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

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Appendix B
Train Performance Calculator Analysis To Support Project Goals

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Federal Railroad Administration
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Appendix B
TRAIN PERFORMANCE CALCULATOR ANALYSIS TO SUPPORT PROJECT GOALS

Introduction

This Appendix discusses the variables, assumptions, and results of the train performance calculator (TPC) analyses informing the Richmond–Charlotte transportation plan.

The purpose of these analyses was to assess and confirm—under varying equipment, infrastructure, and operating scenarios—the capability of the Richmond–Charlotte Corridor to support an intercity rail passenger service that would comply with the States' goals for travel times and reliability. To accomplish this task, the TPC simulates a single train's progress over the route to measure trip time differences between existing and proposed track configurations and geometric characteristics. While this particular technology does not model the interactions among multiple trains, such as would typify practical operations, it does fulfill a critical screening function by scoping out the route's capabilities for high-speed operations, identifying the types of improvements that would realize those capabilities, and projecting the differences between scheduling goals of the States and the likely trip times. It is those differences (if favorable) that could constitute the "pad," or cushion for lateness, which would provide for schedule reliability in the face of random delays that inevitably affect operations. Further operating analyses, described in Appendix C, build on the TPC results by addressing in detail the crucial topic of interactions among trains.

As described in Chapter 3, the States' goal is regularly scheduled, safe, and dependable five-stop rail passenger service between Richmond, VA and Charlotte, NC in less than 4 hours and 25 minutes. For all practical purposes, the 4 hour–25 minute, 5-stop goal equates to the benchmark of 4 hour–20 minute, 4-stop service between Richmond and Charlotte, which was originally applied in the TPC runs.

The alignment analysis described in Appendix A was performed interactively with the TPC throughout the trip time analysis process. Initially, the alignment analyzer developed the speed assumptions that were tested in the TPC process. The final runs described in this appendix used speeds that had either been confirmed or adjusted by a manual alignment analysis process, also described in Appendix A.

Conditions used in the TPC simulations, including maximum authorized speeds, speeds through curves, and unbalanced superelevation, represent the collective best judgment of experienced rail operators based on the assumed design and condition of the fixed facilities, equipment, and appurtenances, as well as on applicable engineering, regulatory, and ride quality considerations. Before high-speed operations are

introduced, however, many of these conditions will have to be analyzed in greater detail, tested to ensure the safety and passenger comfort of the total system, and subjected to all applicable review and approval processes by FRA's Office of Safety.

Background: TPC Running Times, Schedule Times, and Pad

The TPC simulated running time is the best achievable time that may be expected of a given train operated over a railroad line with given physical characteristics. The TPC times are therefore the most optimistic running times for each given train consist.

When train schedules are prepared using TPC simulated times as a basis for the train running times, it is necessary to add an allowance for minor operating irregularities en route, which may be expected to occur on a daily basis, while maintaining a high probability of on-time performance. Several terms are used for this allowance, the most common of which are "pad", "cushion time", or "slop". A discussion of the issue of the amount of pad that should be added to the TPC times is found in a later subsection. The addition of this allowance to the TPC running time will enable trains to perform reliably on a day-to-day basis. The pad also will enable trains to regain any lost time resulting from minor delays (i.e., temporary speed restrictions, diversions around maintenance work, time lost at a station when passenger boardings are slow or heavy, etc.). Pad also provides for two additional components: the probability that not all of the configuration and alignment improvements incorporated into the model will prove physically feasible; and the realization that the model assumes that the train engineer operates the train in a consistent and precise manner in response to speed changes.

The final section of this Appendix, "Synthesis and Conclusions," explores the implications of pad and the limitations of pure TPC running times. It is important to note here, however, that **to reliably meet the trip time goal, TPC running times must be substantially better than the trip time goal.**

Summary of the Cases

As applied in this Appendix, the term "case" represents a single run of the TPC model that incorporates a cohesive set of assumptions about the variables that establish the specifications of that run. Summary Table B selectively lists the most prominent cases undertaken in this analysis, shows the choices of variables underlying each case, presents the relevant results, and provides the basis of the following sections. The section on "Variables Addressed in the Cases" deals with the columns of Summary Table B and explores the options available under each column heading; the "Discussion of the Cases" similarly treats the rows of Summary Table B in some detail.

Summary Table B: Specifications and Results of the TPC Cases. *(All Cases Assume S Line Restoration.)*

Case Number	Number of Locomotives	Propulsion		Hotel power		Number of Cars	Unbalanced Superelevation (inches)	Tilt?		Stops	Alignment				MAS		Minimal MAS if any		Timing, Charlotte-Richmond (hours:minutes:seconds)	Comments
		Diesel	Gas Turbine	From locomotive(s)	From separate source			Yes	No		Existing	Existing Optimized (Includes double-tracking P Line except as noted)	With Contemplated Improvements	With Other Combinations of Improvements	Existing (*Status Quo Ante* for S Line)	Improved (mph)	Charlotte-Richmond	Greensboro-Raleigh only		
1(a)	1	•		•		6	3		•	4	•				•				5:43:32	Baseline case
1(b)	1	•		•		6	3		•	4		•				79			4:47:49	
1(c)	1	•		•		6	4		•	4		•				79			4:45:51	
1(d)	1	•		•		6	5		•	4		•				79			4:40:42	
1(e)	1	•		•		6	7	•		4		•				79			4:37:11	Additional unbalance required tilt. MAS constrains the benefits.
1(f)	1	•		•		6	9	•		4		•				79			4:34:00	This case is only hypothetical as standard Diesel-powered equipment in the U.S. will not safely operate at 9" of unbalance. Other locomotives, now under development, might be certified for such operation. No further details of this case are provided in this Appendix.
1(g)	2	•		•		6	7	•		4		•				79			4:34:00	
2(a)	1	•		•		6	7	•		4		•				90			4:20:05	
2(b)	2	•		•		6	7	•		4		•				90			4:11:29	
3(a)	1	•		•		6	3		•	4		•				110			4:36:52	
3(b)	1	•		•		6	4		•	4		•				110			4:33:36	
3(c)	1	•		•		6	5		•	4		•				110			4:24:30	
3(d)	1	•		•		6	7	•		4		•				110			4:13:39	
3(e)	1	•		•		6	9	•		4		•				110			4:05:30	This case is only hypothetical as standard Diesel-powered equipment in the U.S. will not safely operate at 9" of unbalance. Other locomotives, now under development, might be certified for such operation.
3(f)	2	•		•		6	7	•		4		•				110			3:57:58	
3(g)	2	•		•		6	7	•		4		• *P Line Not Double-Tracked*				110			4:08:04	Not double-tracking the Charlotte–Greensboro line necessitates diverging moves at inter-lockings, with negative impacts on trip times.

Summary Table B, Continued: Specifications and Results of the TPC Cases *(All Cases Assume S Line Restoration.)*

Run Num-ber	Number of Locomotives	Propulsion		Hotel power		Number of Cars	Unbalanced Superelevation (inches)	Tilt?		Stops	Alignment				Fatal flaw in equipment or facility concept?	MAS		Minimal MAS if any		Timing, Charlotte-Richmond (hh:mm)	Comments
		Diesel	Gas Turbine	From locomotive(s)	From separate source			Yes	No		Existing	Existing Optimized (Includes double-tracking P Line except as noted)	With Contemplated Improvements	With Other Combinations of Improvements		Existing	Improved (mph)	Charlotte-Richmond	Greensboro-Raleigh only		
4(a)	2	•			•	6	7	•		4		•					110			3:56:05	
4(b)	3	•		•		6	7	•		4		•					110			3:54:08	
5(a)	2	•		•		6	7	•		4				•	+		110	80		3:50:49	+To establish minimal MASs of 80 mph or more between Charlotte and Richmond would require some additional curve realignments (beyond the contenplated improvements) that could prove to be impractical from the environmental viewpoint.
5(b)	2	•		•		6	7	•		4				•	+		110	85		3:47:18	
5(c)	2	•		•		6	7	•		4				•	+		110	90		3:43:41	
5(d)	2	•		•		6	7	•		4				•	+		110	95		3:40:02	
5(e)	2	•		•		6	7	•		4				•	+		110	100		3:33:47	
5(f)	2	•		•		6	7	•		4				•	+		110	105		3:28:24	
6(a)	2	•		•		6	7	•		4				•	+		110		80	3:47:38	
6(b)	2	•		•		6	7	•		4				•	+		110		85	3:46:19	
6(c)	2	•		•		6	7	•		4				•	+		110		90	3:45:12	
6(d)	2	•		•		6	7	•		4				•	+		110		95	3:44:20	
7(a)	2	•		•		6	7	•		4				•α			110			3:47:02	α With initial optimization of curve alignments, Greensboro to Richmond.
7(b)	2		•	•		6	7	•		4				•α			110			3:44:12	
8(a)	2	•		•		6	7	•		4			•				110			3:50:56	These options represent the "Contemplated Improvements" with various station stop assumptions.
8(b)	2	•		•		6	7	•		5			•				110			3:53:17	
8(c)	2	•		•		6	7	•		6			•				110			3:55:40	
9(a)	2	•		•		4	7	•		4		•					110			3:52:32	
9(b)	2	•		•		8	7	•		4		•					110			4:00:42	
9(c)	2	•		•		10	7	•		4		•					110			4:04:47	
9(d)	2	•		•		12	7	•		4		•					110			4:09:28	

A Note on Direction

Case 1(a), the "baseline"," was run in both directions and showed a longer trip time northbound (05:43:32[1]) than southbound (05:42:27). Existing vertical curvature was the primary factor in the difference in the TPC runs; primarily the ruling grades were in the northbound direction. Since the northbound trip thus presented the more stringent challenge, all subsequent cases were run in the northbound direction only, so as to simulate worst-case conditions.

