# The Seven S-Curves of Adelaide - Part 3

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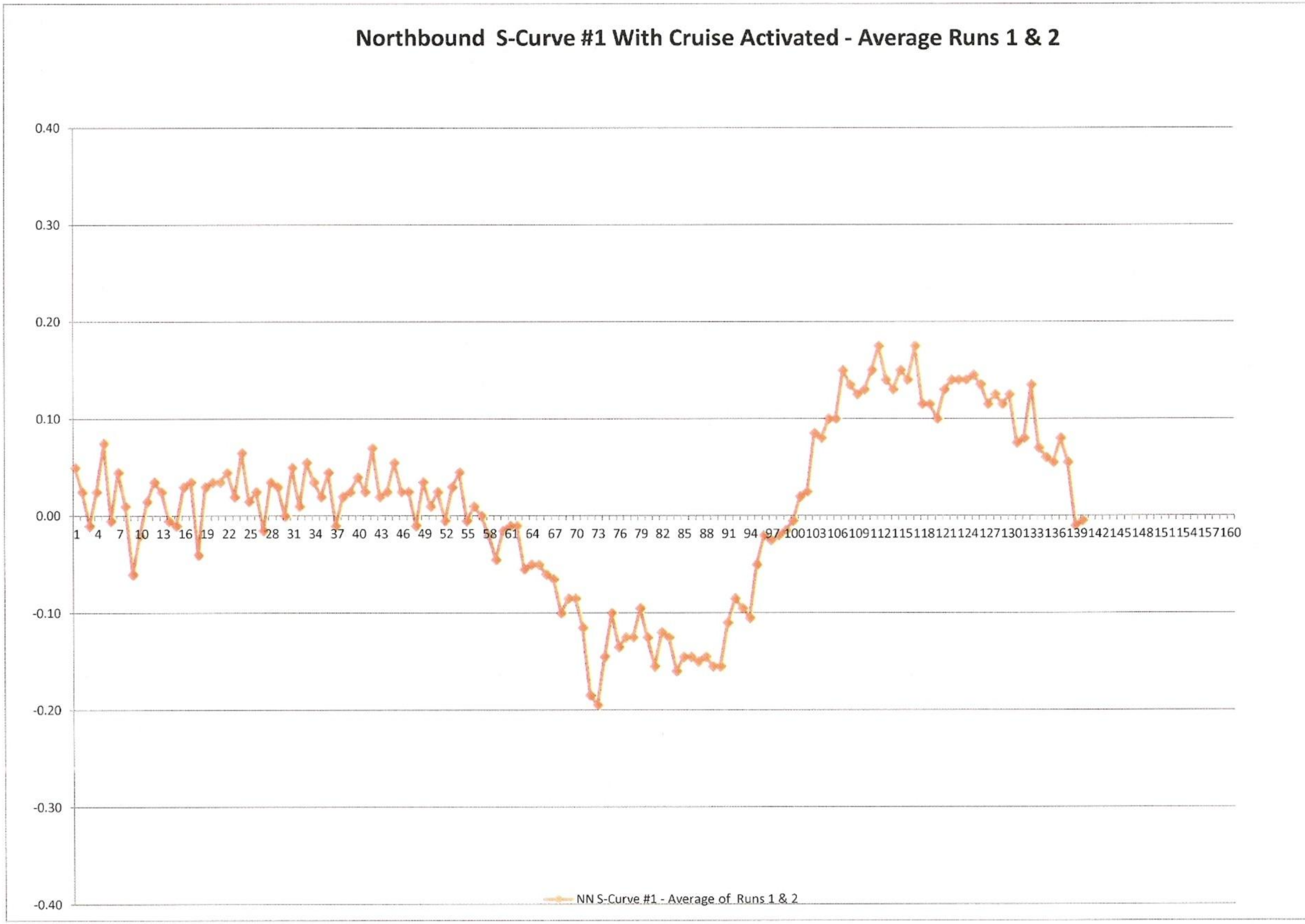
This is the third in a series of articles discussing testing at Gorski Consulting to document roadway effects on potential loss-of-control collisions at seven S-curves on Adelaide Street , north of the City of London, Ontario, Canada. An initial article introduced the roadway and the characteristics of each curve through a series of photographs (Part 1). A second article (Part 2) reviewed the instrumentation and testing methodology used to obtain the data from drive-through tests at the site. The present article (Part 3) will reveal the general results from our testing from each of the seven S-curves.

