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3 **Exploring the Complex Relationship Between Railroad Infrastructure, Operating Constraints,**
4 **Maximum Speeds, and Public Schedules**

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ABSTRACT

Outside the railroad industry, tremendous temptations exist to treat passenger trip times as performance measures or the industry’s health yardstick. However, many factors not known or well-understood by casual observers affect trips times—indeed, some are recognized techniques utilized by infrastructure owners to deliver journey time reductions. Factors triggering running time modifications include: track design, maintenance, layout, special work; infrastructure (structures, signal, power, grade crossings); cant deficiency, tractive effort, braking rates; rules, operating practices, ongoing projects; timetable speeds, and finally schedulers’ decisions on train performance modelling, en-route adjustments, and dwell times. Historical operating documents issued by railroads can be used to reconstruct more specific understanding of what events are associated with which trip time changes, but perishable nature of these ephemeral documents make it difficult. Because some information was never written down, rationale for certain modifications maybe unknowable. At best public timetables offer a general sense of where service offerings were trending; from them it is impossible to know what was really happening. Some opposing industry trends actually give rise to similar schedule impacts, e.g. deferred track maintenance and track rehabilitation both lead to lengthened journey times. Applying forensic analysis methodology to Penn Central’s Mohawk/Buffalo divisions revealed some time degradations can be correlated to specific events associated with downgraded infrastructure and vehicle issues, but overall long-term changes were balanced. Case study of Metro-North’s New Haven Line revealed new stations, necessary safety modifications, increasing congestion, and temporary construction delays all contributed to recent timing changes. To maximize system performance, operators must balance trip-time, capacity, and reliability subject to an overarching constraint of safe operations.

1 INTRODUCTION

2 This paper serves three basic purposes:

- 3
- 4 1. Explains for non-rail-industry audiences many factors behind determination of published public
- 5 timetable trip times between station pairs on conventional railroad networks.
- 6 2. Show that changes in public timetable running times alone is insufficient evidence or
- 7 information to infer or explain happenings in rail industry investment, maintenance management,
- 8 infrastructure stewardship, etc.
- 9 3. Provide ideas on how operating documents (where available) are utilized to reconstruct reasons
- 10 for advertised journey time changes and feel the industry's pulse, while also demonstrating that it
- 11 might not tell the entire story.
- 12

13 It is divided into four major sections:

- 14
- 15 1. Technical and operational factors that affect running times
- 16 2. Operating documents that describe these factors
- 17 3. Methods for constructing a schedule that properly accounts for them
- 18 4. Case studies in forensic schedule analysis:
 - 19 (a) Penn Central's Mohawk-Buffalo Divisions (1956~2010): utilizing only operating
 - 20 documents and modelling methodologies
 - 21 (b) Metro-North's New Haven Line (2009~2016): utilizing institutional knowledge of
 - 22 section schedulers and published sources
 - 23
- 24

24 MOTIVATION

25 Standard methodologies for rail transit planners and schedulers to create service specifications, establish
26 public timetables, create vehicle assignments, traincrew diagrams (pairings), routing plans, and terminal
27 docking plans are well-understood and documented (e.g. (1-3)). However, running times between
28 stations are sometimes seen as empirical observations obtained from operational experience, running
29 time checks, or track occupancy records. Although specialized software is available (e.g. (4,5)) to
30 estimate impacts of numerous factors on runtimes, delays, and network congestion (e.g. (6)),
31 considerations affecting published runtimes are less familiar to outsider stakeholders. Indeed, recent
32 work (7) attempted to infer what was generally happening in the rail industry through retrospective
33 inspection of public timetables. Some outside pressure groups (8), trade press articles (9), and even
34 industry strategy documents (10) cite trip times as a performance measure or goal.

35
36 Advertised times, even in aggregate, should not be seen as performance yardsticks to measure general
37 state of passenger rail. Relationship between system performance capability and published journey
38 times is many-to-one where different confluences of multiple events (some good, some bad) could all
39 result in similar runtime improvements or degradations. Just as it is widely acknowledged that many
40 factors independently cause reduction in on-time performance or line capacity (trains per hour, tph),
41 multiple reasons cause scheduled time modifications; indeed, some factors trade-off with one another.
42 Maximizing on-time performance (11,12) or line capacity is not a reasonable long-term strategy—and
43 good express train running times is only one of multiple factors indicating healthy and well-managed
44 railway systems. The *Railway Races* on Anglo-Scottish grouse trains is one early such example (14),
45 which ultimately ended tragically at Salisbury in 1906 when London & South Western Railway wrecked
46 its premier overnight express with relentless emphasis on journey time.

47

1 Planners performing commuter rail feasibility studies (e.g. (15,16)) are familiar with assumptions and
2 existing conditions that must be defined prior to generating journey time estimates. Beyond
3 infrastructure capabilities and specifications, medium-term operational considerations like track
4 maintenance, train stopping patterns, and rostered equipment all impact advertised trip times. Short-
5 term temporary speed restrictions (TSR), capacity-related delays, or dispatching considerations also add
6 extra minutes, communicated to customers via supplemental schedules or special timetables.

7 **RAILROAD TRACK FACTORS**

9 Track geometry and technologies are fundamental to passenger train operations, ensuring safety at
10 speed. Right-of-way curvature constraints and track design and maintenance parameters are translated
11 to maximum authorized speeds (MAS)—highest speed at which one given train may operate on the
12 given track segment at that specific time—which in turn directly affect published journey times.

13 ***Track Geometry***

14 Figure 1(a) shows a typical Track Chart & Maintenance Program (17) excerpt from a major
15 Northeastern railroad, showing constraints affecting passenger train runtimes. Diamonds above the
16 track are mileposts (MPs). Design track geometry is shown at the bottom. Curve at MP 225 is ~0.3
17 miles long (horizontal scale measurement) and has degree of curvature $1^{\circ}50''$. Design superelevation on
18 Tracks 2&1 is 4". Assuming track geometry is properly maintained within design limits, allowable
19 speeds are given by formulae in 49 CFR 213.329 (Appendix A).

21
22 When contemplating new track construction, track geometry is rarely known before right-of-way design.
23 However, constraining curve radius can be approximated by inspecting aerial photographs or maps.
24 Best-case curve could be sketched out (Figure 1(b)), curve radius measured, then converted to best-
25 possible geometry assumption. (curve radius $\approx 5,730$ feet \div degrees.) A common misconception is that
26 if track geometry is legal at certain speeds, services could operate at that speed. Track speed is the first
27 step in figuring out MAS; many other factors can result in MAS being revised downwards (rarely,
28 upwards). Track speeds provide a lower bound for runtime.

29 ***Track Maintenance***

31 Economic factors like intended traffic, and labor/material costs drive railroad choices of track
32 maintenance levels. FRA's "class of track" designation describes maximum permissible deviation from
33 design geometry in parameters like gauge, alignment, and crosslevel. Whenever track inspectors
34 discover deviations approaching FRA limits, maintenance gangs must be called to restore track profile.

35
36 Track class is an additional constraint over-and-above design geometry. Although a curve geometry
37 might be designed for 75 mph, if track is maintained only to FRA Class 3 standards, passenger trains
38 would be limited to 60 mph. Maintaining to Class 3 standards means, amongst other items, track gauge
39 must be kept between 4'8" and 4'9 $\frac{3}{4}$ " (18). To understand if track maintenance constraints are
40 contributory to lengthening journey times, we can check if FRA track class was downgraded. Some
41 railroads' track charts report this information (Figure 1(a)).

42 ***Special Trackwork***

44 Taking diverging routes through switches and crossings usually requires lower speeds. In North
45 America this is typically shown as a signal speed. Once designed, switch sizes are not normally
46 changed, e.g. No.20 turnouts have a 45 mph MAS.

1 Three situations arise where turnout speeds do change: (1) in track rationalization or normal switch
2 replacement, if space constraints or parts availability dictates, turnouts might be replaced with smaller
3 ones, e.g. No.20 replaced with No.15, with MAS reducing to 30 mph; (2) for speed improvements,
4 straight points may be replaced with curved points, e.g. “curved” No.20 are good for 60 mph while
5 occupying the same footprint; (3) turnouts improperly adjusted, worn, or having incorrect geometry
6 results in TSRs. Advertized running times are affected in each case.

7
8 Special trackwork layouts affect timing in less obvious ways. Removal of critical switches or wyes
9 result in trains making reverse moves to access platform areas or major terminals, adding several
10 minutes. Some railroads eliminated maintenance-heavy switch diamond by replacing standard junctions
11 with single-leads (Figure 1(c)), preserving mainline MAS but requiring diverging moves at lower
12 speeds. Single-lead junctions effectively introduce short single-track segments, additional delays occur
13 when two opposing branch trains need to access the mainline simultaneously.

14 **INFRASTRUCTURE CONSIDERATIONS OTHER THAN TRACK**

15
16 Non-track infrastructure components impact MAS (and triptime capabilities.) Normally, designs
17 maximize latent achievable right-of-way speeds (limited by curvature and terrain). As railroads move
18 through rebuild cycles, components become MAS constraints in some situations.

19 ***Structures***

20
21 Dynamic forces exerted by moving trains on structures are related to equipment axle weights and train
22 speeds. When installed, designs generally support intended maximum load (based on Cooper rating—
23 representation of two typical locomotives and its train) at prevailing line speeds. Situations resulting in
24 structural MAS constraints include: (1) over time, degraded structures are ‘de-rated,’ having their
25 dynamic loads reduced to maintain safety due to compromised members; (2) vehicle weights may
26 increase, resulting in higher loads, thus permissible speeds are reduced to compensate; (3) area linespeed
27 increased due to civil improvements, but a bridge remained qualified only for original speed. Industry
28 references (19,20) on relationships between bridge ratings and speeds are available.

29 ***Signal Braking Distances***

30
31 Standard signalling textbooks (21) or railroad documentation (22) show braking curves for computing
32 minimum signal spacing from design variables like entry speed, vehicle characteristics, number of signal
33 system aspects, and required capacity (minimum permissible headway, tph). Lines are initially equipped
34 with track circuits and signal blocks at correct distances such that all trains (with train-type-specific
35 speed restrictions) can come to a safe stop prior to encountering STOP signal. The system provides
36 sufficient sighting distances and appropriate aspects for anticipated traffic patterns. For given aspects,
37 an inverse relationship exists between capacity and signal design speed. Once installed, track circuit,
38 interlocking, and signal locations are normally fixed. Design speeds are normally higher than civil
39 speeds and therefore do not require restrictions.

40
41 Situations where signal systems requires permanent speed restrictions (PSR) below civil speeds include:
42 (1) traffic pattern changes after signal installation, resulting in inappropriate signal spacing; (2) vehicle
43 characteristics assumptions (e.g. braking rates) in initial design rendered obsolete by vehicle changes
44 (e.g. additional weight), resulting in speed restrictions to match new braking curves to existing signal
45 spacing; (3) track reconfigurations (e.g. siding extension, interlocking expansion) require signal
46 relocations, but desired locations do not work well with existing blocks (expensive to relocate), resulting
47 in lower MAS to provide sufficient braking distance.

