80% weight, and AMPS a 20% weight.

The following table summarizes the aggregate performance for the three weighting profiles. The 67th and 95th percentiles are given with 90% joint confidence.

VTO Accuracy Analysis by Weighting Profile —Nominal 90% Joint Confidence Percentiles

Weighting Profile	67% (m)	95% (m)
Profile 1	82	246
Profile 2	78	223
Profile 3	82	274

The following figures show the cumulative distribution functions for the three weighting profiles. Note that the percentiles that are read from the graphs are not those given in the preceding table. The latter are somewhat larger, so as to achieve the 90% confidence that neither of the true underlying percentiles is larger than the value given.

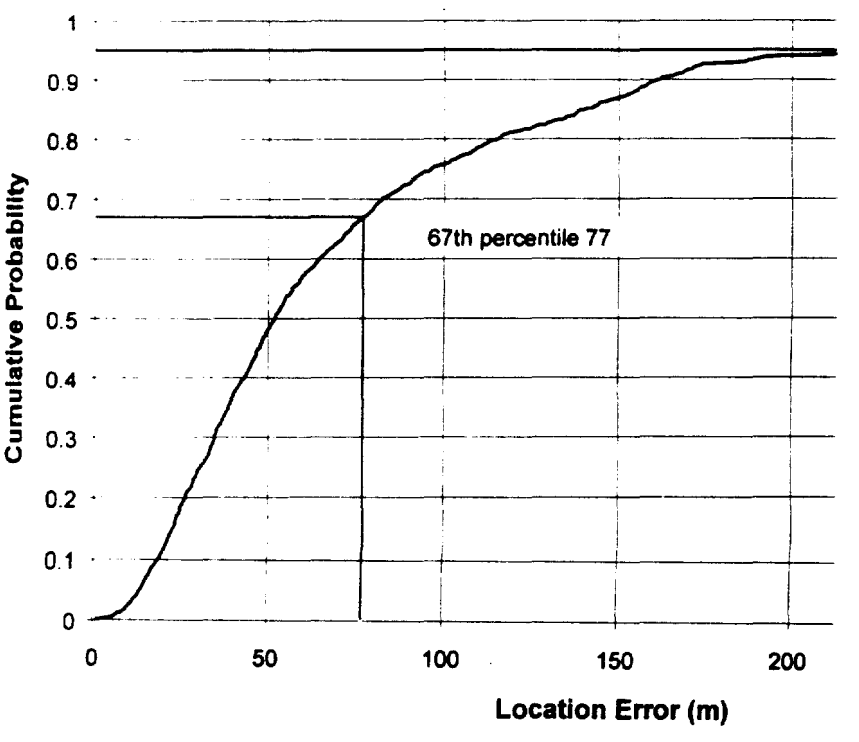

Figure 103: Cumulative Distribution Function for Location Error—Weighting Profile 1

