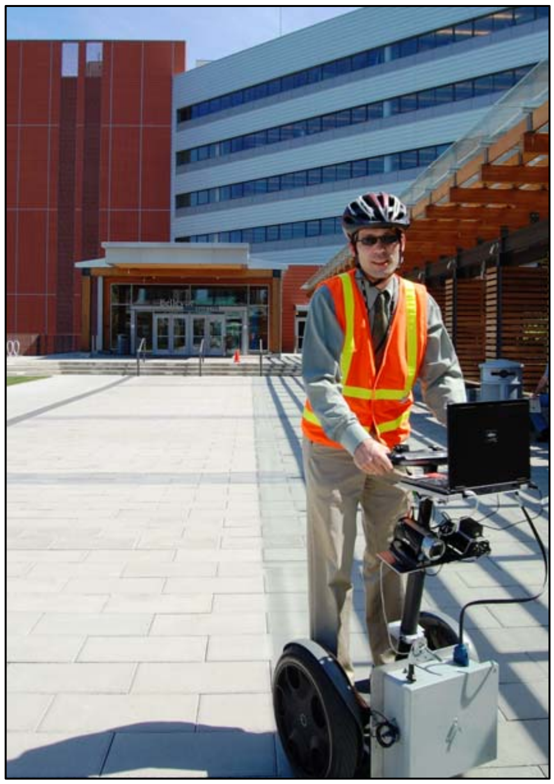
Validation of ULIPs
at Bellevue, Washington



September 2007

CONTRACT NO. DTFH61-06-D-00021

STARODUB, Inc.
3504 Littledale Road
Kensington, MD 20895

Validation of ULIPs at Bellevue, Washington

Background

A modified version of FHWA's prototype Ultra-Light Inertial Profile (ULIP) was developed by Starodub, Inc. to measure grade, cross slope, and bumps for the purpose of ascertaining compliance of sidewalks to the American Disabilities Act. This version of the prototype ULIP is called ULIPs. ULIPs was delivered to the City of Bellevue, Washington in July 2007 by Starodub, Inc. Three days of training on the use of ULIPs was provided at the time of delivery.

Early in September, 2007, at the request of the City of Bellevue, FHWA tasked Starodub, Inc. to go to Bellevue, Washington to assist them in resolving issues Bellevue staff were having in regards to validating ULIP and resolving problems related to data acquisition and data analysis.

Objectives

The objectives of the trip by Starodub, Inc. to Bellevue, Washington were to:

1. Reinforce the training provide during the initial delivery
2. Assist in the field validation study as an advisor
3. Discuss analysis options and parameter settings
4. Gather feedback from the ULIPs prototype testing

Scope

The scope of the trip to Bellevue, Washington covers four primary areas based on discussions and interactions with the Bellevue, Washington staff prior to the trip.

1. Observe ULIP equipment preparation procedures prior to data collection to ascertain if proper procedures are being followed and to determine if the procedures should be modified based on Starodub observations and feedback from Bellevue, Washington staff based on their experiences. Proper data collection procedures are required if accurate data is to be collected. Observe how Bellevue staff perform the data collection and field checking of collected data.
2. Advise Bellevue, Washington staff on the conduct of a validation test including site selection, ULIP data collection, alternative measurement system data collection, data processing/calibration, and data comparison. ULIPs validation was a critical task for this trip as use of the ULIP for ADA sidewalk compliance testing was dependent on having valid measurement data.
3. Discuss with Bellevue staff the various options for processing and analyzing the data including in field and post processing data checks to determine if the collected data was valid on a sensor by sensor basis, and the effect that parameter sensors have on the output measures that are

generated by the ULPs program. Also discuss how the new batch processing equation shell can be utilized in a number of different scenarios to shorten processing time.

4. Gather feedback from the Bellevue, Washington staff regarding any issues or questions on the ULIP prototype testing and provide answers, procedures, and/or advise during the trip and report to FHWA all other feedback on issues or request not resolved during the trip.

Experimental Plan

The initial experimental plan was based on the known issues to be resolved prior to the trip to Bellveue. Other experiments would be likely as Starodub interacts with the Bellevue staff and learn of other issues or measurement needs. Appendix A, “Starodub Bellevue, Washington ULIPs Support Trip Report”, provides a detailed log of all ULIPs activities.

Test Plan

The Experimental Plan included:

1. DMI Calibration, including site selection, data collection, and data processing to determine DMI calibration values for the two Bellevue, ULIP riders. Five runs over the calibration site by each rider.
2. Grade and Cross SlopeValidation including site selection, data collection, data processing to determine Radius Adjustment Parameters for the two Bellevue ULIPs riders, alternative measurement device (Smart Level, digital two-foot long level) grade and cross slope measurements, and data comparison.
3. Repeatablity Measurements for both ULIPs and the Smart Level given fact of ULIPs path variability and imprecise path measurements with Smart Level. The path taken by ULIP on a sidewalk is based on the judgement of the ULIPs rider as to the likely path of a wheel-bound person.

Based on above results and any subsequent or new issues that arise during the Bellevue trip, additional experiments would likely be carried out during Starodub’s visit given sufficient time to conduct such experiments.

Data Reduction Methods

The SEQS Equations shells for Data Acquisition, single case processing, and the new batch processing equation served as the basis for all data reduction. As some of the equation properties are rider specific, versions of these equations shells exist for each rider’s collected data. The four equation shells used or discussed with the Bellevue staff are shown in the next four figures. The equation shells shown in figures 2, 3, and 4 are batch processing shells for processing multiple cases. The batch processing equation shell capability was developed during the second half of August 2007. The Calibration shell executes the Pre-Processing equation module with the recalibration property set to yes. A DMI calibration file is written for each case processed. The batch post-processing equation shell is used to process multiple cases with rider specific parameter properties within the equation modules set for the rider that collected the data.

The QC/QA batch processing shell has the Pre-Processing and Gyro equation shells debug properties set to YES. The graphical display of the data permits visually checking the processed sensor data.