Variables Addressed in the Cases

This section discusses the variables that the TPC model could use to differentiate among cases. Each TPC case represented a unique combination of choices from options from options available within these variables.

Number of Locomotives

Both one- and two-locomotive trainsets were modeled. However, all cases involving high-performance options used two locomotives per train, with instructive results in comparable cases:

Number of Locomotives	Percent Trip Time (Decrease) Versus 1 Locomotive	Minutes (Saved) Versus 1 Locomotive	Compare Cases
2	(6.2%)	(15.7)	3(f) and 3(d)
3	(7.7%)	(19.5)	4(b) and 3(d)
Number of Locomotives	**Percent Trip Time (Decrease) Versus 2 Locomotives**	**Minutes (Saved) Versus 2 Locomotives**	**Compare Cases**
3	(1.6%)	(3.8)	4(b) and 3(f)

The above results suggest that upgrading from one to two locomotives produces a significant performance benefit (almost 16 minutes), but that diminishing returns set in when the consist increases further to three locomotives

Propulsion Source

All runs assumed from one to three up-to-date Diesel locomotives per trainset, except for a single case, 7(b), which made use of two gas turbine-powered locomotives.

Hotel Power

In modern American railroad practice, electrical power for the train's utilities originates in the locomotive (hence the similar terms "head-end power" or "hotel power").[2] This is the assumption in most of the TPC cases; however, one case, 4(a),

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[1] All times in this Appendix are expressed as hours:minutes:seconds.

[2] This contrasts with former practices, inherited from the steam era, in which wheelset-powered generators and batteries produced and stored power for each individual car, in effect by exerting a drag on the forward movement on the train.

explored the option of providing a separate, on-train generator, thereby increasing the locomotive output available for propulsion. This variation reduced the trip time by 0.8 percent (1.9 minutes).[3]

Number of Cars

All trainsets were assumed to have six cars, except for a small number of sensitivity excursions that tested two-locomotive trains with 4-, 8-, 10-, and 12-car consists. Comparative results were as follows:

Number of Cars	Percent Trip Time (Reduction) or Increase Versus 6-Car Consist	Minutes (Saved) or Lost Versus 6-Car Consist	Compare Cases
4	(2.3%)	(5.4)	9a and 3f
8	1.1%	2.7	9b and 3f
10	2.9%	6.8	9c and 3f
12	4.8%	11.5	9d and 3f

The study team regarded the five-minute time savings as insufficient to outweigh the constraint on operating flexibility imposed by a four-car consist limit, particularly at peak weekend and holiday periods when capacity, travel times, and reliability must be optimal to encourage repeat business.

Number of Stops

Most of the runs assumed four intermediate station stops per high-speed train from Charlotte to Richmond. Runs 8(a) through 8(c)—representing the contemplated improvements—tested the sensitivity of travel times to five- and six-stop schedules as well, with the following results:

Number of Stops	Percent Trip Time Increase Versus 4 Stops	Minutes Lost Versus 4 Stops	Compare Cases
5	1.0%	2.4	8(b) and 8(a)
6	2:0%	4.7	8(c) and 8(a)

[3] Compare cases 4(a) and 3(f).

Alignment

All cases assumed reconstruction and rehabilitation of the S Line, Richmond–Raleigh. The "baseline" case (1(a)) assumed that the restored S Line would retain its legacy alignment, and that no changes whatsoever to the existing Charlotte–Raleigh alignment would occur.

Beyond the baseline case, the TPC runs proceeded over time, in tandem with the curve alignment studies, in a coordinated effort to define the level of betterment that would be necessary and sufficient to allow the Richmond–Charlotte Corridor to reliably fulfill the service goals set by the States. Therefore, as recorded in this Appendix, the study team explored a number of experimental avenues before settling on the "contemplated improvements" and accompanying operational plans.

At the outset, most of the cases (numbered 1(b) through 4[4]) adopted the "existing alignment optimized" assumption—with no major curve realignments but with incremental changes in spirals, superelevation, and curvature within the right-of-way, to maximize performance over the road. Except in Case 3(g), also assumed as part of the "existing alignment optimized" was the restoration of double track throughout the Piedmont Main Line between Greensboro and Charlotte, which would affect not only capacity but also individual train performance, in that it would eliminate slow, diverging moves at the turnouts joining single and double track.

Cases numbered 5, 6, and 7 represented experiments in defining potential sets of curve realignments by means of blanket assumptions; in Summary Table B, these are termed "other combinations of improvements" (i.e., "other" than the "contemplated improvements").[5] Finally, as the entire analysis progressed, it became possible to run the TPC simulation over the "contemplated improvements" elaborated iteratively by the study team, and described in detail in the Main Report and other Appendixes.

MAS

The four modeled levels of maximum authorized speed were:

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[4] The sensitivity analyses of train lengths, Cases 9(a) through (d), were also based on the "existing alignment optimized."

[5] Cases 7(a) and (b) represented an advance in the analysis, as described further below. Certain project elements would have overlapped between the "other combinations" and the "contemplated improvements."

- “Existing” speeds—up to 79 mph on existing passenger lines, and, on the S Line, the speed limits for express trains prior to its abandonment;
- A consistent 79 mph MAS;
- 90 mph; and
- 110 mph.

The 110 mph MAS was assumed for all higher-performance options.

Minimal MAS

Experimentation with the imposition of minimal MASs (of 80 mph and above) was an attempt to quickly identify groups of curves that would be ideal candidates for realignment. However, this automated technique identified a number of curves the realignment of which would impose obvious environmental difficulties. As a result, the study team regarded these options—whether applied to the entire corridor or to the H Line alone—as impracticable, and turned to other means of optimizing the alignment.

Timing, Charlotte–Richmond

This column provides a summary result for each case. Further details on the case results appear in Tables B-1 through B-11, which present the results by line segment, and compare the cases incrementally.

Discussion of the Cases

The following sections describe, in some detail, the cases that are listed in the rows of Summary Table B.

Group 1: Conventional-Speed Cases

The TPC analyses began with a group of cases that restricted MASs to 79 mph or below. All the conventional-speed cases shared the following assumptions:

- A trainset consisting of six coaches powered by one P42DC locomotive;
- The former Seaboard Air Line (SAL) trackage between Norlina, NC and Centralia, VA restored;
- Maximum unbalanced superelevation = 3 inches; and
- Four intermediate stops[6]: three-minute dwell at Raleigh, two-minute dwell at Greensboro, one-minute dwell at Durham and Petersburg.

[6] Initially, four stops were planned, and the earlier TPC runs reflect this. A fifth stop at I-485 (i.e., a “beltway”-type station for Charlotte), was subsequently added for planning purposes.

Beyond these common assumptions, the differences among the cases in Group (1) were significant and are discussed below.

Case 1(a): Baseline

To establish a benchmark for current route capabilities (legacy capabilities in the case of the S Line), a baseline TPC run was performed. The baseline conditions included:

- Existing[7] passenger train MASs between Charlotte and Raleigh;
- 1975 passenger train MASs between Raleigh and Richmond;
- No changes whatsoever in the existing active alignment between Charlotte and Raleigh, or in the legacy alignment of the S Line between Raleigh and Richmond;
- Curve-related speed restrictions as shown in NS and CSX employee timetables that were in effect in either in 1999 between Charlotte and Raleigh or in 1975 between Raleigh and Richmond; and
- Other civil speed restrictions, i.e., for grade crossings, local restrictions, etc., were assumed to remain in force.

Under these assumptions, the baseline Charlotte–Richmond timing was 5 hours, 44 minutes. By contrast, as this report goes to press, Amtrak's Charlotte–Richmond timing is 6 hours, 59 minutes—one hour, 15 minutes longer than the baseline.[8] The difference is easily explained by (a) the twelve intermediate stops that Amtrak currently makes, versus the four assumed in the baseline; and (b) the circuitous A Line routing (35 miles longer than the S Line) that Amtrak now uses.

Cases 1(b) through 1(f): Improved Conventional-Speed Cases

Additional cases explored the capabilities of conventional-speed service under the following assumptions:

- The "existing alignment optimized" option would be effected (see page 7); this includes double-tracking the P Line portion of this corridor.
- Non-track-related civil speed restrictions, e.g., for grade crossings, local restrictions, and the like, would be eliminated.
- The track, its supporting structures, and signal systems would be upgraded and/or maintained, as necessary, to eliminate existing physical conditions that restrict speeds below those which the alignment would support.
- MAS would be 79 mph wherever feasible, but no higher.

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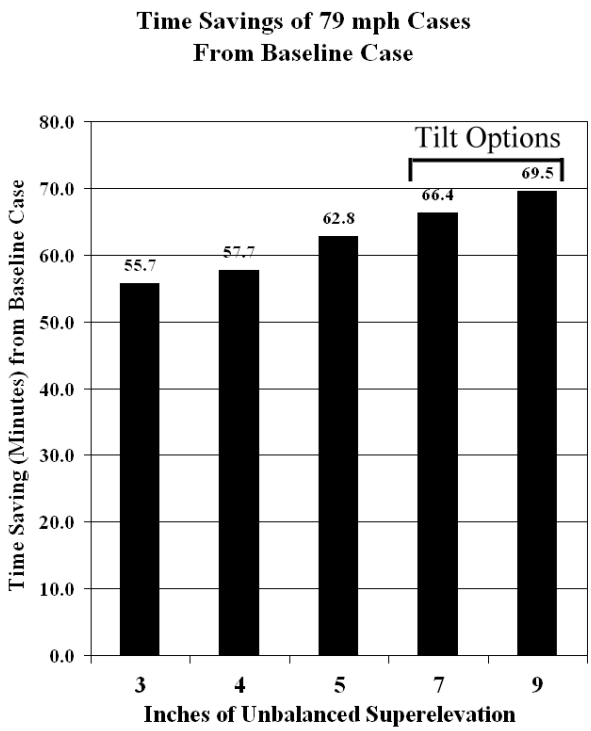
[7] As of 1999, when the analysis for this report began.