1
2 Signal modifications can also require operating speed changes. Removal/addition of automatic
3 intermediate signals result in block length changes, thus changing distance travelled at lower speeds
4 when signal indication is not the most favourable aspect possible. Changes in capability to display
5 aspects results in signals displaying the next most restrictive aspect, changing the speed at which moves
6 could legally be made.

7
8 Systems maintained per original design generally have no impact on operating speeds. However, when
9 signals are modified or simplified to reduce maintenance costs or support different traffic patterns, they
10 could reduce capacity or inadvertently lengthen trip times. References (21,23) in signal design's speed
11 implications are available.

12 13 ***Cab Signal Systems (CSS)***

14 Cab signals are normally designed as overlays to conventional multi-aspect signals. CSS may merely
15 repeat & enforce wayside aspects, provide additional aspects allowing higher speeds, or replace
16 automatic wayside signals with code change points, providing cost savings. Suitably equipped trains
17 can generally access higher MASEs through additional aspects or improved safety from aspect
18 enforcement. CSS does not usually affect trip times once installed, however, where CSS was removed
19 or had capabilities modified (e.g. aspects removed/added), changes to operating speeds can occur after
20 initial introduction.

21
22 U.S. passenger railroads once relied on CSS modifications to enforce curve speeds prior to full Positive
23 Train Control (PTC) implementation, at high-risk locations like Frankford Jct. and Spuyten Duyvil.
24 CSS aspects are enforced at speeds (e.g. 15/30/45 mph) that may not exactly match civil restriction
25 (specified to nearest five mph). Signal engineers use next-most-restrictive aspect at nearest-code-
26 change-point, resulting in e.g. 30mph enforced for 2,200 ft for a 40mph restriction requiring 1,400 ft
27 braking distance. This has measurable impact on triptimes compared to locomotive engineers manually
28 managing deceleration.

29 30 ***Level Crossings***

31 Where roads and railways cross at grade, speed restrictions may be required in high-speed territory
32 (>79mph in U.S.). FRA issued guidelines (24) recommending different protection levels based on train
33 speeds, although it is not clear if this applies to existing crossings or generates new PSRs if crossing
34 protection was not upgraded. In the U.K., enhanced level-crossing protection are required where trains
35 operate at >100mph.

36 37 ***Electrical Supply Infrastructure***

38 On electrified railroads, short-term substation power ratings can limit locomotive power demand (e.g.
39 maximum throttle, or 'dial down' requirements), tonnage, train length, headway, and acceleration,
40 although they do not normally generate speed restrictions. However, resultant achievable speeds could
41 affect runtimes.

42
43 Catenary system designs can have subtle and complex impacts on maximum speeds: catenary pole
44 spacing in central N.J. limits speeds to 140mph even with new constant tension designs (25). Railroads
45 impose TSRs relating to pantograph-catenary contact instability in windy, hot, or cold conditions
46 (typically in variable-tension territory.) Third rail systems are normally limited to 100mph maximum
47 speed; difficulties exist in designing nosepieces to accept shoes at higher speeds.

1 VEHICLE FACTORS

2 Many speed constraints are vehicle-dependent and relate specifically to vehicle performance.

4 *Cant Deficiency (Underbalance)*

5 Limiting speeds (when derailments occur) on continuously welded rail (CWR) with modern fasteners
6 can be much higher than the speed at which passengers feel nauseous or unsteady from curving forces
7 (26). Since passenger comfort constrains MAS, vehicle-based tilting systems were developed to
8 improve comfort, thereby increasing speeds.

9
10 Conventional U.S. passenger equipment normally operate at 3" (76mm) of underbalance; active-tilt
11 equipment operates at 7" (178mm). Each imbalance level gives rise to different MASEs on the same
12 physical curve. Higher underbalances results in faster rail wear. If railroads qualify equipment at a
13 different underbalance level, MAS is changed on most curves, and affects advertised trip times. Figure
14 2(d) shows differential MASEs (27) for United Aircraft's TurboTrain on the Shore Line.

15
16 U.K.'s vehicle size, weight, and suspension design allows conventional equipment to operate at 150mm
17 (5.9") of cant deficiency; at one time Railtrack was exploring operating non-tilt passenger equipment at
18 165mm (6.5") of "exceptional" cant deficiency. Tilting equipment in Europe can operate at between
19 225mm and 300mm of underbalance (28).

21 *Installed Power*

22 On diesel-powered trains, engine horsepower/power-to-weight ratio directly impacts acceleration rates,
23 and maximum achievable speed. Acceleration rates and loading times make tremendous differences to
24 journey times, particularly on curvaceous routes peppered with PSRs or local service with many stops.
25 If railroads improved locomotive horsepower or assigned fewer cars per train, published runtimes are
26 affected. Indeed, British Rail had timing profiles for each consist type down to whether HSTs had
27 seven, eight, or nine coaches, each class of electric locomotives, and trailing tons hauled (Figure 2(j)).
28 When Britain's InterCity 125 HST trainsets were introduced on regional lines with 75~90mph
29 maximum speeds, 10%~15% triptime reductions were nevertheless achieved (compared to previous
30 coaches and locomotives), due to improved acceleration and braking capabilities.

32 *Braking Rates*

33 Vehicle technology advancements gave rise to differential braking rates. Most modern U.S. passenger
34 coaching stock utilizes two disc and two tread brakes per axle; Amtrak's Acela utilizes three disc brakes
35 per axle to achieve 26% better braking rates (29).

36
37 On HSTs, disc-and-tread combinations delivered 9%g (0.88 m/s², 2.0 mphps) of service brake, enabling
38 operations at 125mph on legacy lines equipped with signal systems designed for 100mph (30). This
39 allowed for tremendous time reductions, not only from the 125mph capability but also reduced
40 deceleration time upon approach to every PSR and station stop. Hydrostatic brakes designed to deliver
41 12%g (12% of acceleration due to gravity, 1.17 m/s² or 2.6 mphps) braking rates on British Rail's
42 Advanced Passenger Train was not commercially successful, but electro-pneumatic brakes (EPBs)
43 delivered more predictable and responsive braking performance in suburban multiple-units and heavy
44 freight trains.

45
46

1 OPERATIONAL PRACTICES

2 Operating practices also impact published journey times.

4 *Rules or Staffing-based Delays*

5 Changed operating rules or staffing requiring existing infrastructure to be operated differently (typically
6 for increased safety margin) can lengthen trip times. Examples: (1) some railroads require trains to hold
7 outside station if another train is already platformed (especially at low platforms), resulting in runtime
8 degradation for trains in the opposing direction; (2) reduction in yard personnel leads to more through
9 trains stopping to operate hand-throw switches; (3) reduction in trainman or station positions lead to
10 lengthened intermediate station dwell times; (4) reduction in towerman positions or hours lead to
11 reduced en-route flexibility, making it difficult to pass slower trains or require routing via slower tracks.

13 *Work Zone Delays*

14 Track conditions affect speeds, but so do track maintenance activities. As train volumes increase due to
15 growth or traffic consolidation from duplicate lines, maintenance windows became narrower, making it
16 difficult to perform work effectively and clear up prior to each train's arrival. It is now common for
17 express trains to stop on the mainline while track gangs clear up, and then pass the work site at reduced
18 speeds. Delays from "slow zones" can be so severe that railroads issue special construction timetables
19 (Figure 1(d)) reflecting extended timings.

21 *Single Tracking Delays*

22 On double-track lines, major projects require trains to be single-tracked past the work site when one
23 track is out-of-service. Schedules are written such that opposing trains do not meet near single-tracked
24 sections, so trains do not have to wait to clear. However, moves through interlockings (at either end) are
25 made at reduced speeds; in densely trafficked areas several minutes' wait for opposing trains to clear is
26 inevitable. If track rehabilitation projects are planned in advance, these delays are written into published
27 schedules.

29 *Approach Control Delays*

30 When remotely-controlled switches are thrown from high speed routes to slower routes, most signal
31 systems display restrictive aspects to approaching traffic, to enforce speeds through junctions, even
32 though blocks ahead maybe unoccupied (31,32). In congested locales, this can add minutes
33 (colloquially, "burn time") to runtimes. When routing plans are modified, scheduled times can change
34 substantially.

36 *Train Slot Delays*

37 At junctions or single track territory, trains are planned to operate within designated timetable slots to
38 avoid occupying key interlockings simultaneously. Slots do not always line up with unconstrained
39 running time between them, thus extra time waiting for slots is written into timetables (see "Circle
40 Time" discussion later.)

42 MAXIMUM AUTHORIZED SPEEDS

43 Operationally speaking, railroad MAS is generally given by Employee Timetable. The Timetable is a
44 living document issued to operating employees, periodically updated by proper authority. It is not the
45 only document that governs MAS for a given location at a given time. It is said that "MAS is a long

1 math problem where the answer is a single number.” Although speeds are shown on other sources like
2 track charts, diagrams, etc., speeds shown therein are necessarily simplified, and not authoritative. For
3 simplicity, typical practice in Northeastern U.S. is discussed here.

4 5 ***Hierarchy of Documents***

6 Employees in charge of trains (or trackcars) must be familiar with all operating documents. In
7 descending order of generality:

- 8
- 9 1. Operating Rule Book
- 10 2. Employee Timetable: Schedules & Special Instructions
- 11 3. General Orders
- 12 4. Bulletin Orders
- 13 5. Train Orders (issued by Dispatchers)

14
15 Some railroads also utilize General Notices and Operating Notices, of informational nature.

16 17 ***Operating Rule Book***

18 Rule Books provide instructions governing all aspects of operations and define how other
19 documentation are interpreted. All rules therein apply unless superseded explicitly by more specific
20 instructions. MASes are not discussed here, because speeds are necessarily specific to one location.
21 Geographically specific information is given in the Timetable.

22 23 ***Employee Timetable—Schedules***

24 Employee Timetable contains the authority for train movements under “timetable and train order
25 operation”. Station pages define station locations. Schedule pages (Figure 2(a)) show authority to
26 occupy track by each train at each location at specific times, subject to superiority of trains. Although
27 timetables have more timing points (e.g. interlockings, employee stops) than shown in public schedules,
28 they do not typically provide rationales for timing, thus it is only a little better than public schedules for
29 understanding why running times changed. City-to-city running times divided by rail mileage are not
30 good indicators of MAS, or even average speeds while underway.

31 32 ***Employee Timetable—Special Instructions***

33 Special Instructions are where MASes are defined. MASes are defined under three headings (27):

- 34
- 35 • Maximum Speeds Unless Otherwise Specified (i.e. “Line Speeds”, Figure 2(b)),
- 36 • Permanent Speed Restrictions—Curves & Bridges (also “Civil Restrictions”, Figure 2(c)), and
- 37 • Special Maximum Speeds (more specifically, “Equipment Restrictions”, relating to train
38 equipment operated, Figure 2(d)).

39
40 To figure MAS for specific locations, first look up Line Speed, then check Civil Restrictions and lower
41 MAS if necessary, and finally determine Equipment Restrictions—including blanket and location-
42 specific restrictions. MAS thus determined is the base under normal operations, to which time-specific
43 conditions may be applied.

