Boston–New York Commuter and Intercity Rail Improvement Potential

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Results are presented of a study of potential fixed-plant improvements to commuter and intercity rail passenger service between Boston and New York that was conducted by the Volpe National Transportation Systems Center under the direction of a Departmental Task Force established by the Secretary of Transportation. A range of alternative improvement programs were identified and characterized. A hierarchy of five alternative programs was defined, ranging from a basic set of projects needed to maintain safety and rehabilitate the existing infrastructure (yielding modest performance gains), to programs that also include substantial capital investment in track work, signaling, electrification, and potential curve and route alignments, which could trim up to 1½ hr from the current best scheduled trip time of just under 4 hr. The study found that an investment of about $1.1 billion is needed during the next decade to bring the existing infrastructure to a state of good repair. More extensive programs, reducing trip time to between 2½ and 3 hr, would cost an additional $500 million to $2.5 billion (exclusive of rolling stock). Potential Amtrak ridership gains and societal benefits were estimated in the study, but are not addressed here.

Results of a study of potential system improvements to benefit commuter and intercity rail passenger service in the Boston–New York corridor are presented. Fixed-plant projects needed for system safety, rehabilitation and service improvement were identified. Five alternative overall programs were defined, and the potential Boston–New York trip times for each program under various rolling stock assumptions were estimated. These findings are summarized here.

The study was conducted for the U.S. Department of Transportation (DOT) by the DOT Volpe National Transportation Systems Center (VNTSC) under the direction of a Task Force established by the Secretary of Transportation. Parsons Brinckerhoff Quade and Douglas, Inc., provided technical support to the VNTSC study team in the areas discussed here.

BACKGROUND

The Northeast Corridor (NEC) serves a populous and heavily traveled region. Extensive commuter rail passenger service on the corridor is critical to the metropolitan areas served. Seven transportation authorities and railroads use more than one-half of the 231 route miles between Boston and New York to provide commuter rail services for more than 100,000 riders every weekday. This represents more than 90 percent of NEC riders and two-thirds of total passenger-miles on the corridor.

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The corridor has long had a major role in intercity passenger travel, currently carrying 2.3 million riders annually between Boston and New York. Growth of airport and highway congestion has contributed to increased interest in improving passenger rail performance on the northern half of the NEC. The $2.5 billion Northeast Corridor Improvement Program of the 1970s and 1980s resulted in a reliable trip time under 3 hr for rail travel between New York and Washington, which in turn contributed to a high level of ridership. The shortest Boston–New York rail travel time is currently just under 4 hr, which has not proven to be competitive with air transport for many time-sensitive travelers on this route. The High Speed Rail Task Force of the Coalition of Northeastern Governors has been active for several years in identifying improvements that would yield a trip time of 3 hr or less and encouraging implementation of such improvements.

Much of the corridor's fixed plant, such as bridges and catenaries, is 80 years old or older. As a result, major rehabilitation and replacement have been identified as necessary simply to ensure safety and bring the railroad to a state of good repair. The Northeast Corridor Commuter Rail Authorities Committee has developed an extensive list of work identified by NEC operating authorities as needed for rehabilitation and service improvements. The responsible agencies are planning and conducting programs to meet those needs, but funding constraints are such that the necessary rehabilitation will take many years, and new needs continue to accumulate. Similarly, investments are being made to shorten trip times, but there is no assurance that funds will be available.

The multiple services that the corridor supports are reflected in a complex institutional structure that would shape the implementation of any major improvement program. Table 1 presents the division of responsibilities among various organizations for the Boston–New York portion of the NEC.

PURPOSE

The purpose of the study was to identify and characterize costs and benefits of improvements that could be achieved in commuter and intercity rail service on the Boston–New York portion of the corridor. Reported in this paper is the central effort of that study. The focus is on three basic questions:

1. What improvements are needed to ensure safety and continued reliable operations on the corridor?
2. What could be done to the NEC fixed plant infrastructure to achieve substantially faster and more reliable commuter and intercity rail service?

TABLE 1 INSTITUTIONAL ROLES AND RESPONSIBILITIES FOR THE NEC BETWEEN BOSTON AND NEW YORK

From	To	Distance (miles)	Owner	Maintenance	Dispatching	Commuter Service	Commuter Authority	Freight Service
Penn Station	Harold Interlocking	4	Amtrak	Amtrak	Amtrak	LIRR	MTA	--
Harold Interlocking		--	LIRR	LIRR	LIRR	LIRR	MTA	--
Harold Interlocking	Shell Interlocking	15	Amtrak	Amtrak	Amtrak	--	--	Conrail
Shell Interlocking	NY-CT State Line	10	MTA	MNCR	MNCR	MNCR	MTA	Conrail
NY-CT State Line	New Haven	46	CDOT	MNCR	MNCR	MNCR	CDOT	Conrail
New Haven	Old Saybrook	33	Amtrak	Amtrak	Amtrak	Amtrak	CDOT	Conrail
Old Saybrook	RI-MA State Line	86	Amtrak[a]	Amtrak	Amtrak	--	--	P&W
RI-MA State Line	Boston	38	MBTA	Amtrak	Amtrak	Amtrak	MBTA	Conrail

a. Rhode Island DOT owns approximately 1/4-mile of track through and adjacent to Providence Station.

