Technical Monograph: Transportation Planning for the Richmond–Charlotte Railroad Corridor

January 2004

Appendix A
Curve Analysis Richmond–Charlotte

Federal Railroad Administration
United States Department of Transportation

Appendix A

CURVE ANALYSIS RICHMOND–CHARLOTTE:

SPEED ANALYSIS OF CURVES AND CIVIL IMPACTS

Introduction

Recent simulations and analyses of future intercity, commuter, and freight operating requirements have concluded that significant track changes are required to achieve trip time goals, improve the reliability of intercity and commuter operations, increase capacity, and provide improved operating flexibility. Reconfiguring major terminals and interlockings, removing existing crossovers and turnouts, and installing new (mostly higher speed) turnouts and crossovers to implement desired alignment and configuration changes would satisfy these needs. Revised interlocking layouts also would be required to optimize train operations entering and leaving the additional tracks, and passing sidings that also have been recommended. The number of interlockings that would be modified and the new interlockings that are recommended are significant. Details of recommended programs are contained in the body of the report. The proposed track configurations are illustrated in Appendix D. The interlocking changes that have been recommended are summarized in the body of the report.

Track curvature imposes the most severe constraint on trip time. Consequently, realigning or changing the physical characteristics of existing curves is a primary means of reducing trip times included in this program. Several types of fixed-plant improvements can minimize the constraints to speed associated with curves:

- Increasing superelevation to the maximum allowable for a particular track alignment;
- Changing horizontal and vertical alignment, either within the existing right-of-way, or by acquiring land outside the existing right-of-way;
- Increasing the amount of unbalanced superelevation used to calculate speeds through curves to minimize track shifts; and
- Modifying spirals (the length of track that provides a smooth transition from level, tangent track to curved, superelevated track) by eliminating superelevation runoff onto the adjacent tangent sections.

The rationale for the realignments recommended in this program is summarized in this appendix.

Objective

The results of a speed analysis of curves, and the civil impacts associated with realigning them between Richmond and Charlotte[1] are described in this report. The results of those analyses are summarized in the following subsection.

The goal of the Plan is to reduce the trip time between Richmond and Charlotte to 4 hours 20 minutes. There are several changes to the methods of operation, to the facilities, and to the equipment that can contribute to the overall goal.

One of these changes is to increase the speed of the trains. Increasing the speed may require one or all of the following:

- More powerful or additional locomotives;
- Coaches that can provide comfort at greater unbalanced speeds - tilt vehicles would be needed for operation at unbalanced superelevation greater than 5 inches;
- Tracks and track beds that can withstand the energies transferred at higher speed (including greater imbalance); and
- Alignments that can accommodate the greater speeds without exceeding acceptable limits for:
  - Actual superelevation,
  - Unbalanced superelevation,
  - Lateral acceleration to the passenger
  - Spiral lengths limited by:
    - Rate of change of change of actual superelevation or twist,
    - Rate of change of change of lateral acceleration to the passenger or jerk.

The objective of this analysis was to propose realignments to the existing curves so that proposed speeds can be reached and to identify civil impacts caused by the proposed realignments. The results of the analysis were used to develop a project estimate for realigning curves. The methodology employed to perform the analysis and the results of the analysis are presented in this subsection.

Criteria And Scope

Criteria

The criteria utilized in the performance of this analysis were as follows.

- Maximum actual superelevation should not exceed 6 inches.

[1] The Parsons Transportation Group under contract to the FRA performed the curve analysis.

- Actual superelevation was chosen in increments commensurate with the runoff rates specified by CSX for the segments between Main St. Station and Raleigh and NS for the segments between Raleigh and Charlotte, respectively, and speed.
- Maximum unbalanced superelevation should not exceed 5 inches, which assumes use of non-tilting equipment.
- Maximum lateral acceleration parallel to the floorboards should not exceed 0.15 g.
- For conventional coach equipment at 6 inches of unbalanced superelevation the roll angle should be 2.87 degrees, or less, and lateral acceleration parallel to floorboards should no exceed 0.15 g.
- All actual superelevation should be introduced and removed over the entire length of the spiral; actual superelevation should not be introduced and removed on the adjacent tangents.
- Maximum jerk rate through the spiral should not exceed 0.04 g per sec.
- Track twist rates for alignments at proposed speeds specified by CSXT and NS:

CSX – Richmond to Raleigh

- Speeds from 0 to 50 miles per hour, 1/2-inch per 31 feet or 0.01612903 per foot;
- Speeds from 51 to 70 miles per hour, 1/2-inch per 39 feet or 0.01282051 inch per foot; and
- Speeds greater than 71 miles per hour, 1/2-inch per 50 feet or 0.01 inch per foot.

NS/NCRR – Raleigh to Greensboro to Charlotte

- Speeds from 0 to 60-mph, ½-inch per 31-feet or 0.01612903 inch per foot
- Speeds greater than 61-mph, 3/8-inch per 31-feet or 0.01209677 inch per foot

Scope

The curves to be considered in the analysis were those located between Main Street Station and Charlotte. Studies recently performed for NCDOT proposed maximum speeds for individual curves. These speeds were used as initial speed goals, but were modified as necessary to reflect the iterative analysis process subsequently defined. Maximum speed varied by segment of the corridor:

- Main Street Station to Centralia - 79 mph; and
- Centralia to Charlotte 110 mph.

Presently maximum speed for passenger trains in the corridor is 70 mph (except Centralia to Petersburg which has a 79 mph MAS). Maximum authorized speeds vary by location and are specified in the CSX and NS Employees Timetables. The analysis was based on data taken from a variety of track chart sources between Main Street Station and Raleigh and data obtained from a recent FRA Track Geometry Car Run between Raleigh and Charlotte.

One product of the analysis was the conclusion that, with a limited number of exceptions, each curve on the corridor had to be modified to some degree. For each curve the highest speeds that can be reached without realignment or adjustment to the actual superelevation on each of the existing curves, while satisfying safety and comfort criteria, were initially calculated. An iterative process was then followed to identify the maximum speed attainable (in five mph increments) on each curve. An analysis was then performed to determine changes to superelevation, spiral length, and when necessary degree of curvature for individual curves or groups of curves.

The analysis indicates that the speed improvements can be attained in a limited number of instances by merely surfacing and aligning the track as part of a normal maintenance cycle.

The study identified specific curves that should have their degree of curvature modified to enable speeds to be increased. Curves to be modified ultimately should be selected on the basis of their cost effectiveness - the cost per minute saved as the result of the modification. The analysis would require that Train Performance Calculation (TPC) runs be made to determine the timesavings as the result of each curve modification. The cost of each modification also would have to be estimated, and by dividing the cost by the time for all curve modifications a cost effective listing could be developed, which would assist the planner in evaluating which improvements should be funded.

A second product was the calculation of the highest speeds that can be reached with realignment to improve spiral lengths and with adjustment to the actual superelevation, while satisfying safety and comfort criteria. The result of the analysis was a list of proposed realignments to reach the proposed speeds. In addition to safety and comfort criteria the proposed realignments would comply with standard CSX and NS field maintenance practices. Curves requiring shifts of about 6 inches are shown in Table A-1[2][3]. Curves requiring shifts between 6 inches and 3 feet are shown in Table A-2.Curves requiring shifts in between three- and 10 feet are shown in Table A-3. Curves requiring shifts in excess of ten feet are listed in Table A-4The curves requiring the largest shifts are located on the S Line between Centralia and Norlina, and would be realigned as part of the service restoration, and on the H Line between Fetner and Greensboro. These realignment/relocations may require further study to verify their practicality and feasibility.

The preliminary analysis performed indicated that several undergrade and overhead bridges, and grade crossings would be impacted by the realignments and would have to be modified or rebuilt. Actual bridge impacts would need to be confirmed on a bridge-by-bridge basis. Where undergrade bridges are not located within the body of the curve and the shifts are less than 6 inches, the realignments can be performed with regular maintenance procedures, and would not result in significant additional civil costs. Curves that have turnouts to industrial spurs within their length have been preliminarily identified, but the list would need to be finalized, since turnouts would limit the actual superelevation and the speed in the curve. In these cases the realignment would be more significant resulting in increased costs.

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[2] Curves whose throw would be less than 0.1 feet are not listed.

[3] Compound curves are not listed in the table; the analyzer methodology, subsequently discussed does not address compound curves. The compound curves, for the most part, are addressed in the manual analysis subsection.

The analysis technique (a spreadsheet) made it easier to answer "what-if?" questions, such as, how much would the proposed speed be reduced if speed and consequently the realignment shift was reduced so as not to impact bridge B? Or, how much additional shift would be required to increase the proposed speed on curve A?

The analysis technique resulted in an estimate that is considered accurate to plus and minus 0.1-foot for simple spiraled curves, provided that the radius (degree of curvature) was not changed or the spirals were not changed by a significantly unequal amount. For compound curves the iterative analysis technique is not reliable. For these more challenging realignments manual analyses were performed to determine the shifts. These analyses are discussed in a subsequent section of this Appendix.

Table A-1
SHIFTS BETWEEN 0 AND 0.5 FEET

Cve No	Curve Degree	Radius Feet	North Spiral	South Spiral	Avg Ea Exist	Proposed Speed	Avg Ea Prop	Delta Ea	Optimal Ls	Expected Max Shift
S-LINE										
10.10	1.75	3,274	117	117	1.5	75	1.5	-	190	0.28
10.20	3.50	1,637	93	93	1.5	55	1.5	-	153	0.37
14.00	0.75	7,640	150	150	1.5	110	1.5	-	251	0.22
23.00	2.00	2,865	429	429	5.5	90	4.5	(1.0)	450	0.27
44.10	1.00	5,730	200	200	1.5	100	2.0	0.5	235	0.11
49.00	1.00	5,730	200	200	1.0	100	2.0	1.0	235	0.11
90.00	1.50	3,820	213	213	5.0	85	1.0	(4.0)	263	0.26
91.00	1.50	3,820	213	213	5.0	85	1.0	(4.0)	263	0.26
113.00	1.00	5,730	62	62	1.0	90	1.0	-	197	0.26
125.20	0.50	11,459	93	93	1.5	110	0.5	(1.0)	193	0.10
125.30	0.50	11,459	93	93	1.5	110	0.5	(1.0)	193	0.10
135.00	1.12	5,131	300	300	3.0	110	3.0	-	333	0.17
141.00	1.50	3,820	273	273	3.5	100	3.5	-	350	0.25
150.10	0.75	7,640	200	200	2.0	110	0.5	(1.5)	302	0.28
151.00	0.83	6,876	200	200	2.0	110	0.5	(1.5)	339	0.45
154.10	2.00	2,865	124	124	2.0	70	2.0	-	160	0.15
155.10	0.62	9,291	31	31	-	110	0.5	0.5	244	0.26
H Line										
none										
Piedmont Line										
297.00	2.00	2,865	368	354	3.5	90	4.5	1.0	372	0.19
314.10	2.00	2,865	310	266	4.5	85	3.3	(1.3)	274	0.31
328.00	1.70	3,370	221	310	2.5	90	2.8	0.3	291	0.47
343.00	2.00	2,865	350	354	3.5	90	4.5	1.0	372	0.25
366.00	2.00	2,865	368	381	4.5	90	4.5	-	372	0.10
367.10	2.00	2,865	412	407	4.5	90	4.5	-	407	0.06