[8] Amtrak System Time, October 27, 2003, p. 76.

- Unbalanced superelevation was assumed to start at 3” in Case 1(b), and was increased to 4” (Case 1(c)), 5” (Case 1(d)), 7” (Case 1(e)), and to a hypothetical 9” (Case 1(f)).[9]
- Jerk rate would be restricted to a maximum of 0.04 g/sec.
- All cases with 7” or more unbalanced superelevation assumed the use of tilt coaches, analogous to Amtrak’s Acela coaches.
- In tilting cases, the tilt mechanism was assumed to be cut out under 45 mph and gradually ramped in to its maximum at 60 mph.

With respect to the unbalance and tilt assumptions, readers should note that non-tilting coaches on Amtrak’s Northeast Corridor presently operate with 5” of unbalanced superelevation. Also, since five inches of unbalanced superelevation would permit speeds in excess of 79 mph on certain curves restricted in these cases to 79 mph or less, the full effect of an increase in unbalanced superelevation from three to 5 inches is constrained by the 79 mph MAS.

The results of Cases 1(b) through 1(f) are shown in Table B-1 and excerpted in the figure below.



[9] As explained in Summary Table B, this case is only hypothetical as standard Diesel-powered equipment in the U.S. will not safely operate at 9" of unbalance, because its center of gravity is too high. Other locomotives, now under development, might be certified for such operation.

Table B-1

COMPARATIVE SIMULATED RUNNING TIMES—GROUP 1

With Tilt Trainset Consist - 79 MPH MAS

Four Stops—No Diversions. Times Are in Hours : Minutes: Seconds, and Do Not Include Schedule Pad.

Varying levels of unbalanced superelevation (Eu) from Charlotte to Richmond

		Segment: Charlotte to Raleigh			Segment: Raleigh to Richmond			Corridor Charlotte to Richmond		
Case	Description	Segment TPC Timing	Improve-ment from Baseline	Improve-ment from Previous Time	Segment TPC Timing	Improve-ment from Baseline	Improve-ment from Previous Time	Corridor TPC Timing	Improve-ment from Baseline	Improve-ment from Previous Time
1(a)	P42DC-6-car Trainset, Existing Speeds - **Baseline**	3:07:27	n/a	n/a	2:36:05	n/a	n/a	5:43:32	n/a	n/a
1(b)	P42DC-6-car Trainset, 3" Eu - 79 mph	2:31:25	0:36:02	0:36:02	2:16:24	0:19:41	0:19:41	4:47:49	0:55:43	0:55:43
1(c)	P42DC-6-car Trainset, 4" Eu - 79 mph	2:31:01	0:36:26	0:00:24	2:14:50	0:21:15	0:01:34	4:45:51	0:57:41	0:01:58
1(d)	P42DC-6-car Trainset, 5" Eu - 79 mph	2:28:31	0:38:56	0:02:30	2:12:11	0:23:54	0:02:39	4:40:42	1:02:50	0:05:09
1(e)	P42DC-6-car Trainset, 7" Eu - 79 mph	2:27:06	0:40:21	0:01:25	2:10:05	0:26:00	0:02:06	4:37:11	1:06:21	0:03:31
1(g)	2-P42DC-6-car Trainset 7" Eu - 79 mph	2:25:57	0:41:30	0:01:09	2:08:22	0:27:43	0:01:43	4:34:19	1:09:13	0:02:52

Group 2: 90 mph Cases

Another set of TPC runs projected the time savings from an increase in MAS to 90 mph between Charlotte and Richmond. Seven inches of unbalanced superelevation, with tilting coaches, were assumed. The following conditions applied:

- The “Existing Optimized” alignment was assumed.
- MAS was increased to 90 mph; speeds on individual curves were calculated using a technique developed for this study.
- Positive stops and curve speeds were enforced.
- Spiral length and superelevation of curves were calculated using the curve spreadsheet.
- Tilt cut out under 45 mph and gradually ramped in to maximum at 60 mph;

- Four Intermediate stops: three-minute dwell at Raleigh, two-minute dwell at Greensboro, one-minute dwell at Durham and Petersburg.
- The 90 mph cases included two motive power assumptions:
    - Case 2(a) – one locomotive per train; and
    - Case 2(b) – two locomotives per train.

As shown in Table B-2, the Group 2 cases save over 83 minutes from the baseline timing (case 1(a)), and at least 17 minutes from the comparable 79 mph timing (case 1(b)). With the achievement of 90 mph service, the Charlotte–Richmond timing begins to approach the States' travel time goal, although a 4-hour, 20-minute TPC result—requiring a flawless run—does not provide the pad necessary for reliable service. Figure B-1 plots the time/distance curve for Case 2(a).

Table B-2

COMPARATIVE SIMULATED RUNNING TIMES—GROUP 2

With Tilt Trainset Consist - 90 MPH MAS

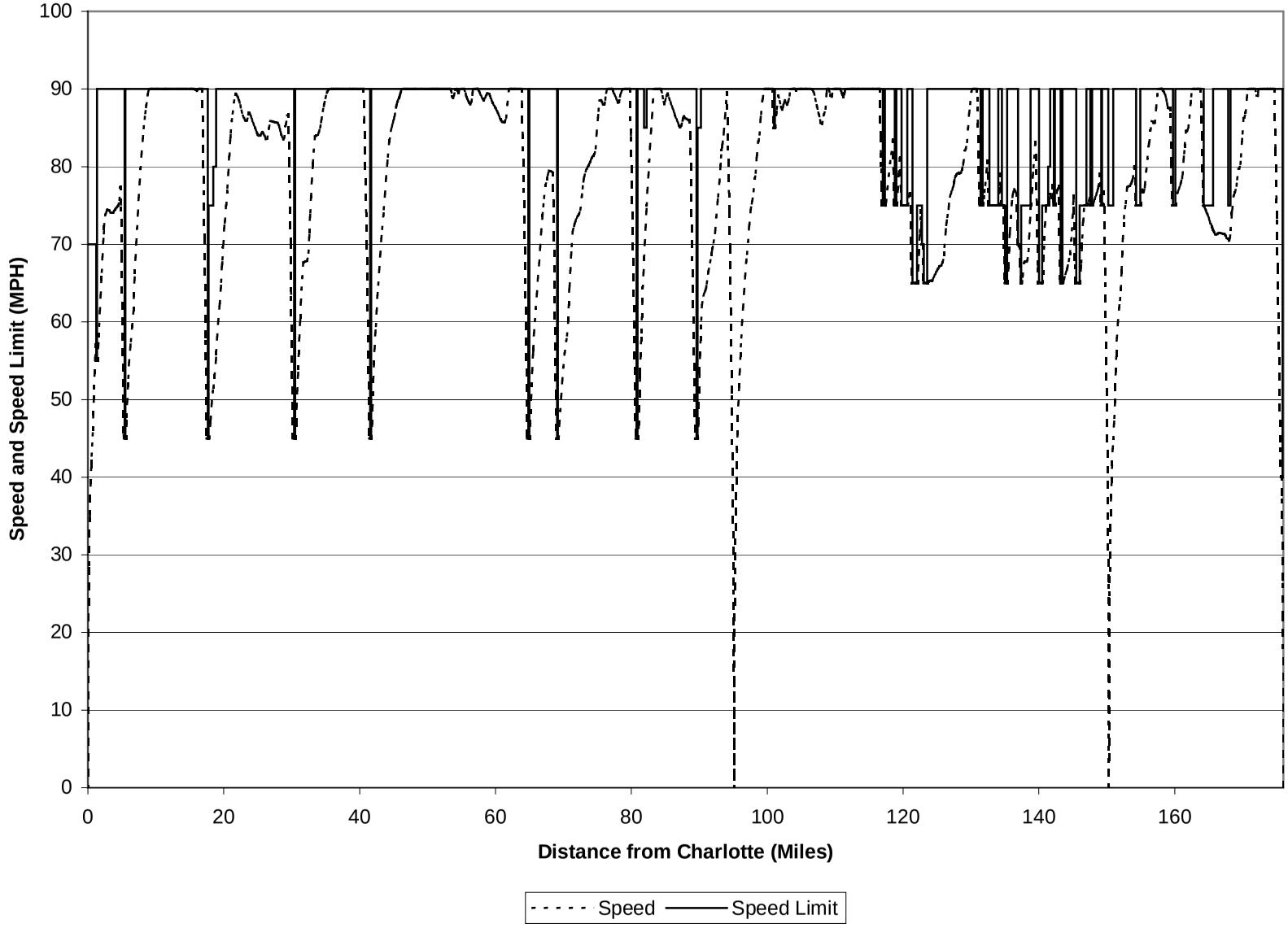
Four Stops—No Diversions. Times Are in Hours : Minutes: Seconds, and Do Not Include Schedule Pad

		Segment: Charlotte to Raleigh			Segment: Raleigh to Richmond			Corridor Charlotte to Richmond		
Case	Description	Segment TPC Timing	Improve-ment from Baseline	Improve-ment from Previous Time	Segment TPC Timing	Improve-ment from Baseline	Improve-ment from Previous Time	Corridor TPC Timing	Improve-ment from Baseline	Improve-ment from Previous Time
1(a)	P42DC-6-car Trainset Existing Speeds - **Baseline**	3:07:27	n/a	n/a	2:36:05	n/a	n/a	5:43:32	n/a	n/a
1(e)	P42DC-6-car Trainset 7" Eu - 79 mph	2:27:06	0:40:21	0:40:21	2:10:05	0:26:00	0:26:00	4:37:11	1:06:21	1:06:21
2(a)	P42DC-6-car Trainset 7" Eu 90 mph	2:17:15	0:50:12	0:09:51	2:02:50	0:33:15	0:07:15	4:20:05	1:23:27	0:17:06
2(b)	2-P42DC-6-car Trainset 7" Eu - 90 mph	2:12:33	0:54:54	0:04:42	1:58:56	0:37:09	0:03:54	4:11:29	1:32:03	0:08:36

Group 3: Initial 110 mph Cases

Another set of TPC runs to determine the amount of time savings to be experienced after increasing MAS to 110 mph between Charlotte and Richmond was performed. Consists of one and two Diesel locomotives were assumed for comparative

Figure B-1: Charlotte to Raleigh, NC -
90-mph. MAS and 7" Eu -
One P42DC Engine + 6 Tilt-Body Cars—Case 2(a)



purposes. Also, special analyses were done of diversions on the P Line between Charlotte and Greensboro, as explained below.