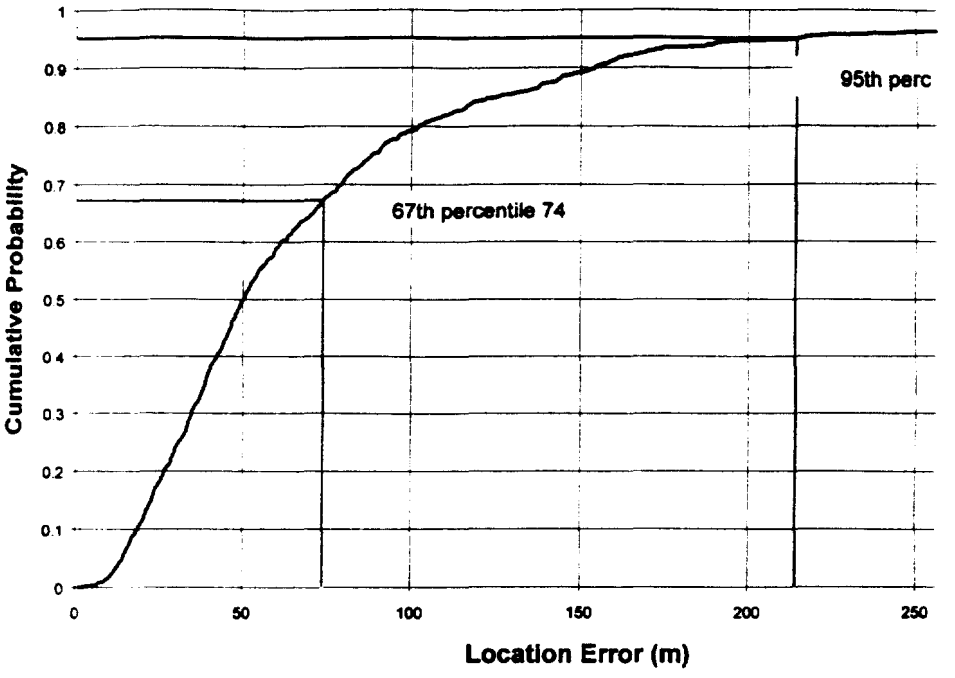

Figure 104: Cumulative Distribution Function for Location Error—Weighting Profile 2

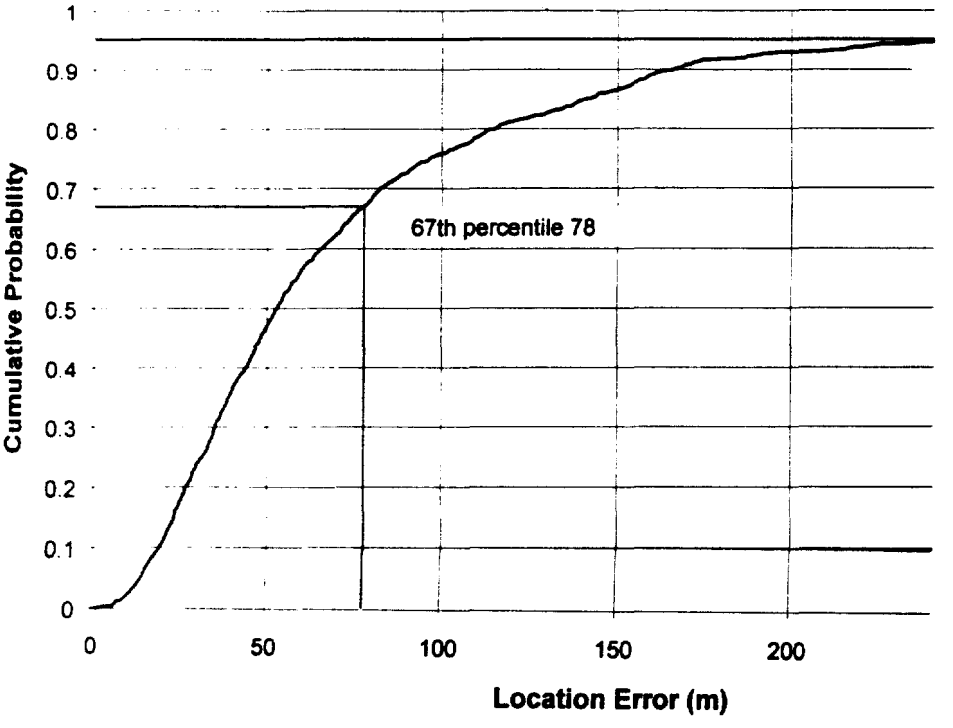

Figure 105: Cumulative Distribution Function for Location Error—Weighting Profile 3

5. Conclusion

At the request of Verizon Wireless, BBN-T (VTO) conducted a rigorous location accuracy trial of the Grayson Wireless Geometrix® geo-location system in the Greater Harris County PSAP test area, consisting of 32 square miles of essentially suburban and highway scenarios. The purpose of the trial was to assess compliance of the Geometrix® system with the FCC requirement for Phase II E911 that a network-based geo-location system shall provide the location of a wireless 911 call with an accuracy of 100 meters, 67% of the time, and 300 meters, 95% of the time.