Table A-2										
SHIFTS BETWEEN 0.5 and 3 FEET										
Cve No	Curve Degree	Radius Feet	North Spiral	South Spiral	Avg Ea Exist	Proposed Speed	Avg Ea Prop	Delta Ea	Optimal Ls	Expected Max Shift
S-LINE										
2.10	2.00	2,865	117	117	1.5	79	2.0	0.5	250	0.71
6.10	2.00	2,865	117	117	1.5	79	2.0	0.5	250	0.71
6.20	2.00	2,865	117	117	1.5	79	2.0	0.5	250	0.71
7.10	2.00	2,865	117	117	1.5	79	2.0	0.5	250	0.71
7.20	2.00	2,865	117	117	1.5	79	2.0	0.5	250	0.71
8.10	2.00	2,865	117	117	1.5	79	2.0	0.5	250	0.71
10.00	2.00	2,865	117	117	1.5	79	2.0	0.5	250	0.71
10.20	3.50	1,637	93	93	1.5	60	2.0	0.5	192	0.72
15.00	1.00	5,730	200	200	2.0	110	2.0	-	334	0.52
19.00	1.75	3,274	500	500	5.0	100	5.5	0.5	550	0.67
32.00	1.00	5,730	200	200	1.5	110	2.0	0.5	334	0.52
32.10	1.50	3,820	400	400	4.0	110	6.0	2.0	600	2.18
34.00	1.50	3,820	400	400	3.5	110	6.0	2.5	600	2.18
36.00	1.50	3,820	400	400	4.0	110	6.0	2.0	600	2.18
40.00	1.00	5,730	200	200	1.5	110	2.0	0.5	334	0.52
42.00	1.08	5,289	200	200	2.0	110	2.5	0.5	345	0.62
44.00	1.75	3,274	500	500	5.0	100	5.5	0.5	550	0.67
59.00	2.00	2,865	390	390	4.5	90	4.5	-	450	0.73
76.00	1.00	5,730	200	200	1.0	110	2.0	1.0	334	0.52
78.00	1.00	5,730	117	117	0.5	110	1.5	1.0	360	0.84
78.10	1.50	3,820	93	-	0.5	105	5.0	4.5	500	2.73
80.10	2.00	2,865	234	234	3.0	90	4.5	1.5	450	2.15
81.00	1.50	3,820	156	156	1.5	90	2.0	0.5	275	0.56
89.00	1.50	3,820	351	351	4.5	85	4.5	-	450	0.86
93.00	1.00	5,730	200	200	1.0	110	1.5	0.5	360	0.65
96.00	1.00	5,730	150	150	0.5	110	1.5	1.0	360	0.78
102.00	1.50	3,820	550	550	5.5	110	6.0	0.5	600	0.77
108.10	2.10	2,728	600	600	6.0	90	5.0	(1.0)	600	2.66
110.00	2.13	2,686	351	351	4.5	90	5.5	1.0	550	2.78
111.00	2.00	2,865	273	273	3.5	90	4.5	1.0	450	1.86
123.00	1.50	3,820	450	450	4.5	110	6.0	1.5	600	1.72
126.20	2.13	2,686	400	400	4.0	90	5.5	1.5	550	2.21
131.00	2.00	2,865	273	273	3.5	90	4.5	1.0	450	1.86
132.00	2.00	2,865	273	273	3.5	90	4.5	1.0	450	1.86
134.00	1.12	5,131	250	250	2.5	110	2.5	-	359	0.54
137.00	2.25	2,547	429	429	5.5	90	6.0	0.5	600	2.88
138.00	1.08	5,289	195	195	2.5	110	2.5	-	345	0.64
139.00	1.08	5,289	195	195	2.5	110	2.5	-	345	0.64
139.10	1.50	3,820	312	312	4.0	110	5.0	1.0	500	1.66
140.10	3.12	1,838	155	155	2.5	70	4.0	1.5	312	1.66
143.00	1.50	3,820	429	429	5.5	105	5.0	(0.5)	500	1.29
144.00	1.53	3,745			3.5	110	6.0	2.5	600	2.92
145.00	1.53	3,745			6.0	110	6.0	-	600	0.91
146.20	1.80	3,183	468	468	6.0	90	3.5	(2.5)	468	2.31
146.30	1.80	3,183	468	468	6.0	90	3.5	(2.5)	468	2.31
148.00	2.13	2,686	390	390	5.0	90	5.5	0.5	550	2.33
148.10	2.13	2,686	390	390	5.0	90	5.5	0.5	550	2.33
149.00	1.12	5,131	250	250	2.5	110	2.5	-	359	0.54
150.00	1.50	3,820	350	350	3.5	110	6.0	2.5	600	2.59
151.10	1.75	3,274	400	400	4.0	100	5.5	1.5	550	1.81
153.00	2.50	2,292	429	429	5.5	80	5.5	-	550	2.15
155.00	2.12	2,707	31	31	0.5	70	0.5	-	222	0.74

Table A-2 (continued)										
SHIFTS BETWEEN 0.5 and 3 FEET										
Cve No	**Curve Degree**	**Radius Feet**	**North Spiral**	**South Spiral**	**Avg Ea Exist**	**Proposed Speed**	**Avg Ea Prop**	**Delta Ea**	**Optimal Ls**	**Expected Max Shift**
H Line										
24.00	3.00	1,910	310	492	3.5	75	5.0	1.5	413	1.73
25.00	3.00	1,910	492	252	3.5	75	5.0	1.5	413	2.58
25.10	3.00	1,910	292	190	3.5	75	5.0	1.5	413	2.94
26.10	3.00	1,910	275	232	3.5	75	5.0	1.5	413	2.60
42.10	3.00	1,910	288	248	3.5	75	5.0	1.5	413	2.56
43.10	3.00	1,910	248	310	3.5	75	5.0	1.5	413	2.58
48.10	2.00	2,865	257	261	2.0	95	6.0	4.0	496	2.80
62.00	2.00	2,865	279	283	1.0	90	4.5	3.5	372	0.89
63.00	2.00	2,865	261	288	2.0	90	4.5	2.5	372	1.06
63.10	2.00	2,865	270	164	2.0	90	4.5	2.5	372	1.64
63.20	2.00	2,865	270	261	2.0	90	4.5	2.5	372	1.05
65.00	2.00	2,865	239	283	2.0	90	4.5	2.5	372	1.21
66.00	2.00	2,865	217	230	2.0	90	4.5	2.5	372	1.36
67.00	2.00	2,865	230	324	2.0	90	4.5	2.5	372	1.28
68.00	2.00	2,865	323	270	2.0	90	4.5	2.5	372	0.96
73.00	2.00	2,865	443	332	4.0	90	4.5	0.5	372	0.84
75.00	2.00	2,865	297	381	4.0	90	4.5	0.5	372	0.78
Piedmont Main Line										
296.00	2.00	2,502	314	328	5.0	90	6.0	1.0	496	2.96
289.00	2.00	2,865	350	416	3.5	90	4.5	1.0	372	0.50
293.00	2.00	2,865	314	328	3.5	90	4.5	1.0	372	0.59
293.10	2.00	2,865	372	319	3.5	90	4.5	1.0	372	0.54
294.00	2.00	2,865	252	252	2.5	90	4.5	2.0	372	1.13
295.00	2.00	2,865	248	345	2.5	90	4.5	2.0	372	1.13
311.00	2.00	2,865	252	372	4.5	90	4.5	-	372	1.09
313.10	2.00	2,865	301	407	4.5	90	4.5	-	372	0.69
322.00	2.00	2,865	332	182	2.5	90	4.5	2.0	372	1.53
342.00	2.00	2,865	332	275	3.5	90	4.5	1.0	372	0.91
343.10	2.00	2,865	261	283	3.5	90	4.5	1.0	372	1.02
345.00	2.00	2,865	328	297	3.5	90	4.5	1.0	372	0.73
347.00	2.00	2,865	416	345	3.5	90	4.5	1.0	372	0.50
354.00	2.00	2,865	266	297	3.5	90	4.5	1.0	372	0.98
358.10	2.80	2,046	235	257	4.5	75	4.5	-	372	1.69
360.00	2.00	2,865	319	416	4.5	90	4.5	-	372	0.53
360.10	2.00	2,865	252	345	4.5	90	4.5	-	372	1.09
361.00	2.00	2,865	297	328	4.5	90	4.5	-	372	0.73
363.00	2.00	2,865	363	416	4.5	90	4.5	-	372	0.50

Table A-3										
SHIFTS BETWEEN 3 AND 10 FEET										
Cve No	Curve Degree	Radius Feet	North Spiral	South Spiral	Avg Ea Exist	Proposed Speed	Avg Ea Prop	Delta Ea	Optimal Ls	Expected Max Shift
S-LINE										
12.00	3.00	1,910	468	468	6.0	75	6.0	-	600	3.07
129.10	2.00	2,865	500	-	5.0	75	5.0	-	500	3.64
156.00	6.00	955	93	93	-	55	6.0	6.0	468	9.16
156.10	6.00	955	93	93	-	55	6.0	6.0	468	9.16
157.00	10.00	573	62	62	-	40	4.5	4.5	279	5.37
H Line										
26.00	3.30	1,736	190	190	3.5	75	6.0	2.5	496	7.39
36.10	1.85	3,097	199	213	2.0	100	6.0	4.0	496	7.25
39.10	4.00	1,432	283	354	3.5	65	5.0	1.5	413	3.05
44.00	1.85	3,097	226	133	2.0	100	6.0	4.0	496	3.81
54.00	2.90	1,976	257	266	3.5	80	6.0	2.5	496	4.69
56.00	1.53	3,745	213	190	2.0	110	6.0	4.0	496	6.59
Piedmont Main Line										
None										

Table A-4										
SHIFTS GREATER 10 FEET										
Cve No	Curve Degree	Radius Feet	North Spiral	South Spiral	Avg Ea Exist	Proposed Speed	Avg Ea Prop	Delta Ea	Optimal Ls	Expected Max Shift
S-LINE										
None										
H-LINE SHIFTS GREATER 10 FEET										
42.00	3.50	1,736	211	261	3.5	75	6.0	2.5	496	16.82
47.00	1.85	3,097	288	279	3.5	100	6.0	2.5	496	22.90
48.00	2.05	2,795	314	230	3.5	95	6.0	2.5	496	175.96
64.00	2.29	2,502	301	328	3.5	90	6.0	2.5	496	75.03
PIEDMONT SHIFTS GREATER 10 FEET										
None										

Methodology

Soft Realignments

There are two types of alignment changes: soft and hard. Soft alignment changes are changes in unbalanced superelevation, lateral acceleration to the passenger, and jerk that do not require physical changes. Therefore, there would be no cost associated with obtaining desired the speeds. These realignments would assume that the existing track twist (rate of introduction of superelevation) is acceptable. However, the present analysis did not identify any soft realignments between Richmond and Charlotte.

Hard Realignments

Hard alignment changes are changes to actual superelevation, degree of curvature, and/or spiral lengths. Hard changes result in a physical change to the track, and when certain thresholds are reached, hard changes would impact adjacent or supporting facilities, such as, overhead bridges, undergrade bridges, signal towers, station platforms, etc.

Actual Superelevation on Tangent, Maximum Twist, etc.

To meet comfort standards it was not considered acceptable to extend actual superelevation or track twist on to the tangents. Introduction and removal of actual superelevation should be linear, and should occur over the length of the spiral. As curve improvements are implemented occurrences of superelevation on tangents should be eliminated.

Shifts and Impacts

Right of way is generally not considered a factor unless the shift is very large and in those cases right of way would have been considered separately. Only a few of the shifts identified in this study were considered sufficient to require right-of-way acquisition; a cost for real estate acquisition has been included in those rare instances. In general, the impacts of track shifts on overhead or undergrade bridges, and grade crossings are of greatest concern.

Although each bridge located on the body of a curve ultimately would have to be individually evaluated to determine the impact of the assumed track shift, for these analyses it was generally assumed that if a specific shift exceeded the followings limits, the bridge would be impacted:

- Open deck bridges with no additional improvement work proposed--any shift or change in superelevation;
- Open deck bridges with through girders, or through deck girders scheduled for tie replacement--6 inches;
- Open deck bridges with deck girders scheduled for tie replacement--1-foot;
- Open deck bridges scheduled for conversion to ballasted deck--2 feet;
- Ballasted bridges--2 feet; and
- Overhead bridges--3 feet.

Bridges requiring replacement should be designed to accommodate the proposed alignment changes.

It also has been assumed that realignments that require shifts of 6 inches, and less, would be accomplished through regular maintenance practices and procedures. If the shift exceeds 6 inches, the track shifting cannot be done as part of maintenance and would require an independently scheduled effort.

Analysis Guidelines, Assumptions and Techniques

The analysis process utilized to analyze speeds and curves, and evaluate impacts on structures is subsequently described. The following are the guidelines, assumptions, and techniques for doing the analysis.

Degree of Curvature, Radius

The radius and degree of curvature were changed on a selective basis to ensure that reliable intercity passenger trip times between Richmond and Charlotte would be obtained.

Actual Superelevation

Superelevation on curves to be modified was assumed to be implemented in increments in accordance with the way superelevation is introduced in the spiral by railroad maintenance personnel.

Unbalanced Superelevation

Unbalanced superelevation was computed from the following equation.

$E_u = 0.0007 * D_c * V^2 - E_a$

Where E_u is unbalanced superelevation in inches

E_a is actual superelevation in inches

D_c is degree of curvature in decimal degrees

V is speed in miles per hour.

In accordance with previous agreed assumptions, unbalanced superelevation was limited to a maximum of 5 inches.

Lateral Acceleration Parallel to the Vehicle's Floor boards

When unbalanced superelevation occurs, passengers are subjected to a steady state lateral acceleration. This acceleration is the component of centripetal acceleration that is parallel to the floorboards of the vehicle. The calculation for this component takes into account the floorboard rotation due to actual superelevation and the roll of the car body as its suspension responds to the centripetal lateral acceleration. The lateral acceleration is computed from the following equation.

$A_L = \{[(E_a + E_u) / G * COS (THETA - PHI * E_u / 6)] - SIN (THETA - PHI * E_u / 6)\} * g$

Where, A_L is lateral acceleration parallel to floorboards in g

THETA is the angle due to the actual superelevation = ARCSIN (E_a /G)

G = distance between rail head centers = 60 inches

PHI is the vehicle roll angle per 6 inches of unbalanced superelevation = 2.87 degrees per 6 inches of E_u.

The PHI value of 2.87 was derived from conventional coach data provided on page 21 of the report for the FRA entitled *Railroad Passenger Ride Safety*, revised April 1989. Conventional non-tilting equipment has to be considered since either tilting or non-tilting equipment ultimately may be used. The tests reported indicated that both the LRC Coach (tilt capability cut out) and the Amfleet Coach reached 0.15 g of steady state lateral acceleration at 6 inches of unbalanced superelevation. By substituting these values into the above equation a PHI value of 2.87 is found calculated all values of actual superelevation up to 6 inches.

For prior projects, review of previous research and consultation with the FRA lead to the recommendation that 0.15 g should be the lateral acceleration limit. This analyses performed assumed that 0.15 g to be the lateral acceleration limit. Vehicle test data indicates that 0.15 g would be reached at 6 inches of unbalanced superelevation; therefore as long as unbalanced superelevation is limited to 5 inches, the lateral acceleration limit of 0.15 g would not be exceeded.

The PHI value is based upon available data for conventional non-tilting equipment. It is unlikely that new, non-tilting equipment would have a larger PHI coefficient, however, it might have a smaller value. A smaller PHI value would result in smaller lateral accelerations (good for passenger comfort) and in shorter comfort spiral lengths that would be based on a maximum jerk rate (jerk rate and comfort spiral are discussed in the following subsection). Consequently, spirals established based on the PHI value of 2.87 would be longer than necessary if the new non-tilting equipment has a smaller PHI. Therefore, the construction impacts resulting from shifts determined by the PHI value established for this report would be conservative.