Abbreviations: CDOT = Connecticut Department of Transportation
LIRR = Long Island Rail Road
MBTA = Massachusetts Bay Transportation Authority
MNCR = Metro-North Commuter Railroad
MTA = Metropolitan Transportation Authority
P&W = Providence & Worcester Railroad

3. What degree of rail service improvement is attainable for various levels of capital investment?

The study was neither a benefit-cost analysis nor a program plan for the improvement of the corridor. No recommendations were made. Rather, the purpose was to clarify the nature and cost of the primary potential improvements that could be made to the Boston–New York rail infrastructure and to provide estimates of potential trip-time reductions likely to result. As such, the study could provide a basis for developing the necessary consensus among owners, operators, and all levels of government for policy formulation and decision making concerning any future corridor improvements. It brings together, in a consistent and comprehensive manner, the results of previous studies, analyses, and estimates by the involved public agencies, operating railroads and others, as well as independent assessments by the study team.

APPROACH

The approach followed in the study was to identify major infrastructure rehabilitation and improvement projects and organize them into a logical hierarchy of overall programs. Project identification was based primarily on previous studies and extensive interaction with the involved parties, particularly the organizations shown in Table 1. Potential savings in intercity trip times from each of the five programs were calculated for various types of rolling stock using a proven Train Performance Calculator (TPC) computer program. The study was focused on fixed plant improvements; rolling stock was considered only in selecting a broad range of alternatives for trip-time calculations. Rolling stock investments and normal operating and maintenance costs were not analyzed.

Key assumptions of the study were as follows:

- Time frame: Project implementation and funding allocation is assumed to occur between 1991 and 2000.
- Route/right-of-way: Improvements considered are primarily within the existing right-of-way, with the exception of a new inland route segment recently studied by Amtrak.
- Rolling stock: Performance projections assume equipment now available or fully developed and tested so that it would be available for revenue service. Rolling stock costs would depend on the level of service and other operational variables.
- Speed on curves: The study assumes that with modern rolling stock and rehabilitated and reconfigured track higher curve speed limits will be acceptable in terms of safety and passenger comfort.

IMPROVEMENT PROJECTS

Eighteen candidate improvement projects were identified and characterized. Five involve safety or basic rehabilitation; thirteen others would improve trip time, reliability, and capacity. Based on initial estimates of time savings and cost, the projects were grouped into programs representing a hierarchical succession of trip-time reductions and total cost. Trip time was calculated for the speed limit profile appropriate to each of the improvement programs and repeated for several categories of rolling stock. Existing travel demand models were used to assess the ridership expected to result from the calculated trip times under reasonable assumptions concerning fare and departure frequency. A brief description of the identified projects affecting specific segments of the corridor follows. A map indicating project location is shown in Figure 1; track work, bridge rehabilitation, signaling, and curve straightening are too distributed to show.

Penn Station (New York) to Shell Interlocking (New Rochelle)

A major safety-related effort is required at Pennsylvania Station. Emergency egress from platforms must be increased, which will be a major undertaking. Similarly, the East River tunnels require new ventilation shafts and equipment, including evacuation stairways. At Harold Interlocking, a grade separation (flyover) where eastbound Amtrak trains cross Long Island Rail Road commuter tracks would prevent delays—

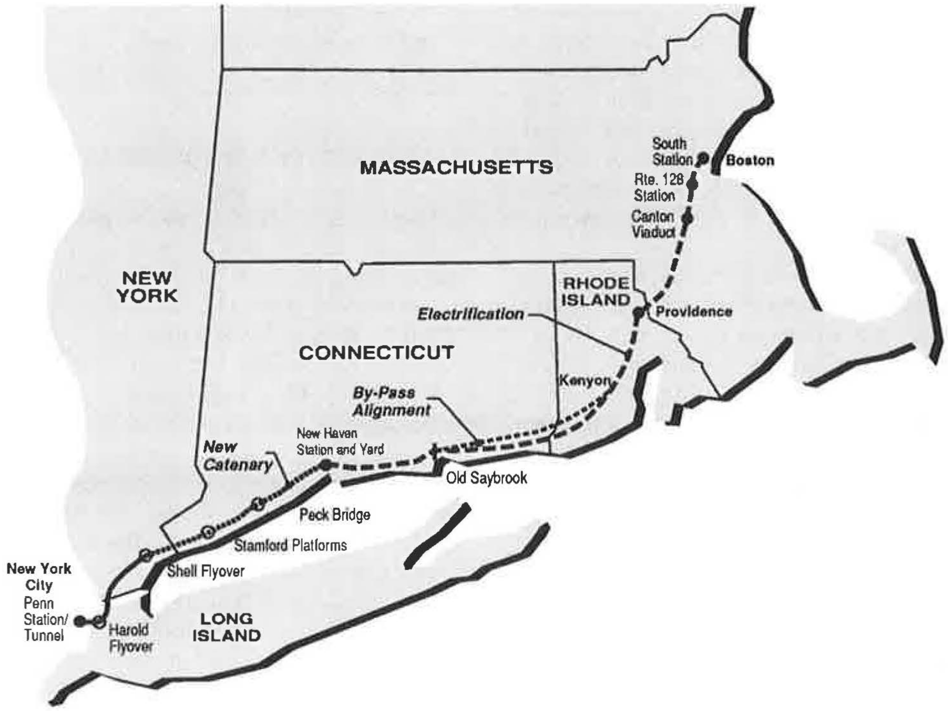

FIGURE 1 Location of potential improvements.