CDMA test calls were made for all the tested scenarios. AMPS calls were only made for 3 suburban scenarios. Analysis of the test results revealed the following:

- Of the 10 suburban scenarios for which CDMA calls were made, 8 scenarios individually met the FCC requirements and one partially met the requirements, while the data for the 10th scenario was not analyzed because of its doubtful validity.
- Of the 3 suburban scenarios for which both CDMA and AMPS calls were made in the ratio of 80% (CDMA) to 20% (AMPS), with the composite data to be analyzed, 2 of them individually met the FCC requirements, while the data for the 3rd scenario was not analyzed because of its doubtful validity.
- Of the 3 highway scenarios for which CDMA calls were made, none of them individually met the FCC requirements.
- When the results from all the scenarios were combined according to three different weighting profiles, and including both AMPS and CDMA calls, it was found that the overall accuracy of the Geometrix® system met the FCC requirements for the GHC PSAP test area. Note that this is true even if one goes by the more strict guidelines of the OET Bulletin No. 71, which require a statistical confidence of 90% for the accuracy estimates.
- Examination of the scatter plots shows a systematic bias in the geo-location estimates relative to the ground truth in most of the scenarios.

While the results of the suburban scenarios tested in the GHC PSAP test area were mostly compliant with the FCC requirements and while the results overall were also compliant, none of the results for the highway scenarios were compliant. Consequent to the BBN-T (VTO) testing, Grayson Wireless has come up with two modifications that they expect will significantly improve the performance in the highway scenarios. Of these, one is an algorithmic change and consists of increasing the dynamic range of the received signal reception. Grayson Wireless believes that this modification will result in a better estimate of the time of arrival of the direct path, which in turn will improve the location accuracy of the TDOA algorithm. The other, a non-algorithmic change, uses a time-stamp for the received signal data collection that is closer to the time at which the ground truth is measured for moving vehicles. Based on their re-testing, Grayson Wireless believes that this will yield a smaller calculated error, the distance between the ground truth and the estimated location.

BBN-T recommends an independent re-test of Grayson Wireless's geo-location system for the highway scenarios to verify the improvements in the accuracy due to the modifications of their system.

Finally, this trial focused on the accuracy aspects of the FCC requirements. However, the FCC requirements also imply that the yield, *i.e.*, the ratio of the number of fixes to the total number of call attempts, be at least 95%. In addition, the FCC guidelines as given in the OET Bulletin No. 71 talk about setting limits to the time to obtain a fix. Both these issues are very important from a practical standpoint. In general the accuracy is expected to deteriorate if one were to also set high yield and small time to obtain fix thresholds. Therefore, BBN-T also recommends that the Geometrix® system be re-tested to ensure that it meets the accuracy requirements and the yield requirements under specific time-to-fix constraints.

Appendix A: Grayson Comments on Test Report

Grayson Wireless has reviewed the test report and finds the results to be accurate and in agreement with the data reduction we performed as part of our participation in the trial. We concur with the conclusions reported, and have undertaken efforts to further improve results for the scenarios where the greatest location errors were measured.

Specifically, we have made modifications to the signal processing algorithms related to making time measurements in moving vehicles where Doppler is present. The algorithms have been preliminarily tested both in Northern Virginia, and in Houston. The Grayson-performed Houston testing was done under similar circumstances to the VTO testing. The results are summarized in the table below. We believe that the results are promising, and may significantly improve the highway scenario results, but believe that further testing and validation by VTO is necessary before any firm conclusions are drawn.

Grayson Retest Summary

Scenario	Location	Description	VTO Data			Grayson Retest		
			67%	*95%*	*Fixes*	*67%*	*95%*	*Fixes*
H1	3	I-610, heavy traffic	195.1m	499.6m	32	93.7m	186.0m	30
H2	2	Rt. 8, 30-40 MPH	151.4m	355.3m	32	80.7m	138.8m	30
H3	1	I-10 Max Speed	308.9m	407.8m	39	48.6m	206.1m	30