The Comfort Spiral, Jerk, and Jolt

The comfort spiral transitions the passenger through a change in lateral acceleration (unbalanced superelevation) at a comfortable rate. Assuming that a vehicle's speed is constant while traversing a spiral, unbalanced superelevation (lateral acceleration) changes linearly as the passenger travels along the spiral. This is because: degree of curvature changes linearly along a spiral; actual superelevation is introduced linearly along the spiral; and vehicle roll is linearly related to lateral acceleration. The change in lateral acceleration is referred to as jerk, with units of g per sec.

The jerk is computed by dividing the change in lateral acceleration (which is found by using the above equation and the change in unbalanced superelevation) by the time it takes for the passenger to travel over the spiral. The time is found by dividing the spiral length by the vehicle speed, with appropriate adjustments for units.

After a jerk rate has been established for a project, dividing the change in lateral acceleration by the jerk rate, and multiplying the quotient by the vehicle speed can compute the minimum comfort spiral length:

$$L_s = A_L / J * V = A_L / 0.04 * 88 / 60 * V = 36.67 * A_L * V$$

Where, L_s is minimum comfort spiral length in feet

J is maximum jerk rate in g per sec

A_L is found from the earlier equation as a function of unbalanced superelevation.

AREMA recommends 0.03 g per sec as a maximum jerk rate, when conditions permit. But where the cost of the realignment of existing tracks would be excessive the AREMA recommends that the jerk rate should not exceed 0.04 g per sec. For this analysis a jerk rate of 0.04 g per sec for non-tilt train equipment was assumed.

The *Railroad Passenger Ride Safety* report, cited above, lists the lateral acceleration and jerk limits for several railroads. Jerk limits range from 0.03 to 0.1 g per sec. It is generally true that when a railroad accepts a higher jerk rate, it accepts a lower lateral acceleration. This is consistent with the observation reported in the same report that people are able to tolerate larger jolts when they are in a lower steady state lateral acceleration environment.

A jolt is also a rate of change of lateral acceleration per second, but it is considered as an occurrence that occurs in 1 second. A jolt is usually a response to a track irregularity. When jolts exceed 0.25 g per sec it is usually a sign that, for that speed, the track needs adjustment. The jerk through a spiral usually occurs over several seconds and, therefore, is not considered a jolt.

Usually back and forth car body rolling occurs when a track irregularity is encountered. The magnitude of the jolt increases as the relative rolling motion of the car body increases. When the jolt is measured as a lateral acceleration parallel to the floorboards, the position of the accelerometer affects the magnitude of the reading. In a double deck car, for the same track irregularity, a passenger on the lower level near the roll center of the car body would feel a smaller jolt than a passenger on the upper level.

The *Railroad Passenger Ride Safety* report also indicates that the researchers did not find any evidence that jerk is a comfort concern. This suggests that the comfort spiral could be shortened until the jerk is 0.25 g per sec. The problem with this approach is that the track has to be maintained in perfect condition. Any track irregularity would result in a total change in lateral acceleration that exceeds 0.25 g per sec.

The French National Railways (SNCF) was found to have the highest limits, 0.15 g and 0.10 g per sec. Since comfort is a subjective feeling of the passenger, the SNCF may be recognizing that the French have a higher threshold to discomfort, or that they may be willing to tolerate a higher percentage of the passengers to be uncomfortable. Or, and perhaps more likely, SNCF has made a commitment to high quality track with tight maintenance tolerances for their high-speed lines. (The British and American comfort criteria were established at comfort limits where 50 percent of the passengers would be satisfied. The Japanese desire to have 90 percent of the passengers satisfied.)

Track Twist

If the track twist, the rate of introduction or removal of superelevation, is too large, safety is impaired. When computing the maximum allowable speed for the existing alignment, the analysis performed verified that the ratio of the existing spiral length to actual superelevation was equal to, or greater than, 62 for speeds below, and including, 90 miles per hour. For speeds above 90 miles per hour, the ratio would be equal to, or greater than, 83.

When the maximum allowable speed did not reach the proposed speed the spirals were lengthened and the actual superelevation adjusted, as necessary, to maximize the speed. A third alternative, decreasing the degree of curvature and adjusting spiral lengths and superelevation was not utilized in this study. Where these alignment changes were required the spiral lengths were changed to satisfy the appropriate actual superelevation runoff rate assumed for the corridor. The new spirals also were checked for jerk. The actual superelevation was adjusted until the jerk criteria were satisfied.

Track Shifts

For this analysis, shifts between the existing and the proposed alignments were computed at 3 points: near each of the curve spiral points and at the mid-point of the body of the curve. The shifts near the curve spiral points were estimated as the difference between the spiral offsets, the "p" distance, for the proposed and existing spirals. At the mid-point of the curve the difference in the external distances for the proposed and existing alignment were estimated to calculate the amount of shift required.

The estimated shifts were checked for an earlier NEC study by running several dummy cogos using typical alignment curve data, and calculating offsets. A range of intersection angles, radii, spiral lengths, and differential spiral lengths, when the existing spirals are unequal, were tested. For simple, spiral curves it was found that the estimated shifts were within 0.1 feet and that they were usually on the conservative side, i.e., 0.1-foot larger than actual. If the proposed alignment has a different intersection angle or a significantly different radius, the estimated shifts become less accurate.

Compound Curves

Compound curves (a combination of two or more curves connected by transition spirals) added another level of complexity to the analysis. A manual technique utilizing USGS maps was utilized to evaluate the limited number of compound curves in the corridor. The methodology is subsequently discussed.

Basis for Existing Curve Data

As with any analysis, the results of the curve analyses performed were only as good as the quality of the available existing data. The best source of data is good mapping or surveyed data points of the existing tracks. Description of an alignment by degree of curvature is incomplete; it is similar to describing a line by its slope. The description of a curve is not complete until the Y intercept is known. Stringline data and track geometry car data also are not ideal sources of data. The degree of curvature is never uniform, always varying. The result is that data elements assumed to describe the alignment might vary greatly from the actual configuration. The variation cannot be determined without mapping or surveyed data points.

The existing data sources used to develop information for the analyses performed were as follows:

- FRA track geometry car charts;
- Earlier work performed by various consultants for NCDOT; and
- Track charts.

The track charts were used for general orientation, but not to define spiral lengths for the curves between Raleigh and Charlotte for which track geometry data was available. The track charts were the only source available for the lines between Richmond and Raleigh, which presently do not have passenger service. The previous work effort was used for background information only; data on proposed curve speeds and previous recommendations were obtained from the reports developed by those studies.

Data relative to the existing superelevation, spiral lengths, curve lengths, and degree of curvature south of Raleigh were primarily developed from an analysis of a recent FRA Track Geometry Car Charts, which were the result of a round-trip run of the corridor.

Although there were possible inconsistencies in the track geometry car data, it was necessary to use them in most instances. The data was valuable for providing the spiral lengths, which were measured directly from the charts of the individual simple and compound curves.

The track geometry car chart data was reduced as follows. The track geometry produces strip charts with fluttering lines. A visual average was made for the degree of curvature and actual superelevation. If the data was not uniform, the curve was subdivided into a compound curve. The distance between uniform curvature data points was assumed to be spiral lengths. The distance between uniform actual superelevation data was not assumed to have any relationship to spiral length because actual superelevation may have been run off onto the tangents and into circular curves.

It was assumed that second, third tracks, and sidings also would be shifted, as necessary, when either would be the inside track on a curve, and thus need to be shifted to maintain adequate clearance to the shifted inner tracks. The costs for this effort were included in the project estimate, but it was assumed that the magnitude of shifts and, therefore, impacts on adjacent right-of-way structures would be driven by the changes required to the high-speed tracks.

For each curve, the existing data from each source was tabulated. The source data was compared, curve-by-curve, and data type by data type. Finally, one set of existing data for each curve was selected and compiled. The compiled data is the most conservative.

Speeds

The existing speeds were taken from the existing CSX and NS Employees Timetables. The proposed speeds were initially taken from the speeds proposed in earlier NCDOT studies. Proposed speeds have been established in multiples of 5 miles per hour.

When determining the maximum allowable speed within the criteria the speed is shown to the nearest downward five miles per hour.

The Alignment Analyzer Spreadsheet

To facilitate the analysis a spreadsheet was developed that allows for the existing speed, degree of curvature, spiral and curve lengths, and superelevation to be input. The input was utilized to perform a variety of calculations. The spreadsheet determined the maximum speed obtainable given the existing alignment and actual superelevation, by only making soft changes, i.e., only changes to speed, unbalanced superelevation, and jerk. For this initial analysis no change to curvature, spiral lengths, and actual superelevation were made. In general it was assumed that the proposed curvature would remain unchanged.

For those instances when superelevation and spiral length changes were analyzed, the spreadsheet was used to determine the shifts associated with changes in actual superelevation and spiral lengths that would satisfy railroad and comfort criteria, and attain the proposed speeds. For the proposed alignment only the proposed speed and actual superelevation had to be input. Unbalanced superelevation, optimal spiral lengths, and shifts were computed. "What if" questions about speeds were asked, and answered, by using different proposed speeds and superelevation for input. Limitations concerning the shift calculations were discussed earlier.

The impact of the proposed shifts on each bridge was evaluated. The criteria used to evaluate the effect of the proposed shifts on bridges included:

- Open deck bridges with no planned work-any shift or change in superelevation;

- Open deck bridges with through girders or through deck girders scheduled for tie replacement--6 inches;
- Open deck bridges with deck girders scheduled for tie replacement--1-foot;
- Open deck bridges scheduled for change to ballast--2 feet;
- Ballasted bridges--2 feet; and
- Overhead bridges--3 feet.

A list all of the curves that required alignment changes to achieve the proposed or optimal speed was developed. It included: proposed speeds, curves requiring 6 inches or less of shift, curves requiring between 6 inches and 3 feet of shift, and curves requiring more than 3 feet of shift.

ALIGNMENT ANALYSIS

Purpose

An Alignment Analyzer consisting of an integrated set of Excel spreadsheet macros was used to perform an analysis of superelevation and velocity alterations to each curve comprising an existing alignment. The Alignment Analyzer is an automated, iterative analysis that optimizes speed, curvature, spiral length, and superelevation for a given alignment. An Excel Workbook for each rail line, or segment of a rail line, utilizes the Excel spreadsheet macros to calculate critical curve data based on assumptions relative to:

- Curve design criteria;
- Unbalanced superelevation;
- Maximum Authorized Speed (MAS); and
- Criteria of the owner of the rail line.

Workbook Organization

Each workbook contains a "Source Data" sheet. All other sheets contained in each workbook are calculation sheets that derive data from the "Source Data." A "File Naming Convention," developed by PTG ensures the uniqueness of each sheet and workbook.

Switchboard

The analyzer macros enable the user to:

1. Select the Data Set to be used;
2. Select the Worksheet to be used, either new or existing;
3. Enter data to the "Source Data" sheet;
4. Establish individual sheets that enable alignment optimization calculations to be performed;
5. Update individual sheets;
6. Generate a curve throw report; and
7. Create a speed deck for use in the Train Performance Calculator.

The Switchboard is the only point of entry to the alignment analysis programs. The "Source Data" sheet is the only sheet that is altered by the user; analyzer specified forms are provided to ensure consistency and enable data validation.

Data Entry

The following data[4] is entered for each curve onto the "Source Data" sheet into a column with the same name:

- Curve number.
    - A unique identifier for each row of data. For ascending mileposts, the second curve in a given mile is X.1, third is X.2, etc (e.g. 24, 24.1, 24.2). The compound spiral between the first and second curves would be X.05, between the second and third would be X.15.
- The number of the Track the data was derived from.
- A Y denotes compound Curves.
- A Y denotes a Reverse Curve.
- The direction, or hand of each curve, either Right or Left Hand Curve, L for Left, R for Right.
- Degree of Existing Curvature in the form (DD.ddd);
    - The radius is calculated as 5729.65/ Degree of Curvature.
- The length of the existing north Or east Spiral (in feet);
    - All three lengths - North/East, South/West Spirals and Body of Curve or the Measured Length of Curve must be provided.
- The length of the body of the existing curve (feet).
- The length of the south or west spiral (feet)
    - If measured data for each curve is not available, the South/West Spiral optionally can be set equal to the North/East Spiral.
- The measured length of curve (feet).
    - Either calculated from the previous three values or measured.
- Existing actual superelevation (Inches).
- The measured distance to next curve (feet)
- The distance to next milepost (feet)

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[4] Data sources include track charts and/or track geometry car strip chart. Normally track chart data is subsequently supported by track geometry car data.

- The passenger train timetable speed, (mph).
- The freight train timetable speed (mph)
- Maximum allowable speed in that area, if such a restriction exists (mph),
    - If there is a speed restriction to a curve for any reason (alignment runs unprotected through an urban area, bridge cannot withstand high speed, etc.) it is entered in this column. Curve optimization is restricted to this value. If not provided, the optimization process would attempt to raise the operating speed through the curve to its theoretical limit/maximum corridor design speed.

Compound Curves[5]

Compound curves are uniquely numbered. There must be as many curve numbers as there are curves following the numbering scheme:

- X.1 for first curve degree
- X.15 for first intermediate spiral[6]
- X.2 for second Degree of Curvature
- X.25 for second intermediate spiral[2]
- Etc.

When a compound curves begins between one pair of mileposts (e.g. MP26, MP27) and completes between a different pair (MP 27, MP28) the curve numbering does not change to match the new milepost but rather continues with the prefix it started with (MP26). This is important for proper processing of the compound spirals.

