



**INTERMITTENT
ELECTRIFICATION WITH
BATTERY LOCOMOTIVES
AND THE POST-DIESEL
FUTURE OF NORTH
AMERICAN FREIGHT
RAILROADS**

TRB 2023

**Alex Lu
John G. Allen
John P. Aurelius**



Williams Junction, Arizona, 2013
Wikimedia User "CSX, LLC" photo (CC BY-SA 2.0)



Berryville, Virginia , 2010
Wikimedia User Jpmueller99 photo (CC BY 2.0)



Conrail E44 #4445, #4464, Maryland, Dec. 1980
Roger Puta photo (public domain)



RF&P Geeps at Fredricksburg, Va., October 1971
Roger Puta photo (public domain)



BC Rail 6002 at Table, B.C., September 18, 1987
Roger Puta photo (public domain)



NRE 3GS21B on Olive St., Anaheim, California, 2007
Matthew "Morven" Brown photo (CC BY-SA 3.0)



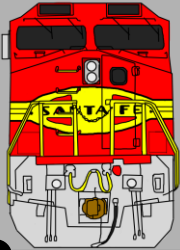
Train 121 with FEC 807 and 302 (LNG Fuel Tender)
Flickr User BBT609 photo (CC BY 2.0)



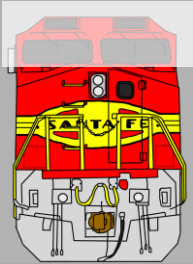
Milwaukee E71, Deer Lodge, Montana, August 1971
Drew Jacksich photo (CC BY 2.0)

BATTERY-ELECTRIC VS. DIESEL

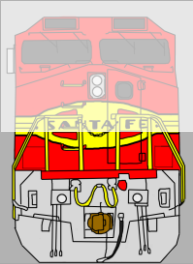
5,000 gals
190 MWh



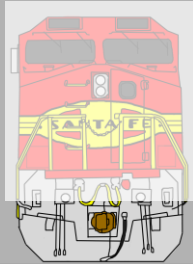
3,750 gals
142.5 MWh



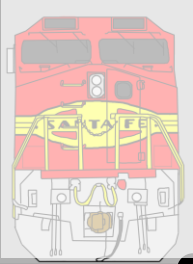
2,500 gals
95 MWh



1,250 gals
47.5 MWh



Refuel

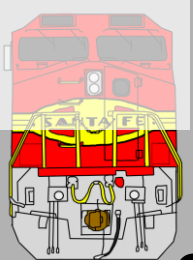
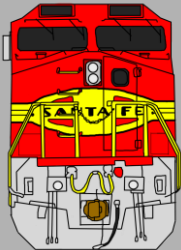
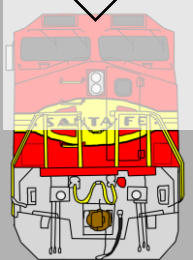
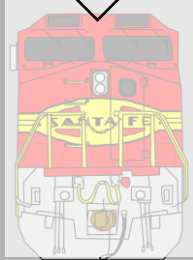
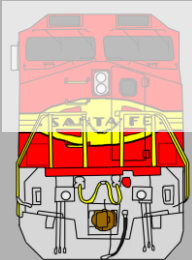
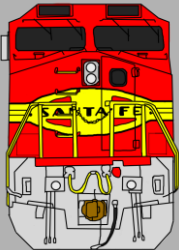
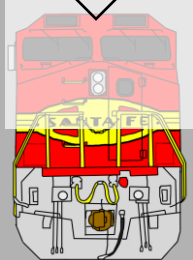
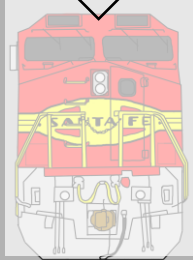
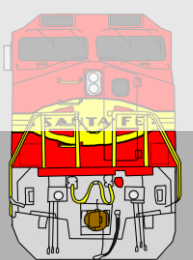
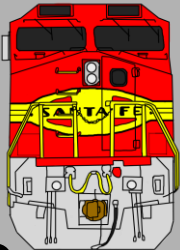


Lineart by RailToonBronyFan3751 at DeviantArt (CC-BY NC 3.0)

