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14. Supplementary Notes			
15. Abstract <u>Purpose and Need</u> Improving the ride quality of these pavements is part of the NDDOT Strategic Business Plan Objective 1.3. It is assumed that stop/start operation of the HBP paver can result in rough pavement. Variation in paver speed can be the result of plant production rate, truck delivery, hauling distance, or equipment operator expertise. In addition to improving ride quality, research from (NCHRP 1-31 Smoothness Specification for Pavements) has indicated that pavement life may be extended by improving initial smoothness. <u>Objective</u> The objective of this project is to determine if there is a correlation between paver motion and the ride quality of new hot bituminous pavements. <u>Scope</u> A lightweight inertial profiler evaluated the new asphalt section. A GPS unit was placed on the paver to record its motion during the paving of the asphalt section. After the project was finished, the lightweight inertial profiler obtained the final profile of the roadway. The paver's motion was then compared to the measured profile of the roadway. Using the captured data from the profiler, GPS unit and the project engineer's comments; conclusions and recommendations for optimizing paving operations will be given. <u>Construction</u> The widening and re-grading of the roadway and the first lift of the asphalt section was completed in the 2003, as part of project AC-HPP-4-052(045)058. Project AC-HPP-4-052(045)058 the intermediate and final lifts of HBP was constructed in 2004. Steve Sink from the Minot District the project engineer and Mayo Construction from Cavalier, ND was the prime contractor. <u>Conclusion</u> Attempting to keep the paver motion constant and limiting the number of paver stops would be recommended as a result this project. It may be impossible to eliminate the paver from stopping, but the number of stops may be reduced by altering paving methods. Also, the length of stops may help reduce the size of the bump. Making the base and first asphalt lift as smooth as possible to reduce the bumps from reflecting there the final lifts is also recommended. Trying to improve aspects of paving may help in improving the ride.			
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**NORTH DAKOTA
DEPARTMENT OF TRANSPORTATION**

**MATERIALS AND RESEARCH
DIVISION**

Experimental Study MR 2004-01

Effects of HBP Paver Motion on Ride Quality

Final Report

AC-HPP-4-052(045)058

February 2005

Prepared by

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Effects of HBP Paver Motion on Ride Quality

Purpose and Need

The North Dakota Department of Transportation (NDDOT) uses hot mix asphalt for different aspects of road construction, ranging from thin lift overlays to reconstruction of asphalt pavements. Improving the ride quality of these pavements is part of the NDDOT Strategic Business Plan Objective 1.3. It is assumed that stop/start operation of the HBP paver can result in rough pavement. Variation in paver speed can be the result of plant production rate, truck delivery, hauling distance, or equipment operator expertise. NDDOT specification 151.04, Bituminous Pavers, requires that “...*the paver shall operate at speeds consistent with continuous and uniform laying of the mixture...*” By optimizing aspects of the paving operation, a higher ride quality may be achieved.

In addition to improving ride quality, research from (NCHRP 1-31 Smoothness Specification for Pavements) has indicated that pavement life may be extended by improving initial smoothness.

Objective

The objective of this project is to determine if there is a correlation between paver motion and the ride quality of new hot bituminous pavements.

Scope

A lightweight inertial profiler evaluated the new asphalt section. A GPS unit was placed on the paver to record its motion during the paving of the asphalt section. After the project was finished, the lightweight inertial profiler obtained the final profile of the roadway. The paver's motion was then compared to the measured profile of the roadway. Using the captured data from the profiler, GPS unit and the project engineer's comments; conclusions and recommendations for optimizing paving operations will be given.

Location

Projects AC-HPP-4-052(044)058 and AC-HPP-4-052(045)058 are located in Ward and Renville Counties on US 52. The projects begin at Station 3145+00 (RP 59.5727), just southeast of Donnybrook. The projects end at Station 3668+40 (RP 69.4765), just southeast of Carpio. The location is displayed in Figure 1.

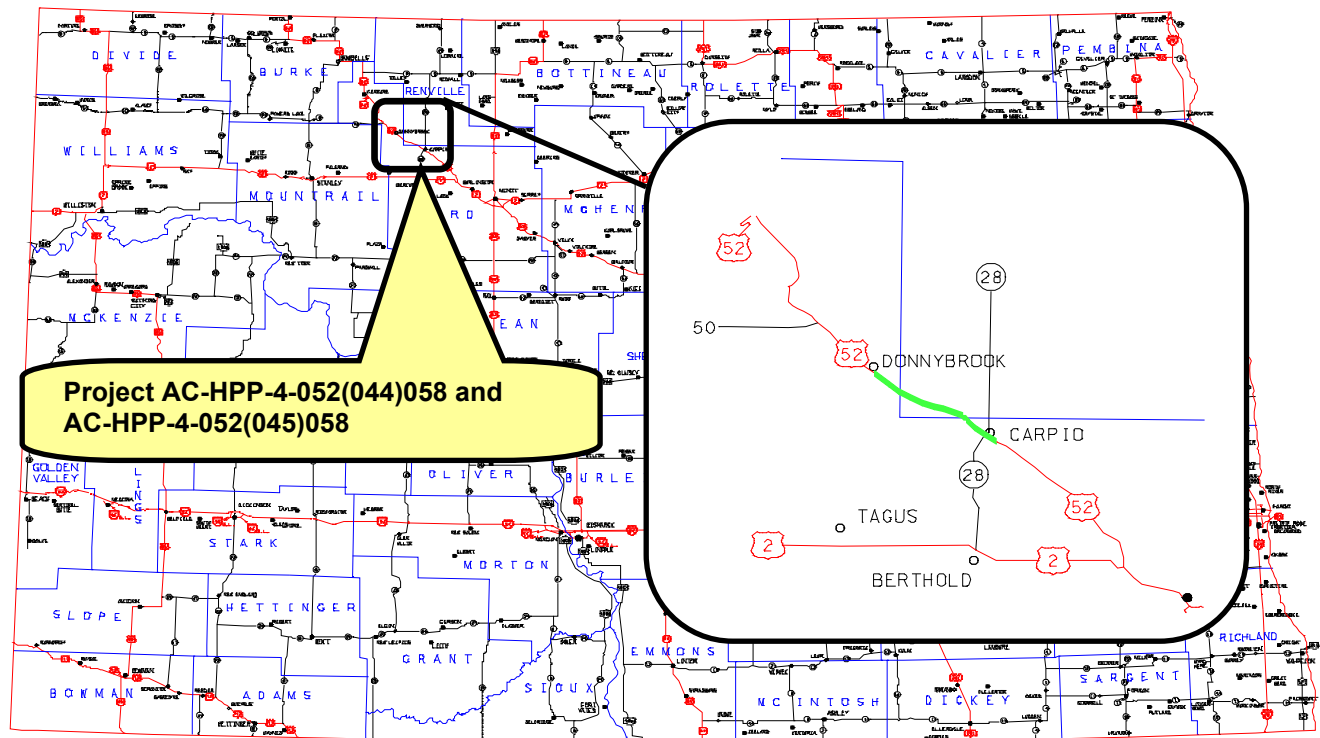


Figure 1 – Project location

Design

The project was re-graded and widened in the 2003 construction season. 1.5" of Hot Bituminous Pavement (HBP) Class 31 (using 58-28 binder) was placed until the intermediate and final lifts of hot bituminous pavement could be constructed in the spring of 2004. The intermediate lift was constructed with 2" of Class 31 (using 58-28 binder) HBP and the final lift was 2" of Class 31 (using 58-34 binder) HBP. A cross section of the roadway can be seen in the Figures 2, 3, & 4 below.

A section of this roadway includes a second research project, ND 2002-01 Base Reinforcement Using Geogrid, investigating the effectiveness of geogrid in maintaining base strength while reducing base thickness. This research project placed test sections of geogrid into the base with different base sections.

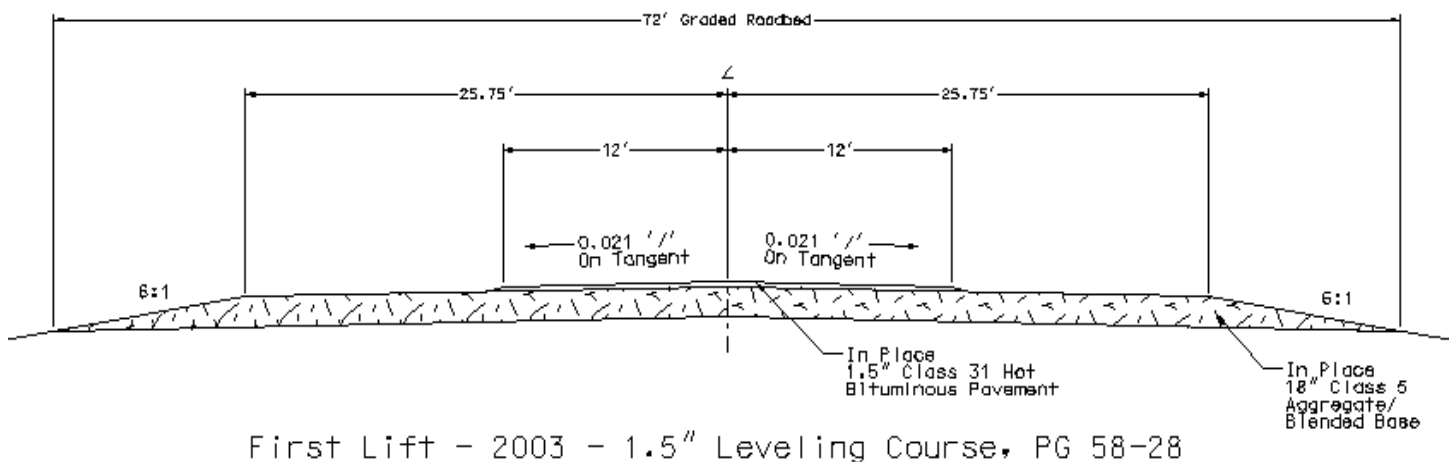
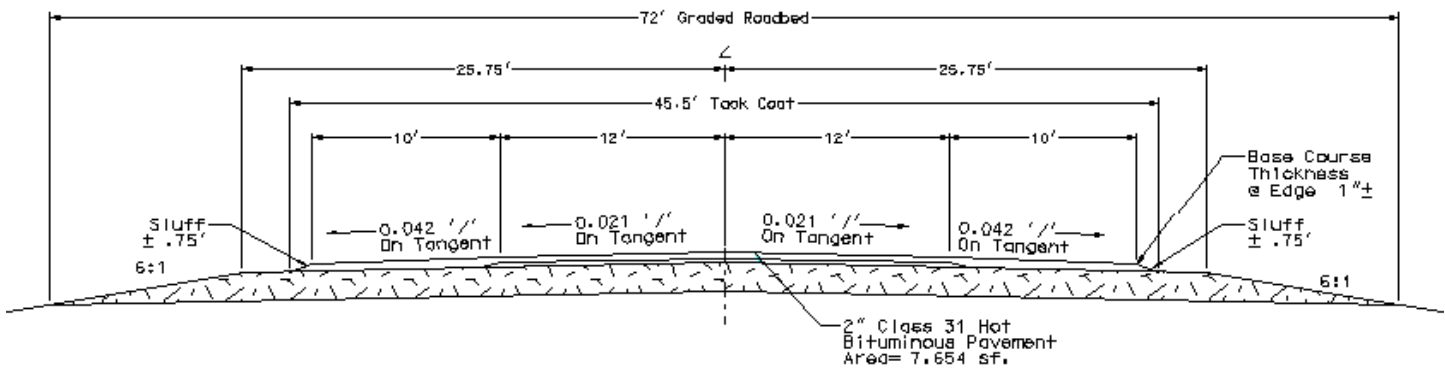
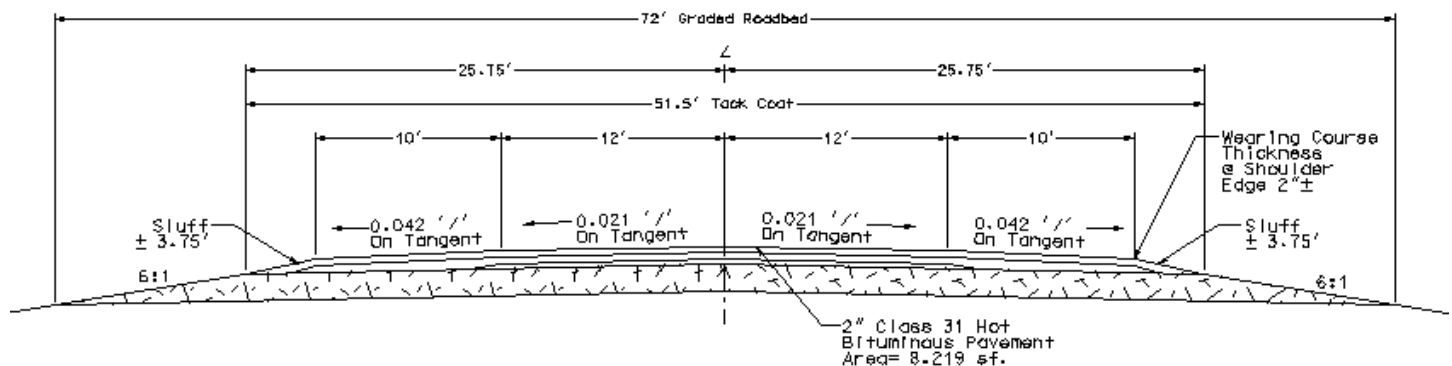


Figure 2 – First lift that was used to protect base and subgrade over 1st winter.