When a compound curve is indicated an entry is automatically placed below the "form" entry. This entry, the compound spiral, has the following values:

- Track No. (Same value as curve above)
- Right or Left Hand Curve (Same value as curve above)
- North Or East Spiral (User prompted for value, feet)
- Distance to Next Curve (Curve above value minus the user entered value)
- Distance to Next Milepost (Curve above value minus the user entered value)
- Both the Degrees of Curvature and Radius are automatically entered as "N/A".

The following fields for the compound curve are calculated as follows:

- Measure length of curve (see Figure 1)

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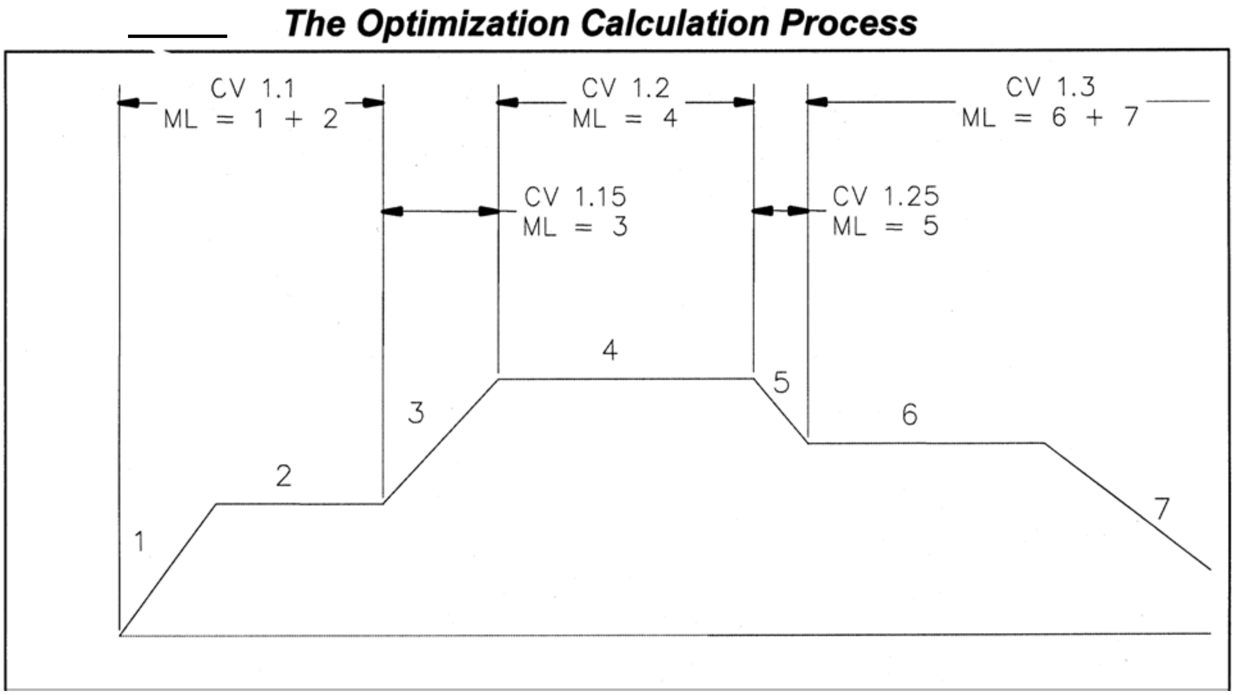
[5] See Appendix 3 for additional information on curve numbering.

[6] Number automatically generated by the program.

- Existing actual superelevation (absolute difference of the previous and following curve Ea)

Figure 1: Compound Curve Measured Length Example



The sequence of the optimization process is as follows. After the source data has been created:

- The options for the analysis are established, and
- The analyses to be performed are defined and run.

The curve option input allows the user to set the following variables:

- Maximum track unbalanced superelevation (Eu) from 1.5 to 9.0 in steps of 0.5 inches.
- Maximum permissible track superelevation (Ea) from 1.5 to 9.0 in steps of 0.5 inches
- Maximum speed from 0 to 110 in steps of 5 mph, plus 79 mph
- Twist calculation formula, the criteria used by the owner/railroad to provide superelevation runoff in uniform increments.

The optimization process would perform specific calculations based either on Tilt or Non-Tilt trainsets. The determination of the calculation performed is derived from the superelevation selected.

Worksheet Naming Convention

The curve option inputs selected become the sheet name under the following part numbering scheme:

NNNTILT-XTWTX

Where:

- NNN is the maximum speed
- TILT is written either as TILT or NTLT
- The first X is the unbalanced super-elevation
- TWT is a three, letter acronym for the operator twist rate equation
- The second X is the maximum permissible track superelevation.

Calculation Alternatives

The user may select any of four series of optimization analyses:

1. Curve, speed, superelevation, and unbalance elevation.
2. Spiral length and comfort index resulting from the curves established by 1.
3. Freight unbalance through the curve established by 1 and 2.
4. Spiral length adjustment to comply and comfortably accommodate the goal speed. The distance the spiral is shifted to establish the spiral length in (2) above, while maintaining the existing curve radius, i.e., degree of curvature.

Each of calculations is discussed below (Formulae are presented both in mathematical terms and in the RC designation defined for row 2):

Proposed Speed and Actual Superelevation

The proposed speed and superelevation values for the curve are entered into specified columns.

For curves, the speed value is used for the start of optimization and is the minimum of:

- The Maximum Speed entered on the Curve Option Input Form; and
- The MAS for the rail line.

The proposed actual superelevation is initialized at the current superelevation. The analyzer performs a series of calculations based on the selected values of superelevation and speed value to determine whether:

- The calculated maximum speed for the curve exceeds the allowable speed,
- The calculated actual total unbalanced exceeds the allowable total unbalance, and
- The Jerk rate exceeds the maximum allowable value.

If the assumed speed and superelevation values exceeds the allowable values, a serried of recalculations are performed until a compliant set of values is arrived at:

1. The superelevation is increase in 0.5" inch increments (or a value in compliance with rail owners criteria) until the maximum Ea is reached, at which point
2. The Ea is reset to the existing and the MAS reduced by 5-mph.

For compound spirals, the assumed speed value is the minimum of each of the curves comprising the compound curve and the superelevation is the average of the preceding and succeeding curves.

Curve, Speed, And Unbalanced Elevation

Maximum speed based on Degree of Curvature (Dc) and actual superelevation (Ea) is calculated using the following formula:

$$\sqrt{\frac{\mathrm{Et}}{0.0007 * \mathrm{D}c}}$$

Total superelevation (Et, usually known as the equilibrium elevation Ee), is the sum of:

Ea+ Eu.

Calculated total superelevation (Et) based on proposed speed, is calculated using the following formula:

$$\frac{4.011 * \text{Proposed Max Speed}^2}{\text{Curve Radius}}$$

Eu based on proposed speed, also delta Eu, is calculated using the following formula:

Et – Ea

Curve Shift Calculations

Three values of spiral length are calculated to determine the optimal spiral length for a given curve.

Minimal Existing Spiral

Spiral length[7] (Ls_1) based on the existing values, is conservatively calculated using the shortest of the two existing spirals, which is calculated from the existing data using the following formula:

Minimum (East Spiral, West Spiral)

[7] There are a variety of formulae to calculate curve length. They are defined in the AREMA manual and in textbooks. Most formulas were developed, over 60 years, as a result of research by AREA, predecessor to AREMA.

Spiral Length Based On Level Of Unbalanced Superelevation And The Proposed Speed

Ls_2 calculated based on the Eu and proposed speed, is calculated using the following formula:

$$\frac{Eu * \text{V} * 88.9}{0.6217 * 304.7851}$$

Spiral Length Based On The Twist Rate, Or The Rate At Which Superelevation Is Introduced Through A Given Distance From The Tangent To The Body Of The Curve

Ls_3 calculated based on the Twist Rate, is calculated using the following formula:

Proposed Speed * Twist Rate

A discussion of twist rates is included in Addendum 2.

Assumed Optimal Spiral Length

Assumed maximum Ls_{max} is derived from the three previous calculations, according to the following formula:

Maximum (Ls_1, Ls_2, Ls_3)

Additional Values Calculated

Alpha (∝), the lateral rotation, used for non-tilt lateral acceleration calculation, is calculated using the following formula:

$$\arcsin\left(\frac{\text{Proposed Ea}}{60}\right) - \frac{\text{Eu} * 0.0500909}{6}$$

Lateral acceleration (g), for non-tilting equipment and all equipment at speeds less than 45-mph:

$$\left(\frac{\text{Proposed V} * 5280}{3600}\right)^2 * \frac{Cos(\alpha)}{32.16 * \text{Curve Radius}} - Sin(\alpha)$$

For tilting equipment when the speed is greater than 45 mph the following formulae are used to calculate the lateral acceleration

If the Eu < 4.2 then 0 otherwise $\frac{0.1 * (Eu - 4.2)}{4.8}$

Jerk Rate (J) at proposed speed with optimal Ls, is calculated using the following formula:

$$\frac{1.467 * g * \text{Proposed Speed}}{Ls_{\max}}$$

A test to determine whether the jerk rate exceeds the assumed maximum value is performed. The Jerk test flag, is calculated using the following formula:

If J > 0.04 then "Trouble"

A test to determine whether the level of unbalanced superelevation exceeds the assumed maximum value is performed. The Eu test flag, is calculated using the following formula:

If Eu > Track Max Ea then "Trouble"

Freight Unbalance Test

The curve defined by the curve calculation process has to represent a balanced approach, i.e., it has to safely and comfortably accommodate all services that would operate in the corridor, at the speed that they would operate on individual curves. The maximum unbalanced superelevation criteria for freight and conventional passenger equipment are not the same as those for tilting high-speed intercity passenger trains. They also may not be the same as those for non-tilting high-speed intercity passenger trains.

The curve analysis process has been setup to verify that comfort criteria are meet for non-high speed rail trains. The curve analysis process also attempts to reduce future maintenance costs. A primary concern of freight rail operators is low-rail wear caused by excessive superelevation to accommodate high-speed rail operations.

The freight unbalance section of the worksheet represents an initial check of the potential for this increased maintenance cost. If the actual superelevation increases significantly, freight trains operating at a slower speed, potentially would be operating at an increased level of unbalanced superelevation, which would result in the center of gravity of a freight car shifting towards the lower rail, increasing the load on the lower rail. This increased load may result in increased maintenance costs, particularly if the amount of unbalanced superelevation becomes a negative value in significantly in excess of that calculated for freight trains operating over the existing railroad. The freight-unbalanced section of the sheet represents an initial review of the data.

Freight total superelevation existing (Ee), is calculated using the following formula:

$$\frac{4.011 * \text{Freight Speed}^2}{\text{Curve Radius}}$$

The level of freight superelevation unbalanced (Eu), is calculated using the following formula:

Ee – Proposed Ea

Spiral Length Adjustments

The amount, in feet, that the existing spiral would have to be shifted, generally inward, to increase, or decrease, so that the optimal spiral length would exist in the track prior to initiating the proposed service at the proposed MAS and speed for each individual curve is calculated using the following process

The existing deflection angle, in radians, for the Southern spiral (θs), is calculated using the following formula:

$$\frac{\text{South Spiral Length}}{2*\text{Curve Radius}}$$

The existing curve delta ($\Delta_{curve,}$ in radians), is calculated using the following formula:

$$\frac{\text{Body of Curve Length}}{\text{Curve Radius}}$$

The existing deflection angle for the Northern spiral (θn), is calculated using the following formula:

$$\frac{\text{North Spiral Length}}{2*\text{Curve Radius}}$$

The deflection angle I, in radians, is the sum of the three previous calculations, is calculated using the following formula:

$$\theta s+\Delta_{curve}+\theta n$$

The existing parallel distance from the tangent track to the point of curve for the Southern spiral (Ps), is approximated as:

$$\frac{\text{South Spiral Length}^2}{24*\text{Curve Radius}}$$

The existing P for the Northern spiral (Pn), is approximated as:

$$\frac{\text{North Spiral Length}^2}{24*\text{Curve Radius}}$$

The proposed deflection angle θ for both spirals (θp), is calculated using the following formula:

$$\frac{Ls_{MAX}}{2*\text{Curve Radius}}$$

The proposed parallel distance from the tangent track to the point of curve (P) for both spirals (Pp), is calculated using the following formula:

$$\frac{\text{Proposed Spiral Length}^2}{24*\text{Curve Radius}}$$

The amount that the southern spiral is shifted (Shift S) is calculated using the following formula:

$$Pp - Ps$$

The amount that the northern spiral is shifted (Shift N) is calculated using the following formula:

Pp – Pn

Therefore, the expected maximum Shift at the spiral ends, is the maximum of the two previous values, or:

$$\text{Maximum}\left(\left|\text{Shift S}\right|,\left|\text{Shift N}\right|\right)$$

Curve Optimization Process

Once all of the source data has been entered and the option values selected, a curve optimization algorithm is automatically initiated and processes each curve in the source data. As of this time, the algorithm does not accurately calculate the shift for compound curves; therefore a separate manual process is still used to evaluate compound curves and spirals.

The purpose of the optimization is to maximize the proposed speed through a curve and minimize the proposed amount of actual superelevation, subject to the limitation of:

- The maximum theoretical speed through the curve based on the degree of curvature and the proposed superelevation,
- The maximum allowable unbalanced superelevation, and
- The Jerk limit test.

During optimization, each successive reduction in proposed speed is rounded to the next lowest five miles an hour, including 79 mph. Additions to superelevation are made in steps of ½-inch, rounded to the nearest half or whole inch.