likely to be much more serious at future, higher traffic levels—but will be difficult to construct while bearing full traffic. Beyond Harold Interlocking on the Hell Gate Line, rehabilitation of the Pelham Bay movable bridge and fixed bridges, improved track, and a potential curve realignment with signal modifications for higher speed limits, are needed. Overhead catenary wire was recently rehabilitated, but the catenary supports still need to be repaired.

Shell Interlocking to New Haven

The Metro-North Commuter Railroad (MNCR) New Haven Line contains a major share of substantial location-specific projects. Shell Interlocking, where eastbound Amtrak trains merge with MNCR traffic, is a significant source of delay for both railroads, and low-speed turnouts limit operating speeds. Two approaches are being considered at Shell to reduce the time required to traverse the interlocking plant and eliminate a major bottleneck:

1. Flyover: Depression of the two eastbound MNCR tracks and elevation of the Hell Gate Line tracks on an overpass, and
2. At-grade: Changes to track configuration and turnouts in the vicinity of New Rochelle, which would increase speeds through the area and reduce conflicts.

Design alternatives are being evaluated by Amtrak, MNCR and FRA for this project.

Operationally closely linked to Shell, island platforms, and related track reconfiguration at Stamford are needed to increase platform access and avoid delays, which quickly propagate to New Rochelle. The catenary from the Connecticut–New York line to New Haven is approximately 80 years old and is well beyond normal service life. It now constrains speed and imposes an excessive maintenance burden; replacement is necessary. A project to replace Peck Bridge, a nominally movable bridge over the Pequonnock River at Bridgeport, has been initiated and must be completed; in addition to preventing a future safety problem, this will permit somewhat higher speeds. Four other movable bridges requiring major work, which is well under way, are those over the Saugatuck and Norwalk rivers and at Cos Cob and Devon. New track configuration at and leading into the New Haven station area would result in significantly faster speeds and improved operations through that area. Although not needed at present traffic levels, the fourth track between New Haven and Norwalk will require rehabilitation or replacement early in the next decade. All of these specific projects would be accompanied by ballasting of open deck bridges and track work and signal modification to permit higher speeds along the line.

New Haven to South Station (Boston)

Electrification of the entire route segment would be accompanied by track work and signaling to support higher speeds. In addition to conversion of open deck fixed bridges to ballasted deck, electrification would require that overhead bridge clearances be increased at many locations. There is also a potential for significant curve straightening, particularly between New Haven and Providence. The movable bridge span at Groton and over the Niantic River requires replacement. The viaduct in Canton, Massachusetts is more than 150 years old and needs substantial modification to allow high speed for certain types of commuter cars. High level platforms at Route 128 station would significantly reduce dwell time at that stop. Nine public and eight private at-grade crossings remain on the New Haven–Boston line—one each in Massachusetts and Rhode Island and the remainder in Connecticut. The Rhode Island crossing is scheduled for grade separation. Other crossings will require separation closure or added protection depending on the level of all service improvements to be implemented.

The Shore Line alignment between Old Saybrook, Connecticut, and the Connecticut/Rhode Island state line contains the most restrictive series of curves on the corridor, as well as five movable bridges over Shaw's Cove and the Connecticut, Niantic, Thames, and Mystic rivers. Although much of the alignment is rural and lends itself to curve realignment projects, achieving meaningful 150-mph stretches in this territory is precluded by various "hard spots" (such as the movable bridges), and 100 to 110 mph maximum speeds are the best that can be reasonably obtained. The movable bridges require substantial expenditures for rehabilitation or replacement and are a source of ongoing maintenance requirements and operating delays.

Amtrak has recently explored bypassing the most heavily curved segment of the corridor—the Connecticut/Rhode Island shore line east of New Haven. The project would consist of construction of a new right-of-way along a different alignment for a distance of more than 40 mi, plus major straightening on an additional 10 mi, with a speed limit of 150 mph for the entire 50 mi. Because of the substantially reduced curvature, the new alignment would permit 150-mph operation throughout its length. This by-pass alignment offers significant trip-time savings.

Summary

In summary, a list of the eighteen candidate projects identified, some aggregate in nature, follows.

System Rehabilitation

- Penn Station and tunnels,
- Catenary replacement,
- Peck Bridge replacement,
- Other movable bridges, and
- Fixed bridges.