Intermediate Lift - 2004 - 2" Base Course, PG 58-28
10' shoulder shall be paved with 12' adjacent lane.

Figure 3 - Intermediate lift put down the following construction season.



Final Lift - 2004 - 2" Wearing Top Course, PG 58-34
10' shoulder shall be paved with 12' adjacent lane.

Figure 4 - Final lift put down after intermediate lift was finished.

Construction

The widening and re-grading of the roadway and the first lift of the asphalt section was completed in the 2003, as part of project AC-HPP-4-052(045)058.

Project AC-HPP-4-052(045)058 the intermediate and final lifts of HBP was constructed in 2004. Steve Sink from the Minot District the project engineer and Mayo Construction from Cavalier, ND was the prime contractor.

Paving Construction

May 18, 2004 Mayo Construction began to pave the intermediate lift with a new Blaw-Knox, model PF-3200 Paver. On the first day a sensor for the screed failed and had to be replaced. Other than a failed sensor there were no equipment problems. A photo of the paver can be seen in Photo 1. The GPS unit can be seen attached to the paver. There were delays throughout the paving of both lifts caused by rain. On June 2, the intermediate lift was finished. Paving for the final lift began June 3 and was finished June 14.



Photo 1 – Photo of Blaw-Knox paver with Trimble GPS receiver attached.

The ten foot shoulders were paved at the same time as the mainline by a second paver. The paver for the shoulders was paving right behind the mainline paver. The paving for both lanes began on the east side of the project and paved to the west side of the project.

Paver Motion

The paver motion was recorded using a GPS receiver (Trimble Pro XRS) and data collector (Trimble GIS TSCe) that was placed on the paver using a mast built out of telspar. A magnet held the receiver onto the mast. The GPS receiver and data collector were placed on the mast and started before the paving began for the day. The battery did not have enough power to last a whole day. Minot district personnel would exchange a fully charged battery at mid-day to keep the data receiver powered the complete day. Data is missing because there are areas where the battery died and the location of the paver was not recorded.

After the paving was finished for the day the data collector and receiver were taken off the paver and the day's data was downloaded onto a personnel computer by Minot District personnel.

Profile

The profile of the road was measured using a Light Weight Inertial Profiler (Dynatest model 6400). The lightweight profiler is mounted onto a Kawasaki Mule Model 500 series. The lightweight profiler collects both wheel paths of a lane on one run of the roadway. Photo 2 displays the lightweight profiler.

South Dakota Department of Transportation (SDDOT) provided the light weight inertial profiler. Ryan Johnson of the SDDOT operated the lightweight profiler. SDDOT uses the lightweight profiler for their asphalt pavement ride specification. Ryan Johnson ran the lightweight profiler April 20, 2004 on the first lift, and he came back on July 28, 2004 to get the final profile of US Highway 52. The lightweight profiler did not run over the intermediate lift due to timing conflicts.



Photo 2 – SDDOT's lightweight profiler.

Evaluation

The evaluation for this research project is primarily based on the profile of the roadway and the motion of the paver. When the paver stops, the screed drops and forms a very small dip visible to the naked eye. The dip cannot be seen by the naked eye after the rollers compact the asphalt pavement. The profile from the lightweight inertial profiler for the last lift is being used to measure the ride quality of the road. The motion of the paver will be determined by GPS unit attached to the paver.

ProVal 2.5, a beta version software, was used to analyze the data from the light weight profiler. ProVal has two programs that were used to convert the raw data from the profiler into a continuous IRI value for the roadway. The programs on ProVal are “Bumpfinder and Grinding” and “Ride Stats Continuous”. A threshold for the IRI is chosen for the two programs and then the software identifies any area on the roadway that exceeds an IRI chosen for the threshold. Figure 5 displays an example of a graph that ProVal 2.5 provides from using the “Bumpfinder and Grinding” and “Ride Stats Continuous” programs.

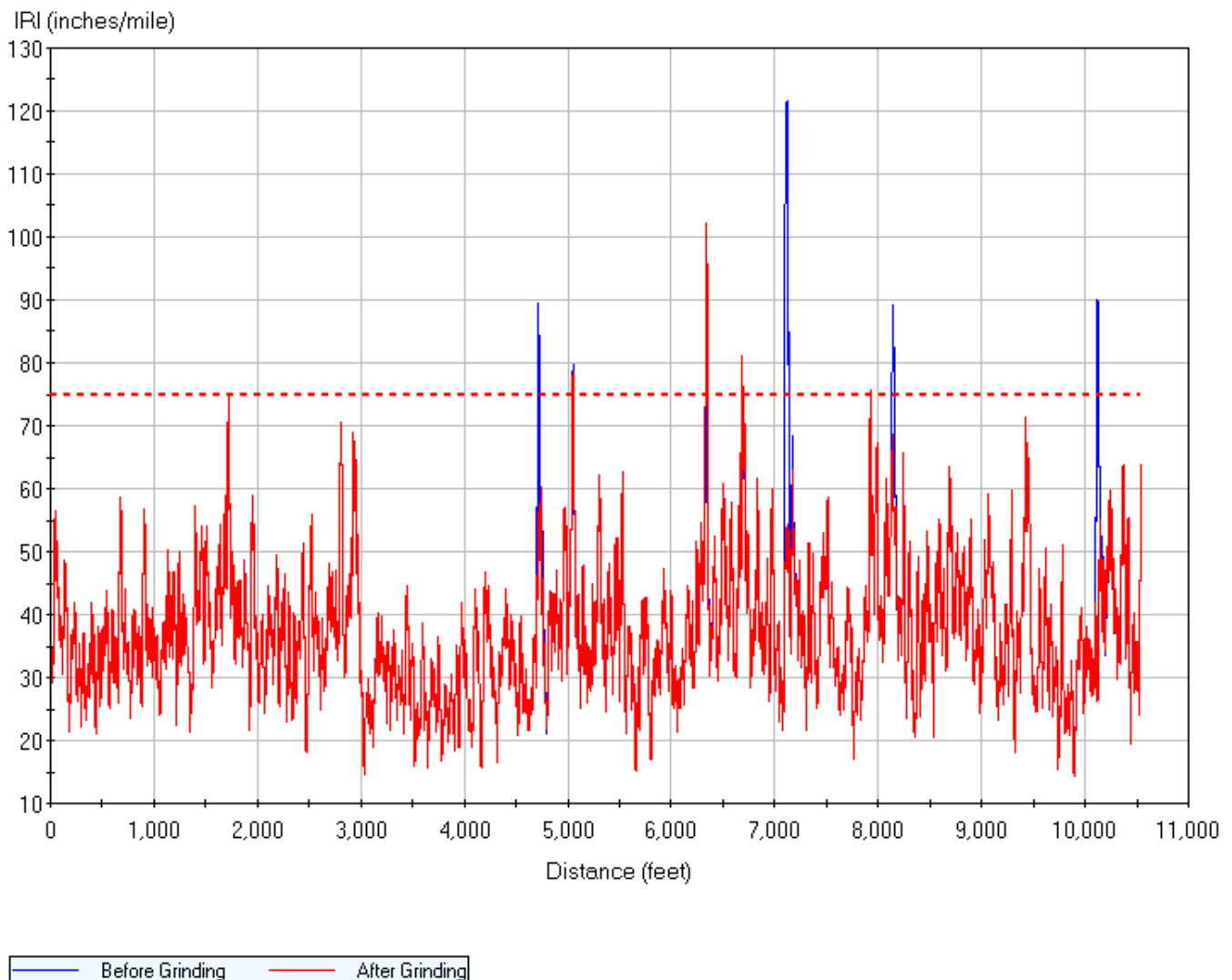


Figure 5 - An example of a graph from ProVal

The NDDOT does not have a ride specification for asphalt, therefore an IRI of 75 was chosen for the IRI threshold. The IRI of 75 was chosen because on the scale NDDOT uses to rate IRI, an IRI between 61 and 95 is categorized as “good”. A score of 75 is a close split of the good category. We are using the better half of good and excellent category for an acceptable IRI. A threshold IRI of 75 also identifies the spikes in the IRI data that appear to be a pavement smoothness problem. The data was first analyzed to determine the location of a paver stop and IRI measurement associated with that location.

There were areas where the paver stops were correlated to the locations where IRI was measured above 75. These are the areas that were $\pm 30'$ of the paver stop and considered close enough to be affected by the paver stopping; and therefore classified as a bump. On the westbound lane; the GPS unit recorded that the paver stopped 138 times. There were 68 areas where the threshold exceeded an IRI value of 75 within $\pm 30'$ from a paver stop. The paver stops that exceeded the IRI threshold of 75 was 49.3 percent in the westbound direction. The average paver speed for the westbound lane was 0.5079 feet per second. On the eastbound lane, the paver stopped 128 times. There were 56 areas where the threshold exceeded an IRI value of 75 within $\pm 30'$ of a paver stop. The paver stops that exceeded the IRI threshold of 75 was 43.8 percent in the eastbound direction. The average paver speed for the eastbound lane was 0.5163 feet per second. These results can be seen in Table 1.

Direction	Wheel Path	IRI > 75	Paver Stops	(IRI >75) \pm 30' of paver stop	% (IRI >75) \pm 30' of paver stop	(IRI > 75) not \pm 30' of paver stop	% (IRI > 75) not \pm 30' of paver stop
Westbound	Inside	86	138	17	49.3%	69	84.6%
	Outside	362		51		311	
Eastbound	Inside	74	128	17	43.8%	57	82.4%
	Outside	244		39		205	

Table 1

The data was then analyzed to identify all the IRI locations where the IRI measurement exceeded the threshold of 75, and their relationship to a paver stop. The areas with an IRI greater than 75, which are classified as bumps, are not all near paver

stops. In the westbound lane only 15.2 percent of the bumps are near a paver stop. In the eastbound lane only 17.6 percent of the bumps are near a paver stop. This leaves an 84.6 and 82.4 percent of the bumps measured in the westbound and eastbound lanes respectively, are caused by some other factor on this project. The breakdown of bumps near a paver stop and total bumps can be seen on Table 2.

The GPS identified 266 stops for both lanes. The Minot district inspectors recorded information of the events that caused the paver to stop, the location of the stop, and amount of time. From the 117 stops, 60 were caused from the absence of trucks, and 34 stops were to allow the 2nd paver paving the shoulder to catch up, and 23 stops due to various reasons such as sampling, rain, material delays, re-fueling, and exchanging the battery on the GPS unit.

Appendix A displays the speed and location for all of the areas where the IRI threshold exceeds 75. In Appendix A, a graphical representation can be seen of the paver speed and the areas with an IRI value exceeding 75. From these graphs it appears that there are many areas where the stopping of the paver may affect the ride. It also displays areas with an IRI problem when the paver was at a constant speed. These areas with the constant paver speed may be caused by a variety of reasons, such as mix control, temperature of mix, and compaction from rollers.

The average time when the paver stopped for the westbound lane was 3 minutes 23 seconds. The average time for a paver stop within 30' of an IRI exceeding 75 is 6 minutes and 57 seconds in the westbound lane. The average time when the paver stopped for the eastbound lane was 2 minutes 41 seconds. The average time for a paver stop within 30' of an IRI exceeding 75 is 5 minutes and 28 seconds in the eastbound lane. The increase in IRI may have been caused by the increase in time before it was rolled.

There also a possibility that the bumps on the first lift or even the base section can be transferred through to the final asphalt course. The bumps measured on the first lift were compared with the bumps from the final lift. There were a total of 1180 bumps in both wheel paths for the first lift of the westbound lane. The final lift has a total of 448 bumps in both wheel paths for the westbound lane. Of these 448 locations, 34 had the exact location of a bump on the first lift. There were a total of 1332 bumps in both wheel

paths for the first lift of the eastbound lane. The final lift has a total of 318 bumps in both wheel paths for the eastbound lane. Also, of these 318 locations, 27 had the exact location of a bump on the first lift. The percent improvement between the first and final lifts is 62.0 percent for westbound and 76.1 percent for the eastbound lane. This decrease in bumps shows that some of the bumps are paved out with each additional lift. These results are displayed in Table 2.

Lane	Lift	Area with IRI >75	Percentage in IRI > 75 improvement between lifts
Westbound	1	1180	62.0%
	3	448	
Eastbound	1	1332	76.1%
	3	318	

Table 2

As expected, the IRI value decreased with the addition of the second and third lifts. The IRI values from the first to the final lift third lift decreased by 28.7 percent in the westbound lane and 35.3 percent in the eastbound lane. The average IRI results for the first and final lift can be seen in Tables 3.