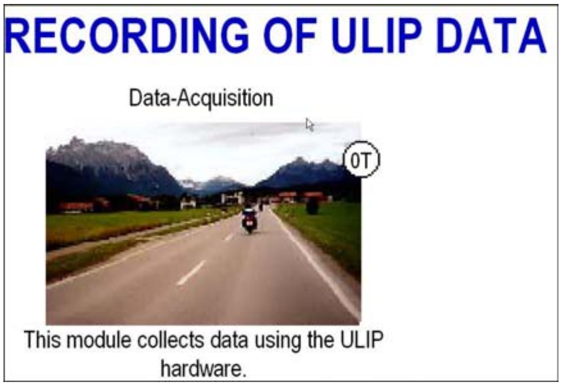


Figure 1. Data Acquisition Shell

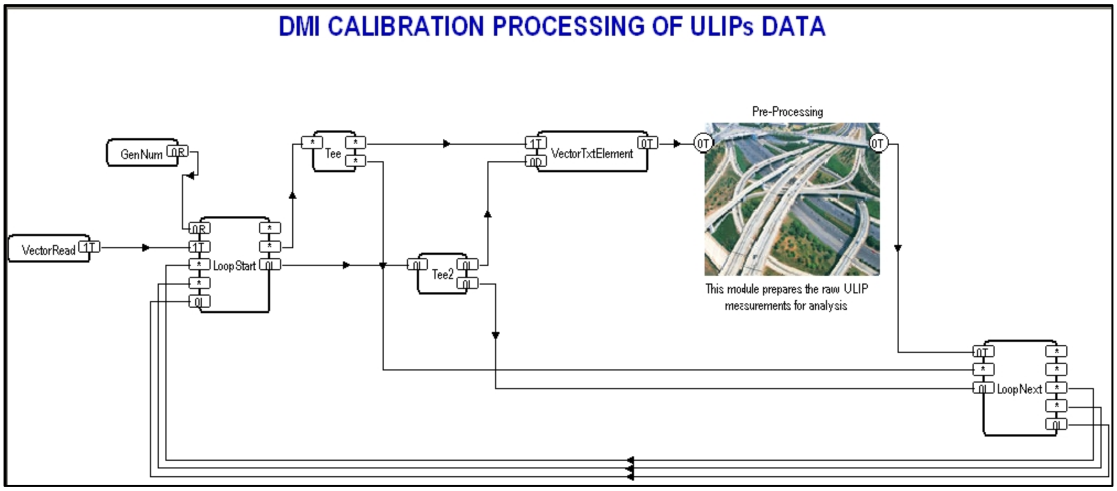


Figure 2. Data Calibration Shell

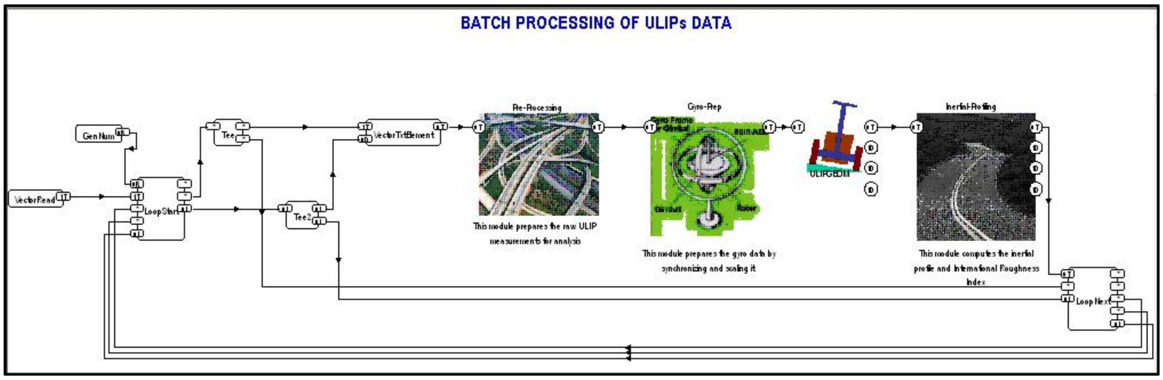


Figure 3. Batch Processing Shell

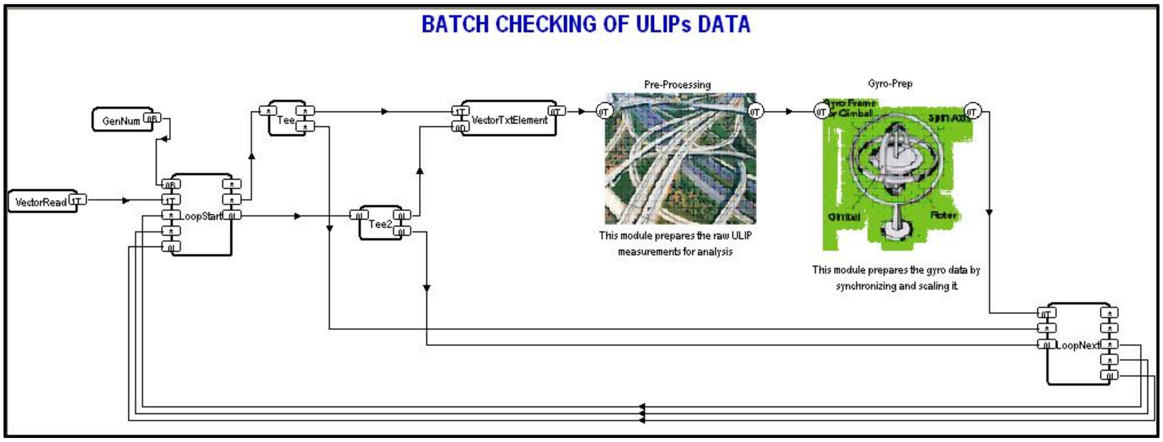


Figure 4. QC/QA Post-Processing Shell

Tests

A number of experiments/tests/calibrations were conducted during the site visit. These tests included.

1. DMI Calibration. Factoria DMI calibration site, multiple runs, both ULIPs riders.
2. Grade and Cross Slope Validation: Factoria Grade and Cross Slope Validation Site, multiple runs, one rider (Sarah). Other rider test cancelled due to rain. Test will be conducted in the near future prior to any additional production data collection.
3. Grade and Cross Slope Averaging Window Size.: Window size investigated for validation and production post-processing. Processed ULIPs data was compared to Smart Level data to determine appropriate averaging window size. Factoria validation site used for this experiments as the crossing driveways and sidewalk transitions provide easily measured features in a relatively short length.
4. Path Variability of Smart Level and ULIPs Grade and Cross Slope. All repeated runs made by ULIPs can be used to determine measured parameter variability. In some cases, ULIPs runs were made where the same path was attempted to be repeated. In another case, same path runs and parallel path runs on the same sidewalk were collected by ULIPs. Smart Level data was collected on five parallel paths on a sidewalk. With this data, expected variation in ULIP data can be ascertained.
5. ULIPs and Rider Stability. Some curb access ramp design/construction at block corners make ULIPs/rider stability at startup difficult. Purpose of this test was to determine how much start-up distance past the curb access ramp is required. A number of operating protocols were run to determine which protocol would be best suited under a given condition.

Results

DMI Calibration

DMI Calibration numbers (tire circumference) for Sept. 17 were very different from the early August numbers. As determined the next day, tire pressure was down 5-6 PSI. Tire pressures had not been maintained or monitored.

Grade and Cross Slope Validation

Using the data from the Factoria Validation site, a Radius Adjustment Parameter for Sarah (one of the ULIPs riders) was established by trial and error comparison to Smart Level data collected at the site.

The graphs showing the Smart Level and ULIPs measurements are provided on the following three pages. Smart Level measurements were taken every 1 foot. ULIPs reported grade is for every foot using a moving average window of 1 foot. The first graph, figure 5, shows ULIPs grade for one run versus Smart Level grade. Grade sign convention is maintained for this plot. The second graph, figure 6, shows ULIP grade for four runs versus Smart Level grade and where grade sign convention has been eliminated as grade is a none directional issue for ADA requirements. The third graph, figure 7, shows ULIPs and Smart Level Cross Slope measurements.

In the first graph, figure 5, for ULIPs and Smart Level grade comparison, it can be seen that the two measurements coincide very well. The four sidewalk-driveway transitions are clear features on the graph.

The second graph, figure 6, shows the grade data for all four ULIPs runs versus Smart Level data where grade sign convention has been eliminated. Again, the graph shows very good agreement between the ULIPs data and the Smart Level data.

The third graph, figure 7, shows the cross slope data for all four ULIPs runs versus the Smart Level data. The ULIPs and Smart Level data agree very well relative to trends. There is one Smart Level point at 148 feet that appears to lie outside of the ULIP data. It is hypothesized that this was either a bad measurement or a very localized feature caused this anomalous measurement. Some path variation in ULIP cross slope data is apparent but not unexpected as similar path variation measurements are also present in Smart Level data.