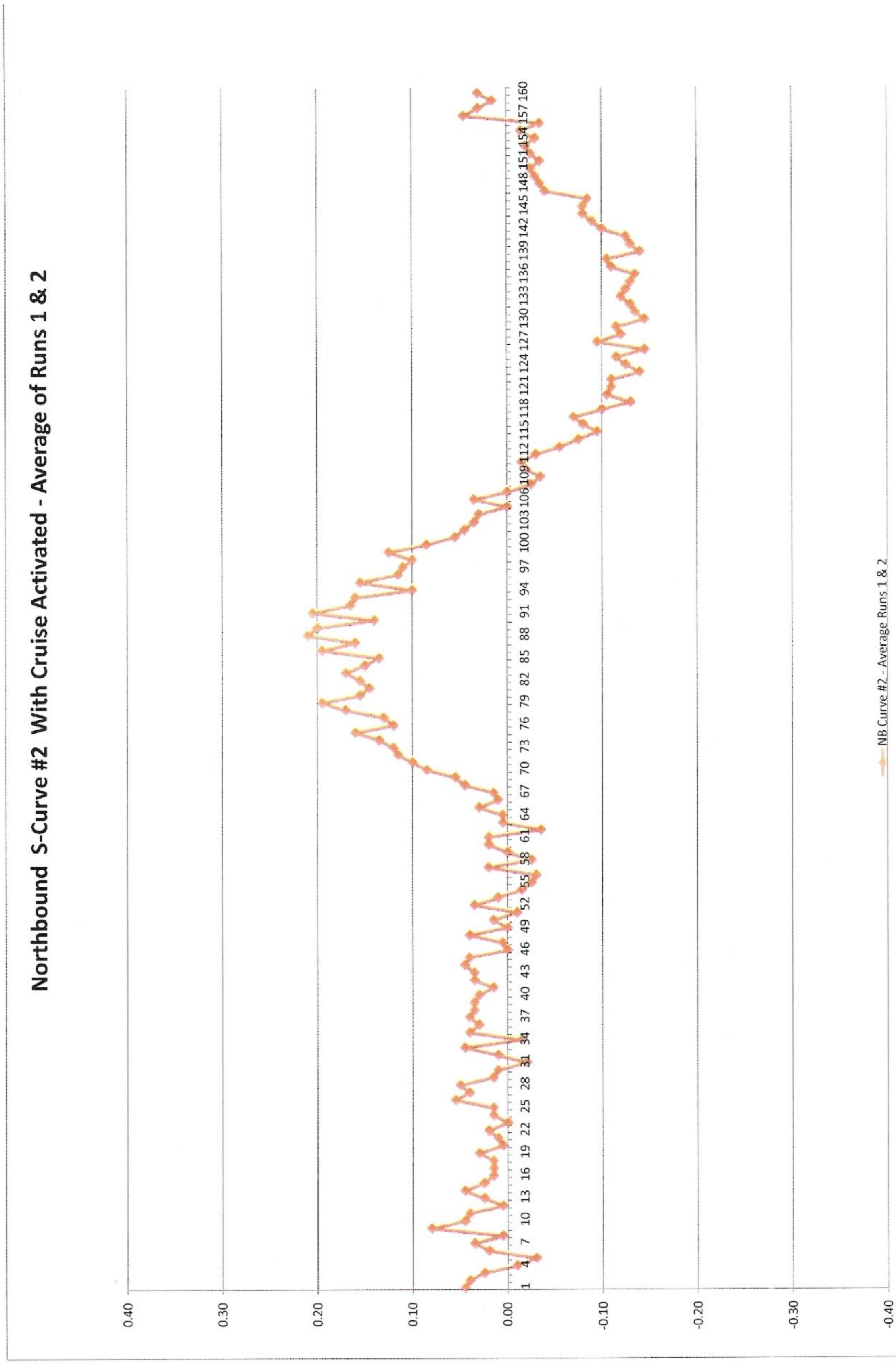
Recall that the results involve testing conducted along seven S-curves that exist along a 12-kilometre distance of Adelaide Street, north of the City of London, Ontario, Canada. Testing was conducted in September of 2012 wherein a vehicle was driven along the study area and data was collected with multiple video cameras and an accelerometer. Data was collected during two rounds of northbound and southbound travel. The test driver set the vehicle's cruise control to 90 km/h, or 10 km/h above the posted maximum speed limit. The driver then maintained that speed, without braking, while travelling through the full set of curves. The test driver also purposely attempted to keep the vehicle centred within the lane even while passing through the curves. The driver also purposely attempted to reduce the speed and magnitude of an any steering motions so that the changes in steering action was minimized to what was essential to keep the vehicle in the centre of the lane with a minimum of corrective steering.