Station Begin	Station End	Wheel path	Eastbound			Westbound		
			Eastbound Average IRI 1st lift	Eastbound Average IRI 3rd lift	IRI % Decrease	Westbound Average IRI 1st lift	Westbound Average IRI 3rd lift	IRI % Decrease
3145+50	3251+09	IW	60.9	38.0	37.6	60.2	39.3	34.7
		OW	73.8	50.4	31.7	64.2	49.6	22.7
3251+09	3356+55	IW	56	36.2	35.4	55.5	39.9	28.1
		OW	66.7	47.1	29.4	61	51.3	15.9
3356+55	3462+12	IW	58.6	35.6	39.2	61.1	40.3	34.0
		OW	65.5	47.4	27.6	65.9	51.1	22.5
3462+12	3567+64	IW	57.4	34.9	39.2	57.5	39.9	30.6
		OW	62.6	44.0	29.7	64.2	49.2	23.4
3567+64	3626+03	IW	84.9	49.8	41.3	93.7	52.1	44.4
		OW	109.3	63.6	41.8	98.1	68.1	30.6
		Average	69.6	44.7	35.3	68.1	48.1	28.7

Table 3

Summary

As seen from the data in the evaluation and appendix, the ride quality of asphalt roads depends on many factors. The ride quality, as represented by IRI, appears to be affected when the paver motion in some areas of the road. It appears that areas close to the paver are affected by the paver stopping. Some possible reasons may be due to temperature of the bituminous mix, roller patterns, temperature HBP is rolled, and existing road surface. When the paver stops, the rollers do not roll to the very end of where the paving stopped. Also the paver may have bituminous mix still in the hopper cooling before it is ever paved or rolled.

On the third lift, there were 68 stops within plus or minus 30' of a bump in the westbound lane with 448 bumps. On the third lift, there were 56 stops within plus or minus 30' of a bump in the eastbound lane with 318 bumps. The westbound lane had a 49.3 percent of stops within 30' of bump and eastbound had a 43.8 percent of stops with a bump.

The IRI difference in wheel paths and bumps reflecting through the lifts makes it

difficult to correlate the smoothness of the road and paver motion or speed. There are too many factors involved to pinpoint the exact reason for all of the bumps, but it does appear that the paver motion does have some effect in some areas with a paver stop. This effect can be seen by the 49.3 and 43.8 percent of the paver stops being within 30' of a paver stop.

There are some areas where the bump from the previous lifts may have reflected to the next lift. There are 34 areas where the first and third lift has an increase in IRI in the identical location for the westbound lane. The eastbound lane had 27 areas where the first and third lift had an increase in IRI in the identical location. The second lift was not measured with the lightweight profiler. If this type of research project is done again the intermediate lift should be measured. The IRI data for the second lift would help make a better correlation for bumps reflecting through the different lifts of the pavement. The IRI does decrease with the addition of the second and third lift, so it appears the bumps from the previous lift can be smoothed out by a lift.

There is an obvious difference in the wheel paths for the whole project. The shoulder wheel path has a higher IRI value than the centerline wheel path. It can be seen in Tables 4 and 5 in the breakdown of the lanes and wheel paths. This happens in most paving projects. The IRI difference in wheel paths could be a possible issue to focus on to help produce a smoother ride.

The paver speed remained very constant. The average paver speed for the eastbound lane was 0.5163 feet per second and the westbound lane had an average paver speed of 0.5079 feet per second. The paver speed varied more while paving through the town of Donnybrook. Paving through the town section was difficult because the paving has to match the edge of the pavement with the curb and gutter. Because of this there are many more bumps through Donnybrook. The roadway through the urban section Donnybrook might not be a good representation for the relationship between the paver motion and smoothness.

Recommendation

Attempting to keep the paver motion constant and limiting the number of paver stops would be recommended as a result this project. It may be impossible to eliminate the paver from stopping, but the number of stops may be reduced by altering paving methods. Also, the length of stops may help reduce the size of the bump. Making the base and first asphalt lift as smooth as possible to reduce the bumps from reflecting there the final lifts is also recommended. Trying to improve aspects of paving may help in improving the ride.

The paver stopping did not cause all of the bumps. Other research may help find or identify why the other bumps are forming. Research should be done on other projects to see if the percentage of paver stops that affect the IRI continues at the same pace. Also if a similar research project is done again, some other factors should be taken into account:

- Measure and record the temperature of the HBP when placed by the truck and when the HBP is rolled.
- The roller patterns should also be monitored.
- The distance between the rollers and paver when it stops.
- The existing road surface should also be taken in account.

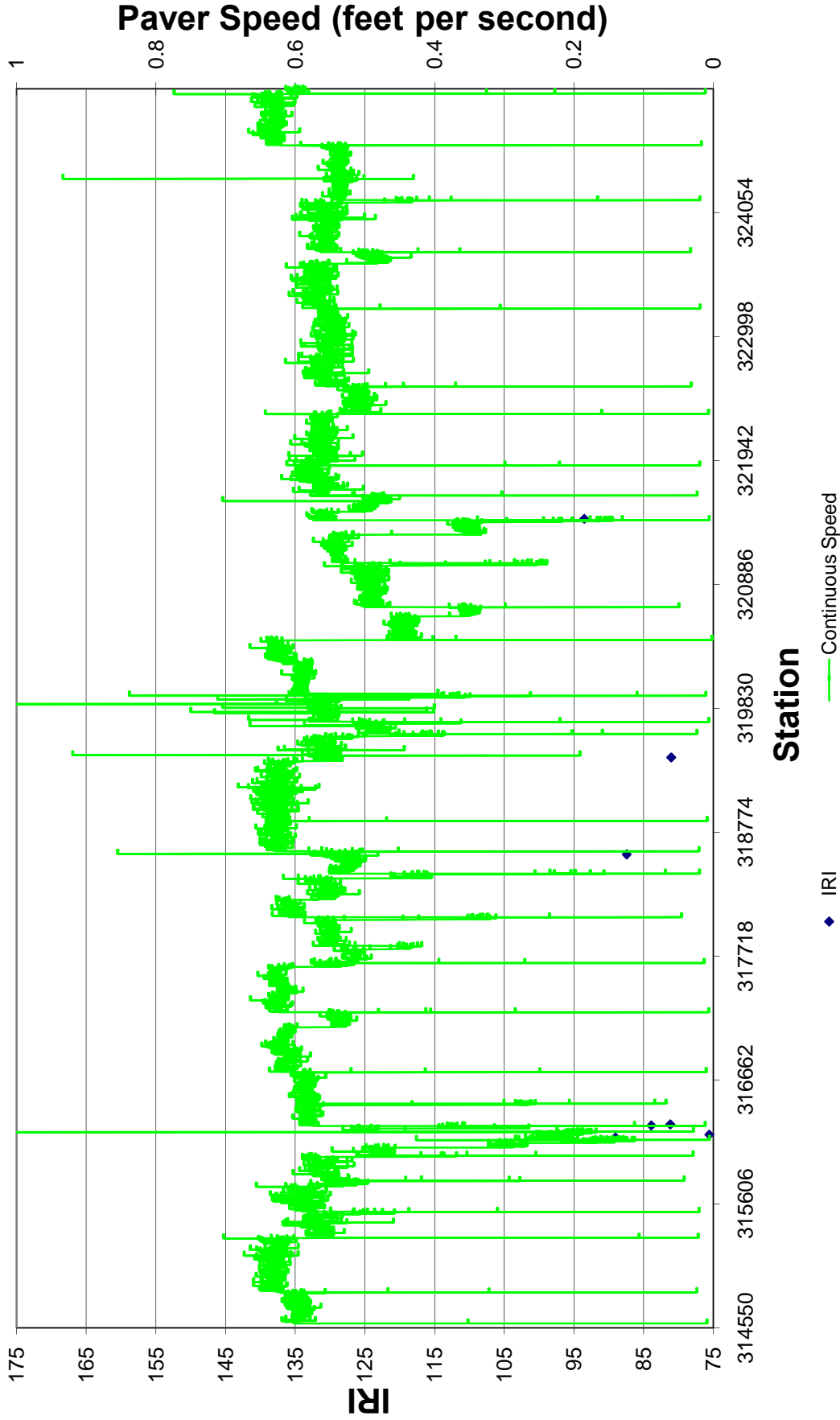
Appendix A

Centerline Westbound Wheel Path

Average Paver Speed Westbound
Final Lift = 0.5079 Feet Per Second

Paving Direction
←

Sta. 3145+50 to Sta. 3251+09

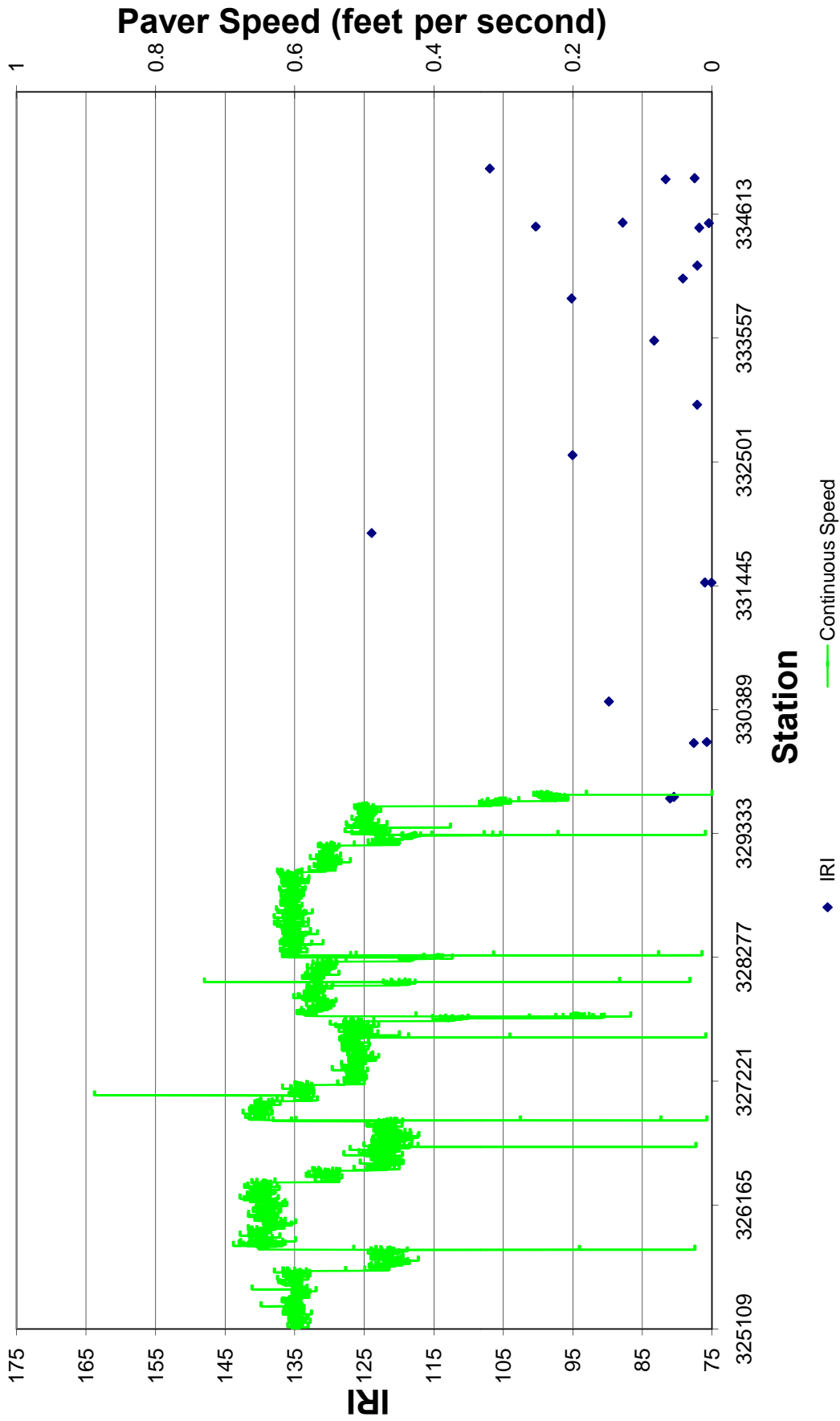


Centerline Westbound Wheel Path

Average Paver Speed Westbound
Final Lift = 0.5079 Feet Per Second

Paving Direction
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Sta. 3251+09 to Sta. 3356+55