1,000 miles

200-mile
Electrified Segment

14.5 MWh

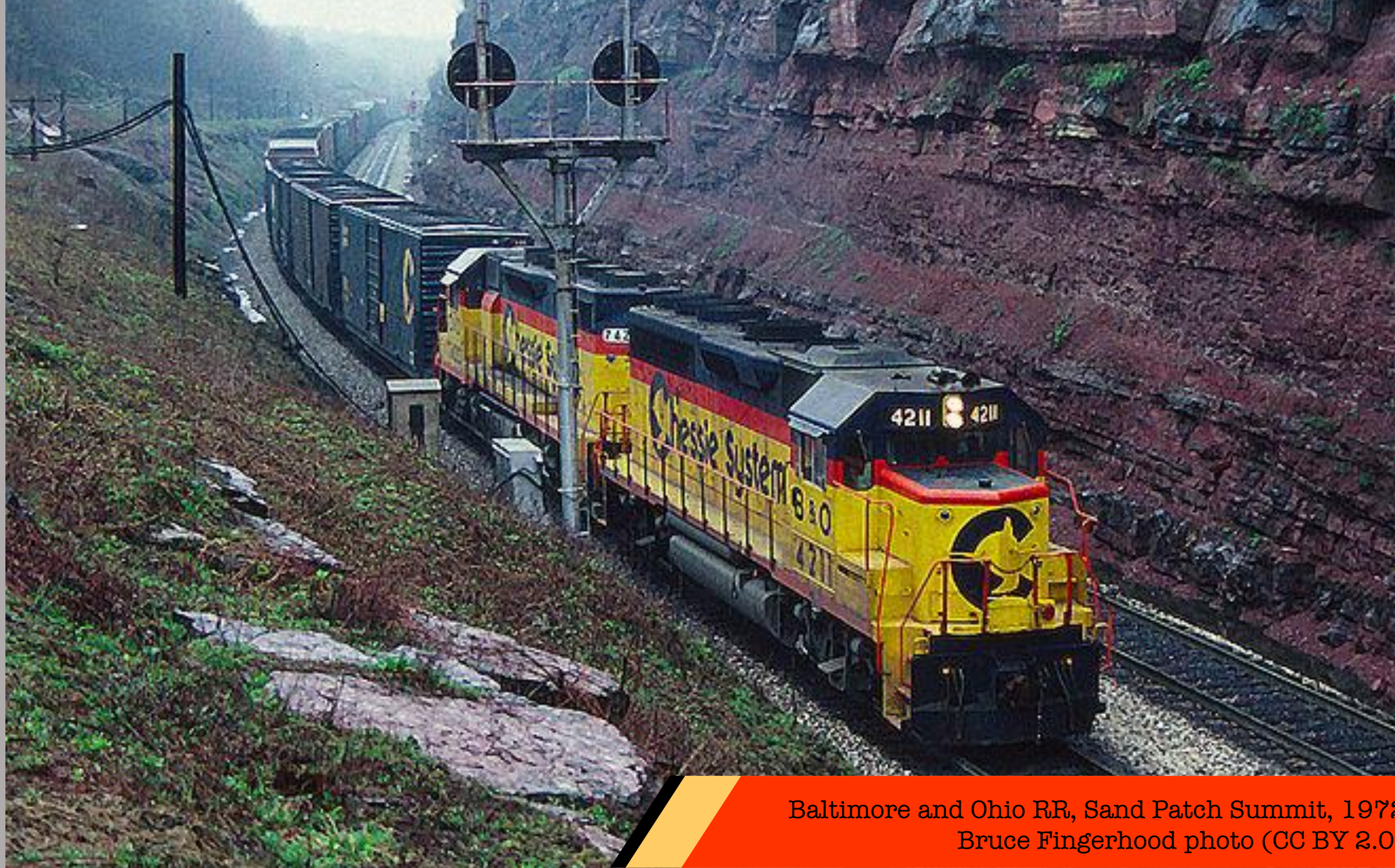


4 hours
hauling @ 3.3 MW
(4,400 hp)

4 hours
charging @ 3.7 MW +
hauling @ 3.3 MW

4 hours @ 7.0 MW





Baltimore and Ohio RR, Sand Patch Summit, 1972
Bruce Fingerhood photo (CC BY 2.0)

CRESTING THE SUMMIT...