Optimized Speed – Goal Speed Comparison

A listing of the optimized speed versus the goal speed for each curve is generated and is used to perform various TPC runs to evaluate trip times between terminals/study endpoints. Those curves that have not attained the desired goal speed, primarily as the result of its degree of curvature are noted. Depending upon the results of the TPC analysis and the need for additional trip time reduction a further analysis may be undertaken. That analysis evaluates the amount that the body of the curve would have to be shifted to obtain a certain level of reduction in the degree of curvature.

For the Richmond to Charlotte Corridor this was necessary and the following process was used.

Analysis To Determine Amount That The Body Of A Curve Must Be Thrown To Reduce Curvature And Enable Goal Speeds To Be Attained

Once the “final” configuration of the corridor in terms of MAS, spiral length, and actual superelevation has been established and the TPC goal time assessed, the throw analysis is performed to determine the maximum amount that the curve would be thrown to enable a certain level of increased speed to be achieved.

The analysis includes the following steps:

1. A calculation sheet for the throw analysis is generated.

2. The Throw Report command from the Switchboard is selected.

3. The existing calculation format is expanded to include a throw analysis and then a new workbook is generated containing all of the data. Each non-compound curve, row, present in the original curve optimization analysis is included in the throw analysis. The throw analysis is performed. Each curve with a Degree of Curvature between 1 (1-degree curves are adequate for 110 mph and the level of adjustment to provide acceptable spiral lengths was calculate by the previous analysis) and 4.5 (it is assumed tighter curves are there for an unmovable reason, smaller curves would not substantially benefit) is analyzed to determine the amount it would have to be relocated inward (“thrown”) from its present degree of curvature to achieve a desired speed. Optimally, based on maximizing the amount of unbalanced superelevation as close to seven inches as practicable, the following degrees of curvature and speeds were used to perform this analysis:

    a. 3.3 degrees (75 mph),

    b. 2.97 degrees (79 mph)

    c. 2.9 degrees (80 mph)

    d. 2.6 degrees (85 mph)

    e. 2.3 degrees (90 mph)

    f. 2.1 degrees (95 mph)

    g. 1.9 degrees (100 mph)

    h. 1.7 degrees (105 mph), and

    i. 1.5 degrees (110 mph).

4. The analysis is initiated with the first optimal degree below the existing curve, i.e., the first throw analyzed for a 3.0-degree curve would be 2.97 degrees. The existing curve is the first listing for each curve. Each thrown curve name is suffixed with the speed for identification purposes (e.g., X-75). All these calculations should be considered proposed based on the “optimized” speed and super elevation. Curves whose degree of curvature is less than one or greater than 4.5 degrees are not analyzed further.

Throw Calculation Process

The intersection angle, I, for the revised degree of curvature for each curve is assumed to remain the same, i.e., the tangents adjacent to the curve are not shifted. The value for the Curve Delta, is therefore calculated using the formula:

$$\mathrm{I} - \theta_{\mathrm{North}} - \theta_{\mathrm{South}}$$

Where $\theta_{\mathrm{North}}, \theta_{\mathrm{South}}$ are the calculate thetas based on the revised degree of curvature.

The proposed P value for both spirals (Pp), is then calculated using the following formula:

$$\left(\frac{\theta_{Prop}}{12}-\frac{\theta_{Prop}^{3}}{336}+\frac{\theta_{Prop}^{5}}{15,840}\right)*Ls_{Max}$$

The following calculations are then appended to the right side of the existing calculations:

Curve decimal degrees (DD.ddd), is calculated using the following formula:

$$\frac{I*180}{\pi}$$

Distance from the point of tangent to point of curve (K) for the original curve is calculated using the following formula:

$$\left(\frac{1}{2}-\frac{\theta_{South}^{2}}{60}+\frac{\theta_{South}^{4}}{2160}-\frac{\theta_{South}^{6}}{131040}\right)*L_{South}$$

For each of the reduced degrees of curvature, the distance from the point of tangent to the point of curve is calculate using the following formula:

$$\left(\frac{1}{2}-\frac{\theta_{South}^{2}}{60}+\frac{\theta_{South}^{4}}{2160}-\frac{\theta_{South}^{6}}{131040}\right)*L_{Max}$$

The proposed distance from the point of intersection to the point of tangent (Ts) for each curve reduction option is calculated using the following formula:

$$\left(R+P_{Prop}\right)*\text{Tangent}\left(\frac{I}{2}\right)+K_{Prop}$$

The distance from the point of intersection to the curve along the curve radius (Es), is calculated using the following formula:

$$\sqrt{\left(Ts_{Prop}-K_{Prop}\right)^{2}+\left(R+P_{Prop}\right)^{2}}-R$$

The maximum throw for the curve reductions is calculated using the following formula:

$$\text{Maximum}(\text{Spiral shift}, E_{Current}-E_{Source})$$

The new proposed arc length is calculated using the following formula:

$$R*\Delta_{Curve}$$

The new Arc length for the base curves is calculated using the following formula:

$$\frac{I*100}{D}-Ls_{Max}$$

For the thrown curves the new arc length for each degree of curvature is calculated using the following formula:

$$\sum\left(2 * L_{max}, Larc_{Prop}\right)$$

If the values for the revised Curve Delta or Arc Length are negative, the cell is highlighted and the new arc length is shown as N/A.

Summary Throw Report

The results of the curve reduction and throw analysis are summarized in a Throw Summary Report, which contains the following data:

- Basic curve number
- Curve Degrees
- North Spiral
- Body of Curve
- South Spiral
- Measured Length of Curve
- Proposed Spiral Length (for Ea shift only)
- Proposed Ea (for Ea shift only)
- Expected Maximum Spiral Midpoint Shift (for Ea Shift)
- Columns for each speed increment, i.e., 75, 79, 80, 85, 90, etc. display the maximum amount of shift required to achieve each desired degree of curvature and speed. The summary process determines whether the throw at the spiral or the body of the curve is the largest throw required. The cell containing the shift value required to achieve the revised goal speed is highlighted. The amount of shift at the spiral is not highlighted. A single line border designates the revised goal speed.

Creating a Speed Deck

Once the Alignment Analyzer has completed its analysis and a set of goal speeds has been defined, a Speed Deck for subsequent input into a TPC analysis is automatically generated. The process does not automatically generate restrictions for reasons other than civil (curve-related) speeds; therefore, the Speed Deck must be edited to include them.

Smoothing

As explained in Appendix B, the TPC simulation indicates the speed achieved as the result of the affect of vertical and horizontal curvature, adjacent speed restrictions, scheduled stops, and other operating issues. The smoothing process enables the planner/engineer to avoid designing a curve to a speed that never would be achieved. For example, in the example below, Curve 367 on the Piedmont Main Line had an assumed goal speed of 110 mph, however, because of the 95 mph speed restriction of adjacent Curves 367A and 366 the goal train only achieves a maximum speed of 97 mph northbound and 88 mph southbound. The train attempts to accelerate to 110 mph after having cleared the 95 mph restriction but has to begin decelerating before attaining the goal speed. Therefore, the goal speed for Curve 367 has been reduced to 95 mph and the amount of relocation required reduced.

Smoothing is the process of determining the design speed for each curve. The process results in the development of a **Round Trip Analysis Smoothing Report**, which is the final step in the Analyzer methodology. The smoothing report is based on a round trip from Charlotte to Richmond to Charlotte with the same train on the assumed corridor configuration, including assumed stops, assumed curve speeds, and assumed speed limits. The report utilizes a round-trip TPC run to determine the maximum speed obtained by the high-speed intercity train on each curve. The maximum speed reached is not the same in each direction. Vertical and horizontal curvature, the proximity of speed-restricted curves, station stops, and other performance considerations affects a trains operation in each direction. The smoothing process avoids the unnecessary expense of constructing a curve to support a maximum speed that would not be achieved in daily operation. On the other hand, because of the potential variation in speed in each direction, the process ensures that the curve would be designed to support the maximum speed attainable through each curve. The smoothing report is automatically generated. This report has the following columns:

- Curve number;
- Assumed Speed Limit;
- Maximum speed achieved on curve in one direction, Charlotte to Richmond in the example shown;
- Maximum speed achieved on curve in the return direction
- Recommended Smoothed Speed, the speed that the curve should be designed to achieve.

Sample Smoothing Table

Curve	Speed Limit	CharlotteRichmond 110Mph 7In TILT 1P42C6 6Stops	RichmondCharlotte 110Mph 7In TILT 1P42C6 6Stops Reversed	Recommended Smoothed Speed (Bold indicates possible reductions)
376	55	55	55	55
374	100	74	100	100
373	110	76	93	**95**
372	110	81	92	**95**
370	110	87	86	**90**
369	110	100	89	**100**
367A	95	95	87	95
367	110	97	88	**100**
366	95	95	87	95
365	110	99	91	**100**
363	95	95	94	95
362	110	102	97	**105**
361	95	95	95	95
360A	95	95	95	95
360	95	93	95	95
359.1	95			95
359	95	90	95	95
358A	95	87	95	95
358	95	89	95	95
357	110	92	100	**100**
356A	110	98	104	**105**
356	110	101	105	**105**
355	110	99	101	**100**
354	95	95	95	95
353	110	94	110	110
352	110	91	110	110
349	110	89	104	**105**
347	95	89	95	95
346	95	95	95	95
345A	95	94	93	95
345	95	95	93	95

Manual Analysis Techniques

The alignment analyzer also performed a series of analyses to determine potential locations where problems might occur as the result of the recommended curve modifications. The primary difficulty identified was that there was not enough tangent available between a pair of adjacent curves to enable the curves to be shifted, a process which lengthens each curve, for the selected speed. The impact of reducing the speed was evaluated and as necessary a manual technique utilizing existing mapping or USGS mapping was undertaken to evaluate alternative methods of realigning the curves or in certain cases a group of curves.

The manual analysis technique also was used to evaluate numerous locations that were identified as potential trip time reduction locations.

The analyses performed are discussed in the following section.

Curve Analysis and Results

S Line –Richmond to Raleigh

The S Line had numerous three and four-degree curves, which unless modified would greatly reduce achievable speeds. The scheduled travel time of the Silver Meteor, the Seaboard Coast Line's premiere train between New York and Florida in 1958 had a travel time of 1-hour and 32 minutes between Richmond and Norlina. The proposed travel time for the Richmond to Charlotte high-speed trains is 1-hour and 15 minutes between Richmond and Norlina. This significant reduction in travel time would be achieved by increasing MAS to 110 mph and by implementing a few short line relocations to eliminate the most restrictive track locations.

Burgess to Norlina

Dinwiddie Relocation (MP S36.8 – MP S39)

A 2.2-mile realignment, requiring a large fill, would eliminate two four-degree curves (65 mph) and reduce a three-degree curve (75 mph) to one degree (110 mph). Speed on the relocated track would be increased from 65 mph to 110 mph. The relocated alignment would reduce transit time almost one-half minute and would be about 0.18 miles shorter.

MP S58.5 TO MP S60.1

Two curves (S58 and S59) in this 1.6-mile segment would be realigned to a 90 mph configuration to eliminate a restrictive 75 mph (three-degree curve) in the stretch between MP S45 and S81. The curve reduction is located within the limits of the proposed Alberta Siding. The revised alignment would reduce transit time almost 0.3 minutes.

MP S62.6 TO MP S66.3

A 3.3-mile relocation would eliminate or reduce the curvature of six (S62, S63, S63.1, S64, S65, S65.1) of the seven curves in the segment that are greater than two degrees. The realignment would cross two ridges separated by a deep ravine in between the ridges. The former S Line crossed the ravine and Great Creek on a 411 foot long DPG bridge about 50 feet high and cut through the ridges with shallow cuts. The ravine would be filled in. The relocated track would cross the ravine at the same location the angle of crossing would be altered, eliminating the possibility of reusing the Great Creek Bridge. Speed on the relocated track would be increased to 90 mph. The revised alignment would reduce transit time almost 0.75 minutes.

MP S66.9 to MP S75.3

The 8.4-mile curve realignment and right-of-way relocation extends into and incorporates the 3.7-mile Skelton Siding. It is proposed that:

- The curvature of four curves (S68, S69, S69.1, S69.2) north of the Meherrin River Bridge be reduced;
- Three curves (S70, S70.1, S70.2) south of the Meherrin River Bridge (MP S70.2) be replaced with one 1.6-degree right hand curve good for 100 mph; and
- A 7,900-foot line south of MP S71 that would replace four four-degree curves (65 mph) with a pair of reverse[8] 1.75-degree curves (100 mph). The relocation would be about 400 feet shorter than the original alignment; and
- A 2900-foot relocation replaces two curves (S74, S74.1) at the south end of the siding with a single 1.5-degree curve (with four inches superelevation restricted to 100 mph). The relocation would provide sufficient room to locate the turnout to the south end of the siding north of the Taylor Creek Bridge.

The revised alignment would reduce transit time almost 1.4 minutes.

MP S77 to MP S77.8 (Curves S77, S77.1 and S77.2)

A 4,600-foot realignment would replace three short three-degree reverse curves (75 mph) with one left-hand one-degree curve (110 mph) and eliminate a reduced speed zone in an otherwise high-speed stretch. The alignment avoids encroaching upon a cemetery adjacent to the right-of-way. The revised alignment would reduce transit time almost 0.5 minutes.

MP S86.1 to MP S87 (Curves S86, S86.1, S86.2)

A 4,200-foot relocation would replace three curves (a left-hand 4.5-degree curve (60 mph), a right-hand 4-degree curve (65 mph), and a left-hand 4-degree curve (65 mph) with one two-degree curve (90 mph, with five inches superelevation). The relocation enables Bracey siding to extend from MP S83 to S87.2. The revised alignment would reduce transit time almost 0.3 minutes.