44 45 ***General Orders***

46 General Orders (GO) are periodically issued documents that make permanent changes to the Rule Book,
47 Employee Timetable, or Timetable Special Instructions under the authority of the Superintendent of

1 Operations. GO (Figure 2(e)) may be issued in sticker form; employees are expected to moisten and
2 paste over relevant timetable pages (like stamps), such that new data covers over superseded
3 information. GOs may also be issued in loose-leaf format, replacing superseded pages.
4

5 When the Engineering Dept. makes permanent changes to infrastructure, resulting in MAS changes or
6 new infrastructure being put “in service”, they are described in GOs (33). If TSRs are in effect for
7 prolonged periods, the Superintendent may elect to print TSRs in GOs.
8

9 GOs could help track general state of railroad maintenance, because it contains a partial history of TSRs.
10 When analyzing GOs, each and every single one must be obtained. They are issued with sequence
11 number and effective date, so completeness of data records are easily determined. Each GO is issued
12 with a summary page describing changes made; thus a reasonably complete history (and corresponding
13 journey time impacts) is usually readily reconstructable.
14

15 ***Bulletin Orders***

16 Bulletin Orders (BOs, e.g. Figure 2(f)) are frequently issued documents making temporary changes to
17 operating documents. Most railroads have a daily BO issued under different names, e.g. Daily Train
18 Operations BO, TSR Bulletin, etc. This document is where most TSR information could be found.
19

20 However, a TSR by definition occurs due to temporary conditions, and thus should not appear as
21 permanent changes to operating documents. Certain TSRs, e.g. allowing tracks to settle for 72 hours
22 after tamping, are lifted in three days. Others, like “mud spot” conditions, might persist for several
23 weeks until track gangs could effect repairs. Other TSRs could be associated with poor tie conditions
24 being unable to hold gauge, leading to downgraded track class, which might not be repairable until
25 rotted ties are replaced by travelling production gangs and could persist for months. These might stay in
26 the BO and never makes it into GOs, as long as authorities intend to capially rebuild track when
27 scheduled.
28

29 BOs carry information on Working Limits, requiring trains to contact Track Foremen to obtain
30 permission through work sites. This generates delays and prescribes an MAS past the work site,
31 although it is technically a signal speed, and not a TSR (Working Limit Stop Sign is considered a
32 “signal.”)
33

34 BO data is perhaps the best resource to understand state of maintenance relating to MAS and
35 consequently published speeds. The challenge is, BOs are temporary changes and therefore never
36 pasted into timetable books. Although operating employees are required to have all BOs in effect on
37 their person while on duty, when they are superseded by Summary BOs, GOs, or Timetable Reprints, all
38 superseded BOs are typically discarded to avoid confusion. Therefore, railroad state of maintenance is
39 perishable information: unless you were there at the time, it is highly unlikely that a reliable, accurate,
40 and complete account of factors affecting travel speeds can be reconstructed.
41

42 Despite computerization, records that change daily are oftentimes not retained electronically for long
43 periods, because business justification for their retention usually is not there. It is said, “in Operations,
44 you’re only as good as your last rush hour; nobody remembers great work you did last Thanksgiving.”
45

46 BOs also promulgate train schedules revisions, typically for special movements—when necessary to
47 convey to all operating employees one-day-only schedule e.g. for Circus Trains. Normally, schedules
48 (and consequently advertised times) are not modified in response to TSRs, even for ones lasting several
49 months. It is therefore difficult to infer state of maintenance using public running times.

1
2 BOs identify general speed restrictions in effect for one-day only, e.g. Heat Restriction, or Reduced Rail
3 Adhesion. Most railroads utilizing CWR issue speed restrictions on exceptionally hot days to guard
4 against track buckling risks (e.g. 20mph MAS reduction when highest forecast temperature is >85°F or a
5 25°F change in temperature (34), although cut-off and restriction severity varies by railroad and region).

6 7 **Train Orders**

8 Train Orders (TO), e.g. “Form D,” “Form M”, or “Form 19,” (Figure 2(g)) are issued to specific trains
9 and may contain instructions superseding anything discussed above. Typical uses include:

- 10
11 • **As Track Warrants** to convey movement authority, e.g. when a superior train is running so late
12 that the Dispatcher allows an opposing inferior train to make progress down the line and meet it
13 at a different siding. Dispatcher issues TOs to both trains superseding timetable authority,
14 instructing superior train to hold at a non-scheduled location, and inferior train to meet it there.
- 15 • **To Remove Track or Signal System from Service**, e.g. when Maintenance Foremen require
16 exclusive use of blocks to effect repairs.
- 17 • **To Issue Emergency Speed Restrictions (ESRs)**, e.g. when routine track patrols find defects
18 like broken joint bars, heat kinks, or pull-aparts such that, to reduce derailment risk, trains must
19 travel at lower than MAS. Engineering documents like the MW-4 (Figure 2(h)) normally
20 prescribe train speeds over each defect type.

21
22 Unfortunately, TOs containing ESR records are also perishable, most railroads requiring retention for
23 only one to seven days. TO is also not the only way to communicate ESRs to train crews. Northeastern
24 railroads allow daily BOs to be amended via radio with additional speed restrictions. Even if historical
25 TOs were available, at best it represents an incomplete record of speed restrictions.

26
27 Computerized records seldom deliver sufficient detail for useful forensics. Centralized Traffic Control
28 (CTC) playback “tapes” or recorded radio voice records are typically expunged after 2~4 weeks, and
29 systems are normally designed for specific known-time event investigation access, rather than extensive
30 data trending analysis.

31
32 Track defect prevalence can correlate with state of maintenance (but it is not an absolute indicator,
33 because maintenance strategy can also drive this number). Broken joint bars rarely occur if track
34 structure is properly supported. Heat kinks are unusual with correctly adjusted CWR, properly ballasted
35 shoulders, and functioning fastening systems. Pull-aparts can occur during extremely cold weather
36 particularly at spots with internal rail defects, head cracks, engine burns, or defective welds; they are
37 minimized by frequent rail grinding and prompt rail repair. Although track inspection records must be
38 kept pursuant to 49 CFR 213.241 and are subject to inspection by the FRA, they are generally
39 unavailable to researchers.

40 41 **DEFINING PUBLIC TIMETABLE RUNNING TIMES**

42 To understand published journey times, it is worth pondering how train schedulers arrive at trip times
43 from constraints discussed above. For clarity, British practice is discussed here. North American
44 passenger schedulers utilize similar concepts (e.g. (6)), but no industry standard exists.

1 ***Train Performance Calculator (TPC)***

2 TPC models locomotive performance over specified terrain with defined speed restrictions. Basic inputs
3 are physical characteristics (speed restrictions, gradients, curvature, station locations), traction
4 characteristics (wheel adhesion, horsepower, braking rate), and load characteristics (tonnage, load,
5 rolling resistance, wind resistance, etc.) The output is unconstrained running time—before considering
6 station dwell times, congestion, signal checks, TSRs, etc. (i.e. theoretical minimum under ideal
7 conditions.) Normally, four Sectional Running Times (SRT) types are given for each station-to-station
8 segment: stop-to-stop, stop-to-pass, pass-to-stop, and pass-to-pass. “Stop-to-pass” means train stops at
9 first station but by-passes second station; acceleration from standing stop at first station is included,
10 required braking to stop when arriving at second station is excluded (but required braking to comply
11 with any PSRs in second station’s limits is included.)

12
13 TPC models are provided by industry vendors (35) and typically validated by running time checks
14 requiring operations of special test trains. To build speed profiles, schedulers traditionally utilize
15 onboard speedometers and record mph readings every few seconds. To understand traction output,
16 another scheduler records throttle and brake positions and times actuated. (Today, this work is
17 performed with computerized dataloggers.) Schedulers also note any signal checks or unusual
18 conditions. Speed profiles and control manipulations are compared to TPC outputs and internal
19 parameters tweaked until it reproduces recorded traction performance under various conditions.

21 ***Square, Circle, and Triangle Times***

22 Building a public schedule from raw running times necessitates addition of extra allowances to ensure
23 train operations reliability and achievability under field conditions (i.e. to make schedules “robust”).
24 The three types of en-route time adjustments are:

- 26 • **Engineering Adjustment [Square Time]** or “Recovery Time”: Extra minutes or fractional
27 minutes inserted wherever major track engineering work or TSRs are in effect. They are
28 location-specific and typically derived by comparing TPC runs under unconstrained condition
29 with TPC runs with TSRs in force.
- 30 • **Routing Time (Circle Time)** or “Pathing Time”: Extra time inserted upon approach to major
31 junctions, to absorb delays resulting from signal checks, waiting for conflicting movements to
32 clear, or as insurance against missing critical slots at busy junctions. They are junction-and-time
33 specific and derived from inspection of stringline charts and junction utilization/clearing times.
34 They are also inserted for trains running on close headways where a following train may operate
35 for long stretches at less than MAS due to adverse signal indications (called “running on double
36 yellows.”) Accuracy and adequacy is critical, as trains missing assigned slots on busy lines can
37 have knock-on effects far beyond the immediate locale.
- 38 • **Performance Allowance <Triangle Time>** or “Pad”: Time inserted upon approach to major
39 stations whose purpose is to absorb unanticipated en-route delays not explicitly allowed for in
40 Square and Circle times, like individual variations in driver performance (i.e. operating
41 techniques and skills of different locomotive engineers), e.g. experienced operators typically shut
42 off power and coast at an earlier point if approaching major terminals with allowance to spare.

43
44 Published departure-to-arrival times are the sum of all appropriate station-to-station times plus any
45 Square, Circle, and Triangle times inserted en-route (Figure 2(j)). Taken together, en-route adjustments
46 should account for all operational and infrastructure factors discussed in this paper’s first half. It is
47 impossible to back-out en-route adjustments from public schedules without access to rail industry
48 documentation. Fortunately, U.K. Network Rail’s Working Timetables (WTT) are published for all to

1 see (36). However, the U.S. passenger rail industry does not generally publish en-route adjustments in
2 schedule documents, not even in Employee Timetables. Adjustments are typically domains of railroad
3 scheduling departments and are known under names like “schedule skeleton.” In some cases, these
4 bases for running times are carried in individual section scheduler’s heads and never written down.

5
6 Understanding scheduling rationale and reasoning behind each adjustment requires either interviewing
7 the section scheduler when the timetable was written, or determining all contemporaneous constraints
8 schedulers should have taken into consideration when determining the published running time.

9 10 ***Station Dwell Times***

11 En-route adjustment do not cover time required for station work, typically defined as the period between
12 time when a train is fully berthed in station (i.e. wheels stop moving), to time when doors are closed and
13 “okay to go” is given.

14
15 Dwell times are open to debate even amongst train schedulers because they can include time required for
16 passengers to make transfer connections, to service trains at major terminals (typically, food and
17 baggage, more rarely, fuel, water, change of gauge, change of host railroad, etc.), required extra time for
18 hand-off between incoming and relief crews, combining or separating a train’s different sections. On
19 commuter lines it also accounts for platform congestion and passengers holding doors. On mixed
20 freight-and-passenger trains it can include required time for switching freight cars. Frailey (37)
21 discusses North American passenger train switching operations extensively, including W.E. Deming’s
22 landmark study for the Burlington Northern.