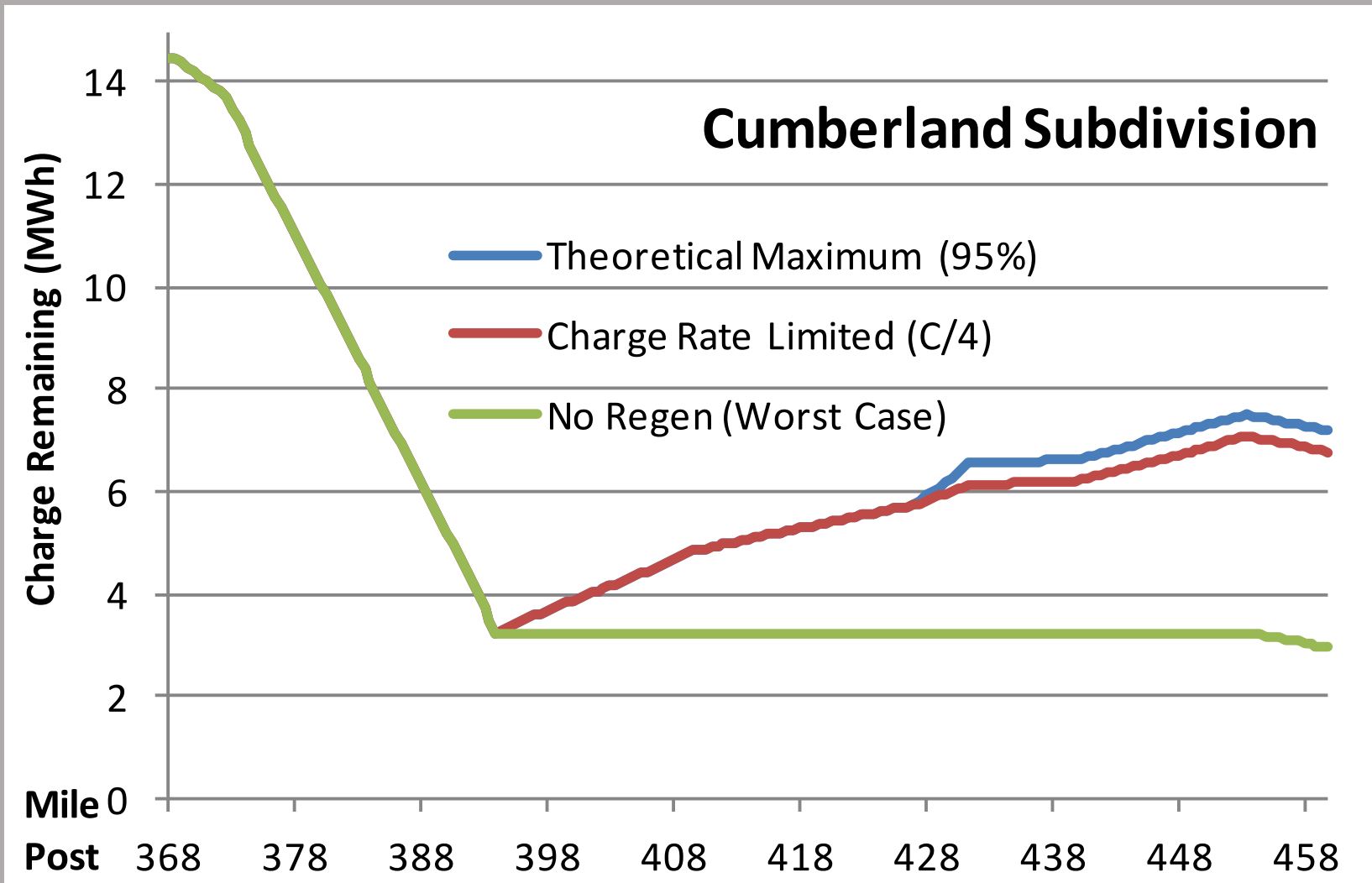
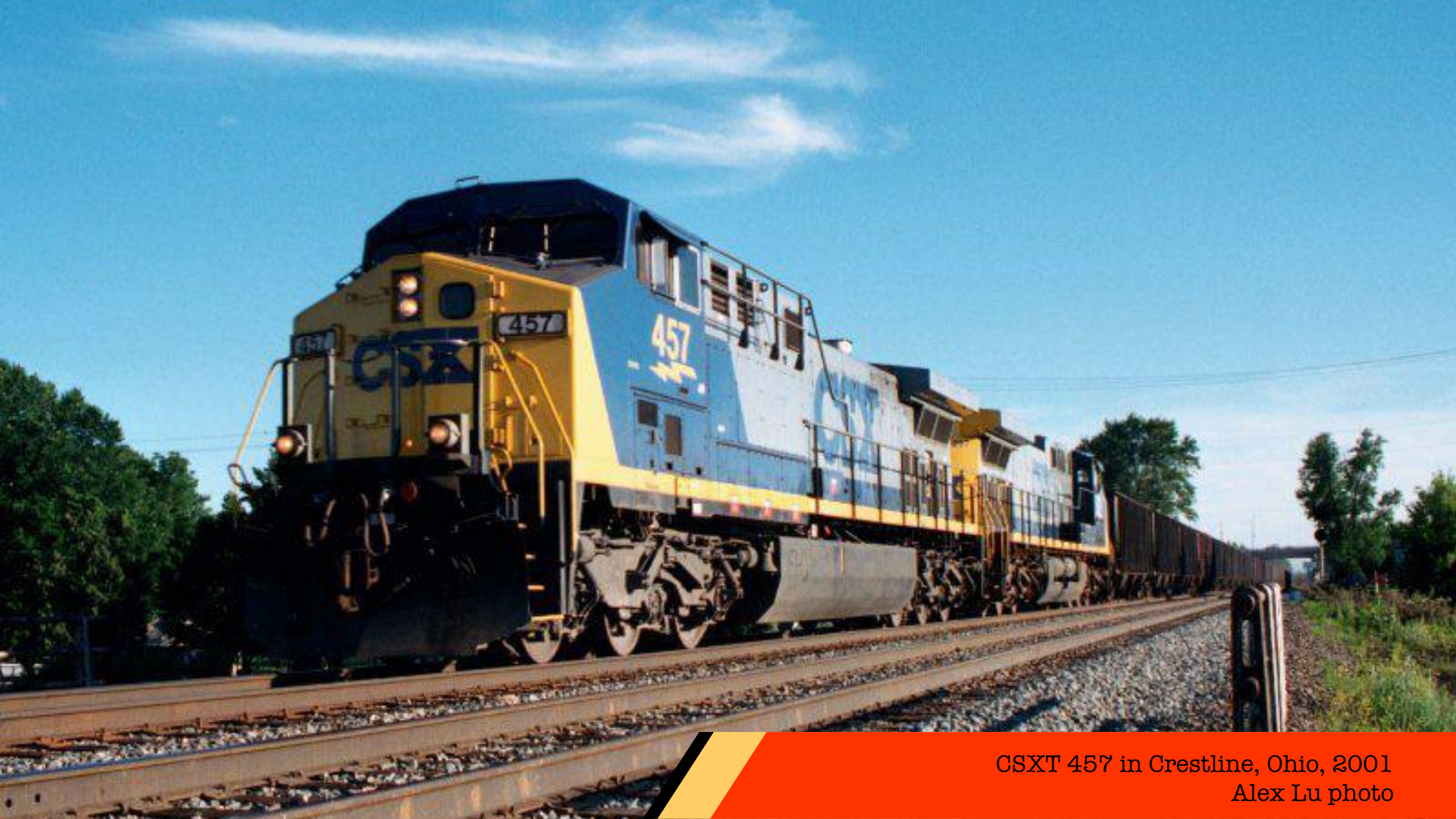


Figure 3(a)