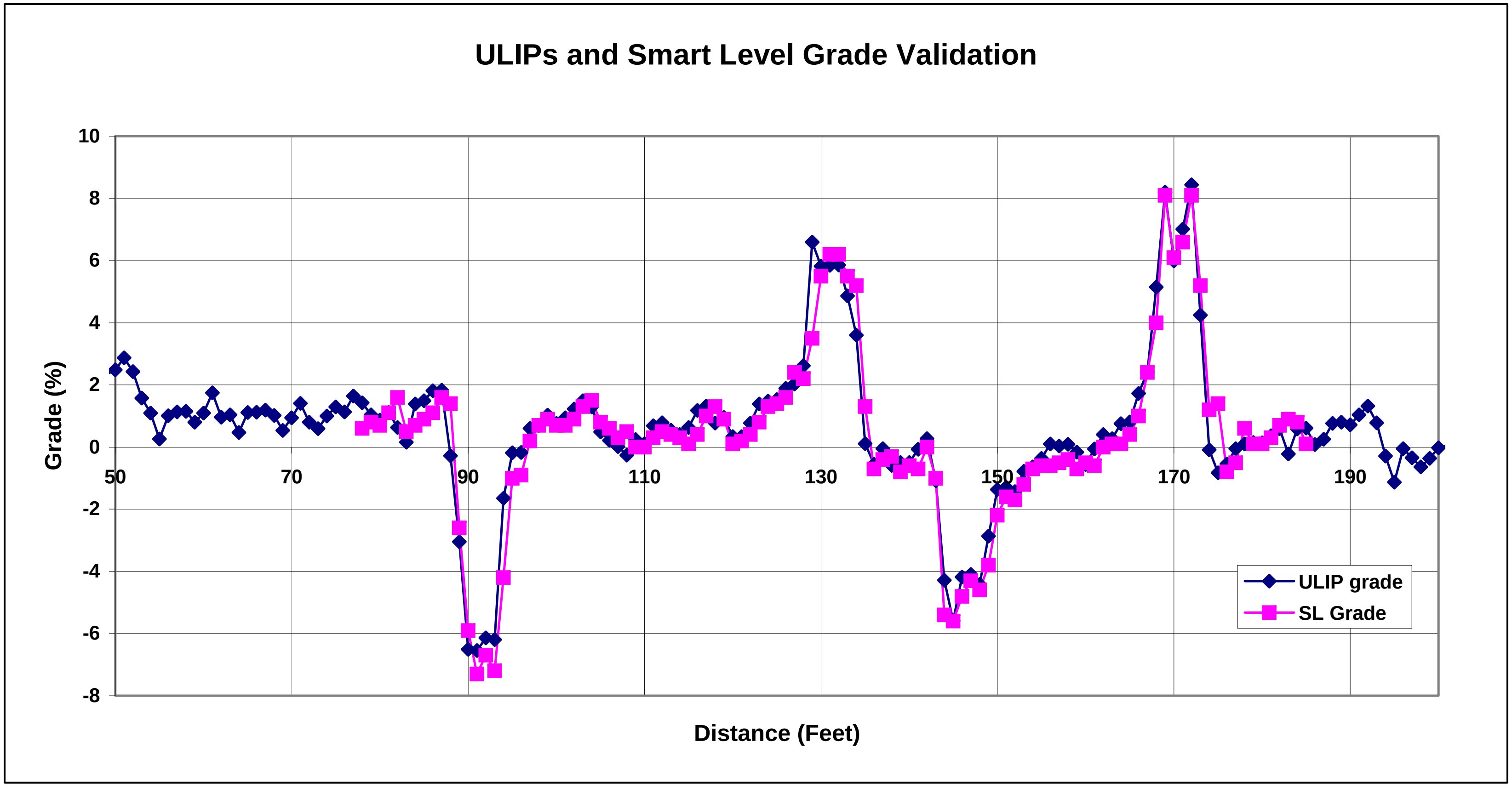


Figure 5. ULIPs Smart Level Grade Validation with Grade Sign Convention Maintained.

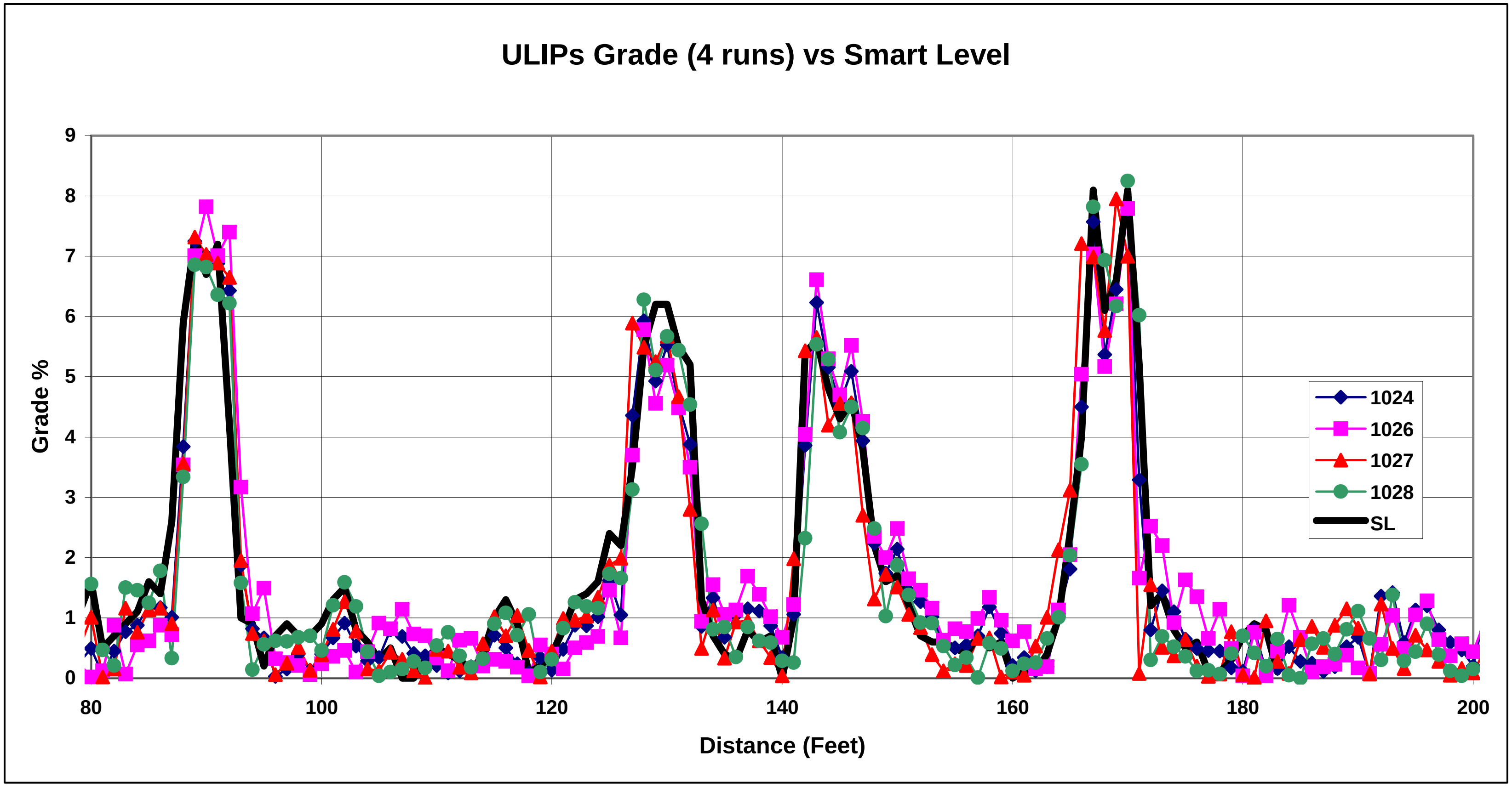


Figure 6. ULIPs Grade versus Smart Level Data with Sign Convention Removed.