The runs determined the time savings resulting from an increase from a 79 mph MAS to a 110 mph MAS for the assumed conditions. The following conditions were used:

- The “Existing Optimized” alignment was assumed.
- MAS was increased to 110 mph; speeds on individual curves were calculated using a technique developed for this study.
- Positive stops and curve speeds were enforced.
- Spiral length and superelevation of curves were calculated using the curve spreadsheet.
- Tilt cut out under 45 mph and gradually ramped in to maximum at 60 mph;
- Four intermediate stops: three-minute dwell at Raleigh, two-minute dwell at Greensboro, one-minute dwell at Durham and Petersburg.
- Speeds were set assuming levels of unbalanced superelevation of from three to nine inches. The last-named level is only hypothetical as standard Diesel-powered equipment in the U.S. will not safely operate at 9 inches of unbalance. Other locomotives, now under development, might be certified for such operation.

As shown in Table B-3, the increase in top speed from 79 to 110 mph (with three-inch unbalance and one locomotive in both cases, 1(b) and 3(a)) yields a time reduction of just under 11 minutes. Beyond that improvement, the use of tilting equipment at a maximum seven inches of unbalance would save over ten minutes more (compare cases 3(c) and 3(d)).

Effects of Adding a Second Locomotive

Vertical elevation has as significant an impact on trip times in the Charlotte to Richmond Corridor as horizontal alignment. Horizontal curvature previously is discussed in Appendix A. The impact of vertical gradient on trip times is illustrated in Figure B-2, which compares Cases 3(d) and 3(f).[10] In the segment excerpted, one P-42 locomotive with six tilt-capable coaches operating at an MAS of 110 mph (assuming seven inches of unbalanced superelevation in numerous locations) never attains 110 mph, even though it appears that sufficient distance is available for the train to accelerate from the lower speed zone to 110 mph. One example is the track segment

[10] In Figure B-2, the vertical scale has been modified from the normal display in which speed on the vertical scale is uniform, to a proportional scale in which the area under the curve created by the plot is equal to time. Since the scale between 0 and 50 mph would dominate the display and the distance traveled at speeds in that range is minimal, that speed range is normally not plotted.

Table B-3

COMPARATIVE SIMULATED RUNNING TIMES—GROUP 3

With Tilt Trainset Consist - 110 MPH MAS

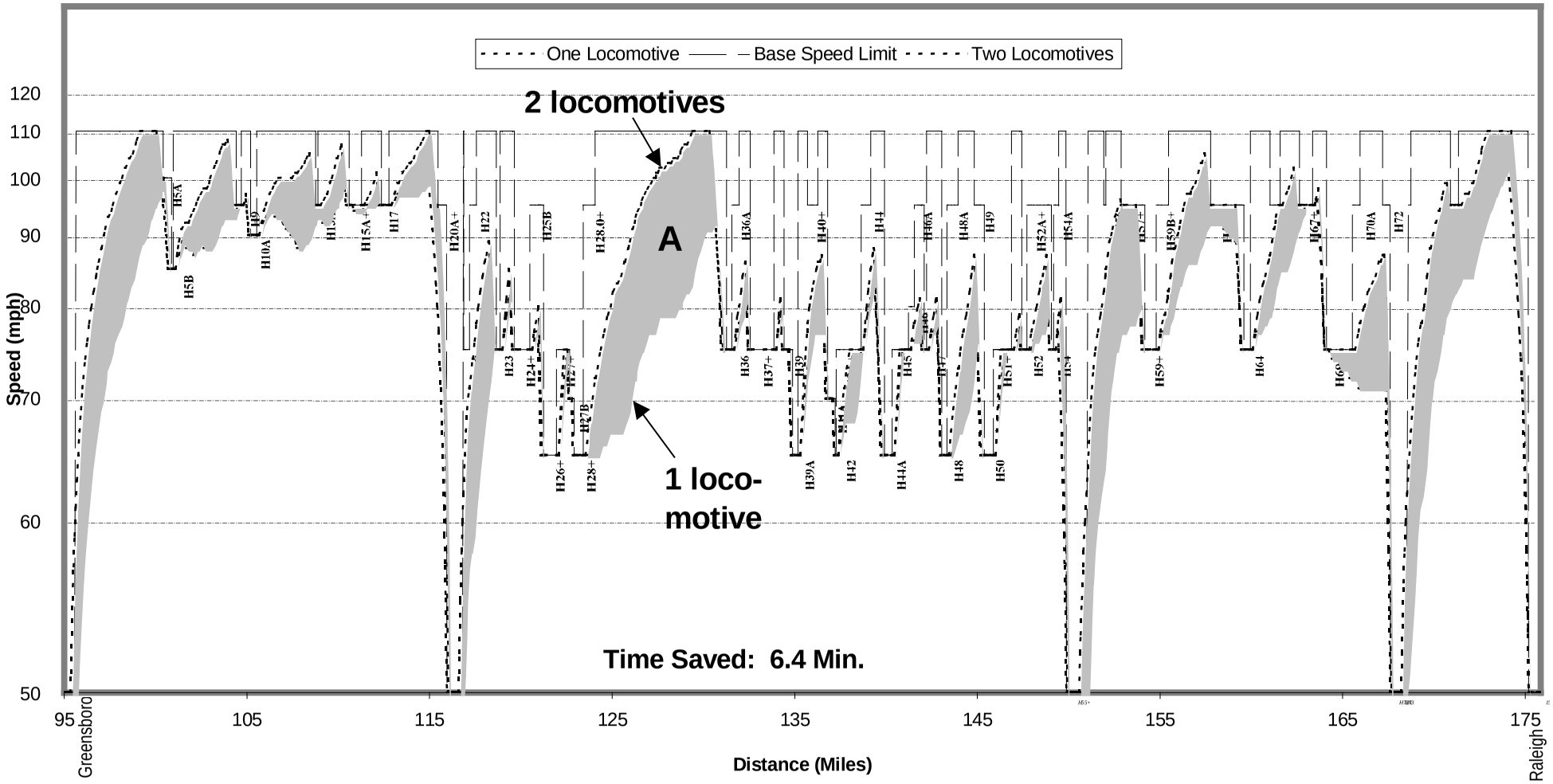
Four Stops—No Diversions. Times Are in Hours : Minutes : Seconds, and Do Not Include Schedule Pad.

Varying levels of unbalanced superelevation from Charlotte to Richmond

		Segment: Charlotte to Raleigh			Segment: Raleigh to Richmond			Corridor Charlotte to Richmond		
Case	Description	Segment TPC Timing	Improve-ment From Baseline	Improve-ment from Previous Time	Segment TPC Timing	Improve-ment From Baseline	Improve-ment from Previous Time	Corridor TPC Timing	Improve-ment From Baseline	Improve-ment from Previous Time
1(a)	P42DC-6-car Trainset Existing Speeds **Baseline**	3:07:27	n/a	n/a	2:36:05	n/a	n/a	5:43:32	n/a	n/a
1(b)	P42DC-6-car Trainset 3" Eu - 79 mph	2:31:25	0:36:02	0:36:02	2:16:24	0:19:41	0:19:41	4:47:49	0:55:43	0:55:43
3(a)	P42DC-6-car Trainset 3" Eu - 110 mph	2:24:18	0:43:09	0:07:07	2:12:34	0:23:31	0:23:31	4:36:52	1:06:40	0:10:57
3(b)	P42DC-6-car Trainset 4" Eu - 110 mph	2:23:36	0:43:51	0:00:42	2:10:00	0:26:05	0:02:34	4:33:36	1:09:56	0:03:16
3(c)	P42DC-6-car Trainset 5" Eu - 110 mph	2:18:37	0:48:50	0:04:59	2:05:53	0:30:12	0:04:07	4:24:30	1:19:02	0:09:06
3(d)	P42DC-6-car Trainset 7" Eu - 110 mph	2:13:04	0:54:23	0:05:33	2:00:35	0:35:30	0:05:18	4:13:39	1:29:53	0:10:51
3(e)	P42DC-6-car Trainset 9" Eu - 110 mph[11]	2:09:24	0:58:03	0:03:40	1:56:06	0:39:59	0:04:29	4:05:30	1:38:02	0:08:09
3(f)	2-P42DC-6-car Trainset 7" Eu - 110 mph	2:03:36	1:03:51	0:05:48	1:54:22	0:41:43	0:01:44	3:57:58	1:45:34	0:07:32
3(g)	2-P42DC-6-car Trainset 7" Eu - 110 mph. Diverging Moves, Charlotte–Greensboro	2:14:33	0:52:54	(00:10:57)	1:54:22	0:41:43	0:00:00	4:08:54	1:34:37	(00:10:57)

[11] This case is only hypothetical as standard Diesel-powered equipment in the U.S. will not safely operate at 9" of unbalance. Other locomotives, now under development, might be certified for such operation.