System Improvement

- Harold Interlocking,
- Shell Interlocking,
- Stamford island platforms,
- New Haven terminal,
- New Haven – Norwalk 4th Track,
- Canton viaduct,
- Track improvements,
- Signal system upgrades,
- Grade crossings,
- Station improvements,
- Electrification,
- Curve realignments, and
- Bypass alignment.

ALTERNATIVE IMPROVEMENT PROGRAMS

Conceptually, a set of alternative programs could be defined by ranking improvement projects in order of cost-effectiveness in reducing trip time, with a hierarchy of programs resulting from working down the list. In practice, three considerations limit the rigor with which that approach can be followed. First, many of the projects are not well defined at present in scope or design, limiting the precision of both cost and time-savings estimates. This renders highly uncertain any explicit calculation of minutes saved per million dollars expended. Second, many improvements provide benefits only in conjunction with other projects. For example, the speed gains from simultaneous signal improvements, track work, and electrification cannot be allocated uniquely to any one of those projects. Third, for projects that address trip-time reliability or system capacity, there is no straightforward way to convert the benefit into minutes; they are simply necessary to creating an improved system.

In spite of these limitations, cost-effectiveness in trip-time reduction remains a useful measure. Ten projects—or appropriate clusters of projects, such as track work and signaling—were found to buy reduced trip time (through a combination of higher speeds and prevention of delays) at an approximate rate of $10 million to $20 million per minute saved. The next most attractive improvement, electrification, was found to be somewhat more expensive in terms of direct time savings, but it offers important additional advantages such as efficient Boston–Washington run-through service, fleet rationalization, and reduced locomotive maintenance expense. The remaining two projects—a program of curve realignments and a segment of new right-of-way—are significantly more costly (per minute saved) than the other projects identified. Each represents a sufficiently large increment in cost and performance to be embodied in a separate program in the hierarchy.

A hierarchy of five alternative programs was defined. All programs include a basic set of five projects needed to maintain safety and rehabilitate the existing infrastructure. The first (System Rehabilitation) consists only of these five projects. The other four include concurrent implementation of system improvement projects, and offer shorter trip times but require higher levels of funding. Each successive program includes all of the projects in the less ambitious programs. Most of the projects that constitute the System Rehabilitation program are already in progress.

Program 1: System Rehabilitation

The System Rehabilitation Program consists of five projects necessary for improved safety and for replacement of major system elements that have exceeded their normal service life. This program represents a continuation of a process now in progress. More than half of the projects are at least partially funded. More than $100 million has been obligated to date. The various responsible agencies are developing long-term plans covering most of the projects that constitute Program 1, although funding constraints limit the pace of implementation.

The rehabilitation projects would be needed for continued safe and efficient operation, in essentially the same form, in the absence of any speed and reliability improvement efforts. Thus, they are necessary elements of all system improvement programs, but need not be completed before initiation of system improvement projects. Program 1 includes two safety projects: replacement of Peck Bridge, and fire safety ventilation and other improvements to Penn Station and the East River tunnels. It provides a necessary framework for substantial improvements in speed.

Program 1 yields improved reliability and reduced trip time for commuter and intercity services. Boston–New York schedules would be shortened by several minutes, primarily by greater speeds at some movable bridges and use of two diesel locomotives (instead of one) between Boston and New Haven. Maximum operating speed is 110 mph. The currently unfunded portion of the cost of this program is estimated to be $1.1 billion (in 1991 dollars). Approximately one-third of this sum has been programmed by the various operating authorities, based on expected funds availability during the next decade.

Program 2: Basic System Improvements

The Basic System Improvement Program includes the five projects in the System Rehabilitation Program as well as ten projects to improve service reliability and speed. More than 30 min can be cut from intercity running time by track work and signaling in conjunction with higher allowed speeds on curves, which increases running speeds to a maximum of 130 mph. Modernization of the New Haven terminal area will eliminate an extended region of slow speeds, cutting an additional 5 min from the trip. Other projects are necessary for capacity enhancement and grade crossing improvements. Flyovers (grade separations) at Harold Interlocking (Queens) and Shell Interlocking (New Rochelle) would ensure service reliability and avoid serious delays at critical points where intercity and commuter lines merge or cross. Island platforms at Stamford would greatly improve flow and capacity at peak hours.

The rehabilitation projects need not be completed, nor some even initiated, before beginning speed and reliability improvements. Most of the system improvement projects in Program 2 are already at least in the preliminary design phase. The best Boston–New York average speed attainable with this program is 75 mph. The program adds a cost averaging $50 million per year over 10 years to the system rehabilitation program, but yields a trip time approaching 3 hr for Boston to New York. Significant time savings and greater service reliability are also achieved for the many rail commuters in the New Haven–New York area.