23
24 Fortunately, station times are easier to understand; they are often published in public timetables for
25 major terminals. However, suburban carriers do not typically publish dwell times at intermediate stops
26 and may even have flag stops or situations (e.g. evening outbound drop-offs) where trains are permitted
27 to operate ahead of published schedule. They can also be hidden, as mixed freight-and-passenger trains
28 can make freight stops with unpublicized dwell times, and trains often have unadvertised operational
29 stops requiring dwell times—even on commuter lines, employee stops or time required to receive train
30 orders are omitted from public schedules.

31 32 **FORENSICS OF RUNNING TIME DEGRADATIONS**

33 Research has thus far established that modifications in public timetable running times result from
34 changes taking place in these general categories:

- 35
36
- 37 • Track design geometry, maintenance, layout, and special work
 - 38 • Infrastructure factors like structures, signal, power, and grade crossings
 - 39 • Wheel-rail interaction issues like cant deficiency
 - 40 • Vehicle factors like tractive effort and braking rates
 - 41 • Operating rules, practices, and ongoing projects to rehabilitate infrastructure
 - 42 • Maximum authorized speeds per Timetable (from above constraints)
 - 43 • Scheduler’s decisions:
 - 44 1. Train performance modelling
 - 45 2. En-route adjustments
 - 46 3. Station dwell times

1 It follows, therefore, to fully understand *What Happened to Speed* (7), specifics of what changed in each
2 category during the study period for the services in question should be examined. Although public
3 timetables offer a general sense of where service offerings were trending, they cannot tell us whether
4 these changes resulted from schedulers' decisions (for either marketing or operational reasons),
5 deterioration of physical infrastructure, ongoing projects to restore the plant, or permanent system
6 upgrades. Indeed some factors counteract one another, or indicate completely opposite industry trends.
7 For instance, deferred track maintenance and increases in track rehabilitation both lead to lengthened
8 journey times, and passengers would be none the wiser.

10 It is possible for published journey times to remain static after substantial upgrades increasing MAS, if
11 schedulers elect to utilize upgraded capabilities to improve reliability or provide additional dwell time
12 for connections at intermediate stations. Triptimes capabilities could be improved even while physical
13 plant is deteriorating by changing operating practices, or reduce congestion by reprioritizing and
14 cancelling trains.

16 Although advertised trip times and the industry's health may not be all that correlated, longitudinal
17 analysis of journey times can be a high-level screening tool to identify corridors of interest where in-
18 depth forensic analysis could reveal reasons behind runtime changes. Secondary sources written by
19 contemporary observers (e.g. (38)) can sometimes provide helpful insight into management actions and
20 decision rationales.

22 **THIS HAPPENED TO SPEED: CASE STUDY OF PENN CENTRAL'S MOHAWK AND BUFFALO DIVISIONS**

23 Exploring this hypothesis a little further, we examine a case study utilizing some sources discussed
24 above. It provides a more specific (but still incomplete) explanation as to *why* public timetables were
25 revised during the study timeframe. Limited to the former Penn Central (PC) Northeastern Region, this
26 methodology can be applied to any corridor of interest.

28 When correlating passenger corridor performance with infrastructure investment, three dimensions
29 should be considered: service speed, capacity (trains per day operated at design speed), and reliability
30 (probability that planned timing is actually achieved). In service design of mixed traffic corridors,
31 published service speeds often results from trade-offs along these dimensions. MAS and resulting SRTs
32 are practically the only elements where infrastructure owners exercise complete control.

34 The *20th Century Limited* in 1966 ran 14% faster (16:00) than *Chicagoan* (18:30), chiefly because of
35 shorter scheduled dwell times (0:35 versus 1:48) at intermediate stations. Today's westbound *Lake*
36 *Shore* (19:05) has less dwell time (1:22) built into its schedule, even when marshalling time at Albany is
37 included, but nonetheless takes 3% longer than 1966's *Chicagoan*.

39 ***Scheduled Dwell Time***

40 Figure 3(a) shows dwell times in the Region of westbound New York-Chicago trains leaving Grand
41 Central Terminal in late evening (*Chicagoan*, PC #63, *Lake Shore*), corralled from contemporary public
42 and employee timetables (27,39-42). A few unpublished times were estimated. Beginning in 1961,
43 dwell times mushroomed, especially during Penn Central's era. Amtrak stopped this in 1971, "making
44 trains worth riding again." Dwell time growth began again at Albany in 1979; however, it was
45 minimized at other locations.

47 Figure 3(b) shows that N.Y. Central assigned dwell times quite deliberately and methodically, with
48 overnight trains having longer dwell times. In 1963, all trains had extra time at Buffalo, even important

1 trains like *20th Century Limited* were booked for eleven minutes. Significant dwell time was also
2 included at intermediate points like Utica and Rochester.

3
4 Dwell times have critical impacts on train operations. When delays occur outside the operators' control
5 (e.g. weather, passenger action, etc.), extra dwell time can help absorb impacts. Typically, schedulers
6 use average running time, but recovery time at major terminals can be derived from 95th-percentile
7 time. Departing westbound, by maximizing the probability of leaving Buffalo on-time (95th-percentile
8 ensures trains leaving Buffalo have only 5% chance of lateness), it minimizes downstream impacts by
9 not having trains operate out of slot.

10
11 Amtrak added extra recovery time at stations where host railroad change is necessary (e.g. Cleveland), at
12 crew change points (e.g. Toledo), to allow time required for coordination between different dispatching
13 offices and relief paperwork.

14 ***Sectional Running Times***

15
16 Figure 3(c) presents a rather complex picture of those same trains' SRTs. Relative periods of stability
17 existed 1983~1997, but gentle upwards trends nonetheless existed, likely contributing to the perception
18 that trains were getting slower. Marked deterioration occurred 1968~1971, adding 35 minutes (12%) of
19 runtime. Another turbulent period arose 1999~2003, likely associated with the Conrail split when major
20 operational changes occurred on the Chicago Line. As passenger train performance became political at
21 the Federal level circa 2008, public timetables became more of a contractual commitment, rather than a
22 reflection of infrastructure capabilities or a quantitative description of operational intent.

23
24 During 1976~1980 SRTs were abnormally long and likely not entirely due to deterioration of
25 infrastructure. Relevant special instructions (40) states:

26
27 "AMTRAK Engines, Class SDP-40F, in number series 540 to 649, are restricted as follows--trains with one SDP-
28 40F Unit alone [...] must not exceed 40 MPH on curves of 1 degree 30 minutes or greater." (PCRR Rule 1157-G1b)

29
30 It then lists 45 and 22 such curves on Mohawk and Buffalo Divisions respectively. These 67 severe
31 speed restrictions applying to passenger trains partly explain increased running times.

32
33 Interestingly, introduction of RoadRailers in 1993, and cancellation of Amtrak Mail in 2004 and
34 ExpressTrak in 2006 did not have noticeable impacts on scheduled times—at least not in this Region.
35 Since mid-2000s, Amtrak has utilized TPC to derive pure run time and produced standardized schedules.
36 Different categories of scheduled time allowances are explicitly documented internally.

37 ***Changes in Infrastructure***

38
39 Figure 3(d) shows histograms of MASes for passenger trains. In October 1970, despite rail industry
40 issues in the Northeast, significant portions of Main Line were available for 75-80 mph operations, with
41 almost 40 miles qualified for 85 mph primarily west of Seneca River (27). However, infrastructure was
42 degrading fast during the first years of Penn Central's bankruptcy:

43
44 "Applies in Buffalo Division: Passenger Trains--79 mph over the entire Division." (PC GO 407 (aa), 1/1/71)

45 "Intermittent inductive Automatic Train Stop [ATS] System on the entire region, out of service." (PC GO 409 (a),
46 2/1/71)

47
48 ATS was deactivated as a maintenance cost-saving measure. By February 1971, numerous TSRs had
49 noticeably increased slow orders in 30, 50, and 60 mph categories (33). ESRs may have been even more

1 numerous. By 1978, the de-facto speed limit over entire Region was 75 mph. As infrastructure slowly
2 returned to a state-of-good repair, speed profiles mostly returned to normal by February 1997, along
3 with substantial new segments of 90, 100, and 110 mph running. Higher-speed running, which requires
4 cab signals and higher superelevation on curves, occurred east of CP-169 where passenger traffic
5 dominates. West of CP-169, where heavy freight trains from Alfred E. Perlman Yard joins the Main
6 Line, the highest MAS was 79 mph.

7
8 Figure 3(e) shows simplified TPC runs using timetable MASEs, indicating infrastructure speed
9 capabilities indeed did degrade beginning in 1971 and reached a low point in 1978, but recovered by
10 1997. This correlates nicely with the SRT findings. 110 mph running contributed 3 minutes' savings
11 between Albany and Schenectady, but Figure 3(f) shows time was lost en-route to Utica due to new or
12 more severe restrictions.

13 14 ***Nothing Happened to Speed (at Least not Around Here)***

15 This is not a definitive history of train speeds on the Mohawk and Buffalo Divisions, but it demonstrates
16 some factors already discussed. Passenger train scheduling is a complex discipline and a multitude of
17 issues are at work, all of which affect public timetable end-to-end trip times. Financial ramifications and
18 difficult public sentiments are consequences of inappropriate advertised running times.

19
20 Over a 50+ year study period, runtimes have basically remained at about 4:45 from Albany to Buffalo,
21 punctuated by periods when specific technical issues (only some of which are known from this analysis)
22 have elongated travel times followed by recovery once issues were addressed. One can either rejoice in
23 the successful achievement of state-of-good-repair, or regret that no true speed improvements were
24 evident from this data.

25 26 **IT'S NOT ABOUT SPEED: CASE STUDY OF METRO-NORTH'S NEW HAVEN LINE**

27 Scheduling is a delicate balancing act. Here, we get behind the scenes a little to understand decisions
28 and analytics supporting these actions performed every day in railroad scheduling offices nationwide.

29 30 ***The Long View: 1940~2009***

31 Figure 4(a) shows running times for one New Haven Line early morning express train (Grand Central
32 arrival at ~08:30) over the last 75 years. Journey times did not change from 1940 to 1970, excepting
33 one minor revision in stopping pattern between 1940 and 1955. Ownership and sponsorship of
34 commuter services turned over to the public sector on October 27, 1970 under a purchase-of-service
35 contract, leading to dramatic changes. Train paths formerly serving intercity clientele originating from
36 far as Springfield, Mass. were truncated to New Haven, Conn. and saw extra stops added for
37 commuters' benefit. In 1973, new 'Metropolitan' M-2 electric multiple unit equipment with better
38 acceleration and top speed was introduced, together with high-level platforms, which enabled additional
39 stops to be added while triptime was further reduced. Timings remained relatively stable until 2009,
40 although increasing customer demand and expectation for service reliability caused slight upward
41 trends. Nonetheless, express trains were still scheduled 14% faster in 2009 versus 1940.

42 43 ***Service Reliability: 1983~2012***

44 Customer demands and operational achievements for more reliable service is borne out in Figure 4(b).
45 From 1983~2012, trade-offs moved towards scheduling longer running times to assure better reliability
46 and to account for expected delays due to track congestion. This was a period of tremendous growth in
47 train volumes and ridership, particularly during rush-hours at Mott Haven Junction in the Bronx (MO)

1 which came to be operated near design capacity. Despite MO having been rebuilt in a new layout with
2 higher-speed switches and CTC cutover in June 1993, it remained a flat junction. Figure 4(c) shows all
3 trains approaching MO from all three lines during typical morning peak. Higher throughputs required
4 more precision in operations (because each train slot was now open for a shorter time-window), which
5 translated into incremental needs for additional recovery time on the approach to MO, adding two
6 minutes. Schedulers carefully balanced triptime, capacity, and reliability but it resulted in a little
7 runtime elongation.