MP S89.4 to MP S91.4 (Curves S89, S90. S90.1)

Curves S89 (2.5 degrees), S90 (3 degrees). S90.1 (3 degrees) south of the Roanoke River Bridge would be realigned to reduce curvature to 1.5 degrees (110 mph). The realignments between MP S89.4 and MP S91.4 would extend a stretch where trains can operate at a constant 110 mph three miles further north and create the longest continuous high-speed stretch (twenty-miles, Bracey (MP S88.0) and MP108.2) between Richmond and Raleigh. The revised alignment would reduce transit time almost 0.2 minutes.

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[8] In this case a 1.75-degree curve to the right would be followed by a 1.75-degree curve to the left.

MP S96.6 to MP S98.6

Reconfiguring the alignment though Norlina between MP S96.5 to MP S98.7 would require a 1.6-mile relocation resulting in a 7,000-foot long one-degree curve (110 mph) connecting the S Line and the Portsmouth Line. The relocation results in the elimination of Curves S96, S98 (the most restrictive at 5.08 degrees (60 mph), and S98.1. The north end of Norlina Siding would be located at the south end of the one-degree curve. The new alignment would require reconstruction of 3500 feet of the former line to Portsmouth and a grade separation. The revised alignment would reduce transit time almost 0.9 minutes.

This relocation would begin at a location south of the Norlina Siding would be within the longest (20-mile) continuous high-speed length between Richmond and Raleigh.

Norlina to Raleigh

The MAS on this 58-mile section previously was 79 mph for passenger trains and 50 mph for freight trains.

Manson Curve

Manson curve (S103) is a 3.25 left hand curve (75 mph) in an area that can and should be 110-mph territory. Curve S102, a two-degree eight minute right hand curve (90 mph), is the south end of the eleven mile stretch of 110 mph running, can easily be reduced to 1.5 degrees or less to achieve 110 mph. Connecting Curve S102 to Curve S104 with a line change, would eliminate Curve S103 and would extend the 110 mph segment five additional miles. The relocation would be approximately 1,000 feet shorter than the current route. A minimum of one-half minute in time would be saved. With this change the south end of the 110-mph running would be at MP S108.3 instead of MP S 102.6.

Curves South of Wake Forest

The distance between the ends of adjacent curves south of Wake Forest (MP S140) are insufficient, to enable the spirals of numerous curves to be lengthened to achieve greater speeds because. Two solutions to increase speeds were evaluated:

- The first modified individual curves to increase the speed from 60 mph, which CSX operated when passenger trains were still operating on the line, to 75 mph.
- The second treats curves as a group and further raises the speed to 110 or 100 mph.

  The curves include:

- Curve 140, a 2-degree curve (95 mph with six inches of superelevation[9]) beginning at MP S140.6 that reverses into
- Curve 140.1, a 1600 foot long 3.12-degree curve (75 mph), which is less than 200 feet from the south end of Curve 140,
- Curve 141, in Forestville, is a right hand two-degree curve (95 mph) that reverses into
- Curve 142[10], a two-degree left hand curve (approximately 100 feet between the two curves) that directly reverses into

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[9] The speed would be 90 mph with five inches of superelevation. The actual superelevation installed as the result of the upgrade program would depend upon negotiations with the railroads.

- Curve 142.1, a 3.25-degree right hand curve (75 mph) that reverses into
- Curve 142.2[11], a 2.25-degree left hand curve (90 mph) (approximately one hundred feet between the two curves) that reverses into Curve 143, a three-degree right hand curve (75 mph) (with less than one hundred feet between the two curves[12]).

Holding Avenue crossing (140.98) in Wake Forest is in Curve 140.1; six inches superelevation would result in a speed of 70 mph with very little realignment work within the town. Seventy mph is an increase from the 45 mph that CSX had when it was running passenger trains over this route. The profile of Holding Avenue through the crossing would have to be revised to enable the superelevation to be installed.

All five of the curves below would be revised to achieve 110 mph:

- Curve 141 would be extended northward and relocated to the inside of the curve approximately 39 feet to obtain a 1.5-degree curve
- It is assumed that Forestville Road would be eliminated and access provided by the proposed Rogers Road Extension to be constructed by a developer. At least one home would by removed by the relocation.
- Curves 142, 142.1, and 142.2 would be eliminated by the construction of a new tangent that extends to Curve 143.
- Curve 143 is also reduced to 1.5 degrees by moving it about 100 feet inward.
- Since this alignment crosses the current alignment in two places, the new line would have to be constructed at the same elevation at those two points to facilitate construction.
- Curve 143.1 is a 1,600 feet long three-degree curve (75 mph) on a 50-60 foot fill across a valley. The curve can be reduced to 1.5 degrees and the speed increased to 110 mph compared to the existing 60 mph by constructing a new fill.
- Curves 144 and 144.1 are both two-degree curves (95 mph) that can be realigned to 1.5 degrees to achieve 110 mph without major reconstruction. The alignment of Curve 144.1 would have to pass through the existing Route US 1 overpass.
- Curve 145 is a 2,300-foot long 3.08-degree curve (75 mph). A 110 mph solution does not appear likely, however by changing the tangent direction between Curves 144.1 and 145, Curve S145 can be realigned to a 1.8-degree with a 100 mph MAS.
- Curve 146.2 (1950 feet long) reverses into Curve 146.3 (1750 feet long) south of Neuse River, both are 3.25-degrees (75 mph), there is about 450 feet of tangent are between the two curves.

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[10] Forestville Road is in Curve 142.

[11] A switch to an industry is located in the tangent between Curves 142.1 and 142.2

[12] A private crossing leading to a cemetery and some homes is located between these curves.

100 mph can be achieved by relocating the tangent between Curves S146.2 and S146.3. New curve 146.2 would be 2600 feet long and Curve 146.3 would be 2250 feet long. A tangent of 200 feet would separate the curves.

The total time saved by the 100 and 110 mph solutions between Forestville and Neuse highway crossing is about 2.6 minutes, a reduction in travel time to 3.4 minutes from 6 minutes:

Segment	Time (minutes) Through Segment		
	Constrained Existing -60 mph	**75 mph Option**	**100-110 mph Option**
MP 141.5-MP 143.5	2.0 minutes	1.6 minutes	1.1 minutes
MP 143.5-MP 145.0	1.5 minutes	1.2 minutes	0.82 minutes
MP 145.0-MP 147.5	2.5 minutes	2.0 minutes	1.5 minutes
Total	6.0 minutes	4.8 minutes	3.42
Time Savings	0.0 minutes	1.2 minutes	2.6 minutes

H Line

Fetner to Greensboro –

Clusters of Curves

Curves H55 to H60.1

These curves are located in a six-mile stretch, extending to MP H62.5 (Curve H62) that can be upgraded to a 110-mph stretch.

Curve H60.1 is a one-degree curve, which would be made good for 110 mph by lengthening spirals. A left-hand industrial switch is located on the low side of the curve and would have to be relocated to enable the curve to be shifted inward.

Curve H60 is a two-degree curve (95 mph) that is proposed to reduce to 1.5-degrees to make it good for 110 mph. It is proposed to grade separate the crossing with Route 1654 to remove a crossing from a curve.

Curves H59 and H59.1 are three-degree curves (75 mph). It is proposed to reduce both of these curves and eliminate Curve H59.2 by a 6500-foot line change. New Curve H59 is reduced to a very short one-degree curve good for 110 mph. Curve H59.1 is reduced to a 1.5-degree curve also good for 110 and as stated before Curve H59.2 has been eliminated.

Curves H56, H57, and H58 are all short two-degree curves (90 mph). Presently their spirals range from 190 feet to 257 feet in length. All three curves can be made good for 90 mph by increasing their spiral lengths to 413 feet and providing five inches of superelevation.

All three curves could be realigned inward less than a foot to provide the desired spirals and superelevation. However, by moving the track inward another three feet each curve can be reduced to a 1.5-degree curve good for 100 mph. Since a new siding through Durham would be constructed in the limits of these curves it is proposed that the existing tracks not be realigned at all but rather the new construction would be a made new main track built with 1.5-degree curves good for 110 mph.

Curve H55.3 is a three-degree curve (75 mph) with very short 199 and 190-foot spirals, which restrict current spirals to 60 mph. Fayetteville Street crossing is in the west spiral of this curve and Ramseur Street is just east of the east end of this curve. The potential for closing Fayetteville Street should be evaluated. Dillard Street would be grade separated. It is proposed that this curve be reduced to 2.5 degrees with 500-foot spirals good for 85 mph. Right-of-way appears available to allow the inward movement of the approximate 32 feet necessary onto the roadbed of former CSX tracks that appear to have been removed. The new east spiral would extend through Ramseur Street crossing.

Curves H55, H55.1 and H55.2 are listed as a compound curve of two degrees, three degrees (75 mph), and two degrees respectively. Upon inspection the curves appear to be a two-degree curve with irregularities in the center. Dillard Street is in the east portion of the curve and to avoid having a highway crossing on a curve with six inches superelevation it should be closed. Traffic can use the Roxboro Street underpass, but preferably Dillard Street would be grade separated This curve can be easily realigned to a uniform 2.1 degrees, so with 450-foot spirals the unbalanced elevation would be 5.1 inches at 85 mph. Curve H55.3 is a three-degree curve (75 mph) with very short spirals of 199 and 190 feet and is currently good for only 55 mph. Fayetteville Street is in the west spiral of this curve and it is recommended that this crossing also be closed.

With this last change, the territory between MP 55 and H62.5, over six miles, can be made good for continuous 110 mph running. The revised alignment would reduce transit time more than 0.6 minute.

Curve H49 to Curve H44

Curve H49, a long 2826-foot two-degree curve, has spirals of 230 and 120 feet. Five hundred (500) foot spirals are required to operate at 95 mph, with six inches of superelevation. It is unlikely these can be achieved because Curve H49 reverses into a long four-degree curve (65 mph) H50 with less than a 100-foot between the curves. Therefore, whatever is done to H49 must be accomplished within the limits of the existing curve. It is recommended that the curve be realigned by shifting the center of the curve outward about 40 feet to create a new 2.28-degree curve, which can be operated at 90 mph with 6.9 inches of unbalanced superelevation. If that large of a shift were not possible a curve realignment resulting in shorter spirals and lower speeds would be necessary[13].

Curve H48.1 is two degrees. The existing spirals of 260 feet need to be lengthened to 500-foot to operate at 95 mph. The existing curve is 2,325 feet long and the curve with the lengthened spirals would be 2,565 feet long, a difference of 240 feet or 120 feet in each direction. That leaves a tangent length of slightly more than 100 feet between Curves H48.1 and H48. Curve H48.1 is located within the limits of the existing Funston Siding. A cut and throw

[13] For example, with 413-foot spirals and five inches of superelevation the curvature would increase to only 2.2 degrees, which is good for 85 mph, and the outward movement of the curve is reduced to 30 feet.

would be made at the north end of the proposed siding so that the existing siding would become the main track and the existing main track would become the siding. Therefore, only the proposed new main track (including the existing siding) would be relocated onto the proposed alignment.

Curve H48, a four-degree curve (65 mph) 1647 feet long, follows two two-degree curves (H48.1 and H49). If Curve H48 could be reduced to two degrees, the three curves (H49, H48.1, H48) could be operated at a uniform 95 mph. Leaving Curve H48 as it is, would place a 65 mph restriction between an area of potential 100 mph running and a area of possible 95 mph running. Shifting the center of Curve H48 inward 200 feet would create the required curve. An inspection of USGS maps indicates no impediments that would prevent the track from being moved[14]. Assuming H48 can be relocated, the new curve would be 3,250 feet long (1,603 feet longer than the existing Curve H48) including two 500-foot spirals. The distance between spirals of Curves H48 and Curve H48.1 presently is 1,032 feet; therefore, the relocated curve would require that all but about 225 feet of that tangent be realigned. This relocation requires that both the main track and the siding be moved.

Curve H47 is a three-degree curve (75 mph). The goal for this curve would be to reduce it to 1.75 degrees to obtain 100 mph. The maximum movement inward for this curve would be less than 35 feet. The new curve would be about 1,775 total feet long with two 450-foot spirals. Curve 47 would be located within the limits of the extended Funston Siding. The current main track would become the siding and would remain in its present location. The new main track would be constructed on the recommended alignment parallel to the siding.

Curve H46.1 is an oddly shaped two-degree 983-foot curve with spirals of 332 and 93 feet. No reason for the 93-foot spiral is evident on a USGS map. The curve would be reduced to 1.75 degrees to achieve the goal of 100mph. A minimum of 450-foot spirals would be required, so the new curve length would be 1,250 feet.

Curve H46 is a left hand 2.8-degree curve (80 mph) that precedes **Curve H45**, a right hand three-degree curve (75 mph).

Curve H44.1, located less than one mile east of H44, is a long four-degree left hand curve (65 mph). Unless the curve is relocated, the curve and Curve H45 would be major impediments to high-speed operation. The existing spirals are far too short to run in the six inches of superelevation required to maximize the speed for this curve, which at most would be 65 mph. The best solution is an 11,000-foot relocation that would raise the speed to 100 mph or better throughout.

The relocation would begin near the NC10 underpass west of the current west end of Curve H44.1. It would cut directly across Stony Creek on a 50-foot fill. All curves on the relocated line are 1.4 degrees good for 110 mph and it is estimated that about 800 feet in distance would also be saved. A discussion of the probable transit time saved would be discussed later.