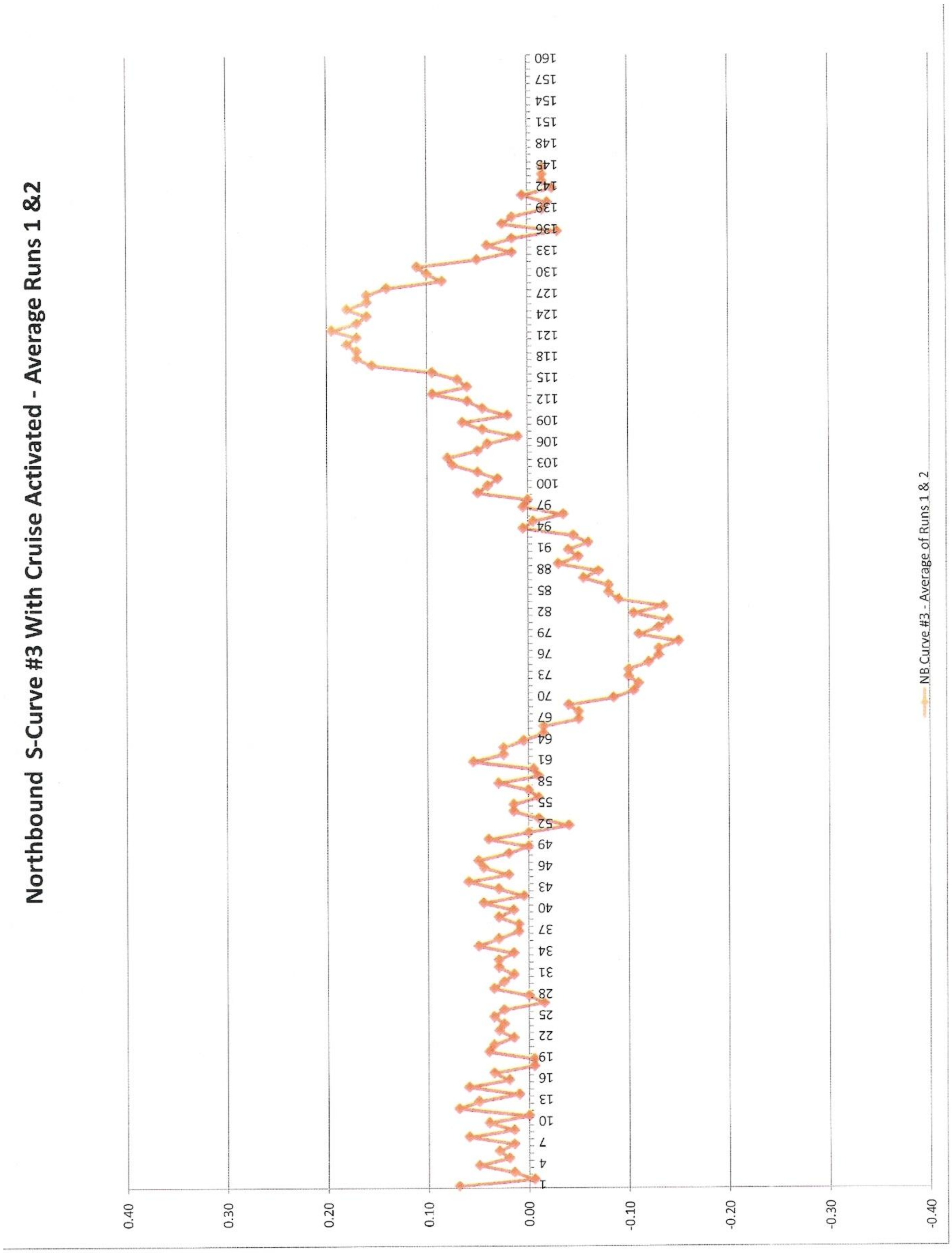
## Results from Testing at the Seven S-Curves