8 ***Impacts of Extraordinary Incidents: 2013***

10 Figure 4(d) shows impacts of three major incidents in 2013. In May, a joint-bar failure resulted in
11 changes to track inspection procedures, which required more on-track time (*II*); in July, a freight-train
12 derailment resulted in an emergency four-month program to eliminate “mud spots” within a busy track
13 section, which introduced TSRs and impacted reliability. In December, an overspeed accident resulted
14 in FRA Emergency Order (EO) 29 requiring a second headend crewmember at braking distance from
15 where MAS decreases by more than 20 mph unless civil speed protection via cab signal modifications
16 were in place.

18 Impacts of these changes are best visualized in Figure 4(e), a colour-chart of minimum observed (i.e.
19 best-case achieved) inbound running times. In Period 1 (before May), peak trains had correct SRTs to
20 maintain reliable service. During Period 3, when TSRs and track outages were in effect for
21 infrastructure remediation, normal recovery times were simply insufficient to absorb delays incurred
22 particularly near MO during morning rush. There was a brief reprise during Period 4 after work
23 completion, but during Period 5 due to operational changes required by EO29, actual running times
24 lengthened again. These impacts were not reflected in public timetables due to their varying nature.

26 ***Addressing the Maintenance/Operation Balance: 2009~2016***

27 Figure 4(f) shows differential SRT analysis from Control Point (CP) to CP drawn from recent operating
28 schedules. We discussed rationale behind each change with section schedulers responsible for the
29 territory. Two changes (green) relate to permanent infrastructure change (two new stations opened); the
30 blue change accounts for EO29 cab signal modifications to provide civil speed protection; and two
31 changes (orange) relate to colour-chart work (Figure 4(e)) that identified increasing congestion around
32 Stamford for which insufficient SRT were previously allocated. Majority of triptime increases (red) are
33 due to planned temporary construction conditions, which are restored when maintenance work was
34 complete.

36 Main reasons behind apparent cumulative increases in triptimes were in fact specific changes happening
37 at accelerated pace due to simultaneous New Haven Line infrastructure improvements taking place.
38 Many projects—like catenary replacement, track maintenance, bridge reconstruction, drainage
39 improvement, and PTC installation—are absolutely vital to state-of-good-repair and usually invisible to
40 commuter ridership. Combination of construction volume and train frequency simply got to the point
41 where moving the few available minutes of engineering allowance around was insufficient to cover all
42 work required, resulting in net journey time increases.

44 **THE NUANCES OF SPEED ON THE RAILROAD**

45 Through technical material presented and case studies, we have seen that right-of-way, track,
46 infrastructure, vehicle characteristics, and operating practices can all affect scheduled times. To
47 properly understand all speed constraints, timetable special instructions, general orders, bulletin orders,

1 and potentially even specific train orders should be studied. When constructing timetables, we add
2 engineering, routing, and performance allowances, and station dwell times to pure run time to arrive at a
3 realistic schedule. Therefore, it is impossible to infer what was happening on the railroad by reading a
4 public timetable.

6 *Speed, Capacity, and Reliability Trade-Off*

7 Figure 4(g) represents one way to consider these issues. To maximize system performance, train
8 operators must balance trip-time, capacity, and reliability subject to an overarching constraint of safe
9 operations. Minimizing advertised journey time is no more of an appropriate goal for the passenger rail
10 industry than maximizing trains-per-hour or on-time performance. Infrastructure investments, when
11 complete, can typically improve all three variables in absolute terms, but when projects seek to
12 “maximize” one variable, they typically do so at the expense of the other two equally important service
13 attributes.

14
15 The authors hope that complex relationships between published journey time and state of the industry is
16 better understood in the public sphere from considerations outlined in this paper.

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30
31

1
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12 Timetable No.6, pp.188-189, effective 1972-10-29—Line Speeds; (c) Civil Speed Restrictions; (d)
13 Equipment Restrictions. Temporary speed restrictions: (e) Penn Central Transportation Company
14 (PCRR) Northeastern Region General Order No.604, effective 1972-12-26; (f) PCRR Northeastern
15 Region, Buffalo Division Bulletin Order No. 6-185, effective 1974-02-20; (g) PCRR Train Order
16 (“Form 19”) advising southbound trains of a track obstruction at Milepost 113-114; (h) PCRR Manual
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34
35

(a) 101 TO BLACK ROCK AND BY-ABS-TCS

WESTWARD—FIRST CLASS

STATIONS	WESTWARD—FIRST CLASS									
	39	5741	15	65	27	25	17	57	19	21
MAIN LINE	The Cayuga Passenger	A.R.R. Passenger	Ohio Limited Passenger	Herkoff Station Passenger	New York Limited Passenger	West Shore Limited Passenger	Wabash Passenger	Glenn Limited Passenger	Wabash Passenger	North Star Passenger
	Daily	Daily	Daily	Daily	Daily	Daily	Daily	Daily	Daily	Daily
See Note										
101	2:38	4:35	6:45	7:05	7:35	8:25	9:20	9:45	11:10	
Albany	2:43	4:40	6:50	7:10	7:40	8:30	9:25	9:50	11:15	
7	2:58	4:55	7:05	7:25	7:55	8:45	9:40	10:00	11:30	
Schenectady	3:16	5:13	7:23	7:43	8:13	9:03	10:00	10:20	11:50	
Hoffmans (CP11)	3:33	5:34	7:43	8:03	8:33	9:23	10:20	10:40	12:20	
Amsterdam	3:41	5:44	7:53	8:13	8:43	9:33	10:30	10:50	12:30	
No. Ilion (CP2s)	4:29	6:30	8:39	8:59	9:29	10:19	11:19	11:35	1:16	
Utica	4:40	6:40	8:50	9:10	9:40	10:30	11:30	11:45	1:26	
Rome	4:45	6:50	9:00	9:20	9:50	10:40	11:40	11:55	1:31	
Canastota (CP24)	5:01	7:10	9:20	9:40	10:10	11:00	12:00	12:15	1:46	
Kirkville (CP35)	5:37	7:43	9:59	10:19	10:49	11:39	12:39	12:54	2:23	
Syracuse	5:56	7:42	9:48	10:08	10:38	11:28	12:28	12:43	2:32	
CP3	5:44	7:50	10:06	10:26	10:56	11:46	12:46	13:01	2:40	
CP5	5:51	8:01	10:13	10:33	11:03	11:53	12:53	13:08	2:47	
CP9	6:05	8:15	10:27	10:47	11:17	12:07	13:07	13:22	3:14	
Lyons	6:37	8:47	10:59	11:19	11:49	12:39	13:39	13:54	3:46	
Newark	7:06	9:16	11:28	11:48	12:18	13:08	14:08	14:23	4:15	
Waynesport	7:03	9:13	11:25	11:45	12:15	13:05	14:05	14:20	4:12	
Brighton	7:16	9:26	11:38	11:58	12:28	13:18	14:18	14:33	4:25	
Rochester	7:22	9:32	11:44	12:04	12:34	13:24	14:24	14:39	4:32	
Ames St. Jct.	7:31	9:41	11:53	12:13	12:43	13:33	14:33	14:48	4:39	
Chili Jct.	7:32	9:42	11:54	12:14	12:44	13:34	14:34	14:49	4:40	
Batavia	8:18	10:28	12:39	12:59	13:29	14:19	15:19	15:34	5:16	
Dapew	8:29	10:39	12:50	13:10	13:40	14:30	15:30	15:45	5:29	
Buffalo	8:30	11:01	1:00	1:20	1:50	2:40	3:40	3:55	6:00	
60A	8:41	11:10	1:04	1:24	1:54	2:44	3:44	3:59	6:04	
6V	8:42	11:11	1:05	1:25	1:55	2:45	3:45	4:00	6:05	
Black Rock	8:53	11:24	1:06	1:26	1:56	2:46	3:46	4:01	6:06	

B Will not carry baggage.
 I No. 15 may leave Syracuse and Rochester 5 mins. in advance of schedule if traffic is received.
 G No. 15 may leave Albany, Syracuse and Buffalo 5 mins. in advance of schedule if traffic is received.
 M Mail Stop.
 T No. 15 may leave Albany and Schenectady 5 mins. in advance of schedule and leave Buffalo at 11:00 P.M. if traffic is received.
 Y No. 27 may leave Syracuse and Rochester 5 mins. in advance of schedule if traffic is received.
 Z No. 17 may leave Syracuse 5 mins. in advance of schedule if traffic is received.

(b) BUFFALO DIVISION

STATIONS	BUFFALO DIVISION									
	39	5741	15	65	27	25	17	57	19	21
Hell Gate Line										
Market										
Main Line										
Albany										
Schenectady										
Hoffmans										
Amsterdam										
No. Ilion										
Utica										
Rome										
Canastota										
Kirkville										
Syracuse										
CP3										
CP5										
CP9										
Lyons										
Newark										
Waynesport										
Brighton										
Rochester										
Ames St. Jct.										
Chili Jct.										
Batavia										
Dapew										
Buffalo										
60A										
6V										
Black Rock										

(c) Mohawk-Hudson Division (continued)

STATIONS	Miles Per Hour
Lyons Falls Branch:	
Between MP 3.5 and MP 5.9	15
Rensselaer-Southward trains approaching Prospect St.	15
MP 11.81, bridge U-7—MP 13.77 and MP 14.13	15
Boonville—Approaching streets	15
Massena Secondary Track:	
Pulaski—Curve at station	15
Richmond—Curve at station	15
Loacon—Approaching street	15
Waterbury—Approaching streets	15
Through Factory Street	15
Lowville Secondary Track:	
Lowville—Approaching streets	15
Carthage—Vye switch at Boyd Road	15
Clayton Secondary Track:	
Philadelphia—Approaching streets	15
Ogdensburg Secondary Track:	
Trains with cars weighing between 160,000 and 210,000 lbs.	8
Between MP 6.1 and MP 6.8	8
Between MP 10.3 and MP 12.0	8
Ogdensburg—Approaching Streets	8
River St., Main St., Monroe Ave. and Albany Ave.	8
G&O Secondary Track:	
MP 6—Switch to sidetrack	15
Empireville—Switches at each end of Scale Track	15
Salisbury—Mile Post 11.9 on curve	15
MP 12—Switch serving International Tail Company	15
West Shore Secondary Track:	
Canajoharie—Curve east of station	6
Over Mitchell St.	6
Troy Secondary Track:	
Forbes Ave. over switch at MP 1	15
Aqueduct Secondary Track:	
Over highway crossings at Aqueduct, Maxon Road and Schenectady	6
Roselevtown Secondary Track:	
Over Raquette River Bridge 2400 feet north of MP 66	5
Fayetteville Industrial Tracts:	
Fayetteville—Over Geneva St.	6
Home Industrial Tracts:	
Over or through streets	8