Program 3: Basic System Improvements and Electrification

Program 3 adds electrification of the route from Boston to New Haven to the projects of Program 2. Electrification, for which initial design funds have been appropriated, eliminates the engine change in New Haven, a saving of almost 9 min, and allows use of electric locomotives for the Boston–New Haven segment. The electric units, with higher acceleration, operating at up to 130 mph, will further reduce trip time by almost 6 mins. Electrification, including associated signal upgrade and bridge clearance projects, also facilitates run-through operation between Boston and Washington, necessary for improving Pennsylvania Station and East River Tunnel capacity and providing high speed service to and from points south of New York. Program 3 yields an average speed for express service, depending on rolling stock, of slightly above 80 mph, with a projected trip time slightly less than 3 hr. Significant time savings are achieved for commuters in the New York area and potentially in the Boston area.

Program 4: All System Improvements and Electrification

This program includes all projects in Program 3 and adds 27 clusters of curve realignments, primarily between Providence and New Haven; maximum speed is 130 mph. The realignments would generally be within existing right-of-way or require only modest excursions from it. They would yield an average speed of about 85 mph. These improvements provide an additional reduction in trip time of about 11 min; the Boston–New York trip could be completed in less than 2¾ hr. Candidate curve realignments are discussed in more detail later.

If the Boston–New Haven line were electrified before implementing realignments, the cost of subsequent curve straightening would be substantially increased. Thus, a choice between Programs 3 and 4 must be made before implementation; Program 4 would not be as practical as a later upgrade from Program 3.

Program 5: Shore Line Bypass

Program 5 adds to Program 4 a new routing to avoid the most curve-intensive portion of the route. The Shore Line Bypass, recently examined by Amtrak, is a 50-mi-long, 150-mph right-of-way to replace the most curved section of the route along the Connecticut and Rhode Island shore east of New Haven. This could yield an average speed of approximately 95 mph. Some elements of Program 4, such as certain curve realignments and bridge rehabilitations, would not be needed if a bypass were constructed. The Boston–New York trip time could be 2½ hr or better, depending on the operating equipment.

In summary, the four system improvement programs yield projected Boston–New York trip times of from slightly more than 3 hr to less than 2½ hr, depending on the level of investment and the rolling stock used, along with substantial speed and reliability benefits for commuter rail service.

PERFORMANCE AND COST OF THE PROGRAMS

The projected minimum running time between Boston and New York City for express (Metroliner-type) service and the

TABLE 2 PROJECTED MINIMUM RUNNING TIME BETWEEN BOSTON AND NEW YORK FOR ALTERNATIVE IMPROVEMENT PROGRAMS

Rolling Stock:	1. System Rehabilitation	2. Basic System Improvements	3. Basic System Improvements and Electrification	4. All System Improvements and Electrification	5. Shore Line Bypass
Current Diesel/ Electric (NEC)[a]	3:47	3:07	System Fully Electrified		
Current Diesel/ Electric with Tilt	3:46	3:02	Diesel-Electric and Gas Turbine Not Applicable		
Current Turbo (Empire Line)[b]	3:48	3:21			
Electric[c]	System Not Fully Electrified		2:52	2:41	2:29
Electric/Tilt			2:47	2:37	2:28
High-Speed Electric[d]	Electric Propulsion Not Usable Over Full Route		2:46	2:35	2:22
High-Speed Electric/Tilt			2:41	2:33	2:21
Total Program Cost ($B)	$ 1.1 B	$ 1.6 B	$ 2.0 B	$ 2.7 B	$ 3.6 B[e]

a. 2 F40P diesel-electric locomotives Boston-New Haven; AEM7 electric New Haven-New York; 10 min. change.
b. Gas Turbine-powered equipment comparable to that used for current Amtrak Empire Line service.
c. 1 AEM7 locomotive, modified for 150 MPH for Program 5; use of 2 AEM7's improves time by 5 minutes.
d. Lightweight, high-powered equipment comparable to TGV or ABB trainsets.
e. Estimate includes adjustment for movable bridge and curve projects made unnecessary by the bypass.

All trains consist of six coaches and make 1 ¼-min. stops at Back Bay, Route 128, Providence and New Haven. Computed times are increased by 5% to allow for operational variability and uncontrollable delays. All programs assume acceptability of higher speeds on curves than are now allowed (6" superelevation, 6" unbalance for conventional coaches and 8" for tilt suspensions).

estimated cost (in 1991 dollars) for each program are summarized in Table 2. Run times are based on computer simulation plus a 5 percent schedule allowance for normal variations and delays. The engineering cost estimates exclude any funds already available for projects in each program. The contribution of specific improvement projects and groups of projects to trip-time reduction, improved reliability, and other service benefits are presented in Table 3.

The four intermediate stops of Amtrak's present New England Express schedule (Back Bay, Route 128, Providence, New Haven) were assumed in travel time estimates. Six-coach trains were selected for train performance calculations, as is consistent with proposed future express service. The trip times in Table 2 are judged to be the best that might be achieved. Reliable attainment of those values would require full validity of all assumptions as well as railroad operations that meet the highest standards of precision and reliability. Practical scheduled running times could be several minutes greater than the values presented in Table 2. An additional stop in Stamford, which is likely for many trains, would add approximately 3 min.