CSXT 457 in Crestline, Ohio, 2001
Alex Lu photo

...AND IN THE MIDWEST

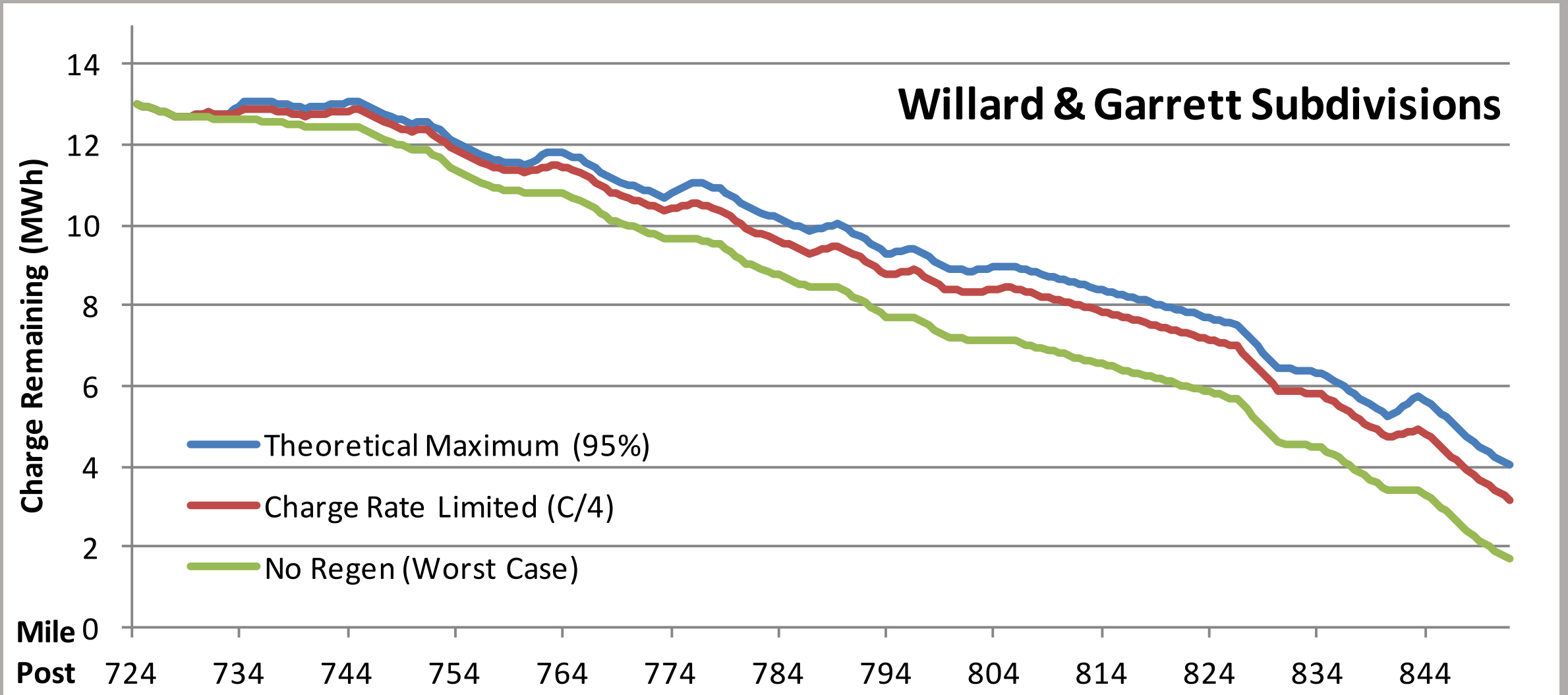


Figure 3(b)