Figure B-2: Cases 3(d) and 3(f)—Effect of Adding Second P42 Locomotive
Greensboro to Raleigh for Example - 110-MPH MAS, Tilt, and 7 Inches of Unbalance



between Burlington (H21.3) and Mebane (H32.6). The controlling grade between Greensboro and Goldsboro (+1.02%) is located between H28 and H29. This is a portion of the approximately 6.5 mile grade between H27.6 and H 34.2. Heading northward towards Mebane, a train after slowing for the two 65 mph 4 degree curves (Curves H28 and H28.1[12]) located at the bottom of the grade, the train with one locomotive never reaches 110 mph in the 10-mile stretch before having to brake for the 3.0-degree curves - H37, H38, H38.1, and H38.2. Several long grades actually serve to reduce train speed in numerous stretches of railroad in which horizontal curvature would permit continuous 110 mph MAS. The difference between the respective performances of the one- and two-locomotive consists becomes evident at grey area "A" on Figure B-2, where the two-locomotive train actually achieves 110 mph for almost a full mile, despite being somewhat restricted by grade. The other, analogous grey areas on the chart show the many locations where the performance of two locomotives makes a perceptible difference: these differentials cumulatively give the two-locomotive consist a 6.4 minute advantage in the Greensboro–Raleigh segment depicted in Figure B-2, and a 15.7 minute advantage over the entire Corridor

The addition of a second locomotive to each trainset would push the differential between 79 mph and 110 mph[13] to just under 50 minutes and, as described in Chapter 4,[14] would materially improve the corridor's ability to approach the States' travel time goals.

Effects of Diversion Assumptions, Charlotte–Greensboro (P Line)

The design of the P Line between Charlotte and Greensboro has direct implications for train performance as revealed in TPC runs. Although originally double-tracked, the line has, in recent decades, been reduced to single track status at four separate locations totaling 35 miles, as described in Chapter 2. Depending on the site-specific design of the turnouts at the transitions between single and double track, a single train may be forced to make multiple diverging moves between Charlotte and Greensboro even in the absence of interference from other traffic—simply because of the layout of the track in this segment.

While most of the TPC cases assumed that continuous double track would be restored all the way from Charlotte to Greensboro, it was also necessary to explore the consequences of retaining the single-track stretches and the resultant diverging moves.

Thus, a set of TPC runs was performed to determine the amount of time loss (or savings) to be experienced if a trainset makes (or does not make) a diverging move at

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[12]Curves are numbered consecutively within each mile, i.e., the first curve between MP H28 and MP H 29 is curve H28, and the second curve is H28.1.

[13] I.e., between Cases 1(b) and 3(f).

[14] See 4-2, 110 mph, two locomotives, existing optimized alignment. Under these assumptions, however, the pad is still insufficient to fully meet the trip time goals, as Chapter 4 makes clear.

45 mph with MAS set at 79 mph and after the MAS has been increased to 110 mph. The trip times assumed that the trains would brake so that speed was reduced to 45 mph prior to entering the interlocking at each single-track-to-double-track junction. The trains were then assumed to accelerate to maximum allowable speed or MAS after the train cleared the interlocking. The following conditions were used:

- MAS was set at either 79 mph or increased to 110 mph; speeds on individual curves were calculated using a technique developed for this study.
- As in the Baseline case, positive stops and curve speeds were enforced.
- Spiral length and superelevation of curves calculated with the spreadsheet were assumed.
- Tilt cut out under 45 mph and gradually ramped in to maximum at 60 mph;
- Intermediate stops at Kannapolis, Salisbury, and High Point were assumed.
- Speeds were set assuming five levels of unbalanced superelevation, ranging from three to nine inches.
- Diversion moves at the following single - double track junction locations were simulated
    - Junker;
    - Haydock;
    - North Kannapolis
    - Reid;
    - Lake;
    - Bowers;
    - Hoskins; and
    - Cox.

Case 3(g) incorporates the results of these analyses. In comparison with case 3(f), Case 3(g) would result in a loss of about 11 minutes of travel time between Charlotte and Greensboro, before taking into account the congestion effects of adding high-speed rail to a partially single-track P Line.

Group 4: Sensitivity Cases—Special Motive Power Options

The study team explored additional motive-power-related options for providing travel time improvements short of major fixed plant modifications. Table B-4 describes two of these attempts: 4(a), which takes hotel power generation responsibilities away from the locomotive and assigns them to a separate generator in one of the coaches; and 4(b), which assumes a third locomotive added to each consist.

Table B-4
COMPARATIVE SIMULATED RUNNING TIMES—GROUP 4
With Tilt Trainset Consist - 110 MPH MAS
Four Stops—No Diversions. Times Are in Hours : Minutes : Seconds, and Do Not Include Schedule Pad.
Tilt operation and seven inches of unbalanced superelevation, Charlotte to Richmond
Assessment of performance gains from separate hotel ("head-end") power source, or three locomotives

		Segment: Charlotte to Raleigh			Segment: Raleigh to Richmond			Corridor Charlotte to Richmond		
Case	Description	Segment TPC Timing	Improve-ment From Baseline	Improve-ment from Previous Time	Segment TPC Timing	Improve-ment From Baseline	Improve-ment from Previous Time	Corridor TPC Timing	Improve-ment From Baseline	Improve-ment from Previous Time
1(a)	P42DC-6-car Trainset Existing Speeds **Baseline**	3:07:27	n/a	n/a	2:36:05	n/a	n/a	5:43:32	n/a	n/a
3(f)	2-P42DC-6-car Trainset 7" Eu - 110 mph	2:03:36	1:03:51	0:05:48	1:54:22	0:41:43	0:01:44	3:57:58	1:45:34	0:07:32
4(a)	2-P42DC-6-car Trainset 7" Eu - 110 mph – **Hotel Power Provided by Separate Source**	2:02:30	1:04:57	0:01:06	1:53:35	0:42:30	0:02:31	3:56:05	1:47:27	0:01:53
4(b)	**3**-P42DC (Hotel power from 1-locomotive) -6-car Trainset 7" Eu – 110 mph	2:01:18	1:06:09	0:01:12	1:52:50	0:43:15	0:01:32	3:54:08	1:49:24	0:01:57

The incremental benefits of these options were minuscule, in comparison with the 105.6-minute savings already estimated for Case 3(f) from the baseline (1a) timing. Moving the hotel power generation from one of the locomotives to a coach would reduce another 1.9 minutes from the travel time, for an incremental savings of only 1.8 percent. This relatively small trip time improvement must come into comparison with the potential loss of revenue space on every train, and the higher maintenance expenses likely to result from adding locomotive-like components to at least one car per trainset.

Similarly, the 2.0-minute (1.8 percent) trip time reduction from assigning a third locomotive to every train would need to be weighed against the added capital, operating, and maintenance costs to support such power-heavy consists.

Subject to the results of future economic studies, the available evidence suggests that these additional motive power options—while well worth the analytical try—would not be cost-effective. They were, therefore, dropped from further consideration in this study.

Groups 5 and 6: Experiments with Minimal MASs

Applying a minimum speed is a means of testing the possible benefits of eliminating the physical constraints that cause a train to reduce speed and accelerate at intermediate points between stations. Frequently it can be more cost effective to make improvements to eliminate such restrictions than it is to raise the overall maximum speed. This is particularly true where fossil-fueled locomotives are employed, because of their lower rates of acceleration.

To test this principle on the Richmond–Charlotte Corridor, the study team conducted two sets of TPC runs. The first set, Group 5, applied various minimum MAS to the entire Corridor, in five-mph increments beginning at 80 mph. Two locomotives, a 110-mph MAS ceiling, and tilting coaches at seven inches of unbalance were assumed. The Group 5 results appear in Table B-5.

When it became apparent that providing for a minimal MAS of 80 mph or more throughout the Corridor would be require too intensive and environmentally controversial an investment, the study team performed a second set of runs (Group 6) applying minimal MASs to the H Line only (Raleigh–Greensboro). Conditions specific to Group 6 were as follows:

- MAS was assumed to be 95 mph between Charlotte and Greensboro; and speeds on individual curves were calculated using a technique developed for this study.
- MAS was assumed to be 95 mph between Raleigh and the south end of curve 103; and speeds on individual curves were calculated using a technique developed for this study.
- MAS was assumed to be 75 mph between the south end of curve 103 and the north end of Curve 56; and speeds on individual curves were calculated using a technique developed for this study.
- MAS was assumed to be 95 mph between the north end of Curve 56 and Centralia; and speeds on individual curves were calculated using a technique developed for this study.
- MAS was assumed to be 95 mph between Centralia and Main Street Station; and speeds on individual curves were calculated using a technique developed for this study.
- As in the Baseline case, positive stops and curve speeds were enforced.
- Spiral length and superelevation of curves calculated using the spreadsheet were assumed.