Four motive power alternatives were considered in establishing the range of trip time that fixed plant improvements

TABLE 3 APPROXIMATE TRIP-TIME REDUCTION AND OTHER SERVICE BENEFITS FOR SPECIFIC SYSTEM IMPROVEMENTS

Improvement Project	Time Saving due to Higher Speeds[a]	Necessary for Capacity and Reliability	Program 2. Basic System Improvements	Program 3. Basic System Improvements and Electrification	Program 4. All System Improvements and Electrification	Program 5. Shore Line Bypass
Canton Viaduct Track Signal System Grade Crossings Station	33 min.	X	These projects, taken together, permit higher speeds--up to 130 MPH, rather than 110 MPH as for Program 1. Approximate trip time reductions: Boston-New Haven, 19 min.; New Haven-New Rochelle, 12 min.; New Rochelle-NYC, 2 min.			
New Haven Terminal Area	5 min.		Permits substantially higher approach and exit speeds in both directions, reducing trip time by approximately 5 minutes, as well as facilitating terminal-area operations.			
Stamford Island Platforms	1 min.	X	Essential to reduce delays, relieve congestion, prevent conflicts at New Rochelle, and increase capacity for commuter service. Also permits higher speed for through trains, gaining 1 minute.			
Shell Interlocking	1 min.	X	Necessary for future capacity and to prevent serious delays to intercity and commuter trains at a high-traffic merge point; it also permits a higher speed and saves approximately 1 minute.			
New Haven-Norwalk 4th Track		X	Required in order to provide adequate capacity for the higher future levels of intercity and commuter traffic.			
Harold Interlocking		X	Major merge and intersection point between intercity and very high commuter rail traffic; separation required to avoid frequent lengthy delays.			
Electrification	15 min.			Electrification saves 9 min. in New Haven by eliminating the engine change. Higher top speed and greater acceleration gains 6 min. between Boston and New Haven.		
Curve Realignments	11 min.				Realignment of curves is projected to shorten trip time by 11 minutes.	
Bypass Alignment	12 min.					150 MPH; saves about 12 minutes.

a. Approximate time saving with respect to trip times for program 1; does not include reduction in pad or improved reliability.

could yield (Table 2). Assessment of the suitability of specific rolling stock to actual corridor operations was not within the scope of the study. The current-technology diesel and electric units on which trip-time projections are based are assumed usable with either conventional coaches or with cars having a tilting suspension, which would permit somewhat higher speed on curves and typically yields about a 5-min time saving. The high-speed electric equipment represents advanced technology now in use in Europe.

The trip-time estimates for turbine power are patterned after equipment now in service on Amtrak's Empire Line, for which two power cars together have a net of 2,280 hp. A version that would use twin turbines of newer design on each power car, with a total power of 5,800 hp, has been proposed. If this equipment were successfully developed and tested, trip time would be substantially improved. However, even an advanced turbine train would be likely to have weaknesses in NEC service. It would not be suited for Boston–Washington run-through service, and concerns about third-rail operation in tunnels and operational reliability and flexibility would have to be resolved.

Rolling stock cost and operating and maintenance expenses were not analyzed in any detail. However, a rough estimate of rolling stock capital cost is possible. Trainsets, consisting of two power units and six coaches, are expected to cost about $20 million each. As many as 15 to 20 such trainsets might be needed to augment the existing fleet, depending on the program selected and the resulting ridership levels. This implies an incremental cost of $300 million to $400 million over several years.

The improvement program to be implemented, which defines the overall rail system of which each project is a part, must be defined before detailed design of that project and sequencing of construction can be completed. Some projects have direct logistic connections with one another, as with track work, signaling and electrification. Others are linked operationally, such as Stamford platforms and improvements at Shell Interlocking, or are connected through the need to minimize disruption of traffic during construction. Improving the corridor one project at a time, without clear definition of the planned end state, would be inefficient and yield poor results.

CURVE SPEED LIMITS AND REALIGNMENTS

Overcoming the basic physical constraint of a highly curved route alignment is central to reducing Boston–New York trip time. The improvement programs described previously approach this challenge in steps. In addition to projects to raise track classification, provide signaling appropriate to high speed, improve bridges, and remove grade crossings, Program 2 includes increasing superelevation to 6 in. wherever possible, and trip-time computations are based on the assumption of acceptability of a 6-in. unbalance. Program 4 goes a step further by incorporating numerous changes in alignment, largely within the existing right-of-way, to reduce curvature. Program 5 is still more aggressive, replacing approximately 50 mi of the route with an alignment sufficiently straight to permit continuous 150 mph operation. The increased superelevation and unbalance, as well as the curve realignments, are critical to the projected trip-time reductions for Programs 4 and 5 and warrant further discussion.

The VNTSC study included examination of each of the approximately 238 curves between Penn and South stations. Along with the curves, other speed restrictions along the existing route were identified. No detailed field examinations were possible in this preliminary feasibility study. Rather, each curve or restriction was examined through each of the following sources:

- Railroad track charts and curvature listings,
- Railroad track geometry car measurements,
- U.S. Geological Survey topographic mapping,
- Railroad valuation maps, and
- Video recordings of right-of-way, which were provided by Amtrak.