(d) BUFFALO DIVISION

STATIONS	Miles Per Hour
Main Line: MP 296.5 to Rayview	30
Bridge 636—Seneca River at MP 319.78	30
Niagara Branch:	
CP H, CP L, E, L, S, when diverting—not exceeding	10
Interiors Wye	15
CP E, J and 59—Track 1	20
Falls Road Branch:	
Lockport—Over streets	20
West Shore Branch East:	
Between MP 147.2 and MP 147.9	10
Between MP 159.8 and MP 161	40
Between MP 161 and MP 162	30
Auburn Branch:	
Between MP 2.0 and MP 8.5	15
Auburn—Over streets and Bridge A-25	15
Over Bridge A-28 at MP 57.14	15
Seneca Falls—Over streets	15
Waterloo—Over streets	15
Seneca Falls—Over streets	15
Phelps—South Wayne Street	20
Phelps Jct. over former P.R.R. crossing	20
Canadawaga—Over West Gibson Street	6
Corning Branch:	
Between MP 113.3 and 15.0 Geneva curves and over streets	20
Sodus Bay Secondary Track:	
Wallington: over Railroad crossing at grade	15
Ontario Secondary Track:	
Between MP 46.8 and MP 46.8	15
Between MP 46.8 and MP 65.0	25
Between MP 65.0 and MP 94.0	15
Between MP 94.0 and MP 110.0	20
Between MP 110.0 and MP 172	70
Watkins—Over streets	12
Wallington—R.R. crossing	12
Highway No. 124—1.5 miles east of Sodus	12
Sodus—Over streets	20
Charlotte—Movable Bridge	12
Hilton—Over streets	12
Applies to Head End of Train only.	
Caledonia Secondary Track:	
Between MP 32.6 and MP 33.0	15
Between MP 33.0 and MP 34.7	15
Between MP 43 and MP 45	10
C & W Jct. over C & W Crossing	10
Charlotte Secondary Track:	
Otis—Over Lyle Avenue	8
Charlotte—Over River Street and wye tracks	10
Rochester Running Track:	
Over highways and streets, except Thomas Ave.	6
Over Geneva River Bridge	6
MP 1.5 and MP 4.9	6
MP 4.7 and MP 5.3	5
Waukegan Running Track:	
Between CP 55 and MP 6.3 (Niagara Tracts)	5

(e) TURBO TRAINS—CURVES, BRIDGES, ETC.

STATIONS	Miles Per Hour
Curve between MP 74 and MP 76	60
Curve east of MP 78	60
First curve west of MP 81	60
Between MP 81.0 and MP 81.3	60
MP 81.9 to MP 82.5	80
MP 82.2 to MP 87.5	80
MP 85.3 to MP 93.2	75
Madison—MP 91.1 to MP 96.4	45
2200-2400	45
MP 101.9 to MP 102.1	70
2242-2247	70
Sound View—MP 112.1 to MP 112.7	60
New London—MP 120.6 to MP 122.5	45
MP 124.6 to MP 125.3	45
Getson—MP 124.0 to MP 124.2	45
MP 125.6 to MP 125.8	50
MP 125.2 to MP 125.6	50
Neonk—MP 129.3 to MP 130.0	60
West Mystic—MP 131.2 to MP 131.8	60
Mytic—MP 132.1 to MP 132.5	50
MP 133.6 to MP 133.9	60
Stonington—MP 134.3 to MP 134.5	60
MP 134.5 to MP 135.9	60
MP 135.9 to MP 136.3	50
MP 136.3 to MP 139.0	75
MP 140.0 to MP 141.4	75
MP 141.4 to MP 142.1	75
Bradford—MP 144.0 to MP 144.4	75
MP 145.2 to MP 145.3	85
MP 147.4 to MP 148.1	85
Shanook—MP 152.0 to MP 152.6	85
Knox—MP 154.0 to MP 154.3	85
East Greenwich—MP 170.5 to MP 170.9	95
MP 171.7 to MP 185.4	95
Previdence—MP 184.9 to MP 185.4	95
MP 185.6 to MP 186.1	95
MP 186.1 to MP 186.3	95
Readyville—Movements to and from Dedham Secondary Track within interlocking limits	15
Movements to and from Franklin Branch between interlocking signals 0.30 mile east and easterly interlocking limits	15
Rock Bay—MP 227.3 to MP 227.7	15
Boston Passenger Terminal	10

FIGURE 2 Operating documents relating to permanent speed restrictions: (a) Schedule pages from New York Central Railroad Timetable Mohawk-Syracuse-Buffalo Divisions No. 19, p.53, effective 1966-04-24; (b) Penn Central Transportation Company (PCRR) Northeastern Region Timetable No.6, pp.188-189, effective 1972-10-29—Line Speeds; (c) Civil Speed Restrictions; (d) Equipment Restrictions.

(a)

PENN CENTRAL TRANSPORTATION COMPANY
NORTHEASTERN REGION
 New Haven, Conn. December 18, 1972
General Order No. 604
Effective 12:01 A.M., Tuesday, December 26, 1972

Applies in All Divisions

(a) **RULES FOR CONDUCTING TRANSPORTATION—C.T. 400**
 Rule Q, of Rules for Conducting Transportation—C.T. 400, revised in accordance with Public Law 91-169, effective December 26, 1970.
 Sticker coupon attached to this General Order must be detached and pasted in the Rules for Conducting Transportation—C.T. 400, as follows:
 Rule Q over Rule Q, on page 4.

(b) **TIMETABLE AUTHORITY**
 N. G. Anders appointed Division Superintendent Buffalo Division, with headquarters at Buffalo, N.Y. Sticker coupon attached to sticker form of this General Order must be detached and pasted over corresponding portion of title page of timetable.

(c) **MEDICAL OFFICERS AND SURGEONS**
 Change address and telephone number of the following Medical officer.
 W. F. Tibbitts, Albany, N.Y.
 From: 149 Washington Ave., Telephone HO 3-4913
 To: 47 Clermont St., Telephone 489-1438.
 Special Instruction 160R-A2, page 75, changed.

Effective 12:01 A.M., Monday, January 1, 1973
Applies in Mahawk-Hudson Division

(d) **ENGINE AND SPECIAL LOAD RESTRICTIONS**
 Engines Class ERS-20, EP 30, GP 32, GRS 22 are prohibited from operating on the Newton Falls Branch between Newton Falls and Benson Mines.
 Special Instruction 1160-A20, page 219, added.

(e) **CURVES, BRIDGES, ETC. MAXIMUM SPEEDS**
 Item 4 of Paragraph (gg) of General Order No. 602, referring to various temporary speed restrictions on No. 4 Track and on Single Track between 125 and CP SM, annulled.

(f) **CURVES, BRIDGES, ETC. MAXIMUM SPEEDS**
TEMPORARY SPEED RESTRICTIONS (MPH) in effect as follows:
 1. Hudson River Connecting Railroad
 Between No. 4 Track Single Track
 125 and CP 3 30
 CP 3 and MP 6 30
 MP 6 and CP SM 10
 Special Instruction 1157-F1, page 208, changed.
 (Page 1 of 3 Pages)

(b)

(Page 2 of 3 Pages, Northeastern Region G.O. No. 604)

Applies in Buffalo Division

(a) **CURVES, BRIDGES, ETC. MAXIMUM SPEEDS**
TEMPORARY SPEED RESTRICTIONS (MPH) in effect as follows:
 1. Belt Line Branch
 Between No. 1 No. 2 Single Track Track Track
 CP 1 and East Ferry St. 10 10
 East Ferry St. and Dewey Ave. 10
 Elmwood Ave. and CP 1 10
 CP 1 and 55 5
 Special Instructions 1157-F1, page 205 and 1157-H1, page 210 and 211, changed.

Applies in New England Division

(a) **SHORE LINE MYSTIC RIVER-EAST MYSTIC**
 That part of Special Instruction 1605-A1, page 253, referring to Rules 605 to 670 inclusive in effect between Mystic River and East Mystic on No. 1 and No. 2 track is annulled.
 Special Instruction 1605-A1, page 253, changed.

(b) **NORMAL POSITION OF SWITCHES AND CROSSOVERS AT SPECIFIED LOCATIONS:**

Switch Located at	Connecting	With	Normal Position Is For Movement
Westfield	No. 1 Yard Tr.	Main Line	To Connecting Track
	CP 3M	Connecting Track	

Special Instruction 1104-A1, page 157, changed.

(j) **PUBLIC CROSSINGS AT GRADE MIDDLEBORO BRANCH SO. BRAINTREE-BRIDGEWATER**
 Crossing Watchman at Plain St. So. Braintree and Broad St., Bridgewater, hours in service, changed.
 The second paragraph of Notes 75 and 78 of Special Instruction 1103-A1 changed as follows:
 2:00 a.m., Sat. to 6:00 p.m. Mon. Tues. to Fri. inclusive 2:00 a.m. to 6:00 p.m. Crossing Watchman will remain on duty until after passage of train symbolized KP, unless otherwise relieved.
 Special Instruction 1103-A1, Notes 75 and 78, page 136, changed.

(k) **FALL RIVER SECONDARY TRACK**
 Item 6 paragraph (c), General Order No. 602 referring to a temporary speed restriction of 10 mph between MP 9 and MP 10, annulled.

CT 10 (REV. 4-71) PRINTED IN USA

PENN CENTRAL TRANSPORTATION COMPANY
NORTHEASTERN REGION
BUFFALO DIVISION
BULLETIN ORDER
 No. 6-185
 Buffalo, New York
 February 20, 1974

Effective 5:01 P. M., Wednesday, February 20, 1974

(a) **CURVES, BRIDGES, ETC. MAXIMUM SPEEDS**
TEMPORARY SPEED RESTRICTIONS (MPH) in effect as follows:

Between	No. 1 Track	Between	No. 2 Track
	Page		Page
	TY		TY
	Ext		Ext
MP 384 and MP 391	60 60 30	MP 354.2 and MP 354.5	50 50 30

Special instruction 1157-F1, page 205, changed.

(b) **MAIN LINE - ALBANY-RENSSELAER TO RAY VIEW Wendo**
 Facing Switch for westward movement on No. 2 Track at MP 422, out of service.

Effective 12:01 P. M., Friday, February 22, 1974

(c) **MAIN LINE - ALBANY-RENSSELAER TO RAY VIEW Rochester**
 Road Channel No. 2 in service at Yardmaster Rochester, Channel No. 1 out of service.
 Special instruction 1704-A1, page 254, changed.

A. J. Conklin
 Superintendent

Posted at _____ By _____ Time _____ M. Date _____ 19____

I hereby acknowledge receipt of Bulletin Order No. 6-185 Rfio Divn

Posted at _____ By _____ Time _____ M. Date _____ 19____

To be detached and promptly forwarded to the Division Superintendent. Signed _____

(c)

FORM 19
PENN CENTRAL CO.
 TRAIN ORDER No. 22
 Date Oct. 26 1972
 To C & E Southward Trains and Foreman M. Sanchez
 At Wenona
 Single track obstructed for maintenance between MP 113 and MP 114 from 9:57 a.m. fifty seven AM to 4:30 p.m. Thursday. Approach the stop signs prepared to stop and stop.
 RPM
 39
 Order No 22 is annulled RPM
 Conv 3:39 PM Cincinnati

(d)

(c) If timber crossties are used, each 39 feet of track must be supported by nondefective ties, as set forth in the following table:

Class of track	Maximum allowable speed (mph) F - P	Minimum number of nondefective ties per 39 feet of track	Maximum distance between nondefective ties (center to center)	Maximum number of successive defective ties (normal spacing)
1	10-15	5	100"	3
2	25-30	8	70"	2
3	40-60	8	70"	2
4	60-80	12	48"	1
5	70-90	12	48"	1
6	70-100	14	48"	1

(d) If timber ties are used, the minimum number of nondefective ties under a rail joint and their relative positions under the joint are described in the following chart. The letters in the chart correspond to letters underneath the ties for each type of joint shown.