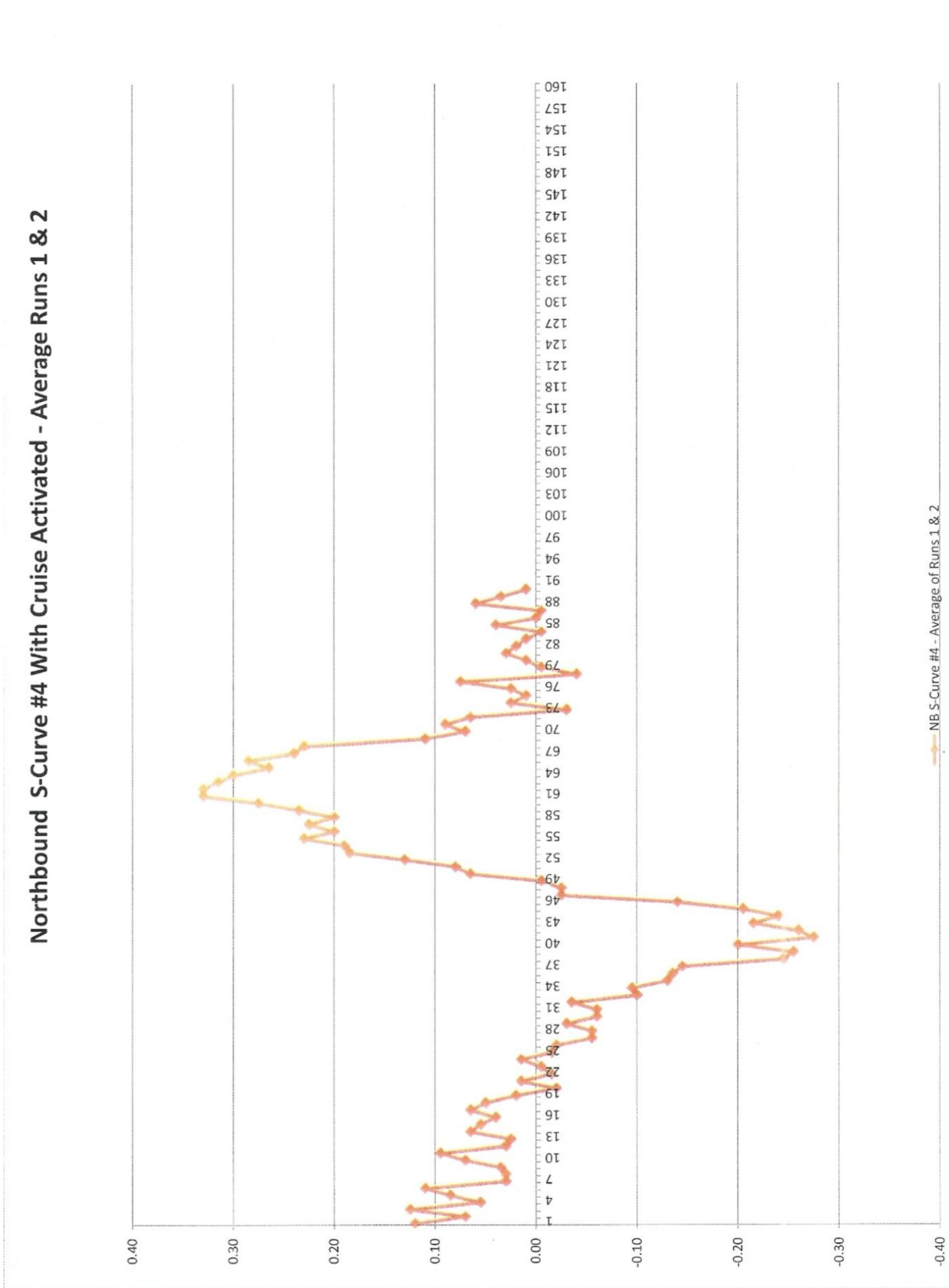
As shown in the following pages (Page 2 through 8), there are substantial differences in the quantity of data points taken from each curve. The data collection was consistently started at the location of the curve warning sign prior to each curve. The data collection was terminated more subjectively by noting when the lateral acceleration appeared to dissipate to values consistent with a straight road. So the differences in the number of data points for each curve truly reflect the differences between the curves.

Although there are obvious differences between all the curves, in our opinion, one can separate them into two groups based on their quality of design. We invite you to examine the charts (below) and consider how the curves might be separated into the noted groups.


Northbound S-Curve #1 With Cruise Activated - Average Runs 1 & 2
0.40
0.30
0.20
0.10
0.00
-0.10
-0.20
-0.30
-0.40
1 4 7 10 13 16 19 22 25 28 31 34 37 40 43 46 49 52 55 58 61 64 67 70 73 76 79 82 85 88 91 94 97 100 103 106 109 112 115 118 121 124 127 130 133 136 139 142 145 148 151 154 157 160
NN S-Curve #1 - Average of Runs 1 & 2


Northbound S-Curve #2 With Cruise Activated - Average of Runs 1 & 2
0.40
0.30
0.20
0.10
0.00
-0.10
-0.20
-0.30
-0.40
NB Curve #2 - Average Runs 1 & 2


Northbound S-Curve #3 With Cruise Activated - Average Runs 1 &2
0.40
0.30
0.20
0.10
0.00
-0.10
-0.20
-0.30
-0.40
NB Curve #3 - Average of Runs 1 & 2