CASE STUDY – INTERMITTENT

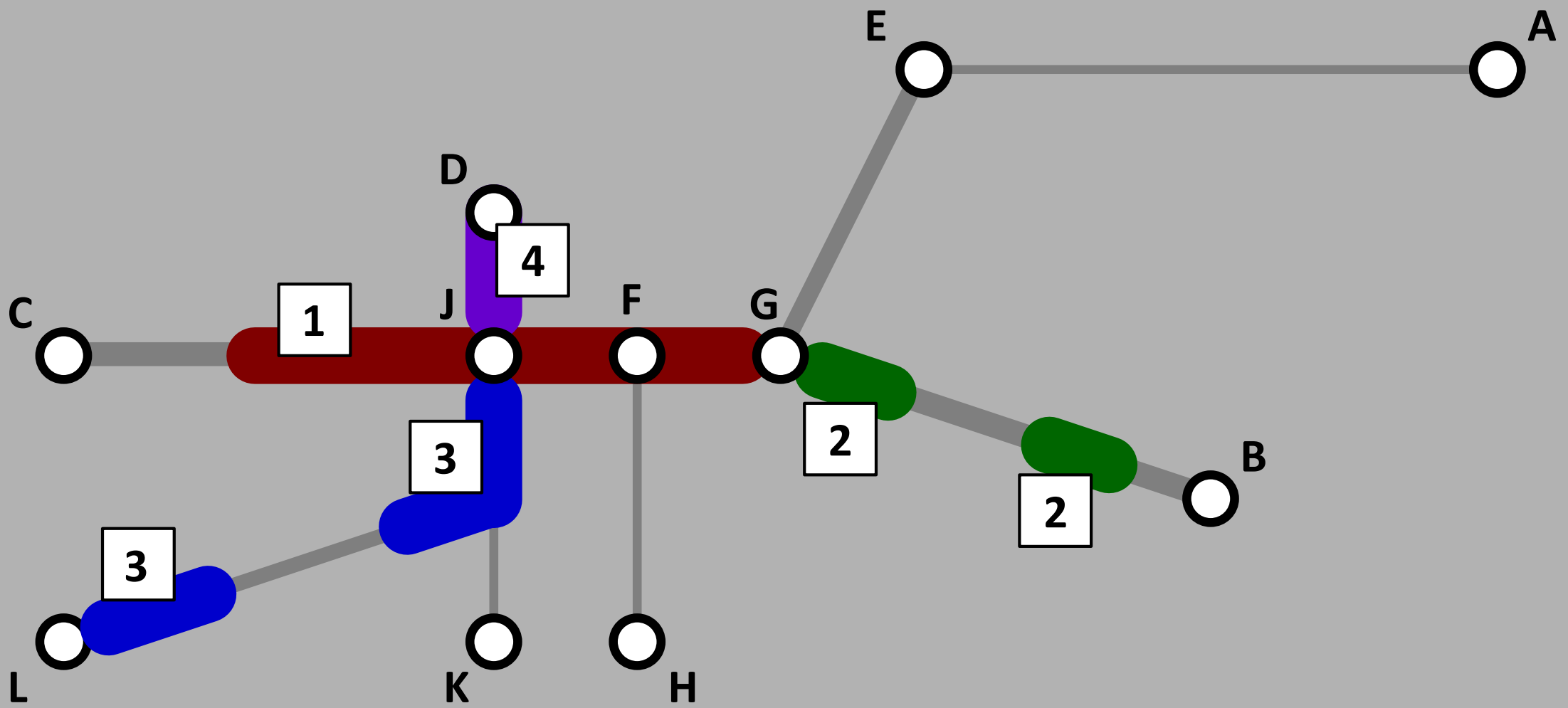
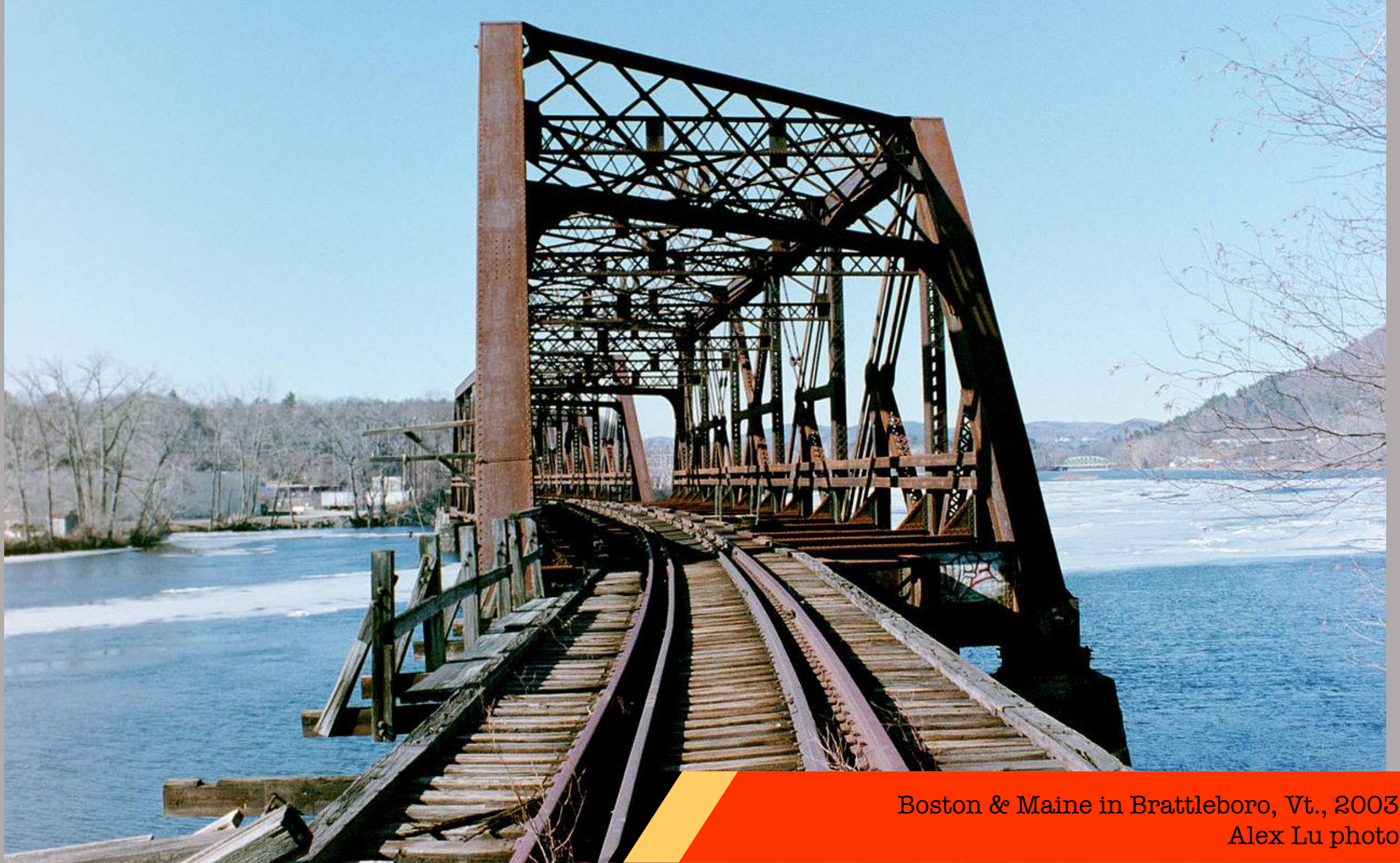


Figure 5(b)