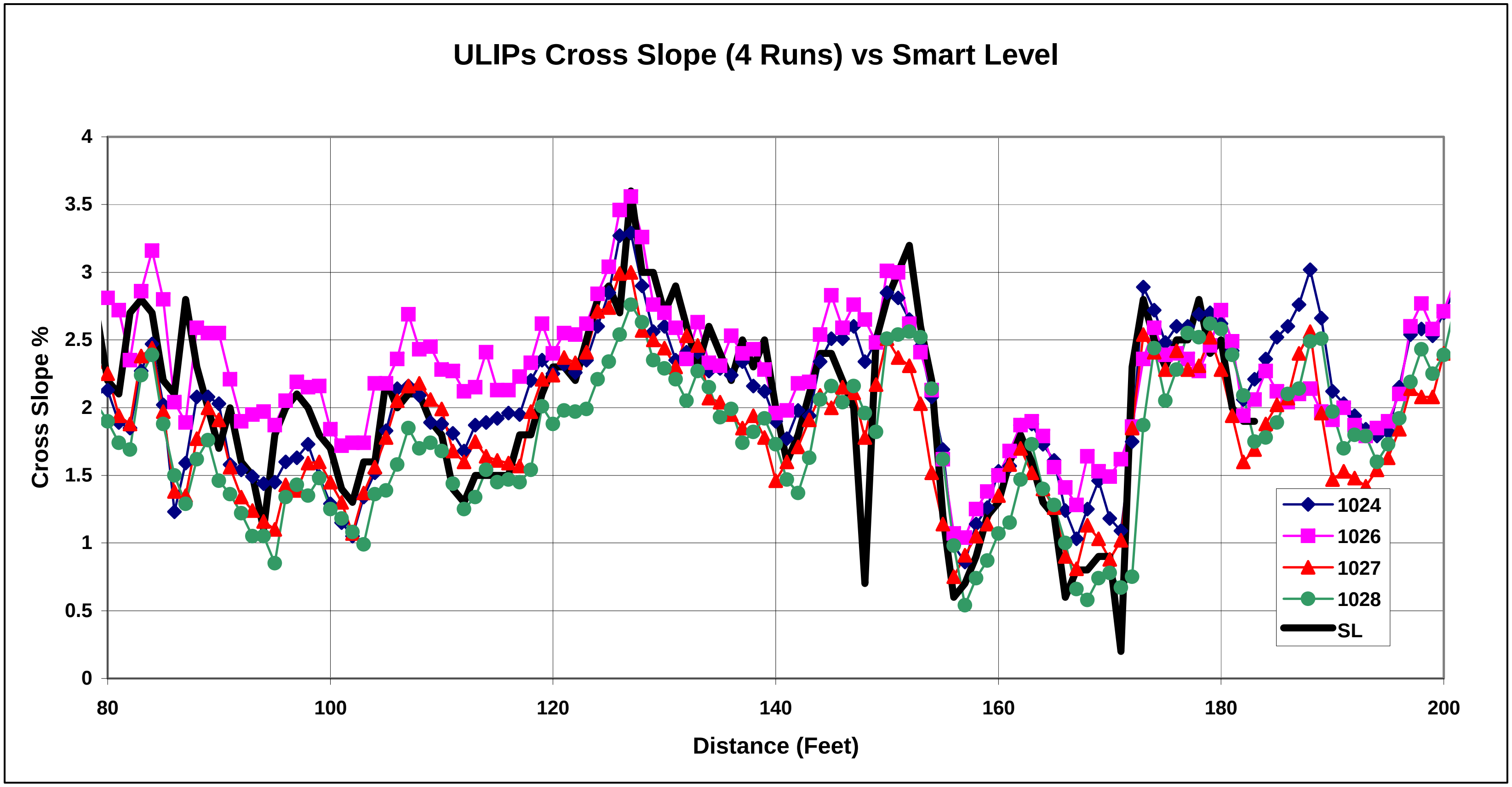


Figure 7. ULIPs Cross Slope versus Smart Level Data

Grade and Cross Slope Averaging Window Size

In the ULIP Geometry Equation, the user specifies the grade and cross slope window size in feet to be applied in a moving average computation. The setting of these values should be determined from review of the ADA requirements. A value of 1 or 2 feet is appropriate for performing validations and for determining the Radius Adjustment parameter in the ULIPGEOM Equation. The graph on the next page, figure 8, illustrates the effect of moving average window size. The larger the value, the more dampened out the features. Data for the graph is from one of the Bellevue block sites. The window sizes shown in the legend represent the values that ULIP will accept as legal values. The graph also confirms why the window size for comparing ULIP data with Smart Level Data for a validation needs be done with a window size of 1 or 2 feet.