Northbound S-Curve #4 With Cruise Activated - Average Runs 1 & 2
0.40
0.30
0.20
0.10
0.00
-0.10
-0.20
-0.30
-0.40
1
4
7
10
13
16
19
22
25
28
31
34
37
40
43
46
49
52
55
58
61
64
67
70
73
76
79
82
85
88
91
94
97
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136
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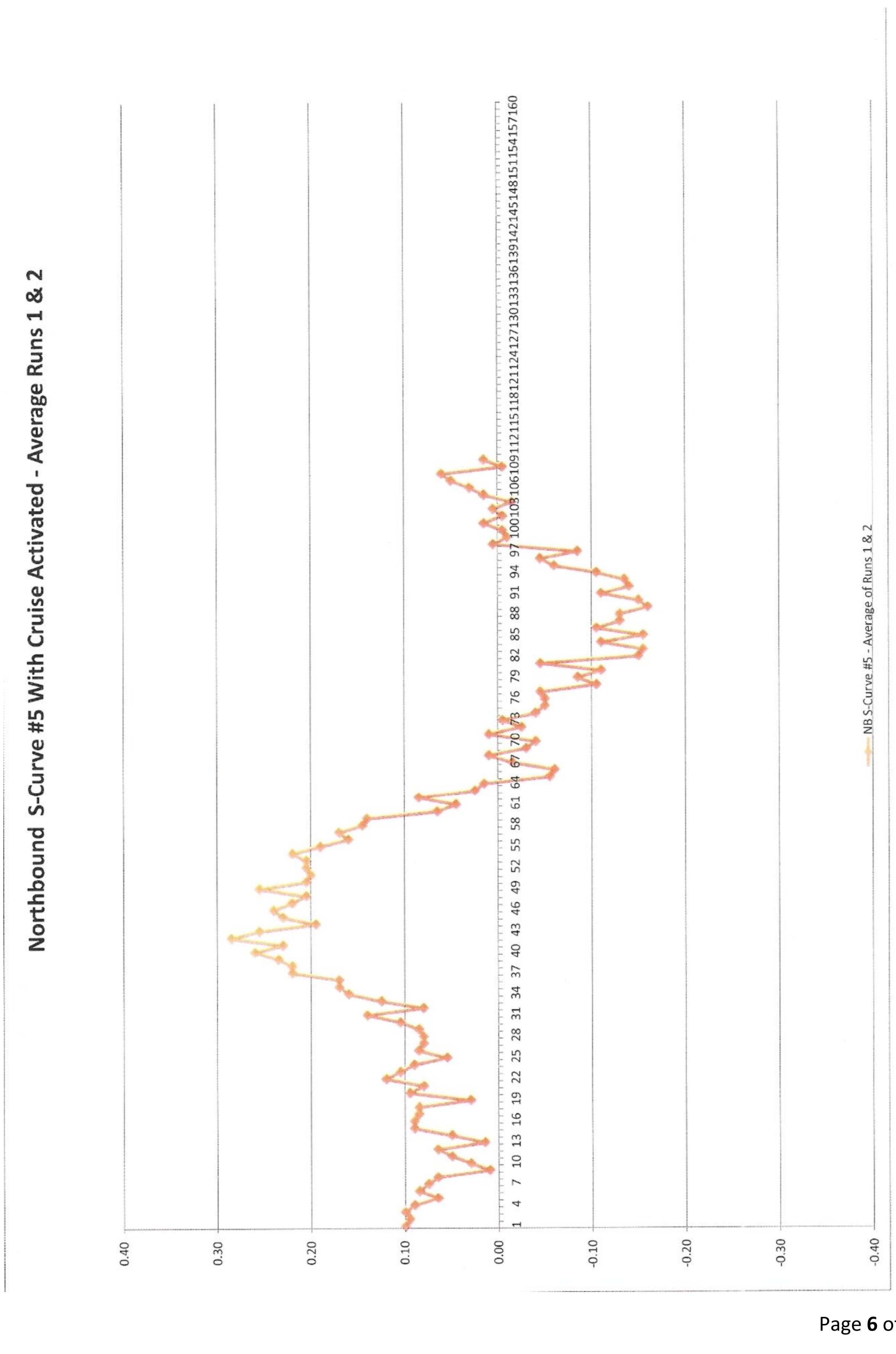
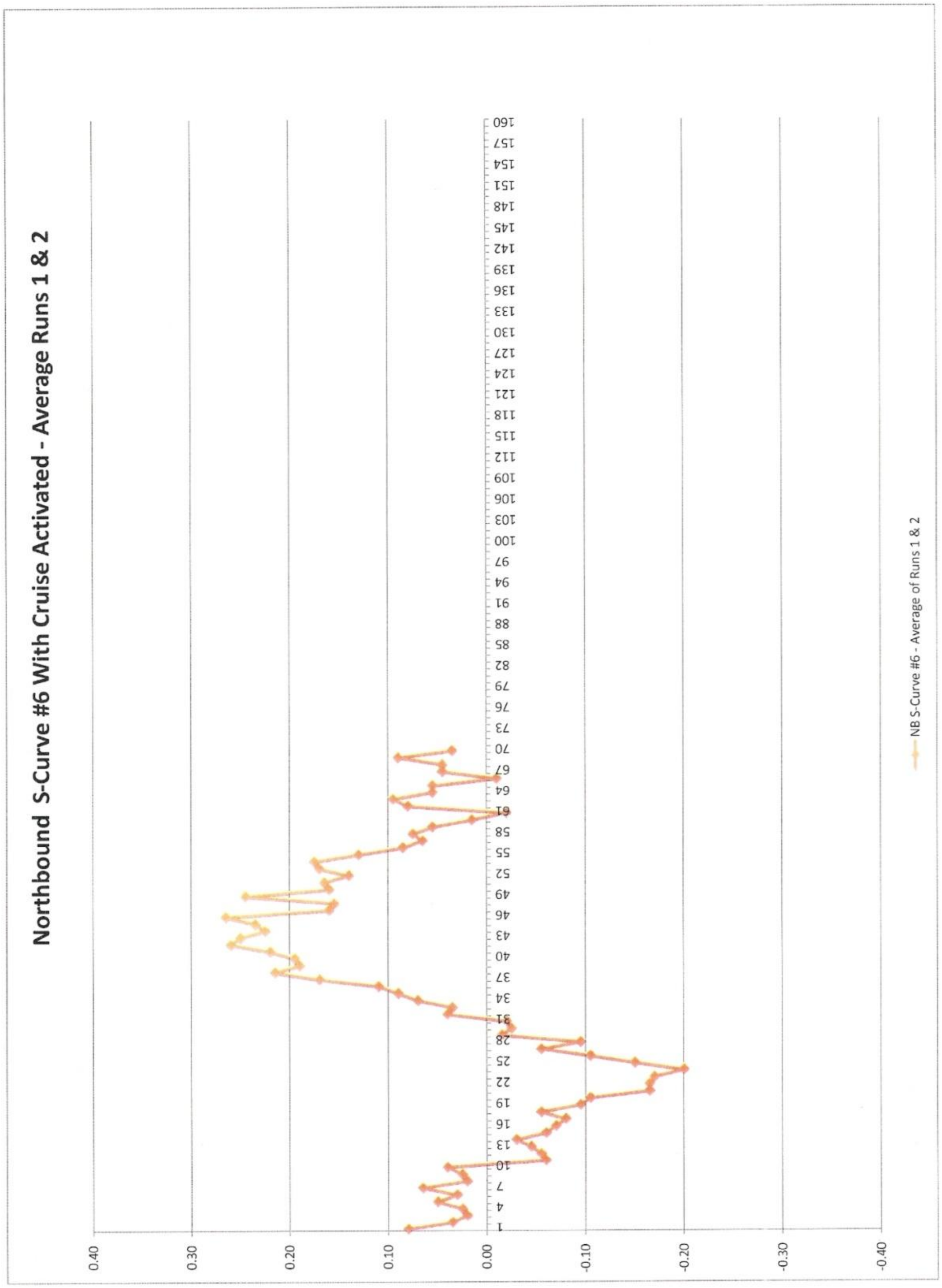
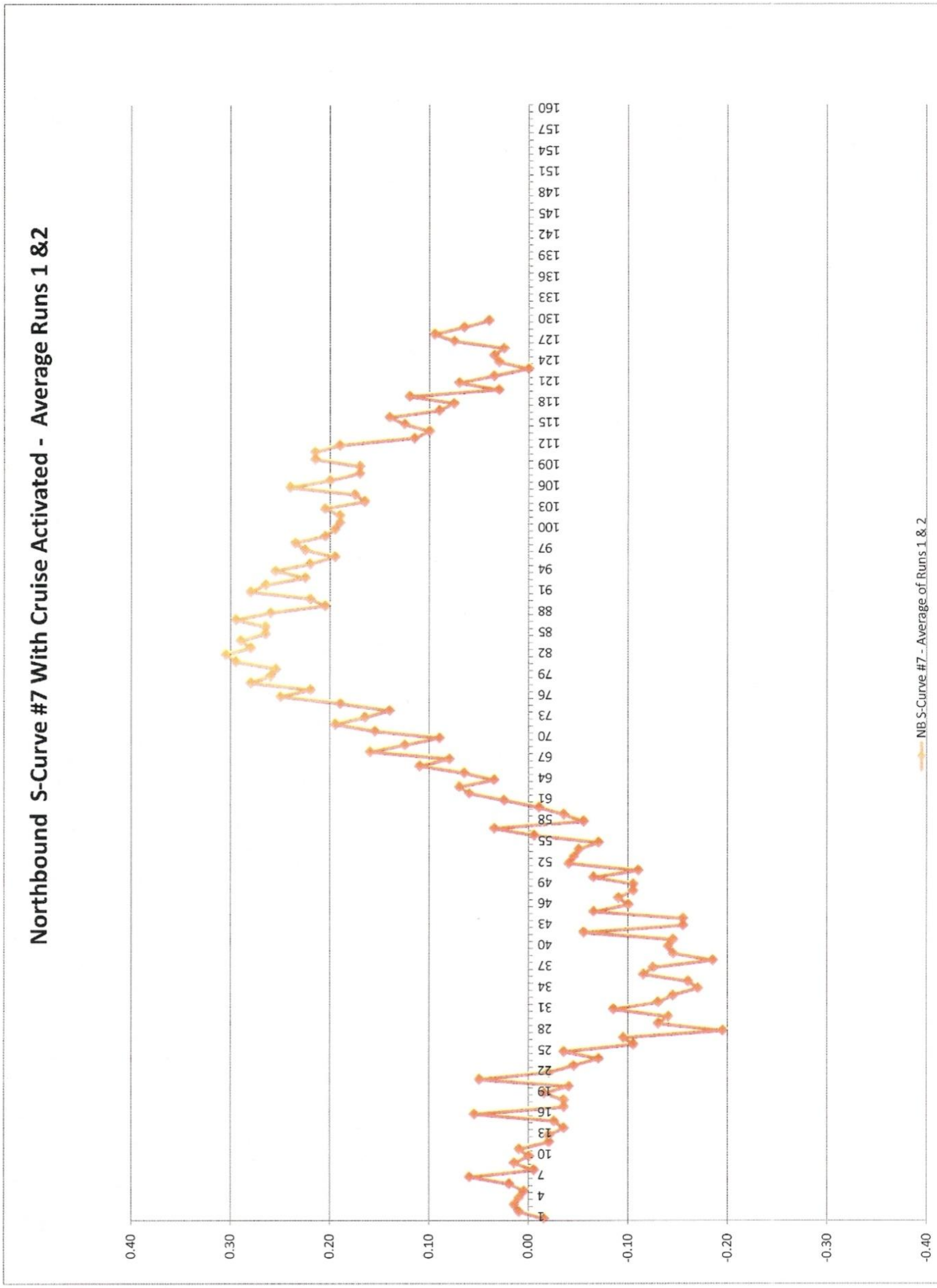
142
145
148
151
154
157
160
NB S-Curve #4 - Average of Runs 1 & 2