Boston & Maine in Brattleboro, Vt., 2003
Alex Lu photo

CASE STUDY – CONTINUOUS

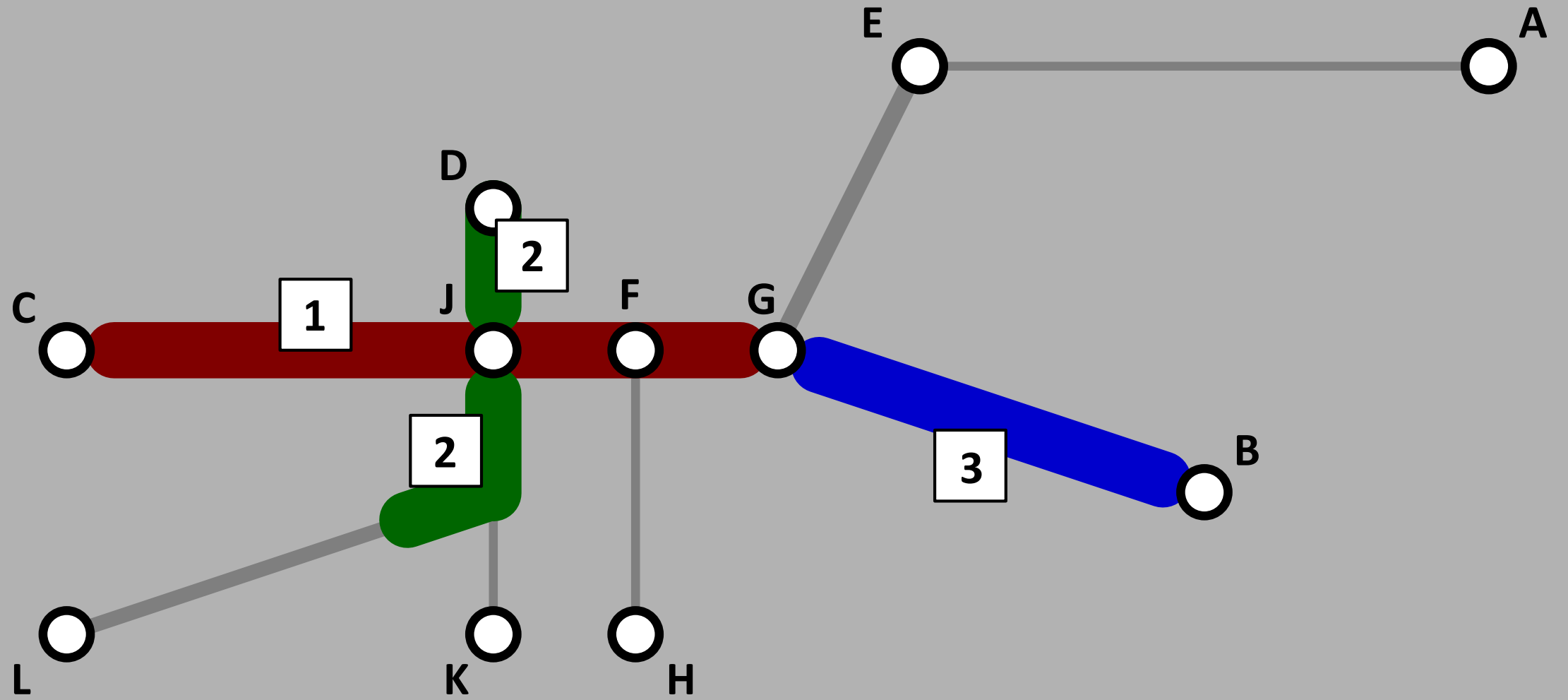


Figure 5(c)