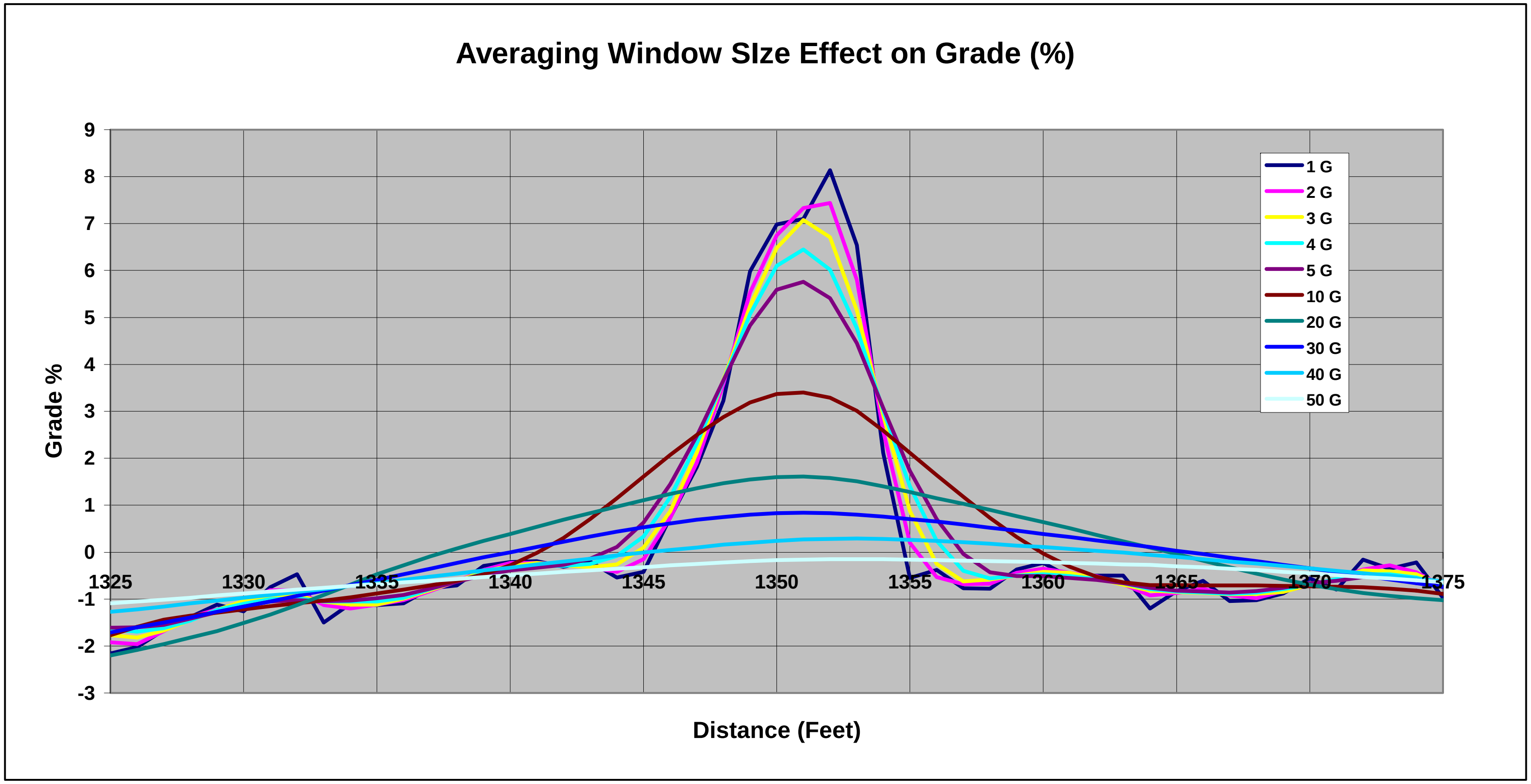


Figure 8. Effect of Averaging Window Size on ULIPs Grade Measurement

Path Variability of Smart Level and ULIPs Grade and Cross Slope

The test site was a concrete sidewalk in very good condition along a driveway to multiple garage entrances to the Bellevue City Hall. Three parallel paths were established for the ULIP to follow, near each sidewalk edge and down the center of the sidewalk. Smart Level readings were taken along each path at one-foot intervals for a distance of twenty feet for the two middle pavement slabs. Measurements were also taken between the center path and the two outside paths. The layout is depicted in figure 9.

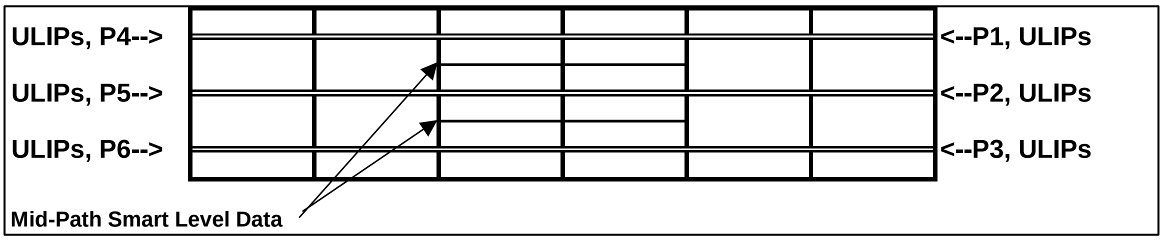


Figure 9. Site Layout for Path Variability of Grade and Cross Slope.

Measurements consisted of both grade (running slope) and cross slope measurements. The Smart Level is a two-foot long device with a digital grade/slope display with display resolution of 0.1 percent. The graphs showing the Smart Level measurements are provided on the following two pages.

For the Path Grade graph, figure 10, the grade along the five paths are consistent in their trend. A variation in grades amongst the five paths is observed. The standard deviation of grade across the five paths at the 21 measurement points ranged from 0.13 to 1.41 with the average standard deviation being 0.37.

For the Cross Slope graph, figure 11, the cross slope along the five paths are divided into two regimes, 1-10 feet and 11-20 feet, with the variation being much greater in the 11-20 foot section. The standard deviation across the five paths at the 21 measurement points ranged from 0.08 to 0.97 with the average standard deviation being 0.46.

These results indicate that variations in grade and cross slope, as determined by the Smart Level measurements, are present on the sidewalk and that measurements taken along a sidewalk path by any measurement device are subject to the same variations in the sidewalk surface. Such measurement variations as a result of measurement path variation need to be incorporated in any validation process and in determining what is appropriate in terms of a moving average window used for an ADA compliance report. Other sidewalks of varying construction in terms of material and construction techniques should be investigated.

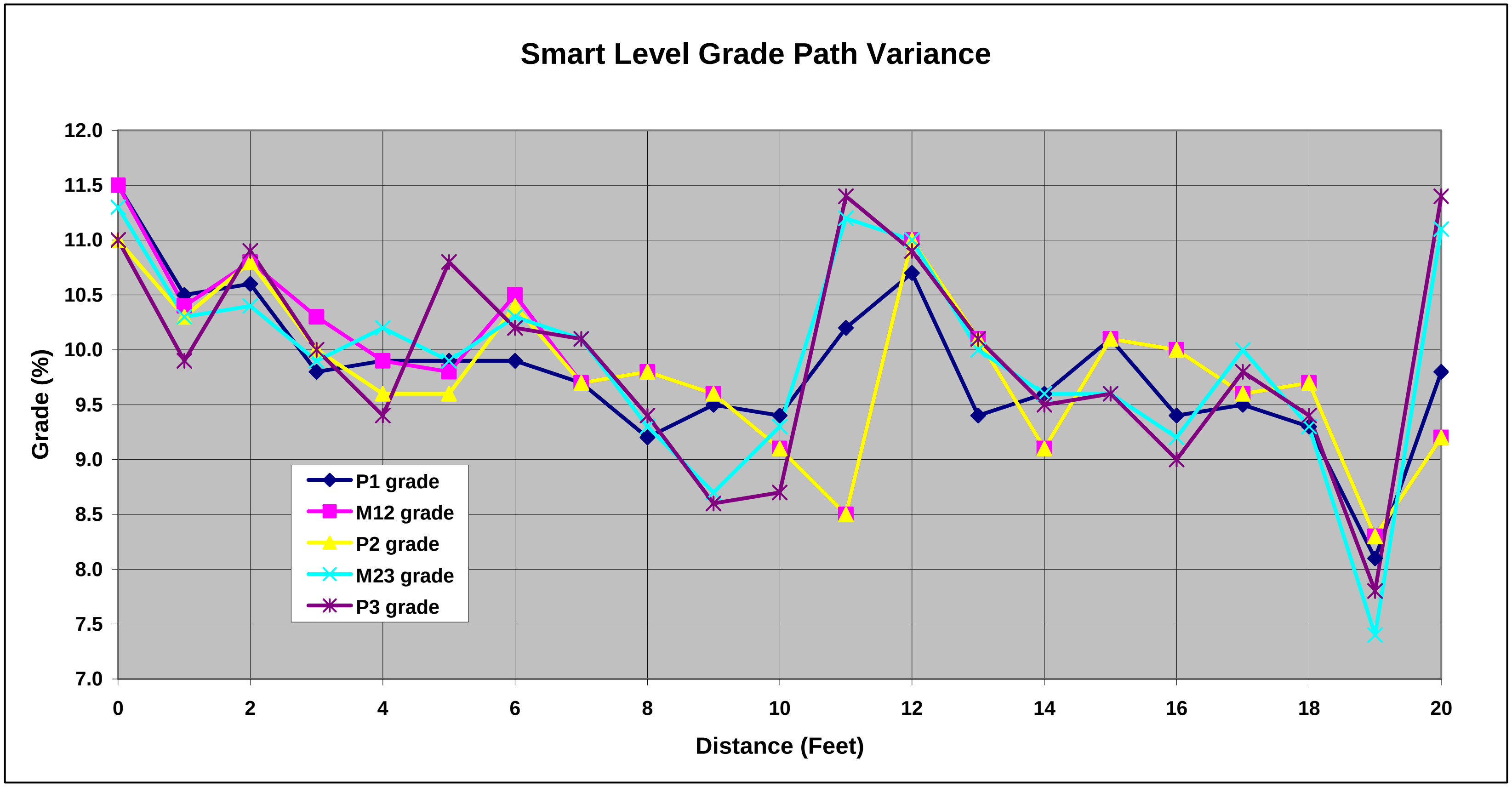


Figure 10. Smart Level Grade Path Variance.

The five repeated ULIP runs on uphill Paths 1, 2, and 3 and downhill Paths 4, 5, an6 had not yet been processed by Bellevue staff for this report. Bellevue staff will perform the analysis for the ULIP data.