Northbound S-Curve #5 With Cruise Activated - Average Runs 1 & 2
0.40
0.30
0.20
0.10
0.00
-0.10
-0.20
-0.30
-0.40
NB S-Curve #5 - Average of Runs 1 & 2


Northbound S-Curve #6 With Cruise Activated - Average Runs 1 & 2
0.40
0.30
0.20
0.10
0.00
-0.10
-0.20
-0.30
-0.40
NB S-Curve #6 - Average of Runs 1 & 2


Northbound S-Curve #7 With Cruise Activated - Average Runs 1 &2
0.40
0.30
0.20
0.10
0.00
-0.10
-0.20
-0.30
-0.40
1 4 7 10 13 16 19 22 25 28 31 34 37 40 43 46 49 52 55 58 61 64 67 70 73 76 79 82 85 88 91 94 97 100 103 106 109 112 115 118 121 124 127 130 133 136 139 142 145 148 151 154 157 160
NB S-Curve #7 - Average of Runs 1 & 2

In our opinion Curves 1, 2 and 3 can be grouped into a higher level of design, while Curves 4 through 7 can be grouped into a lower level of design.

For example, the charts for Curves 1, 2 and 3 show that the first third to one half of the data points are just above the zero level and this would be expected from a straight road with a normal cross fall (cross slope) in the travel lane of about 2 percent. Such a cross fall is incorporated into the design of a road so that rain water will drain toward the shoulders and not remain on the road surface. But this long length of values preceding the curves also tells us that the curve warning sign is placed a long distance prior to the actual curve. As discussed in our previous article (Part 2) the 60 to 65 data points prior to the curve represent a time of about 10 seconds and, at the cruising speed of 90 km/h (25 metres per second), this indicates that the warning signs at these first three curves are located about 250 metres prior to the commencement of each curve.

In contrast you can examine the charts from Curves 4 through 7 and observe that there are very few data points ahead of where the lateral acceleration changes indicating the beginning of the curve. So this indicates that the curve warning signs are placed much closer to the beginning of each curve.

There is still substantial scatter of the data points because the averages are based on only two tests. However, one may also suspect that the data points on the approach to Curves 4 through 7 are higher in value than those same points prior to the first three curves. Again, Curves 4 through 7 exist on tar and chip surfaces and we have observed that they are generally less even than paved asphalt surfaces. In particular the cross fall on the tar and chip surfaces would appear to be greater and more variable and this is exemplified in the apparent higher accelerations and more scatter of the data points in the straight sections of road approaching those curves.

The maximum value of the lateral acceleration is another useful fact that can be viewed in these charts. An interesting observation is that the accelerations during a right curve are slightly lower than those in a left curve and this relationship appears in all seven curves. One can surmise that, because there is a constant cross fall toward the right edge of the pavement this systematic value of about 0.02 g always exists along the length of a road. It is surprising that its effect would also be present within the curves because a super-elevation would exist in the curves and we do not see any reason why this banking of the surface should need to be adjusted by this cross fall.

If there truly is a bias designed into the curves then it could present a safety risk, even though it might be a small one. During extreme motions or at times when the road friction is reduced by snow and ice the maximum available lateral friction may be needed by a vehicle and if that maximum available friction is in right curves than left curves then it might make right curves less safe. The drive wheels of vehicles could be more prone to slippage toward the direction of this biased force. So a front-wheel-drive vehicle could be more prone to under-steer and drive off the right road edge while a rear-wheel-drive vehicle might be more prone to rotate counter-clockwise and perhaps cross a roadway centre-line. This is an issue that needs further evaluation once additional runs reduce some of the data scatter.

Another feature to explore in these charts is the maximum value of the lateral acceleration achieved in each curve. The maximum value of lateral acceleration is generally low in Curves 1, 2 and 3. Whenever there is a right curve the maximum lateral acceleration is below 0.15 g. During left curves the maximum lateral acceleration strays slightly higher than 0.15 g but is still below 0.20 g.

In contrast the values of maximum acceleration for Curves 4 through 7 are higher. At Curve 4 the acceleration reaches almost 0.30 g during the initial right curve and then goes even higher during the left curve to over 0.30 g.

In Curve 5 the initial left curve generates a maximum lateral acceleration above 0.20 g and a respectable range of 0.15 g during the subsequent right curve.

In Curve 6 the initial right curve approaches a maximum of 0.20 g but the maximum acceleration in the subsequent left curve exceeds 0.20 g.

In Curve 7 the initial right curve generates an acceleration near to, or slightly above 0.15, however the subsequent left curve results in a series of data points between about 80 and 110 where the values are generally above 0.20 g.