The first finding of the investigation was that track superelevation is significantly less than the existing alignment could support on both Amtrak and MNCR territory. Thus, the first step was to determine the reduction in trip time if full superelevation were restored.

A theoretical track data set was developed as input for the TPC computer program that consisted of maximum speed limits or maximum authorized speeds for each section of the existing New York to Boston alignment. Several assumptions were embodied in this process:

Six in. of actual track superelevation (*Ea*) was assumed to be present at restricting curves in the route, with certain exceptions, as on the Hell Gate Bridge and in terminal and station areas. Although this amount of superelevation can generally be achieved, isolated instances will occur in which it will prove more complex (and hence more costly) to achieve than is practicable. This may be the case, in particular, at certain MNCR locations at which open deck bridges, curves, existing high-level station platforms, and track centers interact. However, full superelevation appears to be achievable in large measure.

Superelevation

Achievement of full superelevation requires adjustment to the transition curves (spirals) associated with the existing curves. Engineering specifications for spirals generally address two concerns: passenger comfort, which is speed dependent, and car twist, which is not speed dependent but depends on the degree of equalization provided by the rolling stock. Many of the specifications still in use today have their origins in the distant railway past, when truck equalization was relatively primitive.

Amtrak and MNCR specifications are relatively conservative in comparison to those used elsewhere in the world and are more stringent than FRA safety standards. The use of these specifications increases required spiral lengths beyond those used by other passenger carriers and limits the amount of superelevation placed in curves. It was beyond the scope of the VNTSC study to develop standards for spirals, but it appears that future testing, analysis, and refinement of these standards will show that, to a large degree, existing spiral transitions and runoffs can be adequate for full superelevation.

Allowed Unbalance

Unbalanced elevation (*Eu*), or cant deficiency, is a measure of the lateral force on a passenger caused by traversing curves at speeds in excess of equilibrium, or balanced, speed. (Equilibrium speed is the speed at which track superelevation exactly balances this lateral force, and $Eu = 0$). Unbalance affects passenger comfort, but in the range in question does not affect train safety or track stability. Railways in Europe operate priority passenger trains with at least 5-in. unbalance and also allow track elevations in excess of 6 in.; total elevation ($Ea + Eu$) can approach 12 in. on conventional (nontilt) trains.

Recent tests in the NEC have shown that conventional Amfleet cars can operate at 4 to 5-in. unbalance with acceptable passenger comfort. Amtrak has successfully petitioned FRA for permission to operate over designated NEC curves at 5-in. unbalance under specified conditions. The VNTSC curve analysis assumed that with advanced-technology rolling stock (TGV coaches are a well-tested example) a total elevation of 12 in. can be achieved in the NEC. Tests will be required to prove the validity of this assumption, but there is precedent for it internationally. It is an important element of maximizing performance in the existing NEC.

Curve Realignments

A graphic plot of speed versus distance for TPC runs was analyzed to determine the potential for time savings through curvature reduction. In particular, individual curves were examined in the context of their neighbors, and clusters of curves were isolated that which would need to be realigned together in order to achieve significant time savings in a coordinated manner.

The TPC speed limit input data set was modified to reflect increased radius of curvature, and revised travel times were obtained. For each curve, the amount of track shift required was calculated. On the basis of the data sources described previously, adjacent development, wetlands, and terrain were identified, and basic feasibility, cost, and likelihood of environmental constraints were estimated.

Several realignments require modest shifts that are within the existing rail right-of-way. For several other curves the land on either side of the railroad is owned by the same landholder, with the possibility of land swaps. Because the right-of-way is up to 250 ft wide in some locations, the possibility of releasing land from railroad use in conjunction with a realignment is also possible, theoretically allowing an increase of wetlands.

Of the 34 realignments projects examined, 33 are clusters of one to six curves, having estimated costs ranging between \$0.5 million and \$88 million per project. One cluster consists of 11 curves shifted to a largely new alignment over 18 mi between Westerly and Kingston, Rhode Island, estimated to cost \$262 million.

Time savings were estimated using the TPC, assuming TGV 1-6-1 equipment, and 1 AEM-7 locomotive with 6 Amfleet coaches. Time savings for individual clusters range from several seconds to 3½ min for the TGV and up to 2¼ min for the AEM-7 consist. Aggregate time savings of approximately 12 and 10 min are achieved by all realignment projects for TGV and AEM-7, respectively.

The cost-effectiveness of specific realignments ranges from approximately \$31 million per minute saved on the Hell Gate Line to \$142 million per minute saved on the Stamford-Bridgeport segment. The average cost per minute saved is \$70 million overall, or \$59 million excluding Shell-Bridgeport.