Cos Cob Anchor Bridge, Connecticut, 2017
Alex Lu photo

MAINTENANCE AND COMPLEXITY

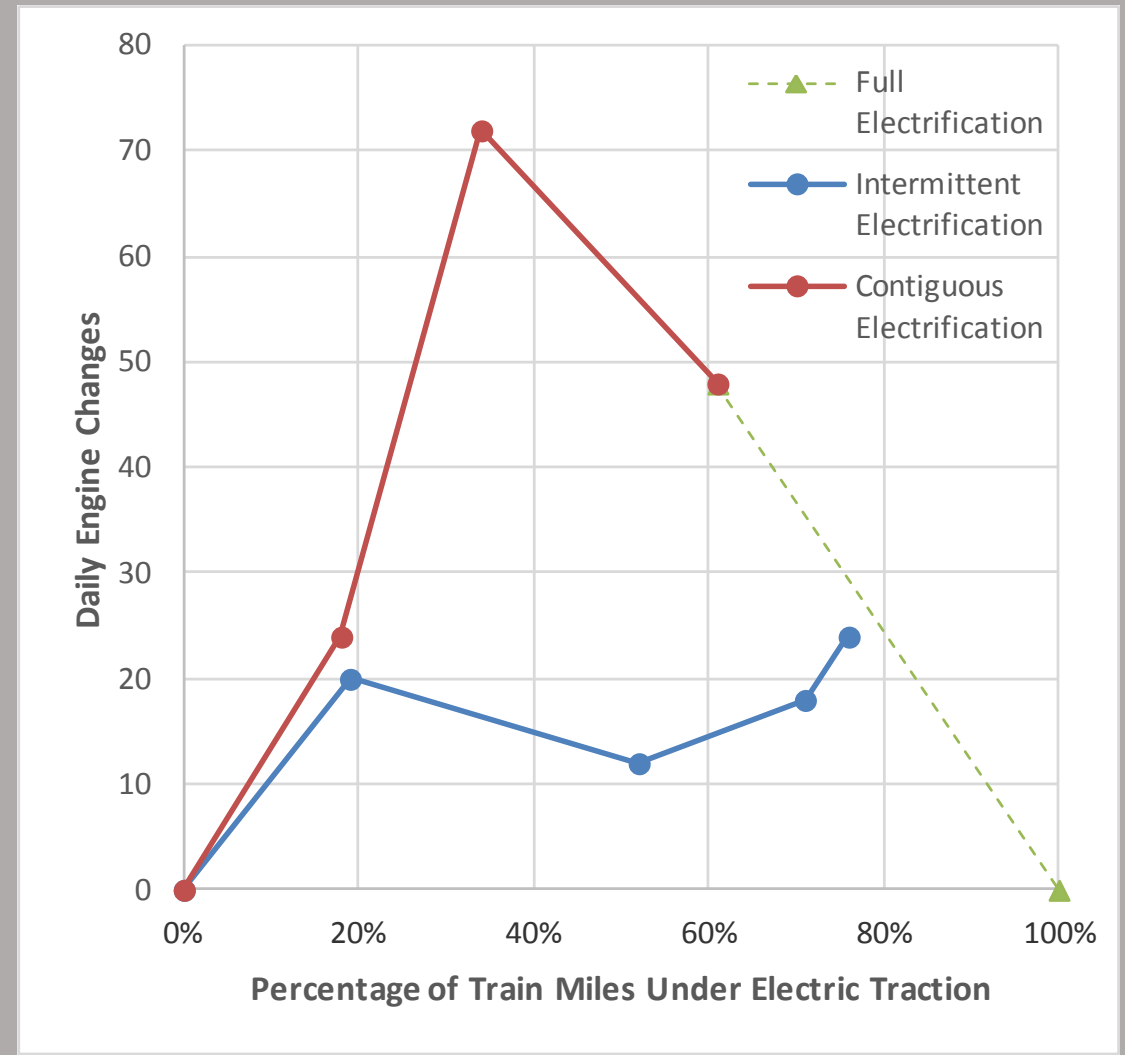
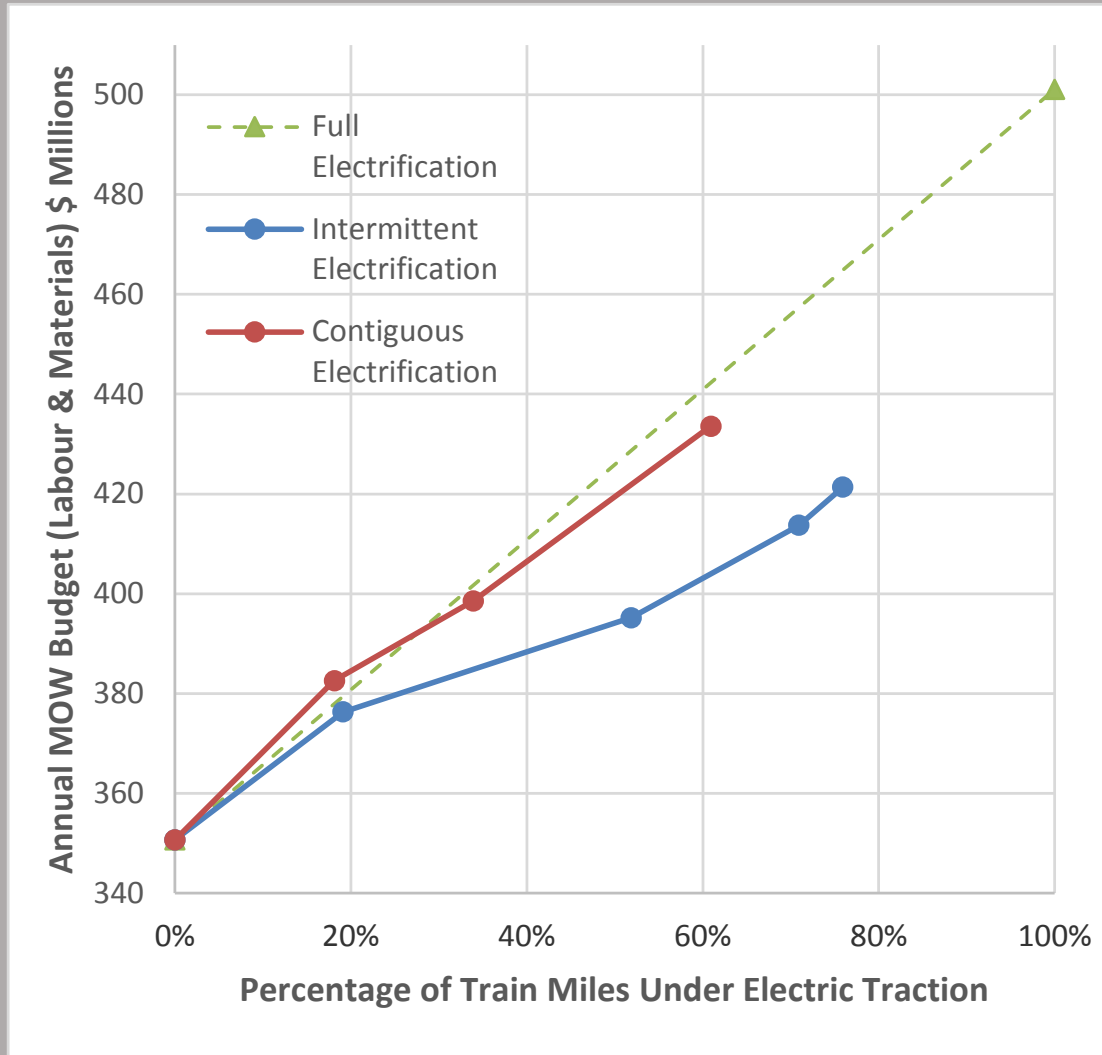


Figure 6(a,b)