So, in summary, there is an obvious difference in the maximum lateral acceleration generated by the two groups of curves. The group containing the higher level of service (Curves 1, 2 and 3) show lower levels of acceleration while the group containing Curves 4 through 7 generate higher acceleration levels.

We can also examine how the acceleration ramps up in each S-curve from one direction to the other. In other words, how quickly does the right curve transition into the left curve and vise versa. Let us consider that the quickness of this transition can be detrimental to the stability of a vehicle. If the driver has the steering set to a certain angle to accommodate the angle of an initial curve it can be destabilizing if the steering wheel has to be turned too rapidly in the other direction to begin the vehicle's travel in a curve in the opposite direction. The portion of the data we need to look at to reveal this possible problem is that portion between the maximum acceleration in one direction versus the maximum acceleration in the opposite direction.

Let us explain with the example of Curve 1. There is an initial curve to the right and at about observation 90 the negative acceleration value starts to change toward a positive acceleration, passing zero at about observation 100, and then it continues to increase to the other extreme of the left curve at about observation 106. So from observation 90 through to observation 106 the lateral acceleration goes from one extreme to another. Although we have discussed in the earlier articles how calculations can be performed with these data, let us review what these 16 observations mean.

Our videotape is comprised of 30 frames per second. We have been taking readings every 5 frames. So there are 6 observations taken every second. So the 16 observations comprise a time of about 2.7 seconds. At the cruise speed of 90 km/h (25 metres per second) our test vehicle travels about 66.7 metres in those 2.7 seconds. In those 2.7 seconds the lateral acceleration changes from about -0.17 g to about 0.15 g, or an absolute difference of 0.32 g ,or about 0.12 g per second. Now let us compare that rate of change to some of the curves containing a less quality of service like Curve 4 for example.

The chart for Curve 4 shows that the maximum lateral acceleration of about -0.28 g occurs at approximately observation 41 of the initial right curve. We then see a rapid change in that acceleration as the vehicle travels onto the opposite, left curve to a maximum acceleration of about 0.33 g at about observation 62 .So in 21 observations the lateral acceleration changes by an absolute value of 0.61 g. The 21 observations translate to an elapsed time of about 3.5 seconds. So the rate of change-in-acceleration is about 0.17 g per second and that is substantially higher than the 0.12 g per second of Curve 1.

Curve 6 also contains a quick change in the lateral acceleration values between its two opposing curves.

In summary, one can see how valuable this tool can be for studying the characteristics and safety of S-curves on rural roadways. In fact these methods can be used to study any type of curve, or any type of road segment. It enables an analyst to study these data and have an appreciation of the road conditions and compare those conditions to other sites.

There are additional cameras and instruments that we could have used in this study and we still may do so in the future. In previous testing we have attached a large protractor to the hub of the steering wheel and focused a video camera onto it as the driver steers in various ways while travelling through a test site. During video analysis we transfer the observations of changes in the steering angle to an Excel spreadsheet. Combined with the other instruments this data provides further information about what steering actions the driver took to achieve the documented lateral accelerations. It also helps to appreciate where the steering actions occur in relation to the curve.

The view shown from the rear camera mounted on the bike rack also helps to inform the analyst about the lateral position of the vehicle in the lane. An interesting artifact of the Adobe Premiere video-editing program is that one can insert text on the videotape that is being viewed on the computer screen. This is helpful because a line can be inserted with the "_" or "-" character anywhere on the screen and this can be used as a reference to evaluate what changes are taking place in the view. So, in the case of the lateral motion of our test vehicle, we can create a line that runs across from the roadway centre-line to the right edge of the lane and this becomes the known width the lane of about 3.5 metres. By inserting additional characters into our line using the "l" key we can create precise increments along this lateral line of 3.5 metres and this line is super-imposed over top of the view from the video camera which shows the left tires of the test vehicle and the roadway centre-line. So as the vehicle moves left and right within the lane we can track its motion by comparing the position of the outer edge of the left tire to the text line and its increments. By this method we can precisely document the lateral motion of the test vehicle within the lane at every frame of the video, if we wanted that much detail. But for practicality, documentations every 5 frames are more than detailed enough.

We have also created an attachment for a video camera that points at the brake and accelerator pedals so that we have some appreciation when these pedals are activated during a test drive. In a normal scenario where we might document the actions of a test subject it would not be uncommon for a typical driver to change speed and even brake and accelerate while travelling through these S-Curves. Documenting these actions and being able to demonstrate their timing is an important and useful part of exploring what goes on when a driver travels through rural curves. Additionally, the camera mounted to the bike rack also points toward the left rear tail-light and so it also displays when that brake light becomes illuminated.

As in anything involving video there is a lot of time consumed in the analysis of the actual videotape. This is one of the drawbacks of these procedures.

In future articles we will discuss the results from further testing as we conduct more replications of the drive-through tests to reduce the extent of scatter. We will also discuss the results from volunteer subjects and how the acceleration values are changed due to normal/typical driving patterns of different drivers.

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