Table B-5
COMPARATIVE SIMULATED RUNNING TIMES—GROUP 5
With Tilt Trainset Consist - 110 MPH MAS
Four Stops—No Diversions. Times Are in Hours : Minutes : Seconds, and Do Not Include Schedule Pad.
Tilt operation and seven inches of unbalanced superelevation, Charlotte to Richmond
Varying levels of Minimal MAS from Charlotte to Richmond

		Segment: Charlotte to Raleigh			Segment: Raleigh to Richmond			Corridor Charlotte to Richmond		
Case	Description	Segment TPC Timing	Improve-ment From Baseline	Improve-ment from Previous Time	Segment TPC Timing	Improve-ment From Baseline	Improve-ment from Previous Time	Corridor TPC Timing	Improve-ment From Baseline	Improve-ment from Previous Time
1(a)	P42DC-6-car Trainset Existing Speeds Baseline	3:07:27	n/a	n/a	2:36:05	n/a	n/a	5:43:32	n/a	n/a
3(f)	2-P42DC-6-car Trainset 7" Eu - 110 mph	2:03:36	1:03:51	1:03:51	1:54:22	0:41:43	0:41:43	3:57:58	1:45:34	1:45:34
5(a)	2-P42DC-6-car Trainset 7" Eu - **Floor = 80 mph**	2:00:43	1:06:44	0:02:53	1:50:06	0:45:59	0:04:16	3:50:49	1:52:43	0:07:09
5(b)	2-P42DC-6-car Trainset 7" Eu - **Floor = 85 mph**	1:59:04	1:08:23	0:01:39	1:48:14	0:47:51	0:01:52	3:47:18	1:56:14	0:03:31
5(c)	2-P42DC-6-car Trainset 7" Eu - **Floor = 90 mph**	1:57:26	1:10:01	0:01:38	1:46:15	0:49:50	0:01:59	3:43:41	1:59:51	0:03:37
5(d)	2-P42DC-6-car Trainset 7" Eu - **Floor = 95 mph**	1:56:07	1:11:20	0:01:19	1:43:55	0:52:10	0:02:20	3:40:02	2:03:30	0:03:39
5(e)	2-P42DC-6-car Trainset 7" Eu - **Floor = 100 mph**	1:52:54	1:14:33	0:03:13	1:40:53	0:55:12	0:03:02	3:33:47	2:09:45	0:06:15
5(f)	2-P42DC-6-car Trainset 7" Eu - **Floor = 105 mph**	1:50:09	1:17:18	0:02:45	1:38:15	0:57:50	0:02:38	3:28:24	2:15:08	0:05:23

- Tilt cut out under 45 mph and gradually ramped in to maximum at 60 mph;
- Four intermediate stops: three-minute dwell at Raleigh, two-minute dwell at Greensboro, one-minute dwell at Durham and Petersburg.
- Speeds were set assuming seven inches of unbalanced superelevation.

The results for Group 6 appear in Table B-6. With respect to the H Line segment of the Corridor, the study team again concluded that it would not be practical to establish an MAS floor and that a more nuanced examination of individual speed-restricted areas would likely yield more useful results. This conclusion influenced the design of subsequent cases.

Table B-6
COMPARATIVE SIMULATED RUNNING TIMES—GROUP 6
With Tilt Trainset Consist – 110 MPH MAS
Four Stops—No Diversions. Times Are in Hours : Minutes : Seconds, and Do Not Include Schedule Pad.
Tilt operation and seven inches of unbalanced superelevation, Charlotte to Richmond
Varying levels of Minimal MAS from Greensboro to Raleigh

		Segment: Charlotte to Raleigh			Segment: Raleigh to Richmond			Corridor Charlotte to Richmond		
Case	Description	Segment TPC Timing	Improve-ment From Baseline	Improve-ment from Previous Time	Segment TPC Timing	Improve-ment From Baseline	Improve-ment from Previous Time	Corridor TPC Timing	Improve-ment From Baseline	Improve-ment from Previous Time
1(a)	P42DC-6-car Trainset Existing Speeds Baseline	3:07:27	n/a	n/a	2:36:05	n/a	n/a	5:43:32	n/a	n/a
3(f)	2-P42DC-6-car Trainset 7" Eu - 110 mph	2:03:36	1:03:51	1:03:51	1:54:22	0:41:43	0:41:43	3:57:58	1:45:34	1:45:34
6(a)	2-P42DC-6-car Trainset 7" Eu – **Floor = 80 mph**	1:59:25	1:08:02	0:04:11	1:48:13	0:47:52	0:06:09	3:47:38	1:55:54	0:10:20
6(b)	2-P42DC-6-car Trainset 7" Eu – **Floor = 85 mph**	1:58:06	1:09:21	0:01:19	1:48:13	0:47:52	0:00:00	3:46:19	1:57:13	0:01:19
6(c)	2-P42DC-6-car Trainset 7" Eu – **Floor = 90 mph**	1:56:59	1:10:28	0:01:07	1:48:13	0:47:52	0:00:00	3:45:12	1:58:20	0:01:07
6(d)	2-P42DC-6-car Trainset 7" Eu – **Floor = 95 mph**	1:56:07	1:11:20	0:00:52	1:48:13	0:47:52	0:00:00	3:44:20	1:59:12	0:00:52

Group 7: Simulations Based on Detailed Analysis of Curve Speeds

Since establishing an 80 mph MAS floor between Raleigh and Greensboro did not prove to be an optimal solution, an analysis of individual restricted locations between Greensboro, Raleigh, and Richmond was undertaken to maximize trip time while minimizing investment in realignments and relocations. The analysis, described in

Appendix A, required several revisions. The trip times resulting from the analysis are contained in Table B-7.

Table B-7
COMPARATIVE SIMULATED RUNNING TIMES—GROUP 7
With Tilt Trainset Consist - 110 MPH MAS
Four Stops—No Diversions. Times Are in Hours : Minutes : Seconds, and Do Not Include Schedule Pad.
Tilt operation and seven inches of unbalanced superelevation, Charlotte to Richmond
Curve Speeds Between Greensboro and Richmond Reevaluated to Maximize Speed, Minimize Cost

		Segment: Charlotte to Raleigh			Segment: Raleigh to Richmond			Corridor Charlotte to Richmond		
Case	Description	Segment TPC Timing	Improve-ment From Baseline	Improve-ment from Previous Time	Segment TPC Timing	Improve-ment From Baseline	Improve-ment from Previous Time	Corridor TPC Timing	Improve-ment From Baseline	Improve-ment from Previous Time
1(a)	P42DC-6-car Trainset Existing Speeds **Baseline**	3:07:27	n/a	n/a	2:36:05	n/a	n/a	5:43:32	n/a	n/a
3(f)	2-P42DC-6-car Trainset 7" Eu - 110 mph	2:03:36	1:03:51	0:15:01	1:54:22	0:41:43	0:06:13	3:57:58	1:45:34	0:15:41
7(a)	2-P42DC-6-car Trainset 7" Eu 110 mph **Optimize Greensboro to Richmond**	1:58:28	1:08:59	0:05:08	1:48:34	0:47:31	0:05:48	3:47:02	1:56:30	0:10:56
7(b)	**2-GT42AC**-6-car Trainset 7" Eu - 110 mph Optimize Greensboro to Raleigh	1:56:48	1:10:39	0:01:40	1:47:24	0:48:41	0:01:10	3:44:12	1:59:20	0:02:50

A four-stop northbound trip time of three hours 47 minutes was established (Case 7(a)). Interestingly, the Group 7 curve revisions resulted in the southbound trip time becoming the controlling element—a reversal of the baseline result.[15] The southbound trip time was approximately three hours and 48 minutes.

As simulated in case 7(b), the use of gas turbine propulsion units would result in a northbound trip time of three hours and 44 minutes and a southbound trip time of three hours and 45 minutes.

[15] See the discussion of train direction on page B-5.

Group 8: With the Contemplated Improvements

The initial manual curve revisions underlying the Group 7 TPC cases identified numerous locations requiring further analysis. This final, detailed manual analysis of individual curves and clusters of curves was based on a review of the results of all the preceding cases and also drew upon problems, such as short tangents between curves and potential environmental issues, identified by the study team. The results of the analysis, incorporating the "Contemplated Improvements" that form the main subject of this report, are summarized in Table B-8.

Table B-8
COMPARATIVE SIMULATED RUNNING TIMES—GROUP 8
With Tilt Trainset Consist - 110 MPH MAS
Four Stops—No Diversions. Times Are in Hours : Minutes : Seconds, and Do Not Include Schedule Pad.
Tilt operation and seven inches of unbalanced superelevation, Charlotte to Richmond
Cases With the Contemplated Improvements and Varying Stopping Patterns

		Segment: Charlotte to Raleigh			Segment: Raleigh to Richmond			Corridor Charlotte to Richmond		
Case	Description	Segment TPC Timing	Improve-ment From Baseline	Improve-ment from Previous Time	Segment TPC Timing	Improve-ment From Baseline	Improve-ment from Previous Time	Corridor TPC Timing	Improve-ment From Baseline	Improve-ment from Previous Time
1(a)	P42DC-6-car Trainset Existing Speeds **Baseline**	3:07:27	n/a	n/a	2:36:05	n/a	n/a	5:43:32	n/a	n/a
7(a)	2-P42DC-6-car Trainset 7" Eu 110 mph **Optimize Greensboro to Richmond**	1:58:28	1:08:59	1:08:59	1:48:34	0:47:31	0:47:31	3:47:02	1:56:30	1:56:30
8(a)	2P42DC-6-car Trainset 7" Eu - 110 mph. Revised Manual Curve Analysis. **With Contemplated Improvements. Four Stops.**	2:02:50	1:04:37	(0:04:22)	1:48:06	0:47:59	0:00:28	3:50:56	1:52:36	(00:03:54)
8(b)	2P42DC-6-car Trainset 7" Eu - 110 mph. **With Contemplated Improvements. Five Stops**	2:05:10	1:02:17	(00:02:20)	1:48:07	0:47:58	(00:00:01)	3:53:17	1:50:15	(00:02:21)
8(c)	2P42DC-6-car Trainset 7" Eu - 110 mph. **With Contemplated Improvements. Six Stops**	2:05:10	1:02:17	(00:00:00)	1:50:30	0:45:35	(00:02:23)	3:55:40	1:47:52	(00:02:23)

With the contemplated improvements in place, analysis concluded that the optimal trip time northbound between Charlotte and Richmond was three hours and 51 minutes with four intermediate station stops.