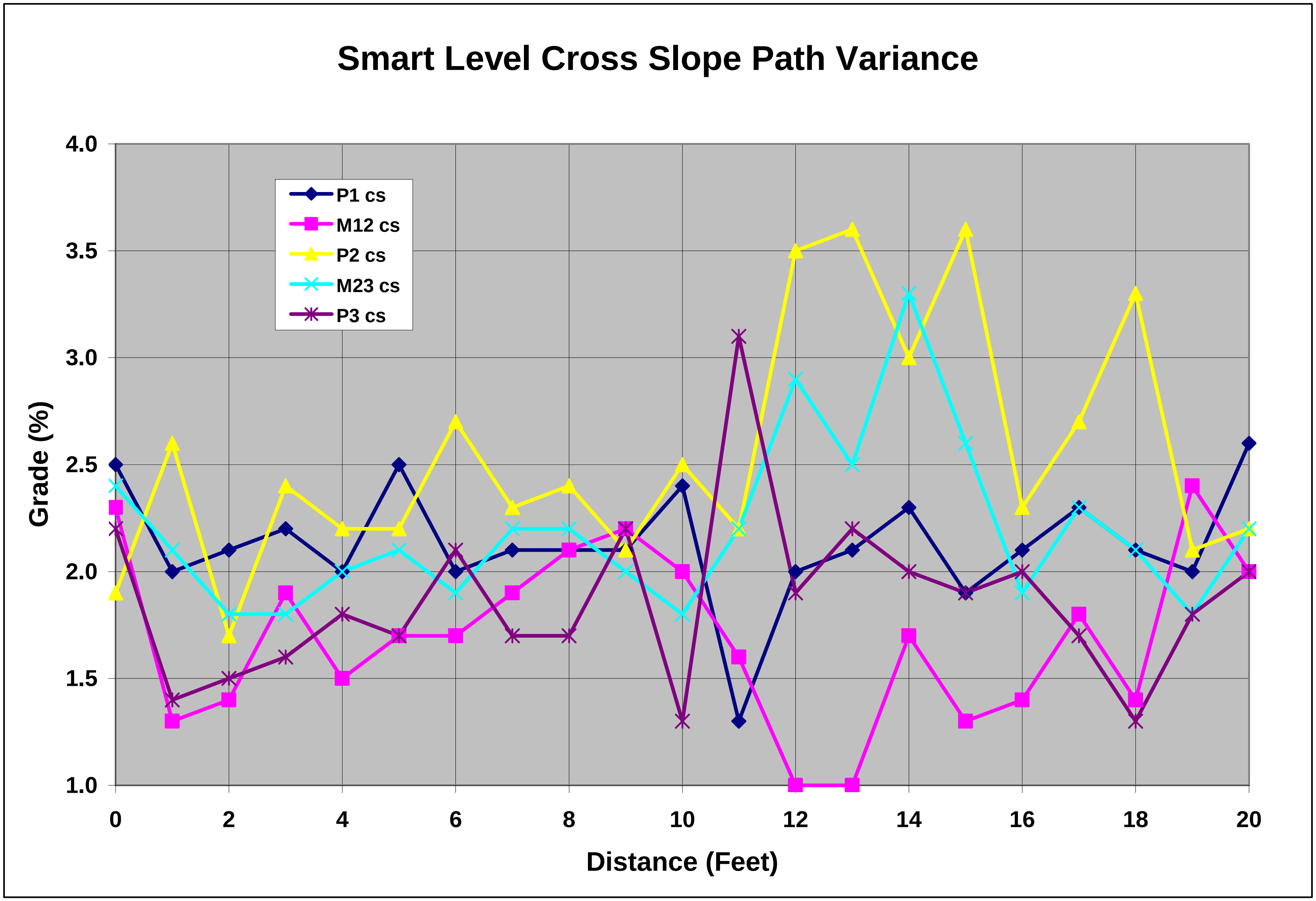


Figure 11. Smart Level Cross Slope Path Variance.

ULIPs and Rider Stability

Results of the two-block continuous data collection run “Consecutive1” is present in figures 12, 13, 14, and 15. ULIPs grade and cross slope data is compared to Smart Level data. The data presented is only one of the runs made during an initial stabilization experiment. Bellevue staff is looking at the other runs and will probably conduct other experiments.

In general, data is sometimes similar but not the same in the curb access ramp area (first part of graphs). This was expected for this site as access ramps are minimally sized and best described as “lumpy”. Area of interest is the area immediately beyond the access ramp. Stabilization is apparent in the graphs. Bellevue staff will use this data to establish stabilization lengths for varying conditions.

It should be noted that full Radius Adjustment Parameter calibration for this ULIPs rider had not yet been performed so a small difference in overall grade is expected even when the ULIPs is stabilized.

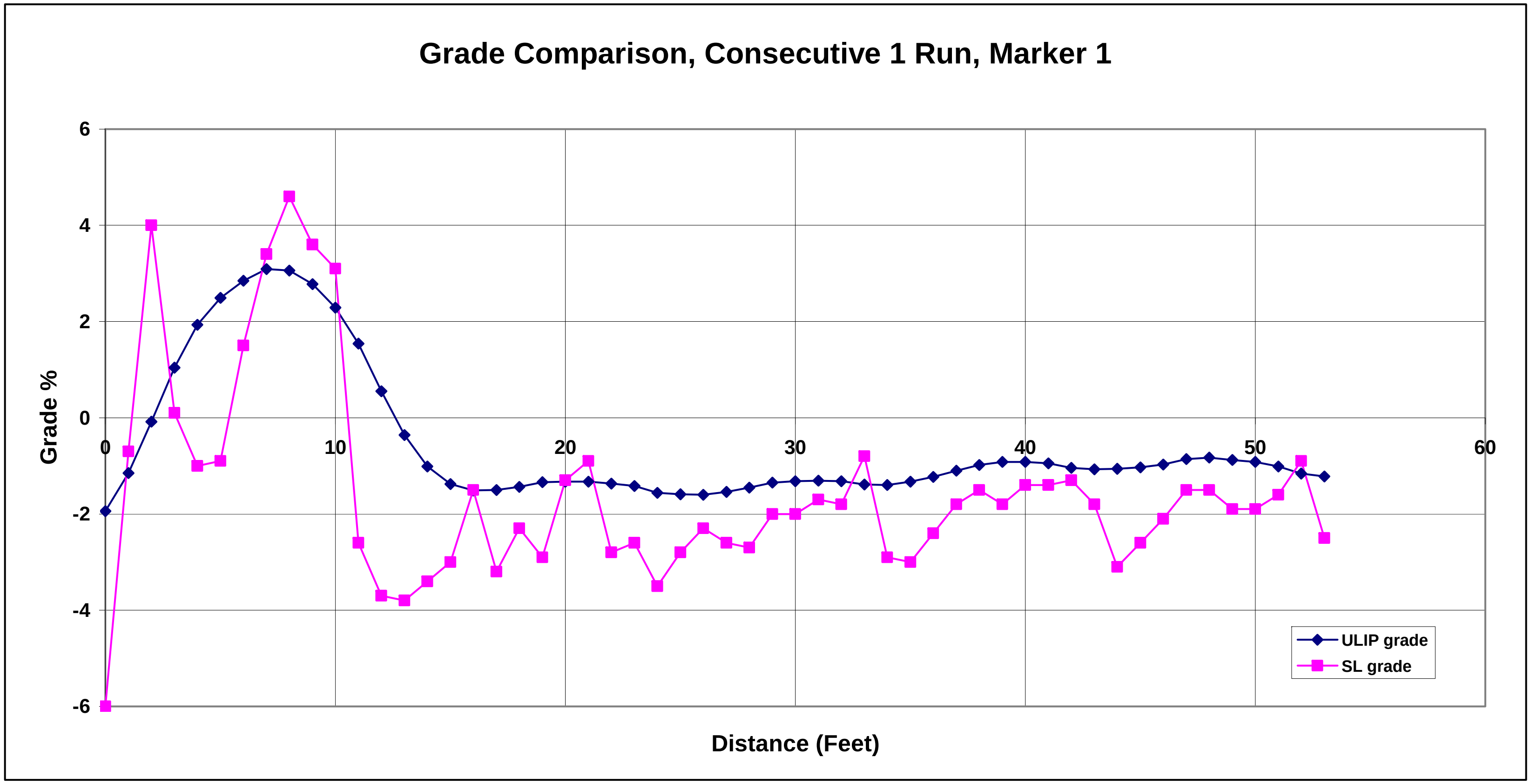


Figure 12. ULIPs/Rider Stability Grade Comparison at First Curb Access Ramp.