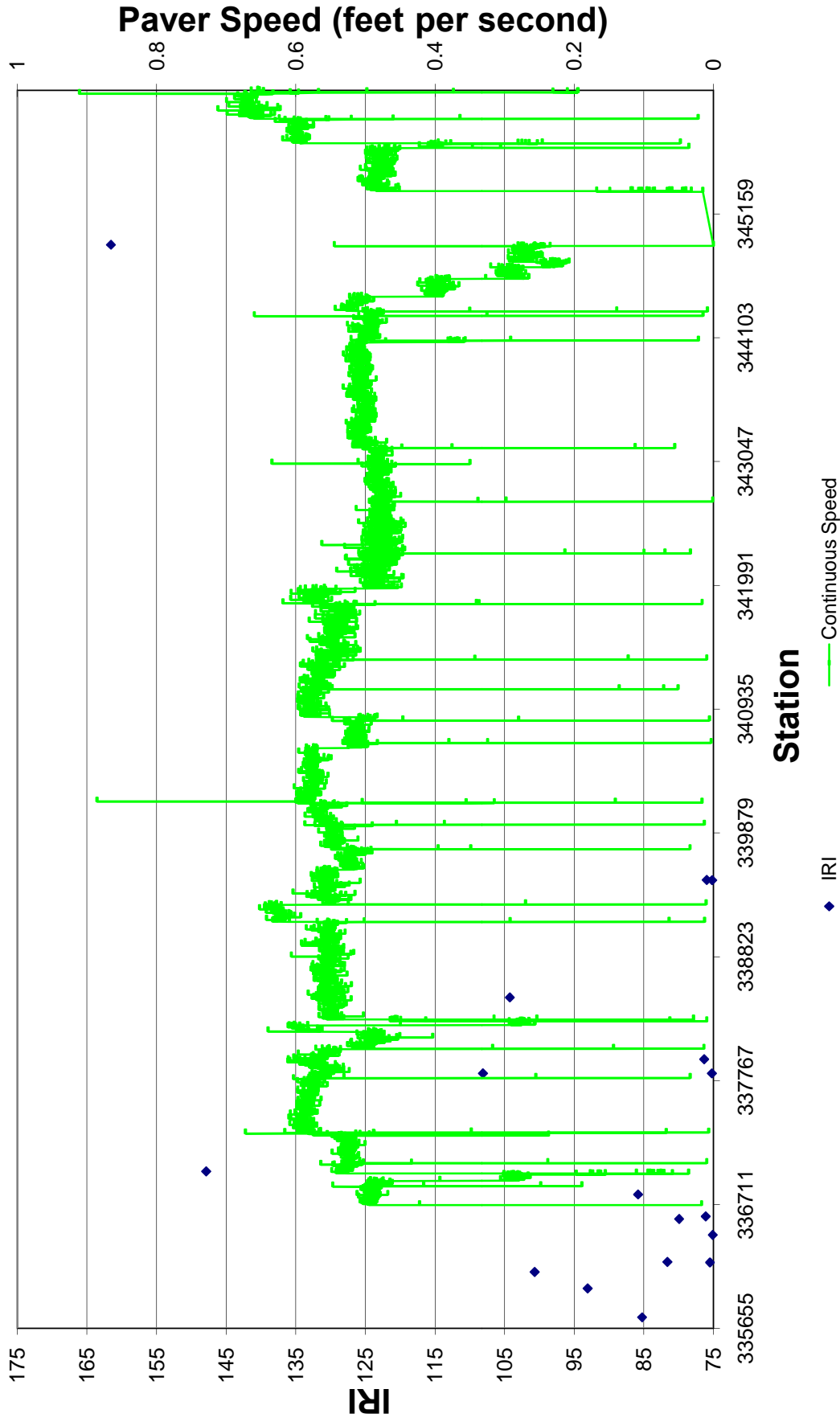


Centerline Westbound Wheel Path

Average Paver Speed Westbound
Final Lift = 0.5079 Feet Per Second

Sta. 3356+55 to Sta. 3462+12

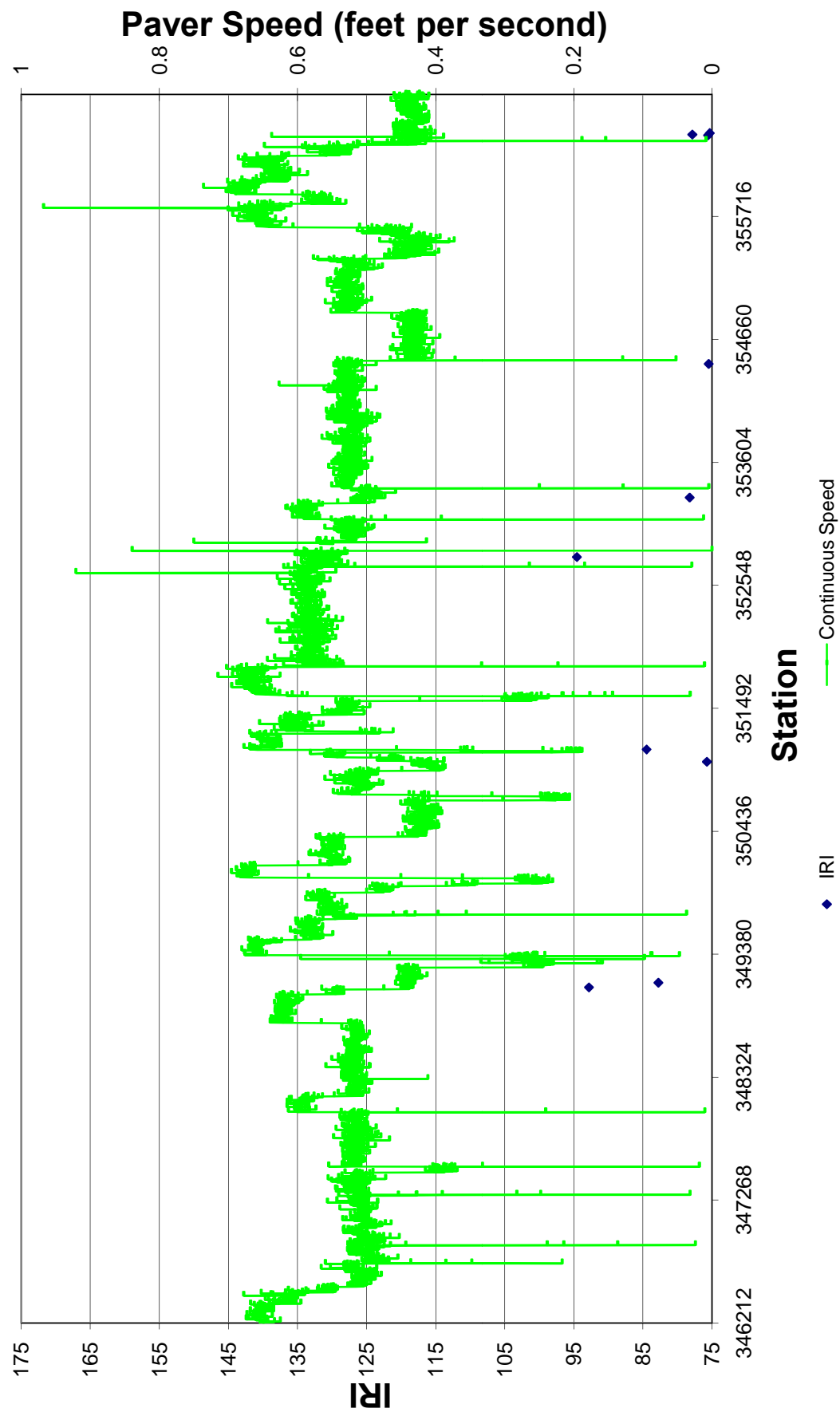
Paving Direction
←



Centerline Westbound Wheel Path

Average Paver Speed Westbound
Final Lift = 0.5079 Feet Per Second

Sta. 3462+12 to Sta. 3567+64



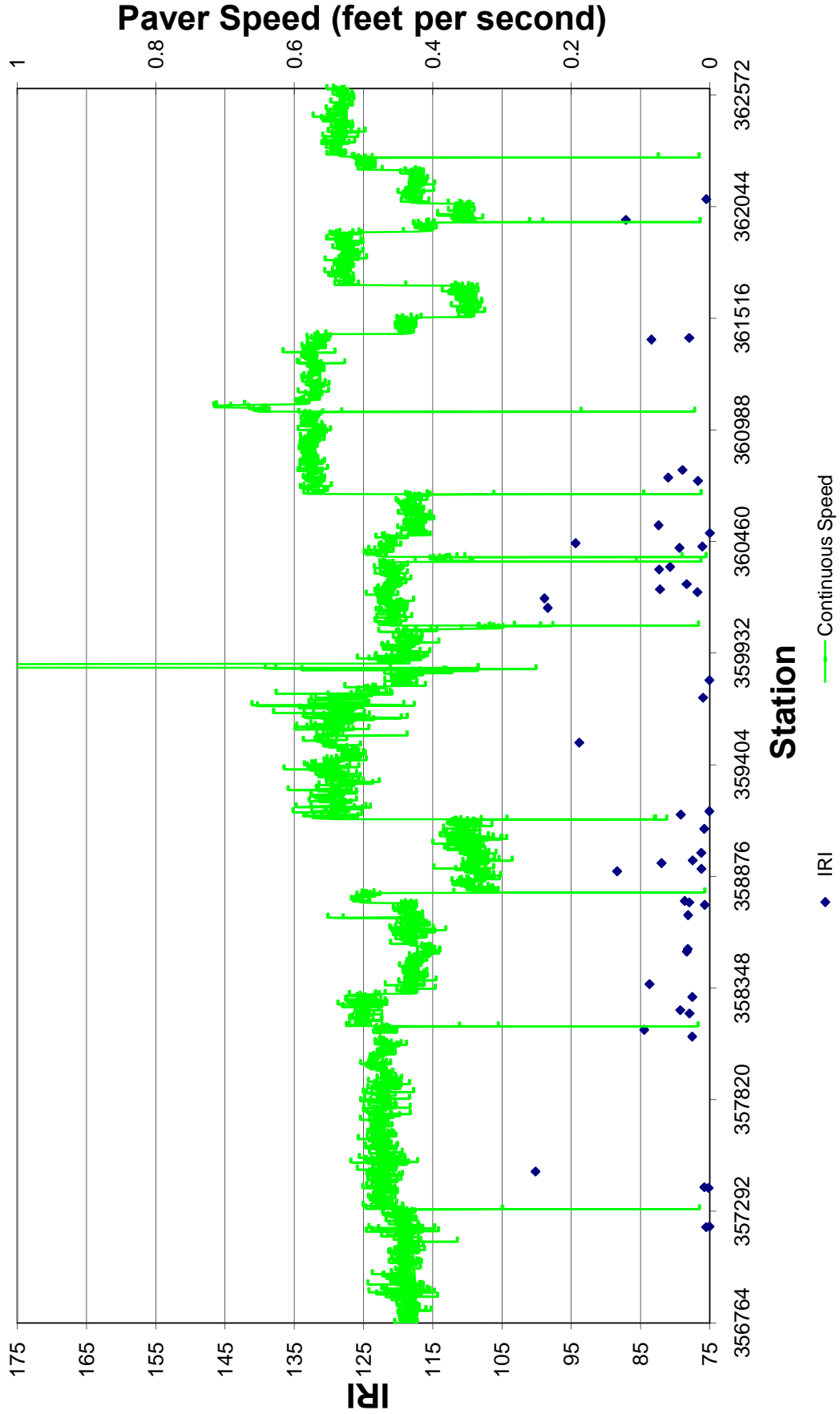
Centerline Westbound Wheel Path

Paving Direction



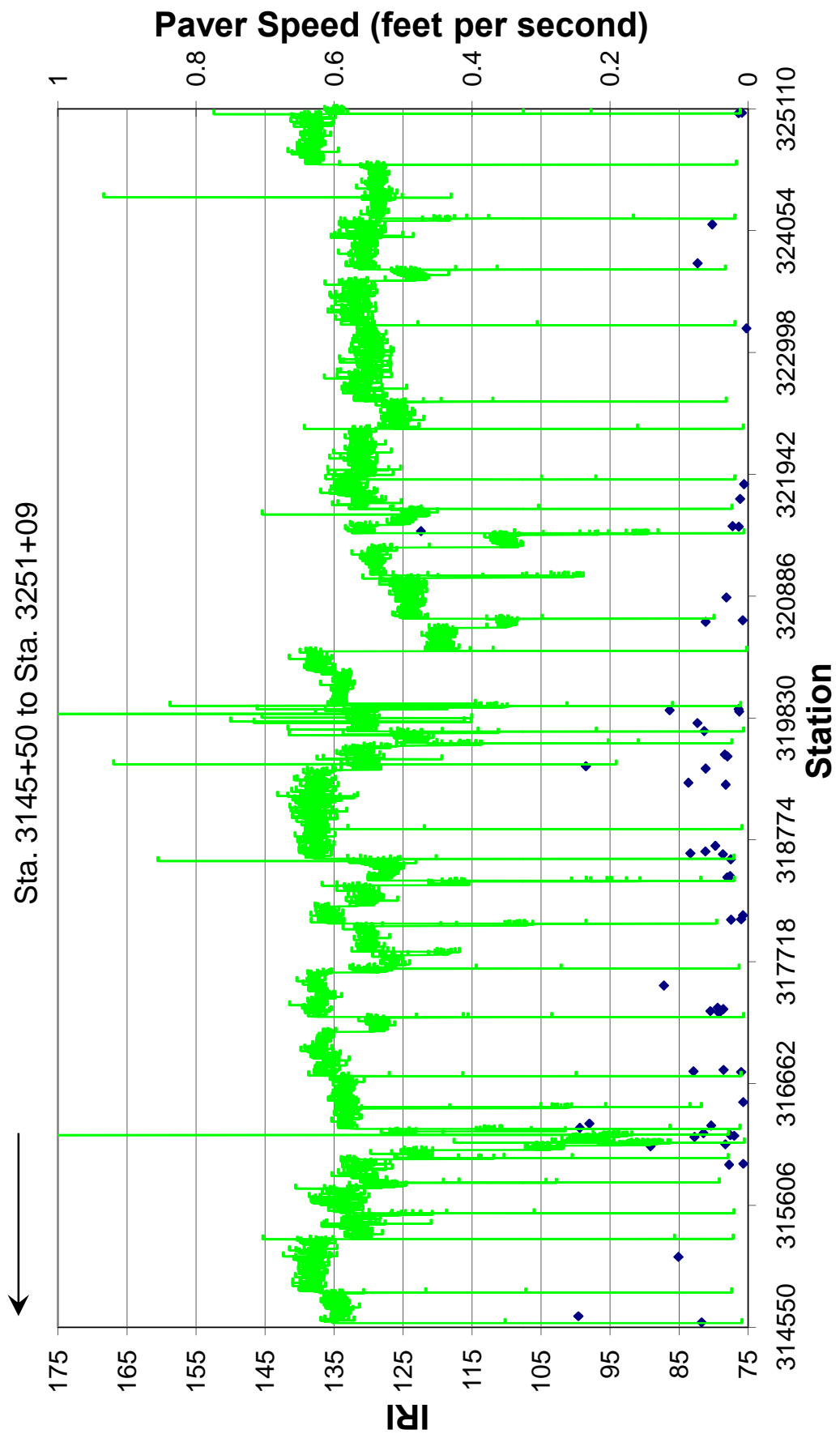
Sta. 3567+64 to Sta. 3626+03

Average Paver Speed Westbound
Final Lift = 0.5079 Feet Per Second



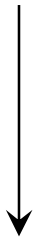
Average Paver Speed Westbound
Final Lift = 0.5079 Feet Per Second