The south end of the Funston passing siding would be located within the limits of the relocation. Initially it was assumed that the west end of the siding would be west of Curve H44.1, which is also coincidentally the west end of the relocation. The siding assumption was made before the relocation was conceived. The existing track throughout the relocated area

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[14] The USGS maps do not show the property usage, so it is not known whether impediments to moving the track exist; further evaluation during final design would be required.

would remain in place as the siding and the relocated track would be the main track. Consequently, curves H46.1, H46, H45, and H44.1 would not be modified. The relocated track would pass over the branch to Chapel Hill and a highway intersection would pass over the relocated track.

Curve H44 is a short two-degree curve 638 feet long including spirals of 226 and 133 feet. Spirals of 250 feet are needed to make this curve good for 80 mph. The resulting curve would have a body of 207 feet and two 250-foot spirals. Increasing the speed to 100 mph would require 450-foot spirals and would require that curvature be reduced to 1.75 degrees. The resulting curve would be 525 feet long and have a body length of only 75 feet.

Between the east end of Curve H43.1 and the east end of Curve H49 the changes outlined make a 4.9-mile long segment that can be operated at a 100-110 mph. The distance saved would reduce transit time about 0.1 minutes. The increased speed on the remaining 4.75 miles would save an additional 1.1 minutes, so about 1.2 minute savings are estimated.

H36 to H38.2 (H36.4 – H38.9)

The next group of restrictive reverse curves is east of Efland. **Curve H38** is shown as a left hand three-degree curve (75 mph) that reverses into **Curve H38.1**, a right hand 3-degree curve. **Curve H38.2**, 3-degree left hand curve, is currently good for 70 mph. Curve H38 reverses into Curve H38.1; its 193–foot east spiral abuts the 192-foot west spiral of Curve H38.1 with no tangent between them. Furthermore, a major bridge over the US70-I84 connector dual highway is in the center of this curve. Thus, the center and both ends of this curve are fixed locations and speed can only be made greater than 60 mph by relocating both Curves H38 and H38.1.

Curve H38.1 referred to above reverses into 3-degree **Curve H38.2** (75 mph). Only 106 feet exists between the spirals of these curves but the 456-foot west spiral of Curve H38.1 adjacent to Curve H38.1 is longer than the 413 feet needed for 75 mph, the maximum achievable speed with 5 inches of superelevation. Curve H38.2 is good for 70 mph, with its present spirals and superelevation.

In lieu of a piecemeal solution of shifting individual curves around to obtain 75 mph, a 7,000-foot relocation is proposed that would reduce **Curves H37** and H38.2 to 1.75 degrees and eliminate Curves H38 and H38.1 altogether and would be good for 100 mph. This relocation would entail a new bridge over the highway. A less ambitious relocation thought to be able to save the current bridge, if it had been constructed so that it could accommodate curvature other than three-degrees, was considered; but photographs indicate the bridge is built to fit only a three-degree curve.

The relocation would facilitate other synergistic changes at Efland. The two-degree **Curve H36.1** can be reduced to 1.75 degrees to match the 100 mph running created by the relocation. That work would be accomplished with an inward movement of the curve at the midpoint about 10 feet.

A solution to **Curve H36**, a three-degree curve, could be somewhat of a problem. If nothing were done to this curve other than lengthening spirals, it would be a 75-mph slowdown bracketed by long stretches of 100 and 110 mph running on either side of it. At a minimum the goal should be to reduce the curvature to 2 degrees to obtain 95 mph. An inward throw of about 120 feet would achieve two degrees; it appears that only one and at most two buildings would be taken. The current main track would remain and would become the new passing siding that would be needed at this location. The current main track would become the siding and a new relocated track would be constructed and become the main track.

The realignment of Curves H36 through H38.2, a distance of about 2.6 miles, would save northward passenger trains about 0.6 minutes. Southward trains would likely save less time because of the grade between Eno River and Efland.

Curves H 28.4 to H26 (MP H29.2 to H26.3)

The compound curves **H28.2, H28.3 and H28.4** can be made good for 95 mph by lengthening spirals. However, the recommended alternative is to realign the curves to make them a simple curve. The resulting 1.56-degree curve would good for 105 mph.

Curves H28.1 and H28. Curve H28 is a four-degree (65 mph) curve located about 450-feet east of Curve H27.2. It is good for 60 mph, as it now exists. The maximum achievable speed with 5 inches of superelevation is 65 mph, which normally could be achieved by lengthening spirals, however, the east spiral of Curve H28 abuts the west spiral of Curve H28.1, and it is not feasible to lengthen the spirals to increase superelevation and speed.

Curve H27.1 has an existing spiral of only 182 feet (good for only 55 mph) at Back Creek Bridge, and a spiral of that length is definitely is not long enough for 70 mph.

The Back Creek Bridge is about 106 feet long and is located between curves H27.1 and H27.2. **Curve H27.2** is a short curve of 758 feet with spirals of 390 feet adjacent to the bridge and 288 feet on the east end of the curve. The body of the curve is only 80 feet long. The east spiral of **Curve H27.1**, a three-degree curve ends at the open deck bridge over Back Creek. **Curve H27** is a three-degree curve (75 mph) with inadequate spirals to allow the maximum achievable speed with 5 inches of superelevation of 75 mph. The short east spiral of this curve abuts the west spiral of **Curve H27.1**. Therefore the ends of both spirals of Curve H27.1 are fixed locations and lengthening the spirals by extending them further onto tangents, as usually done, is impossible. With the existing superelevation and spiral lengths, a tilt train may traverse the Curve H70 at 70 mph.

Two optional relocations to increase speed were evaluated:

1. The first, a 4,000-foot relocation would eliminate Curve H28.1 and reduce the curvature of Curve H28. The relocation would connect Curve H27.2 and Curve H28.2 with tangent track and would raise the speed from 60 to 105-mph.
2. The second relocation, a 6,500-foot relocation would connect Curves H26.2 and H28.2. This relocation would eliminate restrictions on Curves H27, H27.1, H27.2, H28 and H28.1 and increase the speed to 105 mph instead of 60 and 70 mph, and save about 0.6 minutes transit time.

The second relocation is recommended.

Curve **H26.1** is located about 1,000 feet east of Curve 26. **Curve H26.1** is a three-degree curve (75 mph) that reverses into four-degree curve (65 mph) **H26.2** with no distance at all between the two spirals. The short spirals of Curve H26.1 eliminate a simple readjustment as a viable option to increase speed. Because of short spirals Curve H26.2 is good for 55 mph for tilt trains. Any solution must consider Curves H26.1 and H26.2 together rather than individually.

Inward movement of Curve H26.1 curve 34 feet would create a three-degree curve; alternatively an inward movement of 28 feet would create a 3.15-degree curve (still good for 75 mph). Moving the track inward that much may mean becoming too close to some homes adjacent to the rail line. However, by holding the main track near its current position behind the homes they should not be affected by the relocation. Also the track must pass under the existing State Route 1928 overhead bridge.

The inward movement of a 3.15-degree curve near the center of the existing curve would be small, but the right or east end of the curve would move outward towards the highway. It would be necessary to create a new dogleg to return to the original alignment. The west end of the new Curve H26.2 would fall on the original location but the angle of the tangent between Curves H26.2 and H26.1 would be rotated. Rotating the tangent reduced the intersection angles of both Curves H26.1 and H26.2 and provided sufficient room for adequate spirals for Curves H26.1 and H26.2. Both curves should then be good for 75 mph.

Curve H26 is a very short 579-foot four-degree curve (65 mph) with two 190-foot spirals. The USGS maps reveal no obvious reason why Curve H26 must remain a four-degree curve. The maximum achievable speed with 5 inches of superelevation for this curve is 65 mph but 75 mph can be attained with little effort. Shifting the curve less than five feet inward would create a three-degree curve, which with 413-foot spirals is good for 75 mph.

H20.1 to H 21.3 (H20.5 to H22.3)

In Burlington reverse Curves H20.2 and H21 and Curves H21.1 and H21.2 appear to be the result of cuts and throws when tracks were removed. Lengthening both reverse curves should be able to raise the allowable speed to 100 mph or greater. Constructing a new track parallel to the current main track and retiring the current main track could eliminate Curves H21.1 and H21.2.

H 6 to H5.1 (MPH6.3 to H5.6)

Curve H5.3 is shown as a right-hand 2.5-degree curve on the track chart that could be made good fro 85 mph by adjusting the amount of superelevation and the length of the spirals. The north end of Curve H5.3 is only 44 feet from the south end of **Curve H6** - a right hand one-degree curve that easily can be operated at 110-mph MAS by adjusting superelevation and spiral length. The 123-foot Buffalo Creek Bridge is located between Curves H5.3 and H6. It is proposed that the bridge over Buffalo Creek be renewed with a new curved bridge to enable Curves H5.2 and H6 to be realigned into one continuous 1.58-degree curve good for 100 mph.

The distance from the south end of Curve H5.3 to the north end of Curve H6 is 1,965 feet.

Curve H5.1 is shown on the track chart as a 1.8-degree curve, but the curve data[15] shows that H5.1 actually is a compound curve of 1.8 degrees on the west end and 2.1 degrees on the east end (Curve H5.2). The west spiral is 186 feet and the east spiral is 190 feet. A **target** speed for this curve should be 95 mph even though the 2.1-degree portion would not allow it, unless reduced to 2 degrees or less. The length of the curves including spirals is 2,191 feet. Combining the curves into a two-degree curve would lengthen the curve to 2,451 feet, or 300 feet longer than the original curve. Each end of the curve would be extended approximately 150 feet. The north end of Curve H5.3 is 230 feet from the current north end if Curve H5.2 so there is room for the proposed curve lengthening.

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[15] Developed from a recent FRA Track Geometry Car run.

H Line - Individual Curves

Curve H64

Curve H64 is a three-degree curve (75 mph) that would be a restricting curve in an otherwise 90 mph stretch of track. It is recommended that the curve be realigned to become a 2.15-degree curve, which can be made good for 90 mph.

Piedmont Line – NS Washington to Atlanta Main Line

Curve 296

Curve 296 would be realigned to reduce curvature from 2.5 degrees to 2-degree to eliminate an 85-mph restrictive curve in a 25-mile stretch of high-speed running.

Minor Modifications

The following track segments, defined by curves at each end of the segment, were evaluated, but it was determined that significant relocations to increase speed would not be justified. However, it is recommended that curves be adjusted by increasing the amount of superelevation and length of spirals to achieve recommended MAS.

H Line – Raleigh to Greensboro

Curves H72 – H65

Curve H72 and H70.1 are two-degree curves that with five inches of superelevation can be operated at 90 mph. **Curve H70**, a three-degree curve, would be restricted to 75 mph, while **Curve H72** would be restricted to 80 mph by the reconfiguration and realignment of Fetner Interlocking. Therefore, 80 mph is the more appropriate MAS for curves H70.1 and H72. Both curves presently are adequate for 80 mph.

Curves H69, H69.1 and H70 are all three-degree curves (75 mph) with spirals of 314 to384 feet except for the east spiral of Curve H70, which has a spiral of 199 feet. Curve H69 reverses into Curve H69.1, Curve H69.1 reverses into Curve H70, and finally Curve H70 reverses into Curve H70.1. The distance between H70 and H70.1 is 190 feet. The recently constructed Morrisville Road (SR 3060) grade crossing is located in the body of Curve H69.1. These curves can be made good for 70 mph with four inches of superelevation and 331-foot spirals. Increasing spirals to 500 feet to get 75 mph is considered an infeasible option. All spirals, except the 199-foot one, can be easily lengthened to 331 feet with minimal throws of only a few inches. Morrisville Road would be grade separated.

Sharpening Curve H70 slightly to a 3.10 degree curve makes it possible to lengthen the 199-foot spiral to 331 feet without extending the curve into the 190-foot tangent between H70 and H70.1.The revised curve would be good for 70 mph with 6.6 inches of unbalanced superelevation.

Curves H67 and H68 are both two-degree curves, currently good for 80 mph. The curves can be operated at 90 mph by increasing the current spiral lengths from 230-324 feet to 413 feet with minimal shifting of the existing track (one to two feet maximum).

The distance between reverse **Curves H65** and **Curve H66** is only 75 feet. Roadways parallel the track on either side and both curves presently are good for 80 mph. However, by rotating the tangent between the curves slightly only minimal throws would be required to operate both curves at 90 mph

Curves H 63.2 to H60.2

Left hand two-degree **curve H63.1** reverses into right hand **Curve H63.2**, another two-degree curve. The 40-foot distance between the two curves does not provide adequate room to lengthen the spirals of either curve. The short 164-foot east spiral of Curve H63.1 would presently restrict speed through the curve to 60 mph. Recent photographs indicate that the west spiral of Curve H63.1 appears to end about 150 feet east of the I-40 Bridge, therefore, adequate room should exist to enable the west spiral of Curve H63.1 to be extended. The distance between the points of intersection of Curves H63.1 and H63.2 is about 1330 feet, as calculated from the curve data, but at least 1552 feet are needed to put in 413 spirals to achieve 90 mph. Clearly insufficient distance exists to add the longer spirals but the distance can be gained by rotating the tangent between Curves 63.1 and 63.2, which would reduce the intersection angle of both curves. Therefore Curves H63.1 and H63.2 would be upgraded to 90 mph, as both have been given 413-foot spirals for five inches of superelevation. The resulting unbalanced superelevation at 90 mph is 6.3 inches. New Curve H63.1 is 1097 feet long compared to the current 1001 feet and new Curve H63.2 is 1629 feet compared to the current 1579 feet. The distance between curves is 88 feet compared to the current 40 feet.

Associated work: Replace the open deck underpass for State Route 54 (Nelson Road) at the very east end of Curve H63.2 with a ballasted bridge to allow Curve H63.2 to be lengthened.