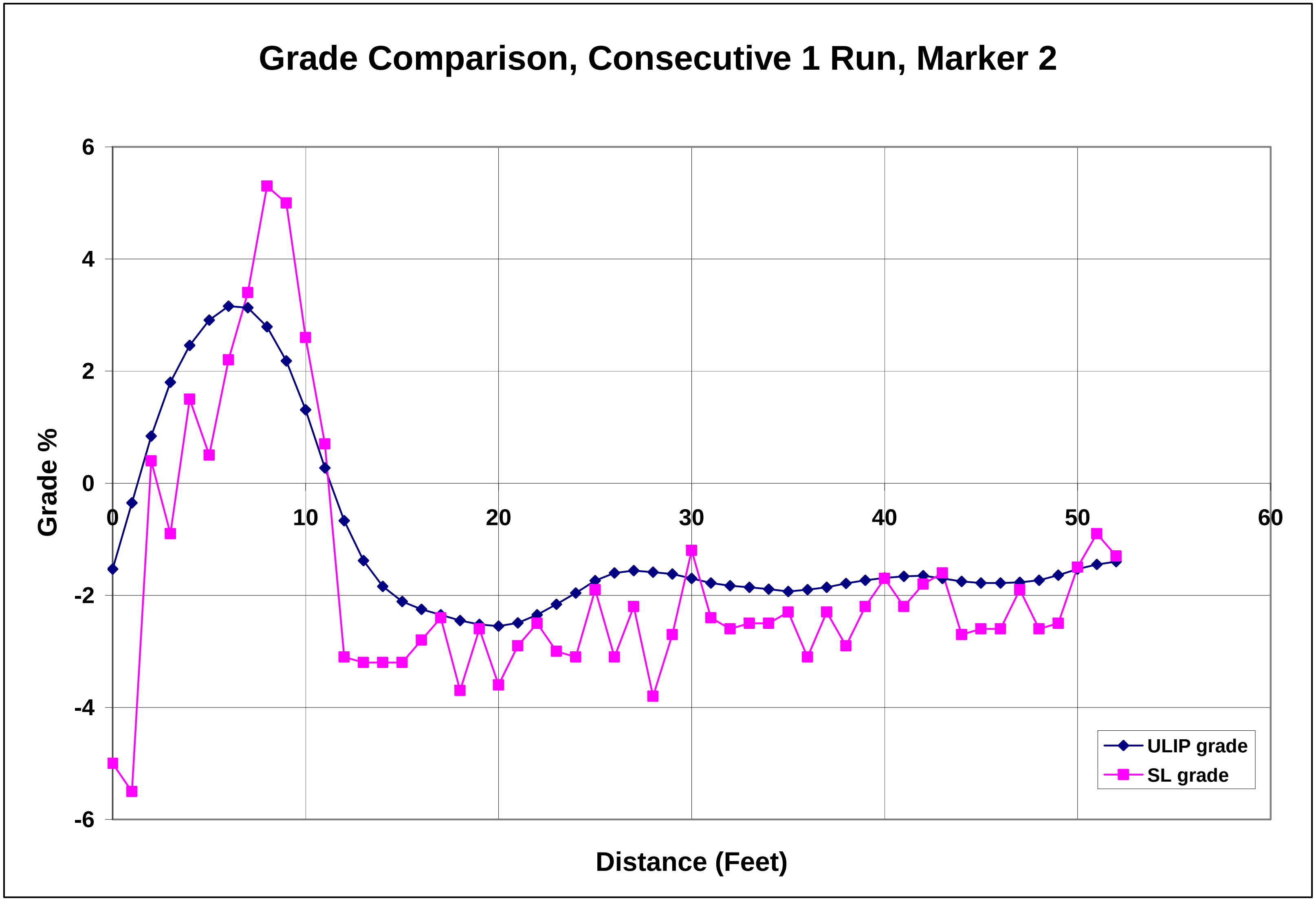


Figure 13. ULIPs/Rider Stability Grade Comparison at Second Curb Access Ramp.

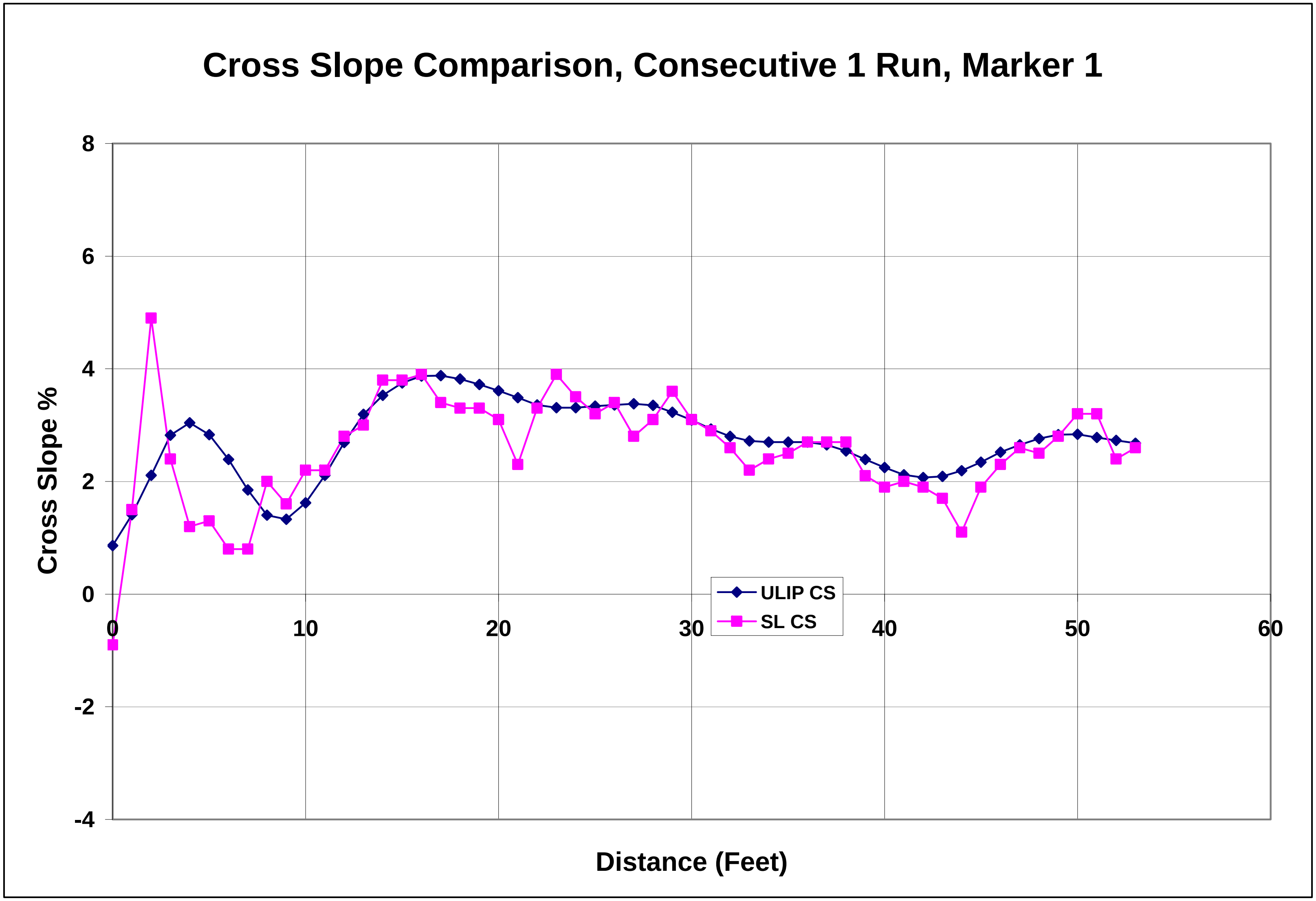


Figure 14: ULIPs/Rider Stability Cross Slope Comparison at First Curb Access Ramp.