Shoulder Westbound Wheel Path



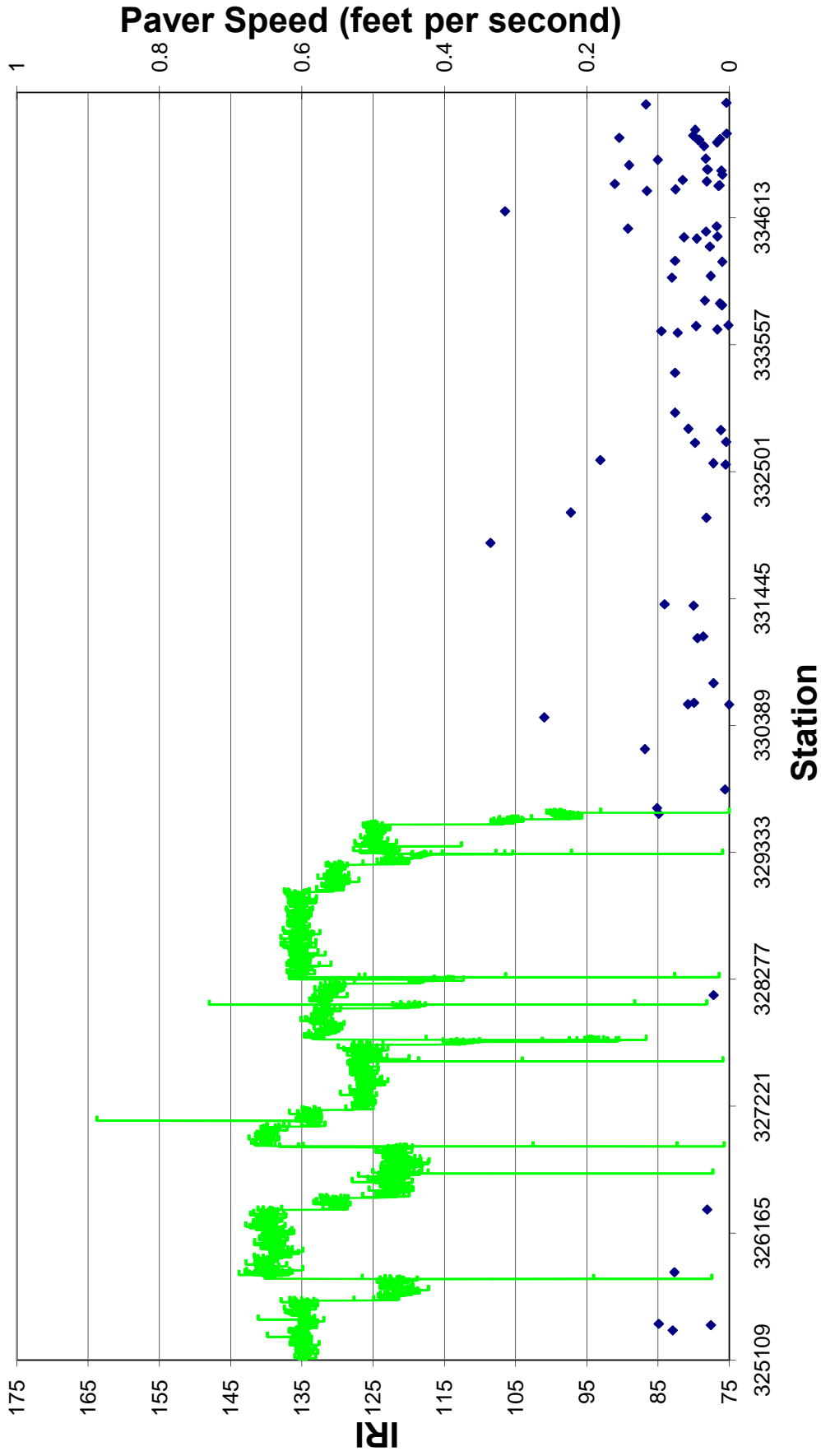
Shoulder Westbound Wheel Path

Paving Direction



Average Paver Speed Westbound
Final Lift = 0.5079 Feet Per Second

Sta. 3251+09 to Sta. 3356+55



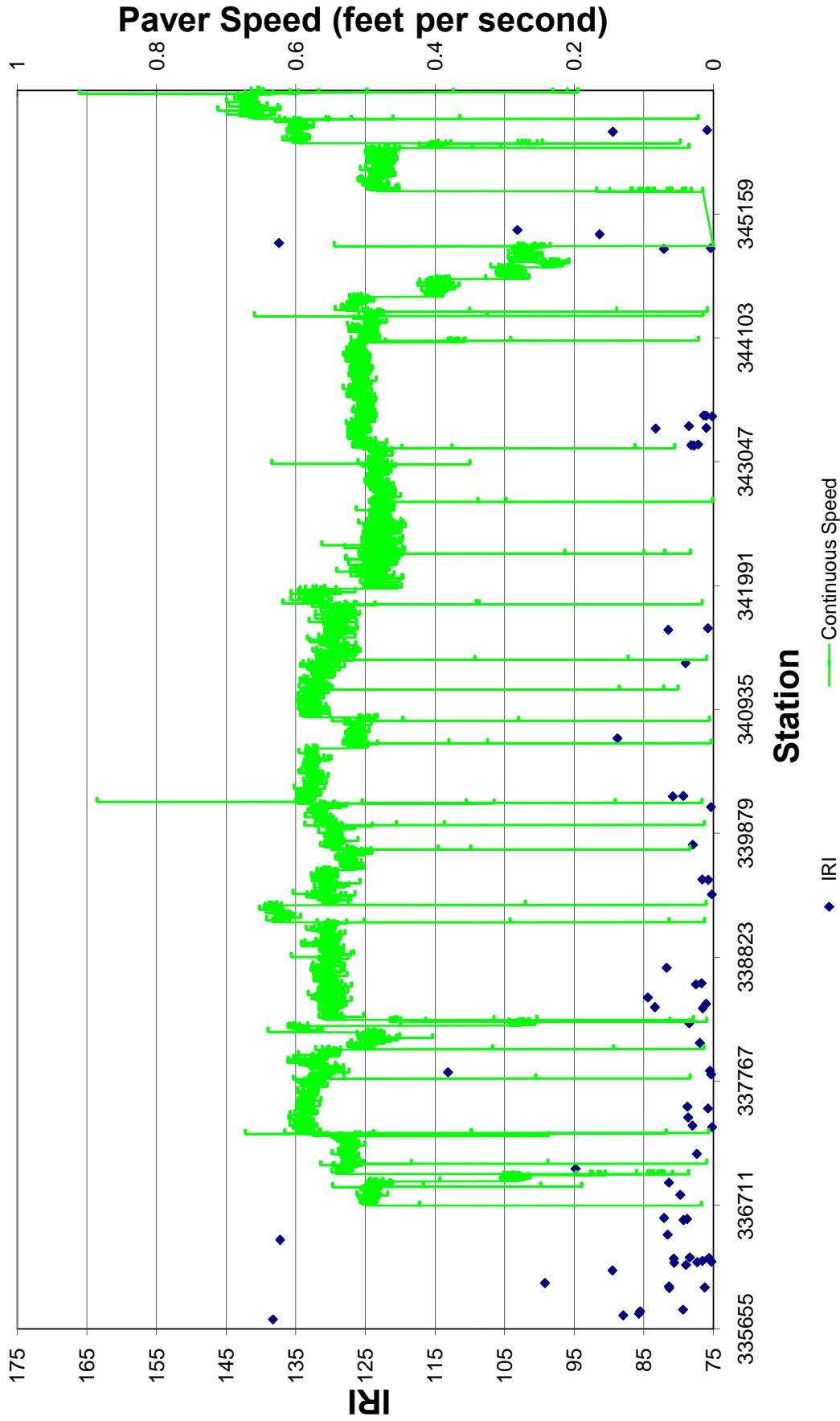
IRI Continuous Speed

Shoulder Westbound Wheel Path

Average Paver Speed Westbound
Final Lift = 0.5079 Feet Per Second

Sta. 3356+55 to Sta. 3462+12

Paving Direction
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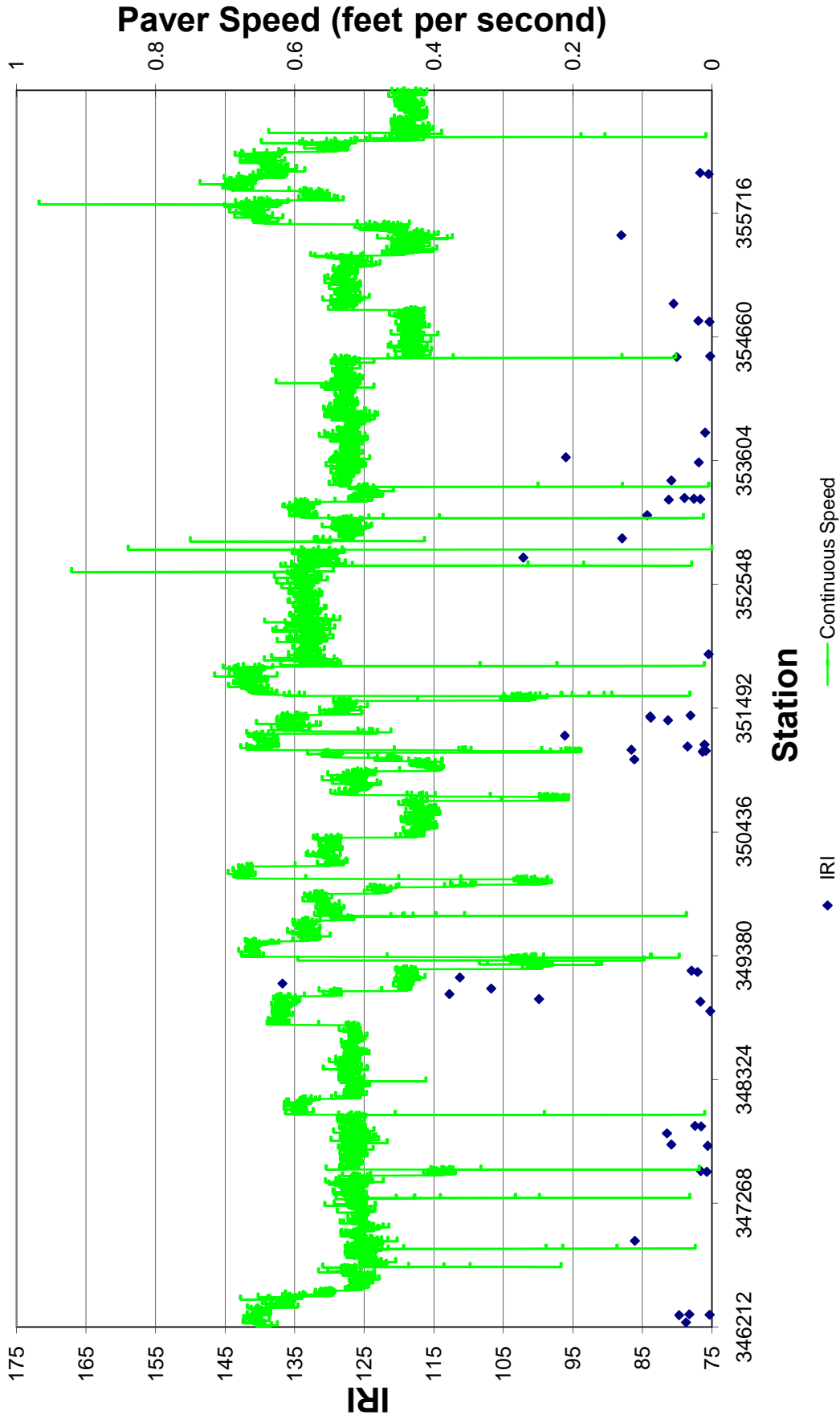