Curve H63 is a two-degree curve with spirals of 261 and 288 feet. It is proposed to lengthen the spirals to 413 feet to obtain 90 mph. The inward throw would be about two-thirds foot. By slightly increasing the degree of curve the center of the curve would not move.

Curve H62 is a two-degree curve with spirals of 279 and 283 feet. It is proposed to lengthen the spirals to 413 feet to obtain 90 mph, an inward throw of only 0.67 feet. By increasing the degree of curve to 2.04 degrees the center of the curve has no movement.

Curves H54.1 to Curves H48.1

Curve H54.1 is a two-degree curve with 275 and 204-foot spirals. An open deck bridge over Gregson Street is located at the end of the 207-foot east spiral of this curve, but the curve is good for 70 mph without change. Increasing this spiral length would make it necessary to replace Gregson Street Bridge with a ballasted deck. It is assumed that the bridge would be renewed in any event so the spiral lengths can be increased to 310 feet to make the curve good for 80 mph. However, the TPC Curve Smoothing Process indicated that the maximum achievable speed through the curve was 75 mph; therefore it is recommended that the speed be increased to 75 mph instead of 80.

Since the next **Curve H54** is three degrees, the best speed that can be achieved on that curve by lengthening spirals is 75 mph. Curve H54 (three degrees) is currently good for 65 mph. Speeds through Curve H54 can be increased to 70 mph by lengthening the spirals from about 260 feet to 310 feet and to 75 mph by lengthening the spirals to 413 feet. Since the two curves to the west are good for 80 mph and the curve to the north is also good for 80 mph, it is logical to make this curve good for 80 mph too. Reducing the curvature to 2.75 degrees would enable that speed to be achieved. The calculated intersection angle is 18.74 degrees, so crafting a 2.75-degree curve would move the center of the curve inward less than 2.4 feet, exclusive of spiral offsets. The current spirals have offset the existing curve 1.7 feet and a 500-foot spiral for a 2.75-degree curve would have an offset of 5.0 feet or an additional inward move of 3.3 feet. Therefore moving the body of the curve inward of less than six feet would create a curve of 2.75 degrees with two 500 foot spirals. The body of the curve would be only 180 feet. **Associated Work:** Buchanan Boulevard is located in the east spiral of this curve. The potential for eliminating the crossing by providing alternative access through the use of underpasses located adjacent to the crossing

Curves H52.1 and H53 are two-degree curves now good for 70 mph without change. Curve H53 has a short spiral of 190 feet that ends at an open deck bridge over Erwin Street. Both curves would be upgraded to be good for 80 mph. **Associated work**: The bridge over **Erwin Street** would be replaced with a ballasted deck bridge to enable the spiral to be lengthened to 310 feet. **Swift Avenue** crossing is located in Curve H53, however there are underpasses less than 1,100 feet away on either side of the crossing; the potential for eliminating the crossing should be evaluated.

The next three curves, **H51, H51.1 and H52**, are all three degrees. Curves H51 and H52 can be made good for 70 mph with only minor tweaking of their spirals and with maximum throws of about six inches or less. Further lengthening the spirals for Curve H52 to optimize the speed and obtain 75 mph (500 foot spirals) would involve shifting track through a major curved bridge over Hilland Road in the center of the curve and is not recommended. All three existing curves are now good for 65 mph.

The most severe of the three curves is H51.1, a 1059-foot curve with spirals of 275 and 199 feet. Normally extending the spirals should be no problem, but Curve H51.1 also contains a major four-lane highway (US 15) curved bridge in the body of the curve. That would prevent moving the track more than a few inches through the bridge. Minimum 360-foot spirals (4.25 inches superelevation) would be required for 70 mph. The existing 200-foot spiral has already offset the track 0.9 feet. The offset for an assumed 3.1-degree curve is 2.8 feet, so the new curve would move inward an additional 1.9 feet if longer spiral is built and the curve sharpened to 3.1 degrees as assumed. The calculated intersection angle is 24.66, so the distance from the intersection point to the center of a three-degrees is 45 feet. To offset the inward movement of the track at the spirals an outward movement of the curve at the center can reduce that distance. For example by making the distance from the intersection point to the center 43.1 feet the center of the curve would not move and the existing bridge may be acceptable. Doing that would increase the curvature to 3.13 degrees; 70 mph would be obtained with 6.5 inches of unbalanced superelevation.

Curve H50 is a long 2935-foot four-degree curve (65 mph) having spirals of 314 and 354 feet. The **goal speed of 60 mph** would be achieved by increasing superelevation to four inches.

Curves H43.1 to Curve H39

Curve H43, a two-degree curve, is 983 feet long including the two spirals. The east spiral is 195 feet and the west spiral is 257 feet and the calculated intersection angle is 15.14 degrees. To make this curve good for 75 mph, spiral lengths of 195 feet and two inches of superelevation are needed. Lengthening the east end of the curve 17 feet to make the curve 964 feet long and create 2.02-degree curve. Less than one -inch throw would be required to accomplish this minor realignment as part of an upcoming maintenance program.

Curve H43.1 and Curve H42.1 are quite similar. Increasing the length of the spirals of each curve to 413 feet and providing 5 inches of superelevation the curves can be made good for 75 mph.

Associated Work: Realigning Curve H42.1, a three-degree curve, for 75 mph would require a new bridge for **Cates Run** (currently 47 feet long). **Curve H41.1** is a 3.5-degree curve that reverses into **Curve 42**, a four-degree curve, with no distance between the two 210 foot spirals. In addition, an industrial switch to Georgia Pacific is located between the curves in the spiral of Curve H42, which would make for a questionable ride at high speed. From a spiral and superelevation standpoint Curve H42 (four degrees) is good for 60 mph, as it now exists. The maximum achievable speed with 5 inches of superelevation is 65 mph, but that speed cannot be achieved without track relocation.

The curvature in **Curve H41.1 would be reduced from 3.5 degrees to 3.15 degrees**, to achieve **75 mph with 5.5 inches superelevation and 455-foot spirals**.

Curve H42 would be reduced from four degrees to three degrees to attain **75 mph with five inches superelevation and 413-foot spirals**.

1. Moving the tangent intersection point of Curve H41.1 west about 200 feet would achieve the 3.15-degree curve desired. That would rotate the tangent between Curve H41.1 and H42 and would create a distance of about 1900 feet between the new intersection points of Curves H41.1 and H42.

These new curves would be good for 75 mph.

Curves H40 and H41 are two-degree curves. The maximum achievable speed with 6 inches of superelevation is 95 mph but because of the proximity of Curve H39.1 that speed appears too optimistic for Curve H40. Curves H40 and H41 are good for 75 mph, as they now exist. **No change is proposed for either curve**.

Curve H39.1 is a four-degree curve. The maximum achievable speed with 5 inches of superelevation is 65 mph.

Curve H39, a three-degree curve, is immediately east of the Eno River Bridge. The curve is currently good for 65 mph and since it is adjacent to Curve H39.1, a four-degree curve (65 mph), it should remain unchanged.

Curves H25.2 to Curves H23

Curve H25.2 is a two-degree curve located just east of the Haw River Bridge. The maximum achievable speed with 6 inches of superelevation would normally be 95 mph but since this curve is adjacent to **Curve H26**, a 75 mph curve, it is not recommended to make this curve good for 95 mph.

Curve H25.1 also is a short three-degree curve (75 mph) with inadequate spirals of 292 and 190 feet good for 60 mph. 413-foot spirals are needed to operate 75 mph, the maximum achievable speed with 5 inches of superelevation. **Associated Work:** To lengthen the 190-foot east spiral a new ballasted-deck **Route 49 bridge** would be required; the current bridge is open deck and the beginning of the spiral is at the very west end of the bridge. The bridge over Haw River is just east of this curve.

Curve H24, a left-hand three-degree curve, reverses into right hand **Curve H25** with no distance between the curves. It is good for 70 mph, as it currently exists. To operate 75 mph, the **target** speed, 413-foot spirals are required. The west spiral for Curve 23 is 310 feet and the east spiral is 492 feet, which is greater than needed. The west spiral for Curve 25 is also 492 feet and the east spiral is 252 feet. By shortening both 492-foot spirals by 50 feet, a tangent distance of 100 feet can be made between the curves. To obtain the 413 west spiral the curve must be extended 62 feet onto the tangent. The current main track would become the siding and a new main track would be constructed north of the current track with appropriate spirals.

With the minor realignments discussed, both Curves H24 and H25 can be operated at the maximum achievable speed with 5 inches of superelevation of 75 mph. The current main track would also become the siding at this location.

Curve H23 is shown on the track chart as a three-degree curve (75 mph) but the curve data shows that it might be a compound curve of 2.4 and 3 degrees. However the body of the 2.4-degree curve is only 84 feet long. The entire length of curve H23 is 301 feet, which is connected to **Curve H23.1** by a 75-foot spiral. That suggests that curve H23 is really not a curve at all but a malformed spiral for Curve H23.1 376 feet long and is considered as such by this analysis. To operate 75 mph**,** the maximum achievable speed with 5 inches of superelevation for this curve, requires not less than five inches superelevation and a 413-foot spirals. The current spirals are 376 feet (Curve H23) and 368 feet in length, so only a modest lengthening of the spirals is needed to achieve a speed of 75 mph. Pomeroy Street crossing is in the curve and the turnout to Cannon Mills, an active industry, comes off the high side of this curve, however a siding would be needed in this area so the current main track can become the siding. In that way the industrial switch would come off the siding with less superelevation than the main track and the new main track would be constructed north of the current main track with the appropriate spirals.

Addendum 1

Typical Source Data Arrangement

Cve No.	Trk No.	Cmpnd Curve	Reverse Curve?	R/L Hand Curve	Curve Degrees (Feet, Existing)	Radius Feet (Feet, Existing)	North Or East Spiral (Feet, Existing)	Body Of Curve (Feet)	South or West Spiral (Feet, Existing)	Measured Length Of Curve (Feet)	Exist Ea From Trk Chart (Inch)	Dist to Next Curve (Feet)	Dist to Next MP (Feet)	TimeTable Speed (Mph)	Frt V (Mph)	MAS (Mph)
136.70	3	Y		L	1.3	4,407				789	4.5					25
136.75	3			L	N/A	N/A	-	-		-	3.3			0	0	
136.90	2	Y		L	2.4	2,387				1,020	1.3					25
136.95	2				N/A	N/A	-	-		-	1.3			0	0	
137.00	2	Y		L	1.1	5,209				205	0.0					25
137.05	2				N/A	N/A	-	-		-	0.5			0	0	
137.10	2	Y		L	6.3	917				260	0.5					25
137.15	2				N/A	N/A	-	-		-	0.0			0	0	
137.20	2				2.2	2,604	-	115	150	265	0.5					35
137.50	2				7.9	730	135	325	155	615	2.0					45
138.10	2				5.9	979	155	485	130	770	1.3					45
138.50	2				1.0	6,031	105	245	175	525	0.5					45
109.40	3	Y		L	1.0	5,730				1,472	**1.0**					45
109.35	3				N/A	N/A	-	-		-	**3.3**			0	0	
109.30	3				5.1	1,131	-	195	160	355	**4.3**					45
109.20	3				2.8	2,046	148	79	130	357	**1.8**					45
109.10	3				4.7	1,219	125	171	177	473	**3.5**					45
108.90	3				2.0	2,865	130	849	130	1,109	**1.8**					45
108.60	3				5.2	1,113	241	292	200	733	**3.8**					65
108.50	3	Y		L	4.5	1,283				496	**3.8**					65
108.45	3				N/A	N/A	186	-		186	**2.5**					
108.20	3			L	1.4	4,093				760	1.3					65
108.10	3				2.0	2,865	-	470	335	805	2.0					65
106.50	3				2.1	2,772	190	817	292	1,299	**4.3**					70

Addendum 2

Twist Equations

Twist equations

Amtrak

Speeds from 0 to 50-mph, ½-inch per 31-feet or 0.01612903 inch per foot

Speeds from 51 to 70-mph, 3/8-inch per 31-feet or 0.01209677 inch per foot

Speeds greater than 71-mph, ¼-ich per 31-feet or 0.00806452 inch per foot

Metro-North

Speeds from 0 to 60-mph, ½-inch per 31-feet or 0.01612903 inch per foot

Speeds from 61 to 90-mph, 3/8-inch per 31-feet or 0.01209677 inch per foot

Speeds greater than 91-mph, ¼-ich per 31-feet or 0.00806452 inch per foot

CSX

Speeds from 0 to 50-mph, ½-inch per 31-feet or 0. 01612903 per foot

Speeds from 51 to 70-mph, ½-inch per 39-feet or 0.01282051 inch per foot

Speeds greater than 71-mph, ½-inch per 50-feet or 0.01 inch per foot

Norfolk Southern

Speeds from 0 to 60-mph, ½-inch per 31-feet or 0.01612903 inch per foot

Speeds greater than 61-mph, 3/8-inch per 31-feet or 0.01209677 inch per foot

The twist criteria of other major carriers or property owners would be added as information becomes available.

Addendum 3

Line Numbering

The recommended scheme for curve numbering is defined in this Appendix. It would require some modification as unique situations arise, but should be adhered to as much as possible.

Each line of a given run shall be denoted with a unique, thousands place identifier. The first (or starting line) is assigned the zero thousands. Curve numbering, as noted earlier, begins with X.1. Thus, if the first curve occurs between milepost 5 and 6, its name would be 5.1. A curve between mileposts 5 and 6 in the second line would be 1005.1, and so on. This convention would accommodate up to ten different lines and nine curves in a given mile (9001.0) while using only six characters for the name. The benefits of this scheme are easy sorting and filtering of continuous reports of the entire run and avoidance of duplication of names.