The analysis indicated that the addition of a fifth stop at an I-485 Beltway Station north of Charlotte would increase the trip time by approximately 2.5 minutes to three hours and 53 minutes. The analysis concluded that the addition of a sixth stop at Henderson, North Carolina on certain trains would increase the trip time by an additional 2.5 minutes to approximately three hours and 56 minutes.

Although not directly affecting the Richmond–Charlotte downtown-to-downtown travel times, the addition of a station south of Charlotte, at Charlotte Airport, also was studied. The station would be located about 5.4 miles south of the new Charlotte downtown rail passenger station. The study team assumed that southbound trains whose schedule would be extended to Charlotte Airport Station, would have a three-minute dwell at Charlotte. The trip to the airport station would take approximately 10 minutes.

Group 9: Sensitivity Cases—Train Length

The cases in Groups 3 and 4 explored the effects of varying the motive power arrangements on each train over the “existing alignment optimized”; Group 9, likewise, analyzes the effects of varying the number of coaches per train. While Group 9, too, assumed the existing alignment optimized, the results are applicable to a system based on the contemplated improvements as well. Table B-9 summarizes the Group 9 results.

As shown in Table B-9, each pair of cars added to the standard six-car train adds approximately three to four minutes to the TPC timings. On the other hand, reducing the train lengths from six to four coaches saves about 5½ minutes between Charlotte and Richmond. While this latter time savings is attractive, it is more likely to be theoretical than practicable, as operating timetables must be based on the longest regularly-operated trains if service reliability is to be maintained throughout the year. Further detailed demand, cost, and operational studies would be required to assess whether a change from the assumed six-car consist would accord with the long-term economics of the service, when equipment investments, operating and maintenance expenses, supportable frequencies, ridership, and revenues are all taken into account.

Group 10: Effect of Adding Intermediate Station Stops

As reported in Table B-10, additional TPC runs analyzed the effects of adding specific station stops to the schedule under various assumptions for MAS and unbalanced superelevation.

Table B-9
COMPARATIVE SIMULATED RUNNING TIMES—110 MPH MAS—GROUP 9
Four Stops—No Diversions. Times Are in Hours : Minutes : Seconds, and Do Not Include Schedule Pad.
Tilt operation and seven inches of unbalanced superelevation, Charlotte to Richmond
Effects of Train Length on Performance

Case	Description	Segment: Charlotte to Raleigh			Segment: Raleigh to Richmond			Corridor Charlotte to Richmond		
		Segment TPC Timing	Improve-ment From Case 3(f)	Improve-ment from Previous Time	Segment TPC Timing	Improve-ment From Case 3(f)	Improve-ment from Previous Time	Corridor TPC Timing	Improve-ment From Case 3(f)	Improve-ment from Previous Time
1(a)	P42DC-6-car Trainset Existing Speeds Baseline	3:07:27	n/a	n/a	2:36:05	n/a	n/a	5:43:32	n/a	n/a
3(f)	2-P42DC-**6-car** Trainset 7" Eu - 110 mph	2:03:36	n/a	1:03:51	1:54:22	n/a	0:41:43	3:57:58	n/a	1:45:34
9(a)	P42DC- **4-car** Trainset 7" Eu 110 mph	2:00:19	0:03:17	0:03:17	1:52:13	0:02:09	0:02:09	3:52:32	0:05:26	0:05:26
9(b)	2 P42DC- **8-car** Trainset 7" - 110 mph	2:04:52	(0:01:16)	(0:04:33)	1:55:50	(0:01:28)	(0:03:37)	4:00:42	(0:02:44)	(0:08:10)
9(c)	2 P42DC-**10-car** Trainset 7" Eu - 110	2:07:11	(0:03:35)	(0:02:19)	1:57:36	(0:03:14)	(0:01:46)	4:04:47	(0:06:49)	(0:04:05)
9(d)	2-P42DC-**12-car** Trainset 7" Eu - 110 mph	2:09:45	(0:06:09)	(0:02:34)	1:59:43	(0:05:21)	(0:02:07)	4:09:28	(0:11:30)	(0:04:41)

The following conditions were used in these station stop analyses:

- MAS was set at 79 mph or increased to 110 mph; speeds on individual curves were calculated using a technique developed for this study.
- As in the Baseline case, positive stops and curve speeds were enforced.
- Spiral length and superelevation of curves calculated using the spreadsheet were assumed.
- Tilt cut out under 45 mph and gradually ramped in to maximum at 60 mph.

Table B-10 Allowances for Intermediate Station Stops Unbalanced superelevation 7 inches		
	Time Allowance	
Station (See Note)	79 mph MAS	110 mph MAS
I-485‡	n/a	0:02:21
Kannapolis	0:02:39	0:02:19
Salisbury	0:02:56	0:03:29
High Point	0:02:32	0:03:09
Greensboro*	0:03:56	0:04:42
Burlington	0:02:47	0:02:57
Durham*	0:02:41	0:02:49
Cary	0:02:43	0:02:59
Raleigh*	0:03:57	0:03:57
Henderson	0:02:54	0:03:23
Petersburg*	0:02:41	0:03:09

Note: Appendix F shows how all these locations are assumed to receive improved service (by different types of corridor trains) as part of the transportation plan. This table simply estimates the time allowance that the timetables should associate with corridor trains that stop at each place.

* Asterisks indicate station stops already assumed in the four-stop schedule. For these stations, the allowance timings shown in this table are for the sake of completeness only.

‡ I-485 would be included in the assumed five-stop schedule. See Appendix F.

In general, at the 110 mph MAS, each additional station stop would add from two to four minutes to the projected schedule. The time penalty for a specific stop would depend (a) on the train speed that the track geometry would permit were the stop omitted, (b) and on the projected passenger volumes at the station. At most stations, depending on site-specific details, the allowances for added stops would decrease if the MAS were held to 79 mph.

Synthesis and Conclusions

Recap of the Analysis

Various options to reduce trip time were systematically evaluated; the relative benefits of each, in terms of time saved, were determined. A great variation in benefits and costs in the range of alternatives evaluated was identified. Some of the options created significant benefits at relatively low costs. Other options resulted in relatively minor benefits at relatively high costs. The following description provides an indication of the projected benefits of the options considered.

Several scenarios, each with several options, were examined. The most basic scenario, optimizing the existing alignment, gave the largest increment of improvement. Each scenario initially was based on a 4-stop run between Charlotte and Richmond. Adjusting superelevation and spiral length to optimize the speed through curves, while upgrading the track and signal system, resulted in a 16 percent reduction in trip time with a conventional Amtrak-type train at a maximum authorized speed (MAS) of 79 mph. Increasing superelevation and unbalance, raising the MAS, substituting tilting equipment, and increasing horsepower produced a noticeable improvement, but did not suffice to reliably meet the trip time goals. For that purpose, sufficient additional time saving can only be obtained through a combination of more costly improvements.

The trip time between two points is affected by numerous considerations. For this analysis the primary factors evaluated included:

- The assumed maximum authorized speed (MAS), whether it be 79, 90, or 110 mph,
- The amount of unbalanced superelevation, and
- The speed to be achieved on specific curves.

Additional factors affecting trip time include:

- The number of stops and the dwell time for each stop,
- The assumed method of enforcing speed restrictions,
- The train consist operated,
- The number of coaches, and whether the coaches are tilting or non-tilting,
- The type of locomotive and its characteristics,
- The spacing of signals,
- The speed capability of switches at the locations where mandatory train diversions are required (e.g., on the P Line, at junctions between single- and double-track segments),
- The location and number of non-rail related civil speed restrictions; and

- A variety of lesser factors.

The influence of these latter factors is normally minimized through the consistent application of assumed operating conditions for each TPC run. The assumptions relative to each TPC run are described in the body of the text.

A critical factor to the successful implementation of incremental high-speed rail service operated in a mixed-mode environment is **Ride Comfort**, as experienced and perceived by the passenger. The analyses performed to establish the maximum speed for each curve, which are described in Appendix A, included consideration of factors that serve to theoretically optimize ride comfort.

Whether the trip time goal is reliably met is determined by additional factors, most importantly the capacity of the rail line to adequately handle the levels of intercity passenger, freight, and commuter trains, if applicable, that are projected to be operated. Capacity considerations were not addressed in this part of the analysis. They were evaluated by means of a separate set of operations simulations, which are described in Appendix C. **For this analysis capacity is not a factor. A TPC run only assesses the time required to move a train over the railroad, and the varying speeds it is able to maintain en route.**

When considering run times it is important to realize that actual scheduled run times between two points will be longer than TPC-projected trip times. **Additional time must be added to projected trip times to accommodate the uncertainties (realities) of everyday operation. This difference is compensated for by "pad."** The trip times referred to thus far in this Appendix reflect perfect runs under ideal conditions and do not include pad. However, pad must be considered in evaluating whether a given TPC-simulated time would, in practical terms, meet a trip time goal on a reliable basis. This method of comparison is the subject of the following section.