Shoulder Westbound Wheel Path

Average Paver Speed Westbound
Final Lift = 0.5079 Feet Per Second

Sta. 3462+12 to Sta. 3567+64

Paving Direction
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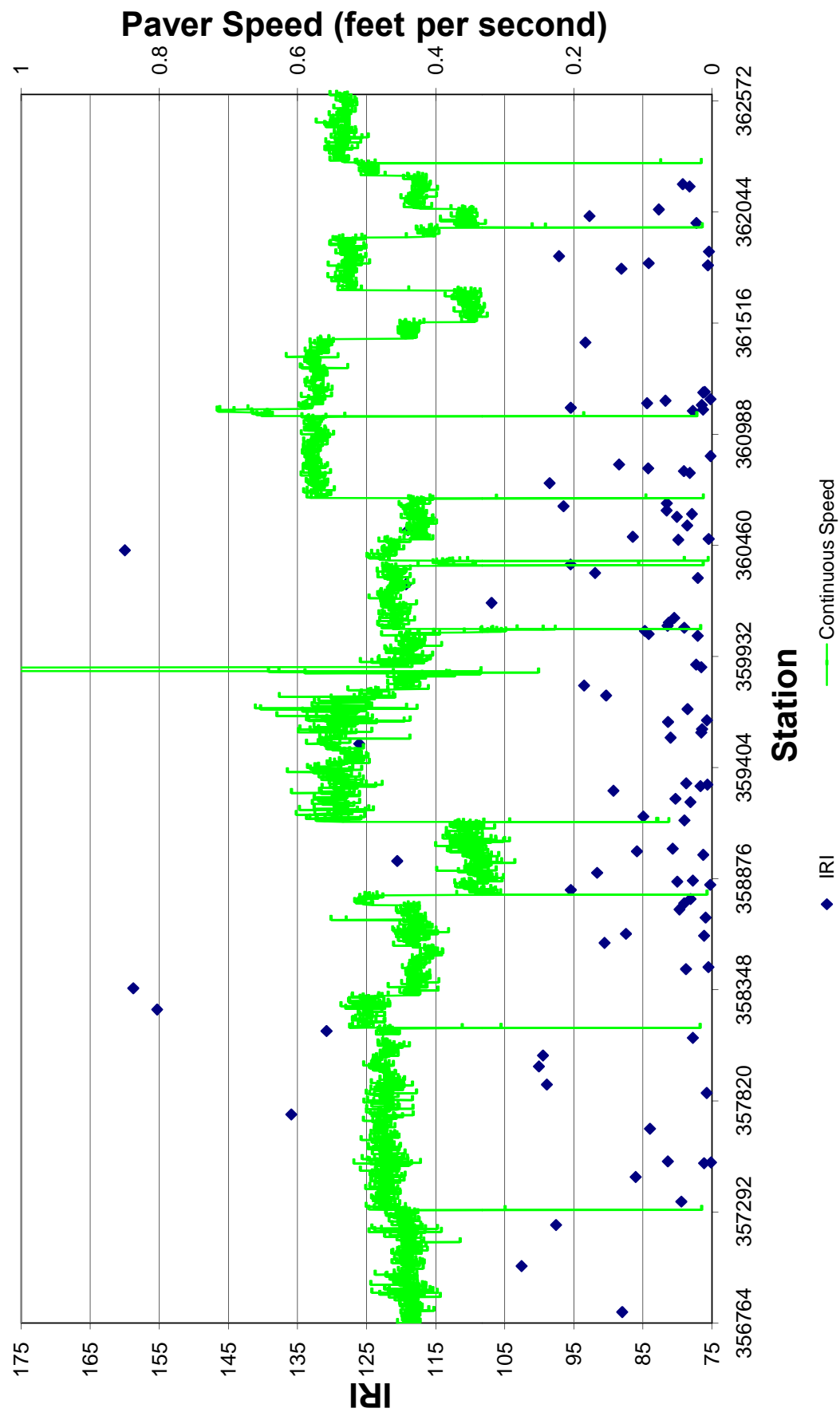


Shoulder Westbound Wheel Path

Average Paver Speed Westbound
Final Lift = 0.5079 Feet Per Second

Paving Direction
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Sta. 3567+64 to Sta. 3626+03

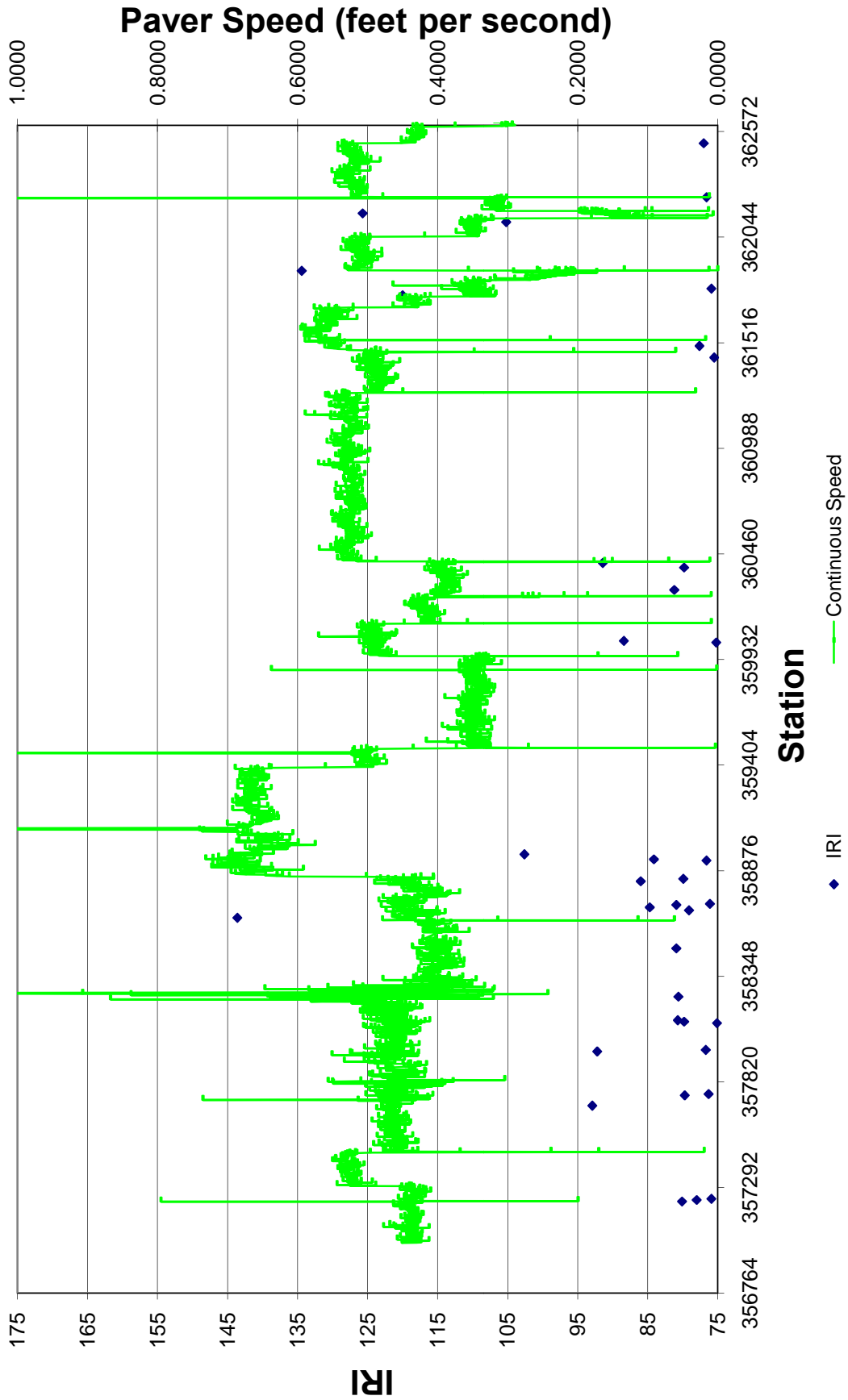


Centerline Eastbound Wheel Path

Average Paver Speed Eastbound
Final Lift = 0.5163 Feet Per Second

Paving Direction
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Sta. 3567+64 to Sta. 3626+03