CONCLUSIONS

1. Rehabilitation Program 1, with a cost of about \$1.1 billion, is needed to ensure safety and maintain the present level of intercity and commuter rail service between Boston and New York. Some of this work has been initiated by the responsible agencies. These projects will contribute to corridor safety and reliability well into the next century.
2. Trip time can be improved substantially using existing technology and with little or no excursion beyond the existing NEC right-of-way. The time for a trip from Boston to New York could be reduced to approximately 2½ to 3 hr, depending on rolling stock and level of investment.
3. Much of the investment would be in segments heavily used by commuter rail passengers. These commuters would experience long-term service improvements comparable to those for intercity riders, as well as increased system capacity.
4. The currently unfunded cost of the improvements necessary for substantially reduced trip time, in addition to the \$1.1 billion for rehabilitation, would range from \$500 million to \$2.5 billion in 1991 dollars, depending on the level of trip-time improvement sought. Initial work is being undertaken on many of the needed projects, although only a small part of the needed funding has been identified and no coordinated overall program exists. The programs could be implemented within 8 to 10 years; service improvements could be apparent within 5 to 6 years. The necessary additional rolling stock (15 to 20 trainsets) is estimated to cost approximately \$300 to \$400 million.
5. Commuter and intercity schedules and service reliability will suffer during implementation of any major improvements; the degradation of commuter service between New Haven and New York could be significant for several years. A concerted effort will be required to design and sequence the improvements in a manner that minimizes disruption of service.
6. Commuter railroads will be subject to new operating constraints, costs, and requirements concerning track maintenance, compatibility of rolling stock, and dispatching. This will require arrangements for equitable sharing of costs, responsibilities, and access between commuter and intercity operations.

OTHER CONSIDERATIONS

Rolling Stock

The selection of a rolling stock alternative depends not only on the trip time it makes possible, but also on capital, operating, and maintenance costs; reliability; suitability for run-through operation between Boston and Washington; and other characteristics and operational considerations.

The performance of advanced-technology high-speed foreign trainsets in the U.S. railroad environment remains to be evaluated. Demonstrations, trial use, and testing of a variety of motive power and rail car suspension technologies during the lengthy period of fixed-plant improvements would provide a good foundation for future long-term fleet acquisition decisions.

Electrification

Electrification between Boston and New Haven has important benefits and implications beyond travel time. Operationally, electrification harmonizes operations in the north and south ends of the corridor, making it possible to use high-performance electric trainsets running between Boston and Washington, with few trains being turned around in New York. This provides needed capacity at Pennsylvania Station and in the tunnels serving it.

Corridor Capacity

Corridor capacity was not explicitly examined in this study. On the basis of the improvements defined in Program 2 as a minimum, capacity appears to be adequate for anticipated commuter and intercity traffic through 2010. At Pennsylvania Station and the East River tunnels operational improvements or changes may be required to avoid serious impacts, particularly on commuter operations. At other locations the system will be near or at its limit, and a concerted and integrated effort will be required to maximize corridor capacity for all services.

Operating Standards

The projected higher speeds in all programs are based on the assumption that FRA, MNCR, and Amtrak will approve higher speeds on curves and define standards for rolling stock and inspection and maintenance procedures necessary for safe and comfortable operation at those speeds.

Institutional Coordination and Integration

Successful implementation of any major improvement program and practical attainment of the trip times estimated in this study will require a reinvigorated institutional and procedural framework. The direct responsibilities and objectives of the several owning and operating organizations differ significantly. The specific form of some projects, as well as the manner of implementation and cost allocation, can only be determined through compromise based on full consideration being given to all viewpoints. All parties—railroads, government agencies at all levels, and transportation authorities—will need to work in a highly coordinated and cooperative manner to define and realize a common vision of integrated NEC rail services with equitable distribution of all capital and operational costs.

Accessibility of Railroad Stations

The Americans with Disabilities Act of 1990 established specific accessibility standards for physically handicapped passengers for intercity and commuter rail stations and passenger cars. The station improvements project in this study includes an estimate for provision of high level platforms and pedestrian overpasses at those Amtrak stations between Boston and New York not currently so-equipped. However, the special nature of the requirements of this act is considered beyond the general scope of the study, particularly insofar as commuter stations and rolling stock is considered.

NEXT STEPS

Possible alternative improvement programs were identified and characterized in the study described here. No recommendations were made, and no specific plan for upgrading the NEC was presented. Any program of the complexity and magnitude associated with the NEC would have to be preceded by attainment of consensus among the many involved private and public bodies as to goals, funding, and implementation process. Were a program to be initiated, other topics would need to be addressed to support design, construction, and scheduling decisions for any improvements. Logical next steps for any major improvement program should include the following:

1. Testing and analysis to confirm the acceptability of higher speeds on curves and to define standards necessary for safe and comfortable operation at those speeds;
2. Analysis of long-term operating and maintenance costs of alternative improvement programs and rolling stock choices;
3. System capacity and traffic conflict analysis, addressing both long term outlook and impact on phasing of construction projects;
4. Data collection and analysis to refine ridership projections and expected commuter and intercity benefits; and
5. Examination of the future role of rail freight transportation along the corridor and the freight railroad impacts and benefits associated with corridor improvements.

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