Supported Joint:

Suspended Joint:

Class of track	Maximum allowable speed (mph) F - P	Minimum number of nondefective ties under a joint	Required position of nondefective ties
1	10-15	1	X, Y, or Z
2	25-30	1	Y
3	40-60	1	Y
4	60-80	2	X&Y or Y&Z
5	70-90	2	X&Y or Y&Z
6	70-100	2	X&Y or Y&Z

(e) Except in an emergency or for a temporary installation of not more than 6 months duration, crossties may not be interlaced to take the place of switch ties.

5213.113 Defective rails.

(a) When it is known by track supervision, through inspection or otherwise, that a rail in a track contains any of the defects listed in the following table, a person designated under 5213.7 (a) or (b) shall determine whether or not the track may remain in service. Operation over that rail is not permitted until:

(1) The defective rail is replaced; or
 (2) The remedial action prescribed in the table is initiated.

Defect	Percent of rail head cross section From To	Remedial action	Max. speed (mph)
Detected transverse defect ¹ in non-control cooled rail	0 - 19	Limit speed to	10
Transverse fissure ² 100 & Over	20 - 99	Limit speed to	10
Compound fissure ³	100 & Over	Visually supervise ⁴ each operation over defective rail	--
Detected transverse defect ¹ in control cooled rail	0 - 19	Apply joint bars ⁵ to defect within 20 days. Until joint bars are applied limit speed to	10
Fracture	20 - 99	Apply joint bars ⁵ to defect within 10 days. Until joint bars are applied limit speed to	30
Engine burn	100 & Over	Apply joint bars ⁵ to defect within 10 days. Until joint bars are applied limit speed to	50
Defective weld	100 & Over	Apply joint bars ⁵ to defect. Until bars are applied visually supervise ⁴ each operation over defective rail	50

FIGURE 2 (CONTINUED) Operating documents relating to temporary speed restrictions: (e) Penn Central Transportation Company (PCRR) Northeastern Region General Order No.604, effective 1972-12-26; (f) PCRR Northeastern Region, Buffalo Division Bulletin Order No. 6-185, effective 1974-02-20; (g) PCRR Train Order ("Form 19") advising southbound trains of a track obstruction at Milepost 113-114; (h) PCRR Manual for Construction and Maintenance of Track (MW-4) detailing speed restrictions for each type of track defect.

GC26 CARSTAIRS, MILLERHILL & EDINBURGH TO NORTH BERWICK, BERWICK & BRANCHES			Consist-based timing profiles: InterCity 125 diesel trainset with 2 power cars and 9 coaches.										Diesel freight train, 595 gross tons.		UP
			WEEKDAYS												
Train ID			2Y94	5Y94	9O84	9O84	1E02	2Y06	2Y60	5Y33	1E05	1E05	5S99	2Y82	
Departs From				07:38 Haymarket	07:30 Glasgow Central	07:30 Glasgow Central			07:10 Glasgow Central	08:38 Haymarket	08:00 Glasgow Central	08:00 Glasgow Central			
To					Paris Nord	Paris Nord	London Kings Cross				London Kings Cross	London Kings Cross			
Timing Type				EMU	EMU	E110/373	E110/373	HST/2+9	EMU	DMU(S)	EMU	91/410	91/410	D595	DMU(S)
Days Run				SX	SX	SX	SO	SO	SO	SX	SX	SO	SX	TThO	SO
Operating Chars										Y		EP	EP	Q	
CARSTAIRS	Arr	1													
Carstairs East Jn	Dep	2													
	mgn	3													
	Arr	4			07/56	07/56						08/28½	08/28½	4 JUN	
	Dep	5			07/58½	07/58½						08/31½	08/31½	22 SEP	
Benhar Jn	Arr	6													
Fauldhuse	Arr	7													
Breich	Arr	8													
Addiewell	Arr	9													
WEST CALDER	Arr	10													
Livingston South	Arr	11													
Midcalder Goods Loop	Arr	12													08.41
	Dep	13													08.46
	Dep	14													
	Dep	15													
Midcalder Jn	mgn	16				(2)									[2]
	Arr	17													
	Dep	18													
	Dep	19		07.59	07RM56 07+58	08/10	08/12				08/X21	08/44	08/44		08/X51
Kirknewton	Arr	20													08.53
Curriehill	Arr	21													08.58½
Wester Hailes	Arr	22													09.02
Kingsknowe	Arr	23													09.04½
Slateford	Arr	24													09.07
Slateford Jn	Arr	25					[2]<1>				[2]	[2]<1>	[2]<1>		[2]
Haymarket	Arr	26				08/21	08/21				08/40	08/53	08/53		09/10
	Dep	27									08.43	08RM46 (1)			(1) 09.13
Haymarket	Dep	28													
Princes St Gardens	Dep	29													
	Arr	30													
	Arr	31													
	Arr	32													
EDINBURGH	Arr	33													
	Arr	34													
EDINBURGH	Dep	35													
	Dep	36													
Craigentinny T & RSMD	Dep	37													
Powderhall Refuse Siding	Dep	38													
Leith South	Dep	39													
	Dep	40													
Portobello Jn	Dep	41													
Musselburgh	Dep	42													
	Dep	43													
	Dep	44													
Haymarket West Jn	Dep	45													
Gorgie Jn	Dep	46													
Craiglockhart Jn	Dep	47													
Niddrie West Jn	Dep	48													
Millerhill L.I.P.	Dep	49													
MILLERHILL S.S.	Dep	50													09+33
	Dep	51													
	Dep	52													
Monktonhall Jn	Dep	53													
Wallyford	Dep	54													
Prestonpans	Dep	55													
Prestonpans U.P.L.	Dep	56													
	Dep	57													
Cockenzie Power Station	Dep	58													
Blindwells Opencast	Dep	59													
Longniddry	Dep	60													
Drem	Dep	61													
	Dep	62													
	Dep	63													
NORTH BERWICK	Dep	64													
	Dep	65													
Dunbar	Dep	66													
	Dep	67													
Oxwellmains	Dep	68													
Torness Power Station	Dep	69													
Innerwick G.S.P.	Dep	70													
	Dep	71													
Grantshouse	Dep	72													
	Dep	73													
Reston	Dep	74													
	Dep	75													
Signal EG402	Dep	76													
	Dep	77													
BERWICK UPON TWEED	Dep	78													
	Dep	79													

FIGURE 2 (CONTINUED) Operating document showing schedule detail: (j) Railtrack Working Timetable showing use of Square, Circle, and Triangle times and Consist-based Timing Loads on the East Coast Mainline in Scotland.

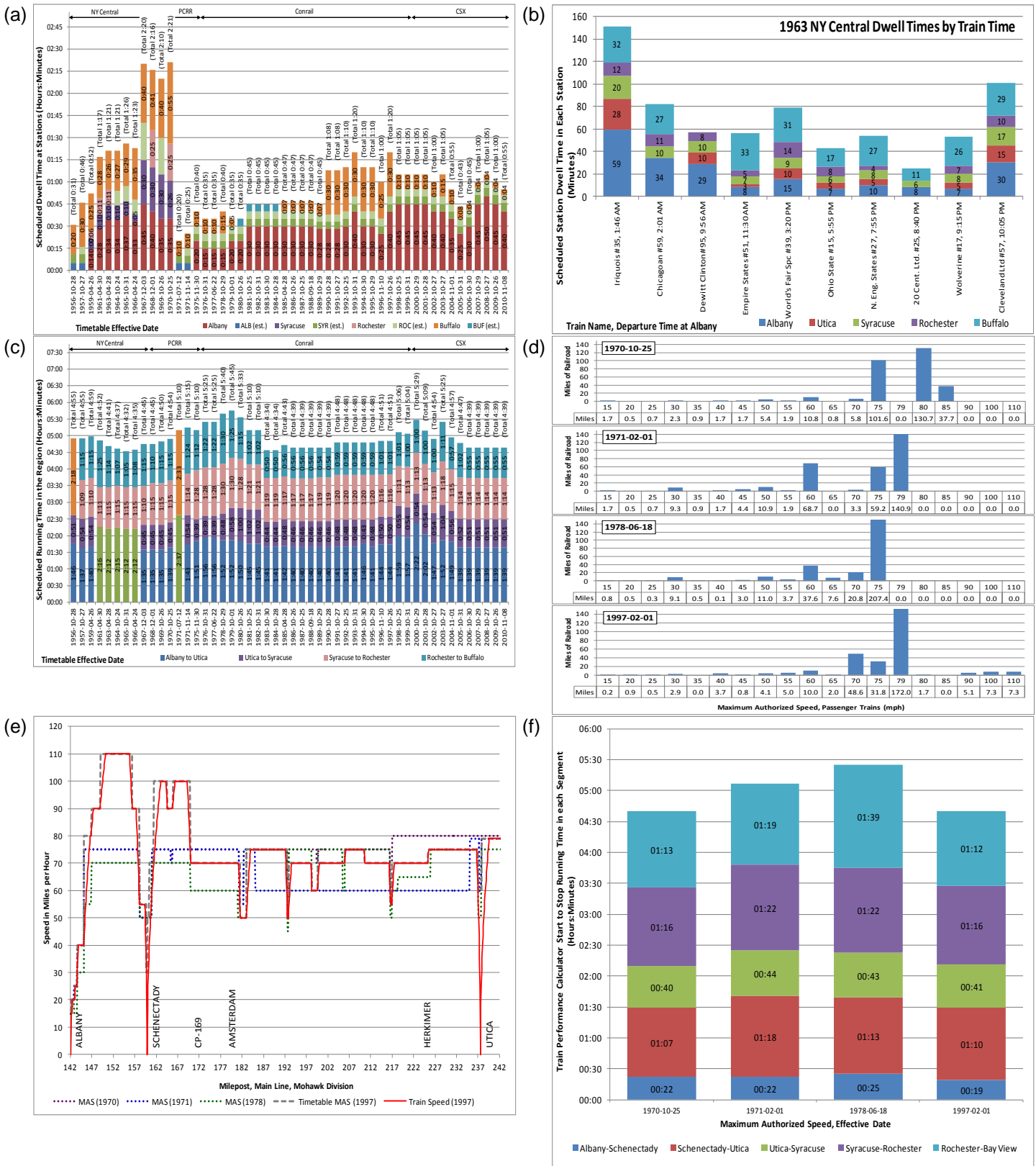


FIGURE 3 Longitudinal Analysis of Schedules and Speeds on the Penn Central Northeastern Region, Mohawk and Buffalo Divisions, 1956-2010: (a) *Lake Shore Limited* Dwell Time Analysis; (b) 1963 NY Central Railroad Dwell Time by Train; (c) Sectional Running Time Analysis; (d) Maximum Authorized Speeds; (e) Train Performance Curve from Albany to Utica; (f) Minimum Achievable Running Time per Simplified Train Performance Calculator.