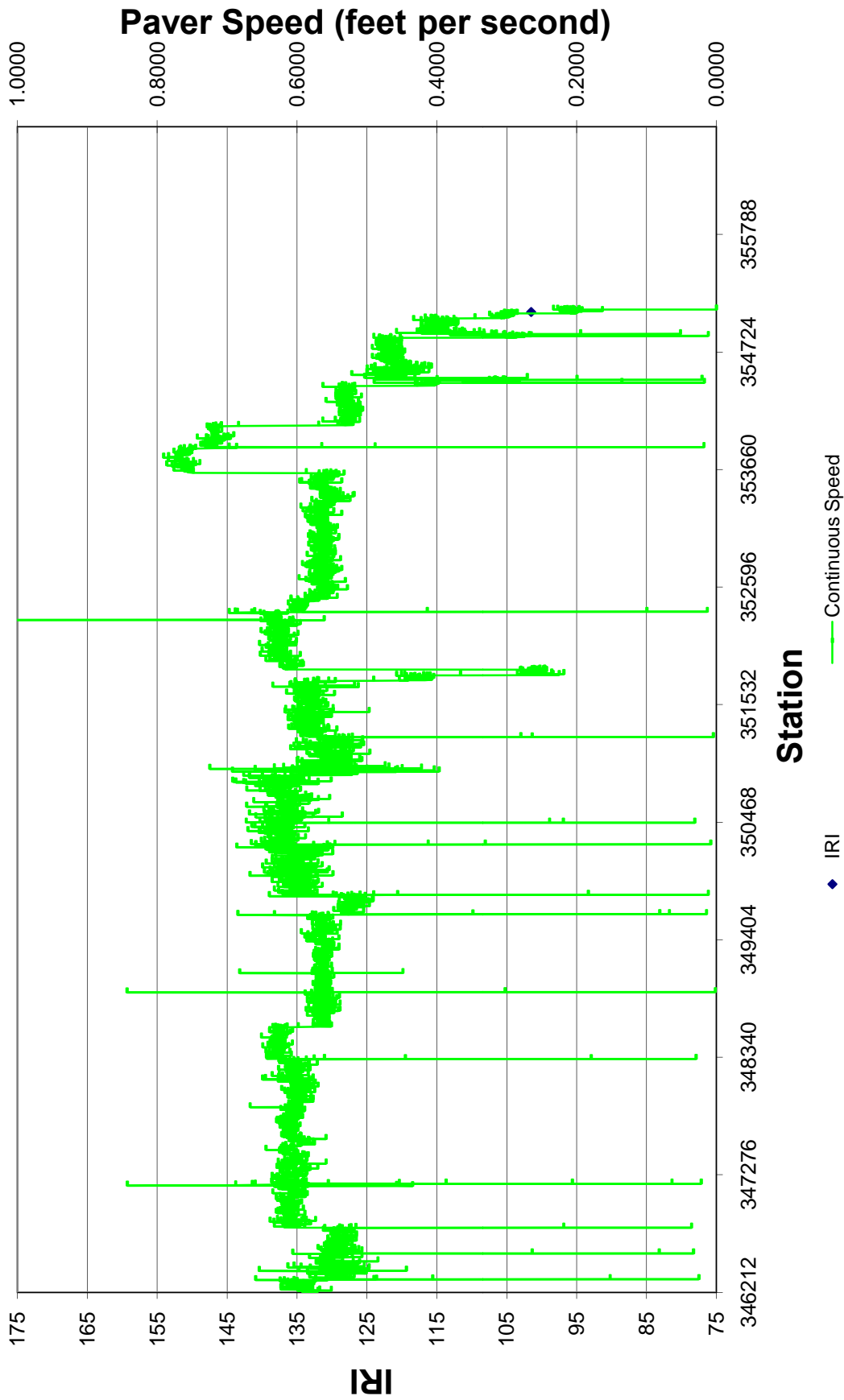
Centerline Eastbound Wheel Path

Paving Direction



Average Paver Speed Westbound
Final Lift = 0.5163 Feet Per Second

Sta. 3462+12 to Sta. 3567+64

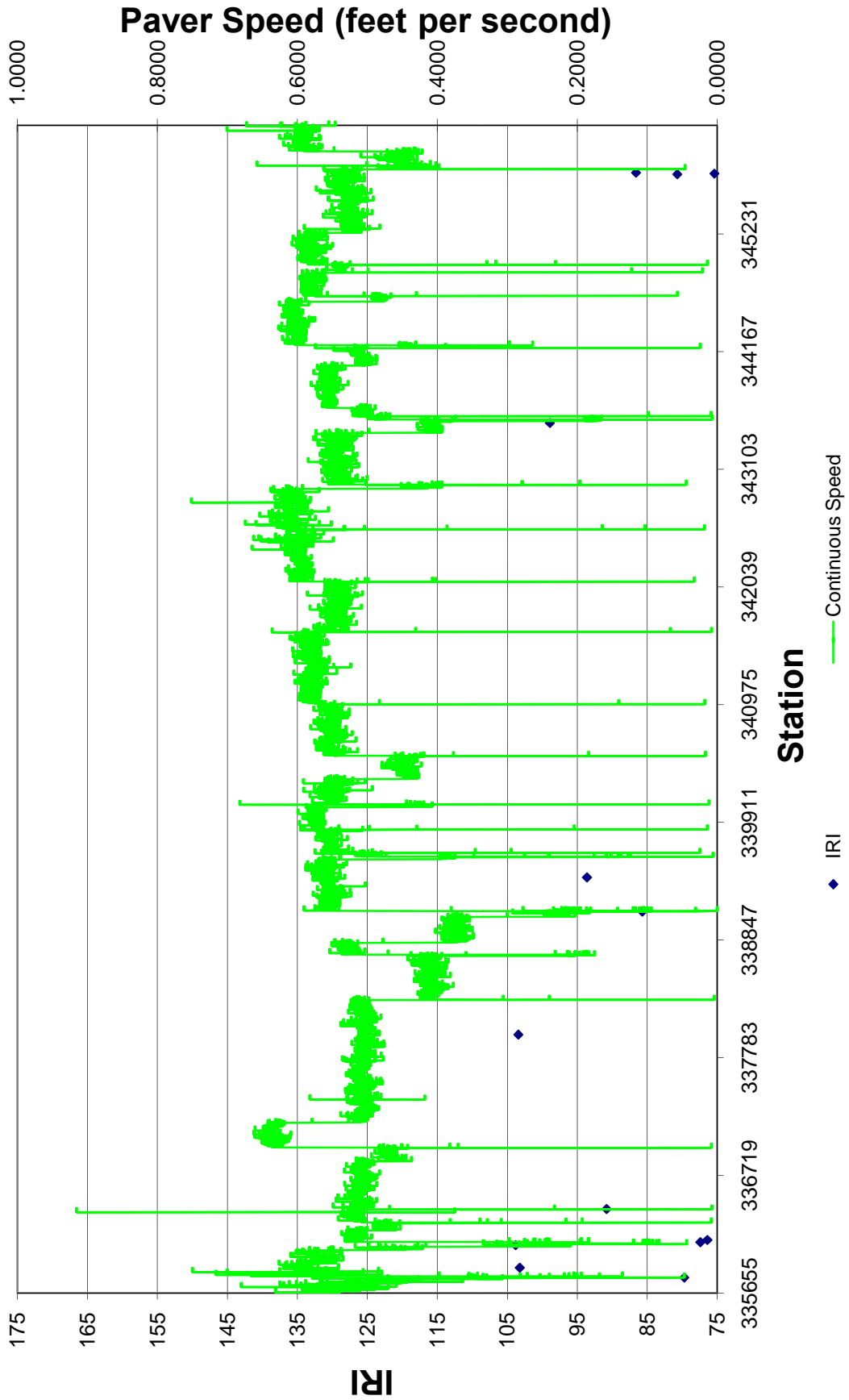


Centerline Eastbound Wheel Path

Average Paver Speed Eastbound
Final Lift = 0.5163 Feet Per Second

Sta. 3356+55 to Sta. 3462+12

Paving Direction
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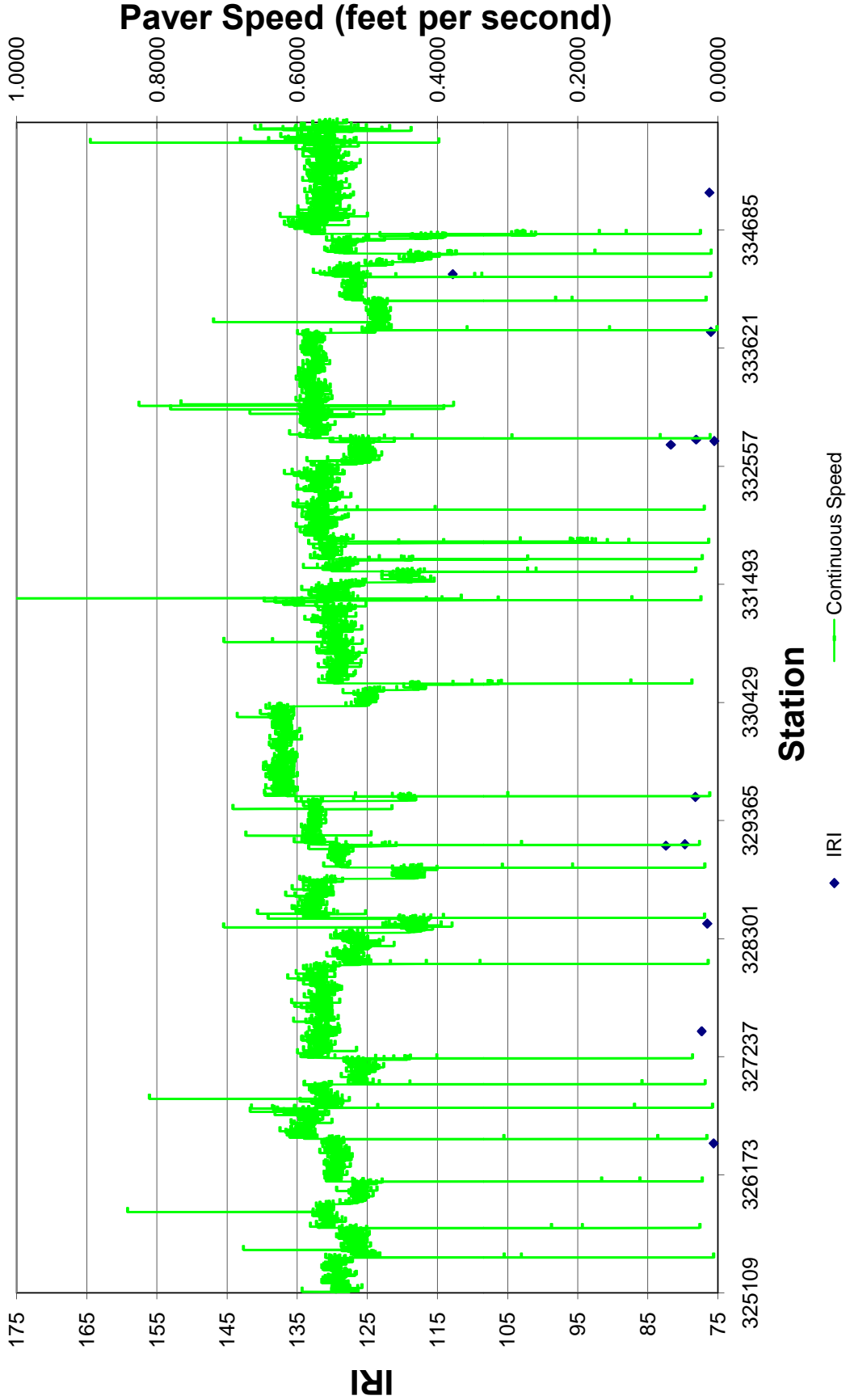