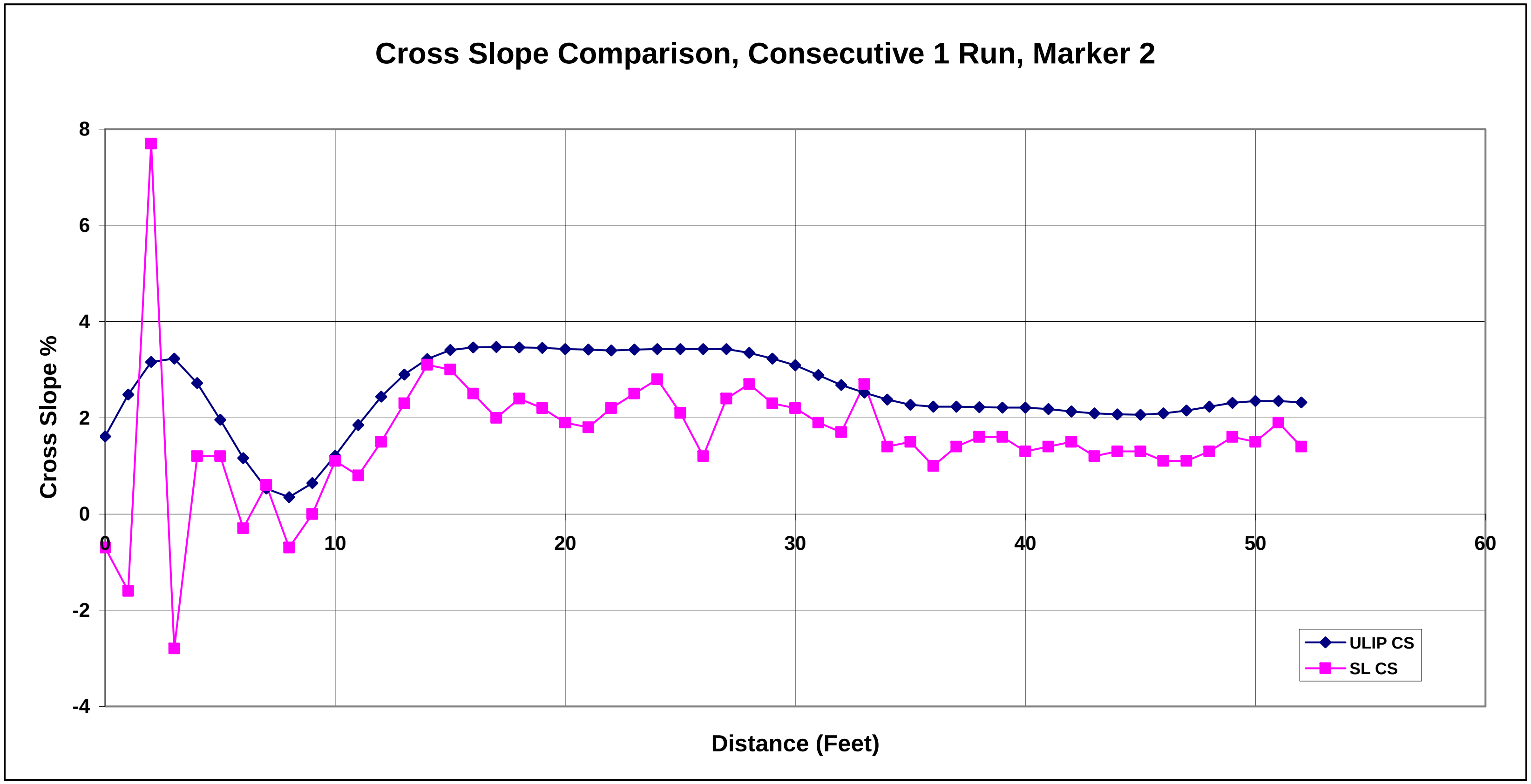


Figure 15: ULIPs/Rider Stability Cross Slope Comparison at Second Curb Access Ramp.

Discussion

The results presented for the tests conducted with the ULIPs and Smart Level in Bellevue, Washington indicate that the ULIPs does measure grade and cross slope at a good level of accuracy given measured path variability. This level of accuracy is achievable when operational protocols are followed in regard to ULIPs system checks in preparation of a day's data collection and when field data collected data is reviewed immediately after the data collection via the debug mode option.

When the users of a ULIPs system are not engineering oriented in terms of their background, additional training is required on the protocols to be followed for system preparation, data collection, and problem identification and solution in the field. In addition, it is necessary for the users to know the basics of how the ULIPs system works so they can understand the implications of any proposed deviations from current operational protocols.

Discussions with Bellevue staff provided additional information as to the behavior of the ULIPs system components and helped in determining what operation protocols needed to be emphasized and what protocols should be modified or added.

Based on the experience gained in working with the Bellevue staff, ULIPs user manual and operations guide should be updated to include the knowledge gained from the field trip to Bellevue.

Bellevue staff have unprocessed ULIPs data runs that can be analyzed and reported for Path Variability of grade and cross slope. Additional data runs exist for the ULIPs/Rider stability issue at curb access ramps that are currently being processed and analyzed by the Bellevue staff.

Based on training provided Starodub, the Bellevue staff is preparing a problem identification and resolution guide based on reviews of the raw DAQ data and data processed by the Bre-Processing routine and the ULIPGEOM routine.

Bellevue needs to develop guidelines as how the ADA specifications are to be used in determining non-compliant sidewalks. The ADA does not provide clear methodological procedures for measuring or evaluating grades and cross slopes in a practical sense. Given the demonstrated variability of grade and cross slope due to path variance influence, sharp compliant/non-compliant thresholds with no error or practical allowance values would like result in too many non-compliant sidewalk sections.

Based on concerns Bellevue Washington staff had about the quality and useability of the data collected during the Summer of 2007, a methodology (as presented in Summer.xls) was developed to check on the quality of the data collected and how a DMI calibration value and a Radius Adjustment Parameter can be established for the this data.

Conclusions

There are three primary conclusions based on the work conducted on the field visit to the Bellevue Washington ULIPs staff.

1. ULIPs does provide accurate Grade and Cross Slope measurements when operated within the protocols establish when the system was delivered and as modified during this visit.
2. Adequate training on the use of the ULIPs for data collection, data reduction, and data analysis is a key component of a successful application of ULIPs.
3. Bellevue Washington ULIPs staff now appear to be sufficiently trained and possess a level of understanding of how the ULIPs works, protocols that need to be followed, more knowledgeable about the procedures for calibration and validation, and the analysis parameter effects on ULIP data.