Analyzing Trip Time Attainment Using Pad

The basic performance of any train set (cars and locomotive[s]) over a given route, and for a defined stopping pattern, is computed using a Train Performance Calculator (TPC) that has been programmed and calibrated to produce an accurate computation of the train's speed, energy consumption, and resulting schedule time **under ideal circumstances**. As this Appendix repeatedly points out, the TPC simulates the ideal operation of a single passenger train operating over a hypothetical, Charlotte to Richmond route configured and realigned to support high-speed passenger rail service. The TPC's running time thus represents the optimal physical performance of the equipment and its operator, with the train running unencumbered by other trains on its route. These conditions obviously will not occur reliably for real, day-to-day operations, so further adjustments to the basic TPC running time must be made to reflect all the factors that will reduce performance, and increase running times, from the TPC optimum.

The process of analyzing optional alignment and configuration alternatives includes the use of pad to determine the likelihood that the trip time goal would be reliably attained. Richmond–Charlotte corridor alternatives were evaluated for their ability to provide TPC travel times that would be sufficiently better than the States' desired times, so as to provide a pad that would allow for reasonably foreseeable operating contingencies.

The goal of adding "pad" to a train schedule is to produce a schedule that can be operated reliably, repetitively, and with a high degree of confidence. A reliable schedule is essential to satisfy the expectations of the riding public, which needs to know when it will arrive at a given station, and the by train operator, which needs to plan equipment cycles and service frequency. As direct Richmond-Raleigh-Charlotte express service over the contemplated route was not customary in the pre-Amtrak era, there is no historical performance data for rail service planners to draw upon for the Southeast Corridor high-speed service between Richmond and Charlotte. Therefore, schedule design standards and the results of train operations simulations performed for the study were used to estimate how much "pad" must be added to the optimum TPC running times to produce a reliable train schedule.

The FRA and Amtrak have historically used a seven percent planning schedule pad to evaluate train schedules for multiple-track high-speed corridors, and this pad was the starting point in the development of the schedule pad to be used to analyze train schedules for the Southeast Corridor between Richmond and Charlotte. The planning pad comprises three main components that account for:

- Inability to implement all recommended improvements,
- Operator/vehicle variability, and
- Rail system performance.

Accounting for Inability to Implement Improvements

The amount of pad built into the planning level analysis of a project provides allowance for likelihood that some of the recommended configuration and alignment improvements might not be implemented for physical, cost, environmental, or other public interest reasons.

Accounting for Operator/Vehicle/Operations Variability and Rail System Performance

The amount of pad also provides allowance for the reality that:

- Train operations are never precise, things just never go quite according to plan, station stops are slower, bad weather slows operations, equipment failures do occur, etc.,
- Vehicle performance is never uniform,

- Train operators do not consistently and instantaneously adhere to all changes in speeds along the route, and
- Trains incur small increments of delay en route, and overtake and meet other freight and passenger/commuter trains, while still maintaining a high probability of on-time performance.

Recognizing that typical day operations introduce periodic train delays and fluctuations in train speeds along the route, pad takes into account variables that occur in ”typical” as opposed to “ideal day” operating conditions. Accounting for rail system performance may account for between 2 and 3 percent of the 7 percent pad.

Accounting for Anticipated Richmond to Charlotte Train Operations

Typical daily variations also include the likelihood that passenger trains would have to divert from one track to a second track to avoid slower moving trains, or divert to a siding in single-track segments to enable a passenger train in the opposing direction to pass. The likelihood of train diversions and meets occurring is significantly greater in the Richmond to Charlotte corridor than in the mainly-double-track Washington to Richmond segment of the Southeast Corridor. More than 60 percent of the Corridor would be operated as a single-track railroad with sidings. The remainder of the Corridor, basically Richmond to Centralia and Greensboro to Charlotte, would be double tracked with occasional passing sidings and additional tracks to support increased levels of through and local freight operations.

Additional schedule allowances also must be made for:

- The large number of Norfolk Southern freight trains operating on the NS main line between Greensboro (Elm) and Charlotte, and
- The occurrence of meets involving two passenger trains on the single-track segments, situations that will **always** result in delaying one of the passenger trains.

Each time a passenger train is required to slow down, enter a siding, and wait for the passenger train coming in the opposite direction to go past, the train adds an average of 9.5 minutes of delay to it performance. Simulation indicated that passenger trains on the 157-mile segment between Richmond and Raleigh and the 73-mile segment between Fetner and Greensboro, where more than twice the number of passenger trains each day (9 pairs, versus 4 pairs north of Raleigh) operate, have a probability of incurring 1.2 meets per day. These meets would produce an expected average delay in excess of 11 minutes for each Charlotte to Richmond train.

This is a much higher exposure to train conflicts than is encountered on the typical Amtrak high-speed operation, which are 2-3-4 track corridors, with limited freight operations.

Between Greensboro and Charlotte on the recommended 2- to 3-track main line, the volume of freight trains ensures that sidings and tracks where passenger trains would otherwise pass without delay will be occupied by freight trains, increasing the probability of some delay to the passenger trains, often simply slowing down while the slower freight trains get out of the way.

The resulting running time for a planned “5 stop” train between Richmond and Charlotte breaks down this way:

- TPC – Pure Trip Time with five intermediate stops – 3 hours, 53.3 minutes (Case 8(b)),
- Typical, 7 Percent Pad – 16.4 minutes – consisting of:
    - Rail system performance – 5.9 minutes,
    - Other factors – 10.5 minutes,
- Single Track Conflicts – 11.4 minutes or 4.9 percent, and
- Multiple Track Congestion – 3.9 minutes or 1.7 percent.

The simulation of corridor operations indicates that a 4:20 four-stop schedule, split into 2:00 hours Richmond-Raleigh and 2:20 between Raleigh and Charlotte, could be operated with over *90 percent reliability*—9 out of 10 trains make the Richmond—Charlotte run within 4:20.

The Ongoing Use of Pad

The TPC simulation database would be continuously updated during the design and construction phases of a project. The database also would be modified to incorporate the performance capabilities of the trainsets selected to operate the high-speed rail service. As the definition of the project became more accurately defined, the likelihood that the schedule goal will be achieved would be continually evaluated, and the schedule and pad adjusted as necessary. The amount of pad would be reduced to reflect the improved level of confidence that alignment and configuration improvements would be funded and implemented. Ultimately, the pad would become the time built into a schedule to enable trains to incur small increments of delay en route, overtake and meet other freight and passenger trains, and still maintains a high probability of on-time performance.

Trip Time Goal Status

The TPC simulations have clearly indicated that the performance characteristics of the intercity rolling stock will be critical to achieving the trip time goal of less than 4 hours 25 minutes for five-stop service between Richmond and Charlotte.

To determine whether a reliable five-stop[16] intercity service of less than 4 hours, 25 minutes can be operated, Table B-11 was prepared to summarize the overall

Table B-11
SIMULATED RUN TIMES
AND AVAILABLE PAD
Compared to Hypothetical 4-Stop 4-Hour 20-Minute (260-Minute) Goal
[5-Stop Goal = 4-Hour 25-Minute (265-Minute)]

Case	**Simulated Run Time**	**Pad (minutes.)**	**Pad (% of TPC Time)**
Existing, 1 P42+6 Amfleet	343.5	N/A	N/A
90 mph/7" Eu/ P42	260.1	-0.1	N/A
90 mph/7" Eu/2 P42	251.5	8.5	3.4%
110 mph/7" Eu/1 P42	253.7	6.3	2.5%
110 mph/7" Eu/2 P42	238.0	22.0	9.2%
110 mph/7" Eu/2 P42 Separate Head End Power Source	236.1	23.9	10.1%
110 mph/7" Eu/2 P42, 80 mph Floor Raleigh - Greensboro	227.6	32.4	14.2%
110 mph/7" Eu/2P42 Recommended Alignment	230.9	29.1	12.6%
110 mph/7" Eu/2P42 Recommended Alignment – **Five Stops**	233.3	26.7 (31.7 Compared to 265 minutes)	11.4% (13.6% Compared to 265 minutes)

running times for various alignment and train consist options. The results are shown for speeds computed for the varying levels of unbalanced superelevation and Maximum Authorized Speed between Richmond and Charlotte that have been simulated. The amount of pad available for each run also is shown in the table.

[16] A four-stop service was initially planned, however, a fifth stop at a beltway-type station north of Charlotte, called I-485, was added toward the end of the planning process.

Using 4 hours 20 minutes as the goal speed for a four stop service and 4 hours 25 minutes for a five-stop service and the 29.1[17]-to 31.7[18]-minute pad recommendation mentioned in the previous section, it is clear that **only the cases in which 110 mph MAS, seven inches of unbalanced superelevation, and two power units are assumed resulted in a run time that provides the recommended pad.** The 90 mph 7-inch two locomotive case provides less than 9 (3.4 percent) minutes of pad. A reliable 90 mph 6-inch two locomotive schedule would be three hours and 45 minutes, arrived at by adding 33.5 minutes (13.3 percent) of pad to the four hour, 11.5 minute TPC time.

The service goal for acceptable on-time performance has yet to be established. It is believed that an on-time performance of at least 90 percent should be established as a goal for Richmond to Charlotte train service: such a level would represent the optimal compromise between service quality and required investment, as the additional pad required to meet the trip time goals at higher reliability levels would come at an increasingly high cost per minute.

As previously discussed, a number of potential changes in the conditions upon which the TPC results are based might occur, which further erodes the amount of available pad. For example:

- There may still be some question as to whether all of the curve modifications that are assumed in the TPC runs are feasible from an engineering standpoint;
- If a 110 mile-per-hour MAS cannot be achieved, there is a significant increase in TPC running time; and
- If an unbalanced superelevation lower than 7 inches must be used, the trip time suffers.

[17] I.e., 3 hours 50.9 minutes to 4 hours and 20 minutes—Case 8(a).

[18] I.e., 3 hours 53.3 minutes to 4 hours 25 minutes—Case 8(b).