Centerline Eastbound Wheel Path

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Paving Direction
←

Sta. 3251+09 to Sta. 3356+55

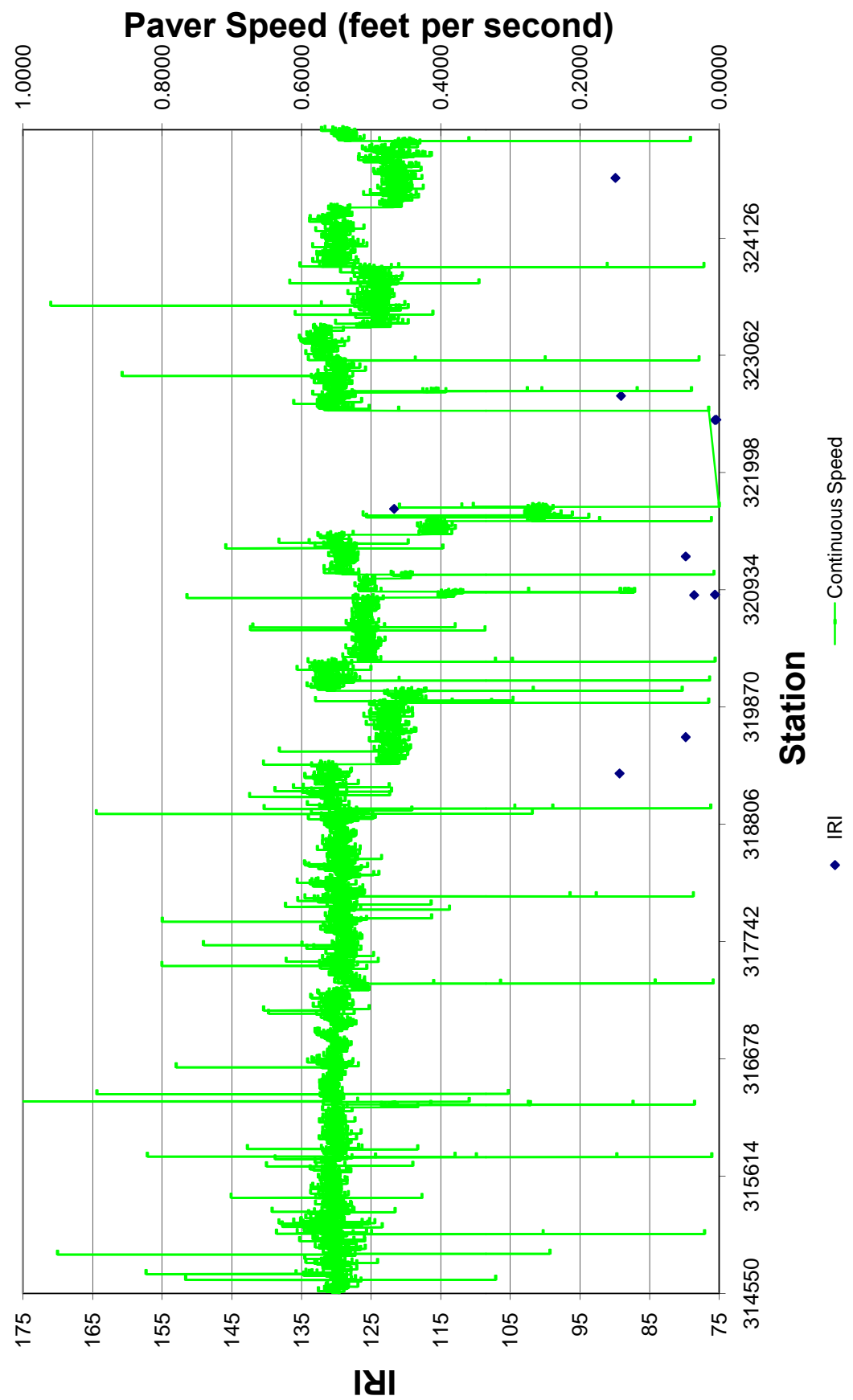


Average Paver Speed Eastbound
Final Lift = 0.5163 Feet Per Second

Centerline Eastbound Wheel Path

Sta. 3145+50 to Sta. 3251+09

Paving Direction
←

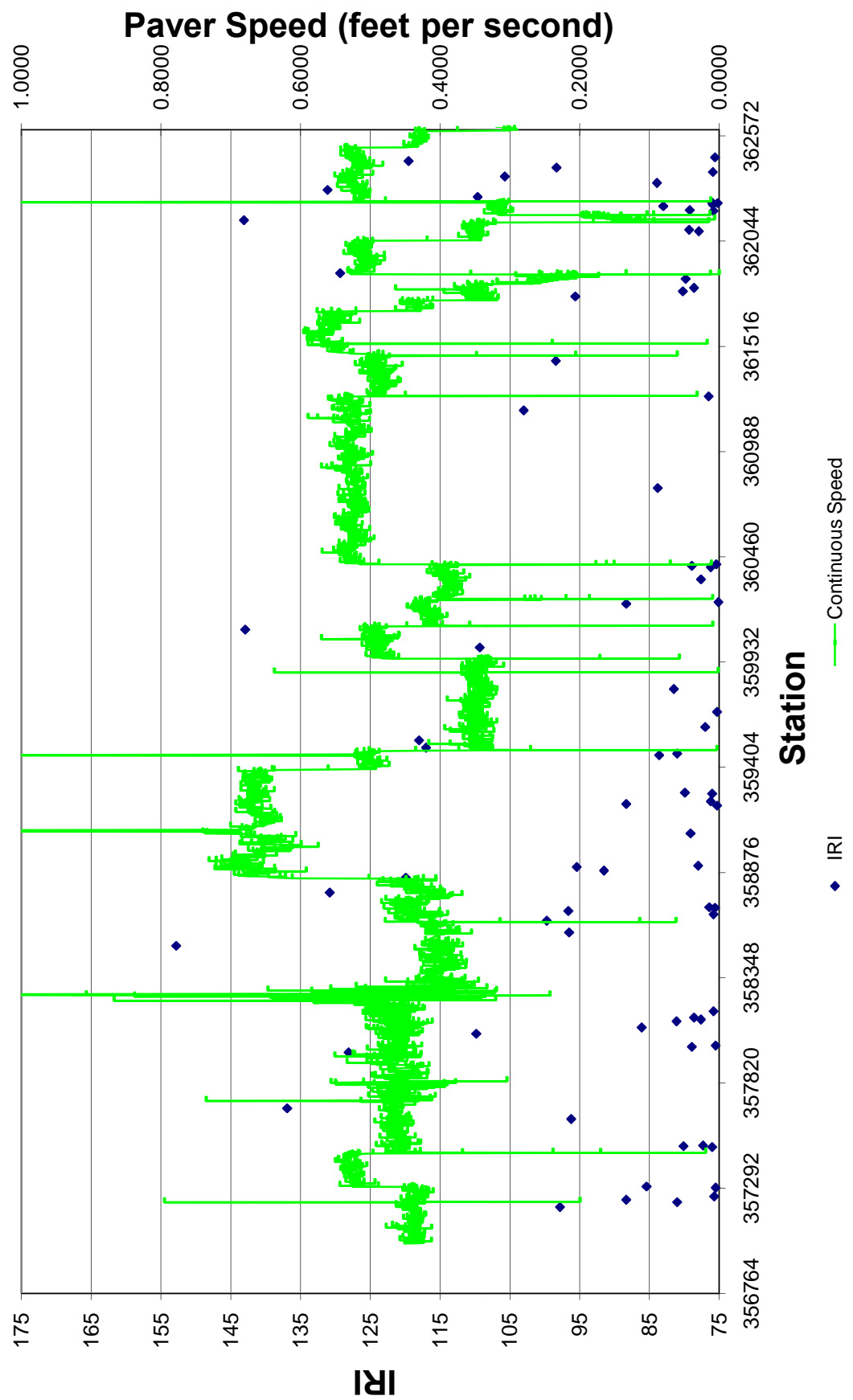


Paving Direction
↓

Shoulder Eastbound Wheel Path

Average Paver Speed Eastbound
Final Lift = 0.5163 Feet Per Second

Sta. 3567+64 to Sta. 3626+03

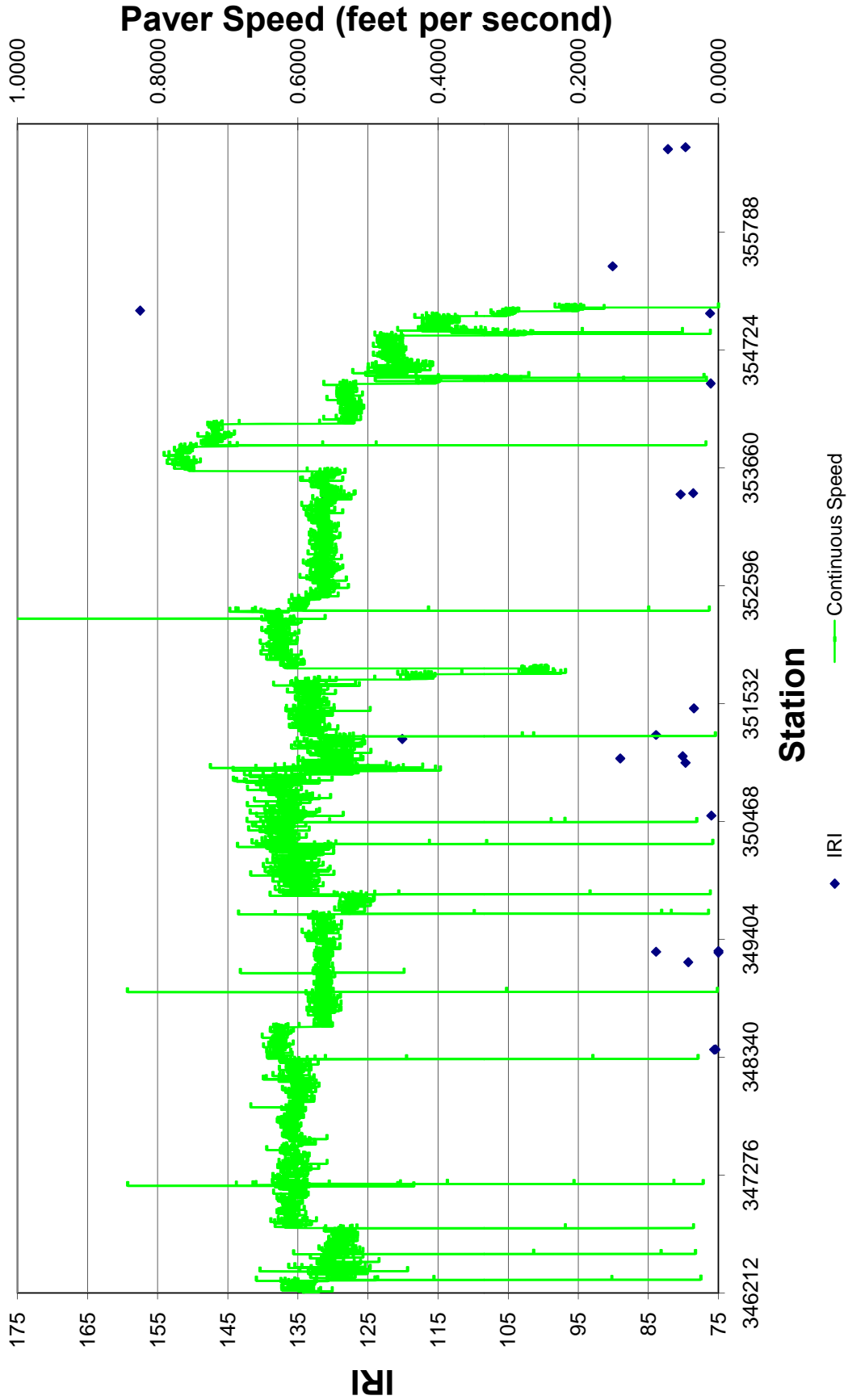


Shoulder Eastbound Wheel Path

Average Paver Speed Eastbound
Final Lift = 0.5163 Feet Per Second

Paving Direction
←

Sta. 3462+12 to Sta. 3567+64

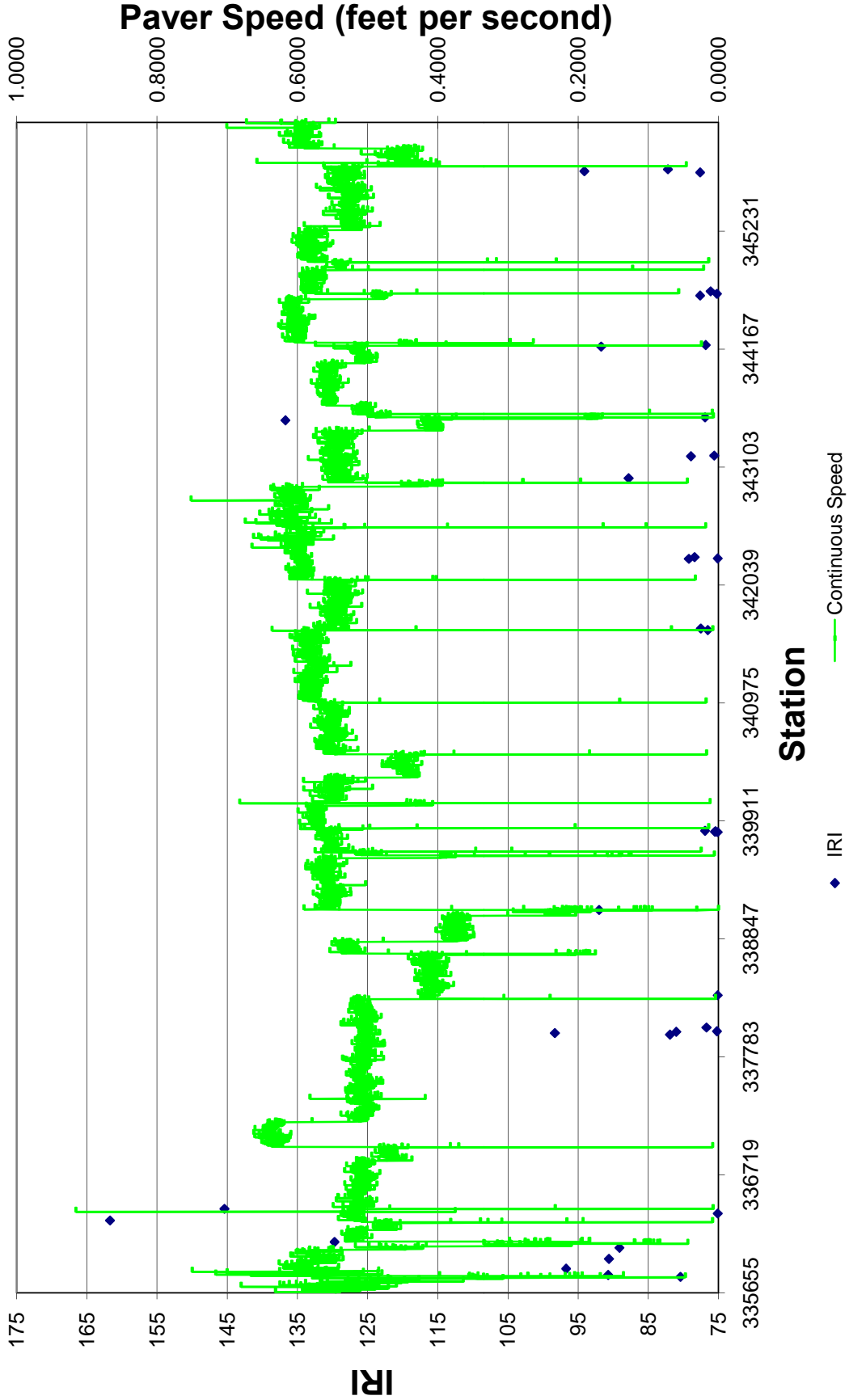


Shoulder Eastbound Wheel Path

Average Paver Speed Eastbound
Final Lift = 0.5163 Feet Per Second

Sta. 3356+55 to Sta. 3462+12

Paving Direction
←

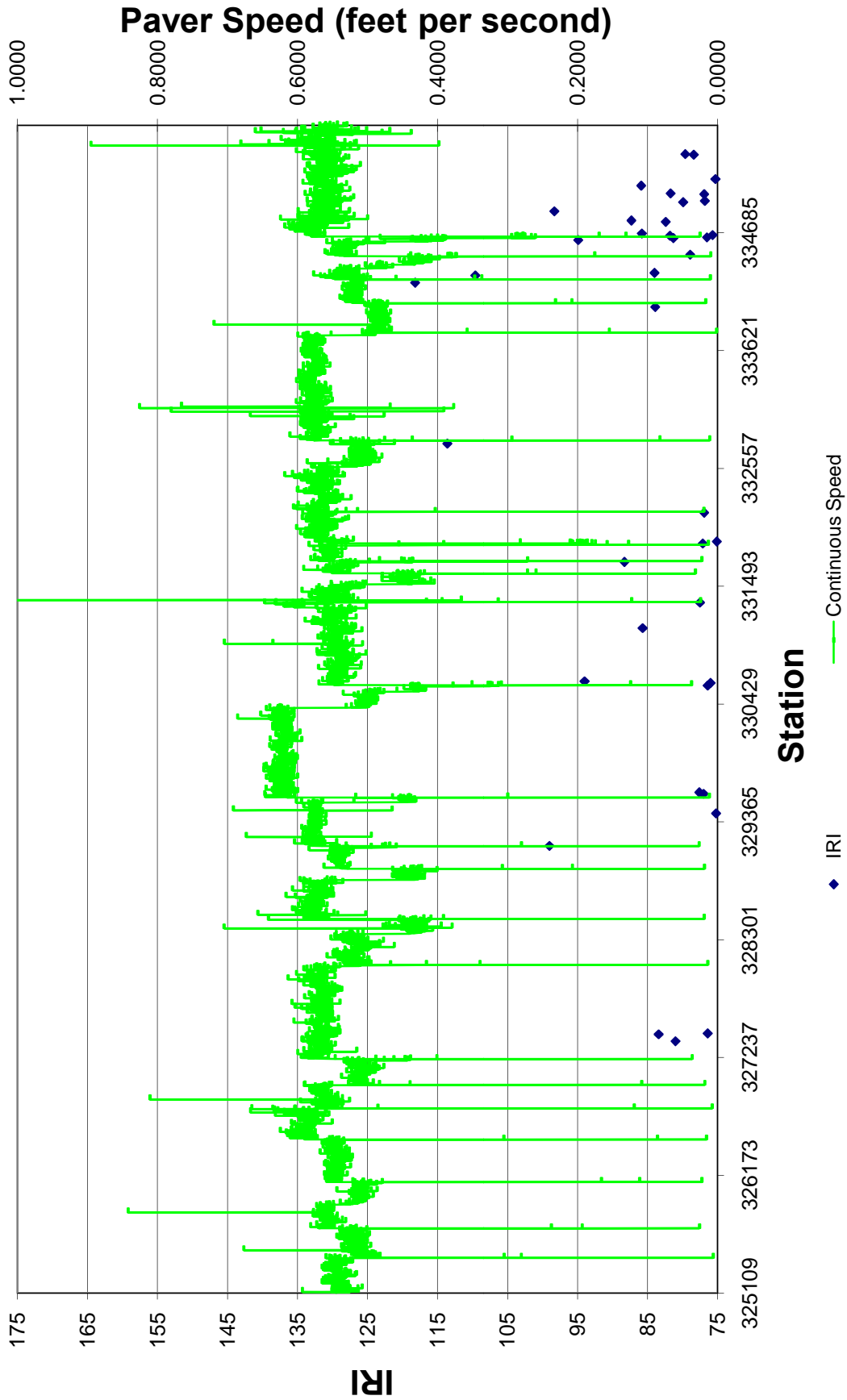


Shoulder Eastbound Wheel Path

Average Paver Speed Eastbound
Final Lift = 0.5163 Feet Per Second

Paving Direction
←

Sta. 3251+09 to Sta. 3356+55



Shoulder Eastbound Wheel Path

Average Paver Speed Eastbound
Final Lift = 0.5163 Feet Per Second

Sta. 3145+50 to Sta. 3251+09

Paving Direction
↓