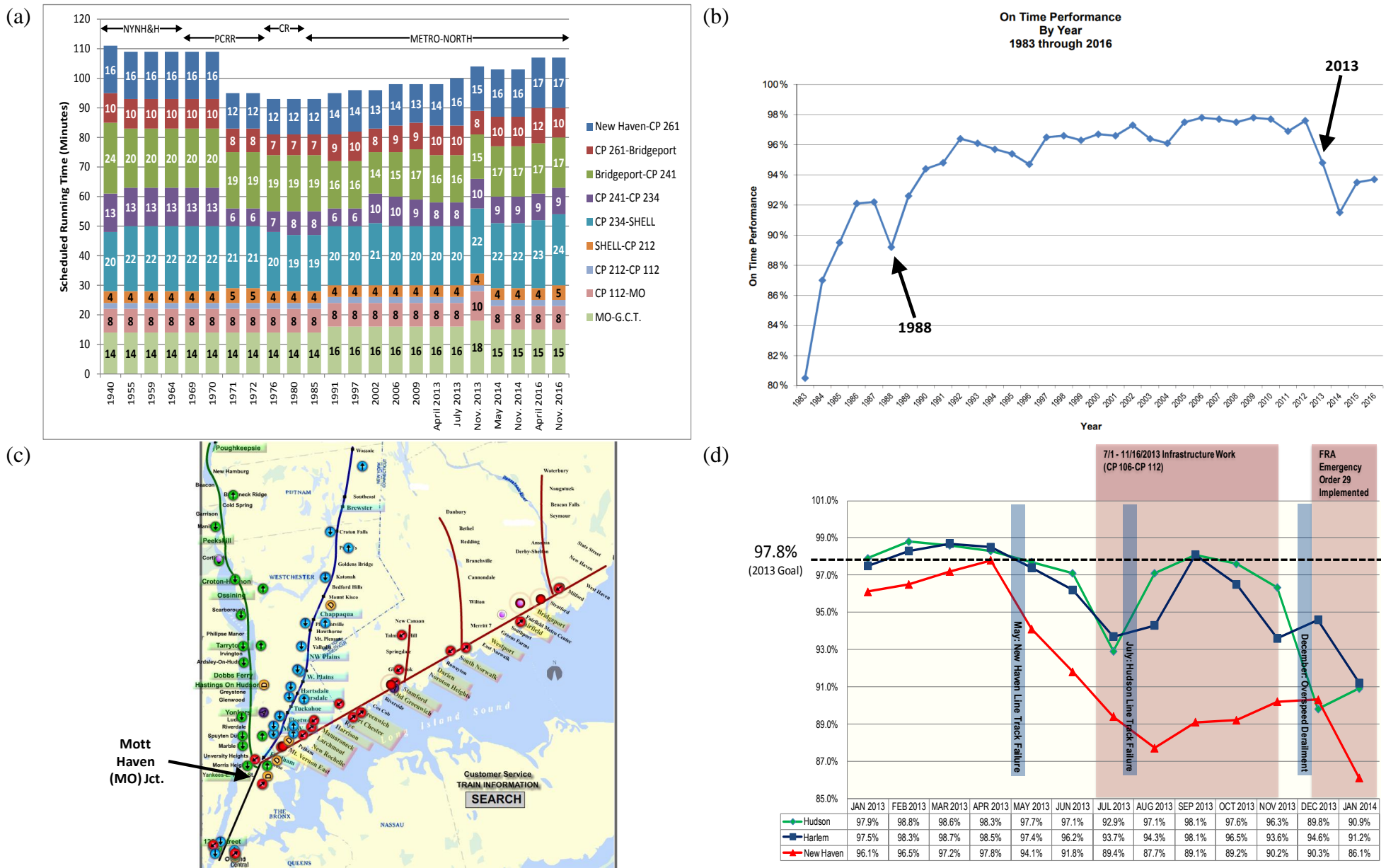
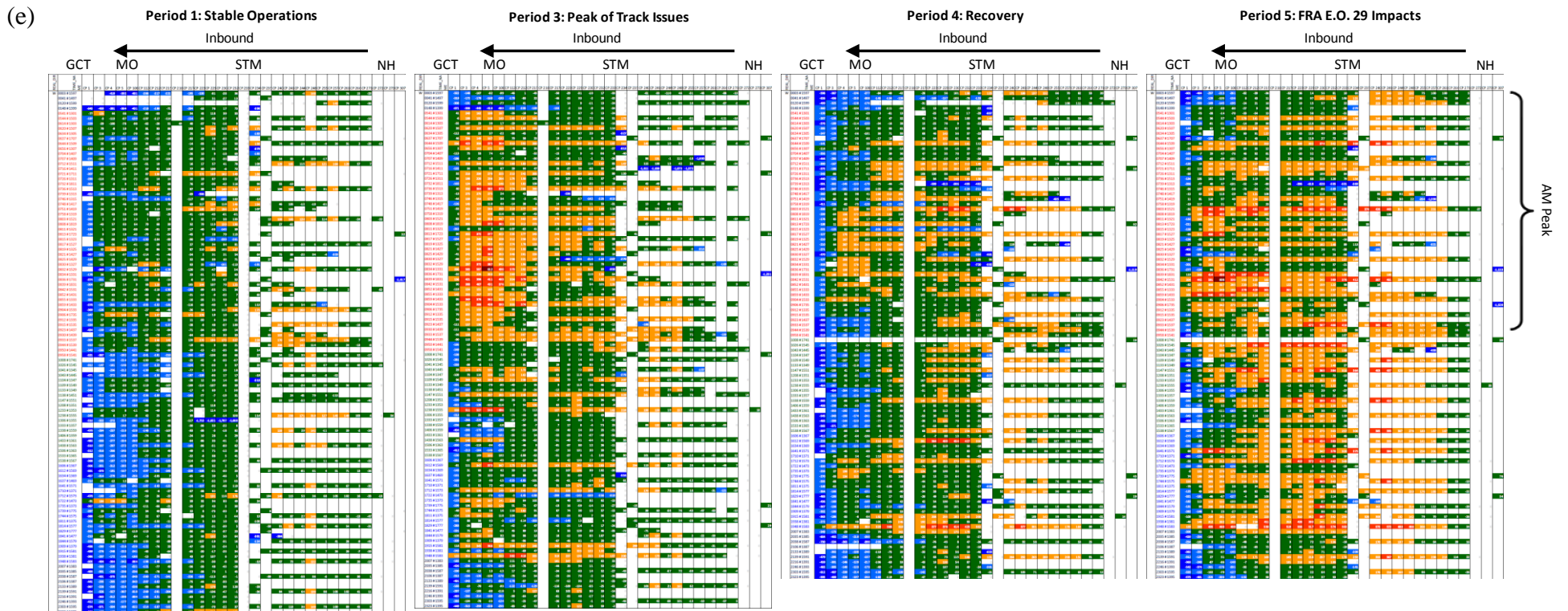


FIGURE 4 Case Study of Schedules and On-Time Performance (OTP) on the Metro-North New Haven Line: (a) Express train running times by line segment 1940~2016; (b) OTP history 1983~2016; (c) Train tracker showing peak utilization at around 7:45 AM weekdays; (d) Monthly OTP in 2013.



(f)

- Fairfield Metro passenger station opened December 5, 2011.
- West Haven passenger station opened August 18, 2013. Continuing adjustments reflect fine-tuning based on practical experience.
- Cab signal dropdowns provided for MAS reductions of more than 20 mph. Running time added to reflect new infrastructural constraint.
- Additional two minutes needed to accommodate Devon Transfer project. Upon project completion, extra time was removed.



Effective Date	10/27/02	10/01/06	10/18/09	04/07/13	07/01/13	11/17/13	05/11/14	11/09/14	04/03/16	10/02/16
Train #	1527	1527	1527	1527	1527	1527	1523	1523	1523	1523
N.H.-CP 271	3	3	3	3	3	3	3	3	3	3
CP 271-CP 266	5	5	5	5	(+2) 7	(-1) 6	(+1) 7	7	7	7
CP 266-CP 261	5	(+1) 6	(-1) 5	(+1) 6	6	6	6	6	(-1) 7	7
CP 261-CP 257	5	(+1) 6	6	(+1) 7	7	(-2) 5	(+2) 7	7	(+2) 9	(-2) 7
CP 257-CP 255	4	4	4	(+1) 5	5	(-1) 4	4	4	4	4
CP 255-CP 248	6	6	6	(+1) 7	7	7	7	7	7	7
CP 248-CP 244	4	4	4	4	4	4	(+1) 5	5	5	5
CP 244-CP 241	3	(+1) 4	(+2) 6	(-3) 3	3	3	(+1) 4	4	4	4
CP 241-CP 234	10	10	(-1) 9	(-1) 8	8	(+2) 10	(-1) 9	9	9	9
CP 234-CP 229	8	(-1) 7	7	7	7	(+1) 8	8	8	(+1) 9	9
CP 229-CP 223	6	6	6	6	6	6	(+1) 7	7	7	7
CP 223-CP 217	7	(-1) 6	6	6	6	(+1) 7	(-1) 6	6	6	(+1) 7
CP 217-CP 215	1	(+1) 2	2	2	2	2	2	2	2	2
CP 215-CP 212	3	3	3	3	3	3	3	3	3	(+1) 4
CP 212-CP 112	2	2	2	2	2	2	2	2	2	2
CP 112-MO	8	8	8	8	8	(+2) 10	(-2) 8	8	8	8
MO-G.C.T.	16	16	16	16	16	(+2) 18	(-3) 15	15	15	15
Total Trip Time	96	98	98	98	100	104	103	103	107	107

Running time studies showed that trains are short on time in this area due to increasing congestion from additional movements in Stamford.

Additional time provided to accommodate track remediation work in the Bronx. Removed when project complete.

Time needed for crossing moves due to bridgeplates being needed at local stations to support track and catenary renewal projects requiring continuous track outages.

stable operating environment
(programmed engineering adjustments move with work location)

fast-changing operating environment
(additional repair work occurring in many locations simultaneously)

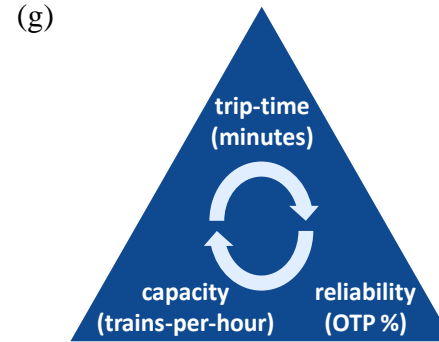


FIGURE 4 (CONTINUED) Case Study of Schedules and On-Time Performance (OTP) on the Metro-North New Haven Line: (e) “Heat maps” showing OTP by train by location in 2013; (f) Running time revisions 2002~2016 with reasons for changes; (g) Maximizing system performance requires train operators to balance trip-time, capacity, and reliability subject to overarching constraint of safe operations.