CAPITAL AND COST-EFFECTIVENESS

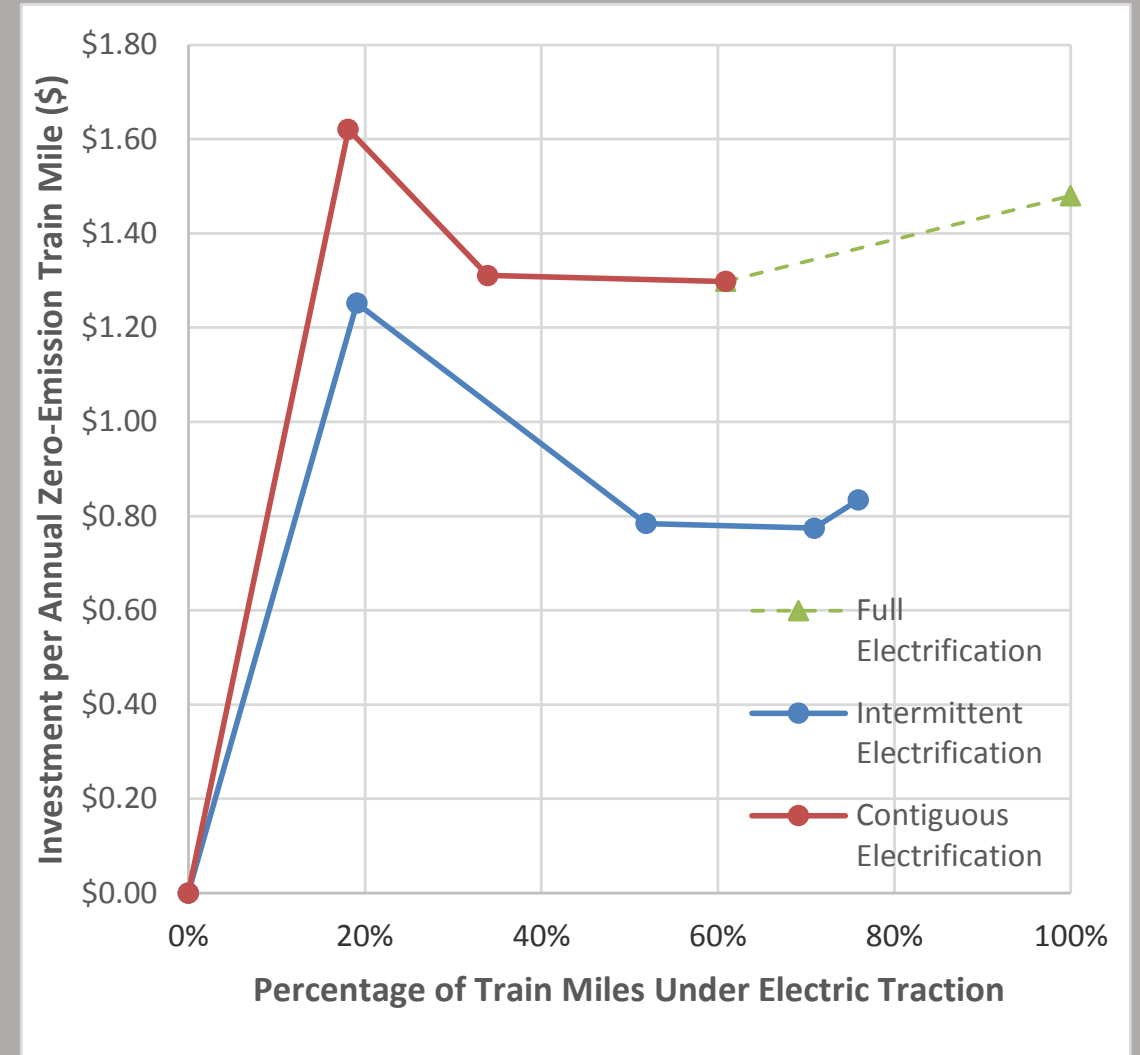
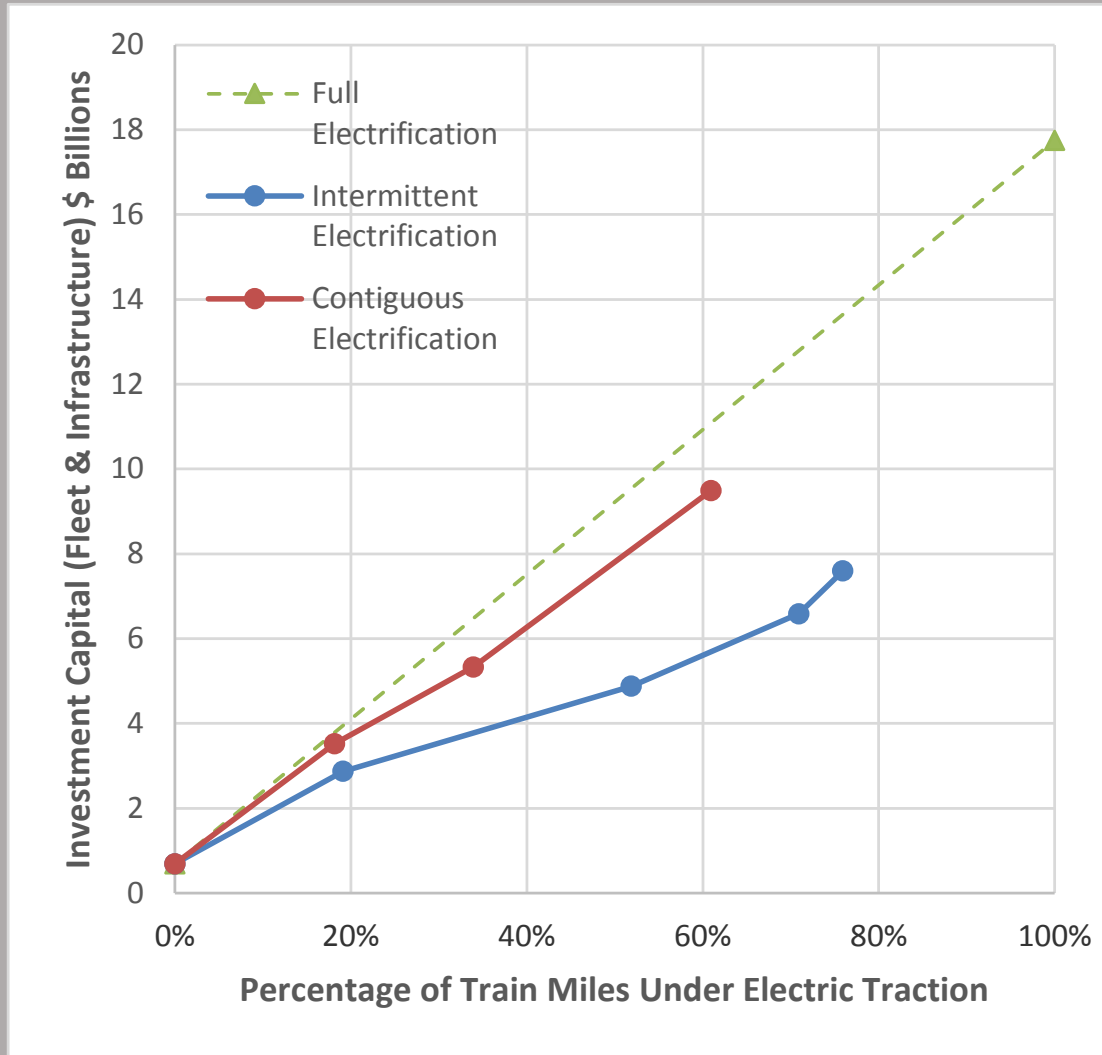
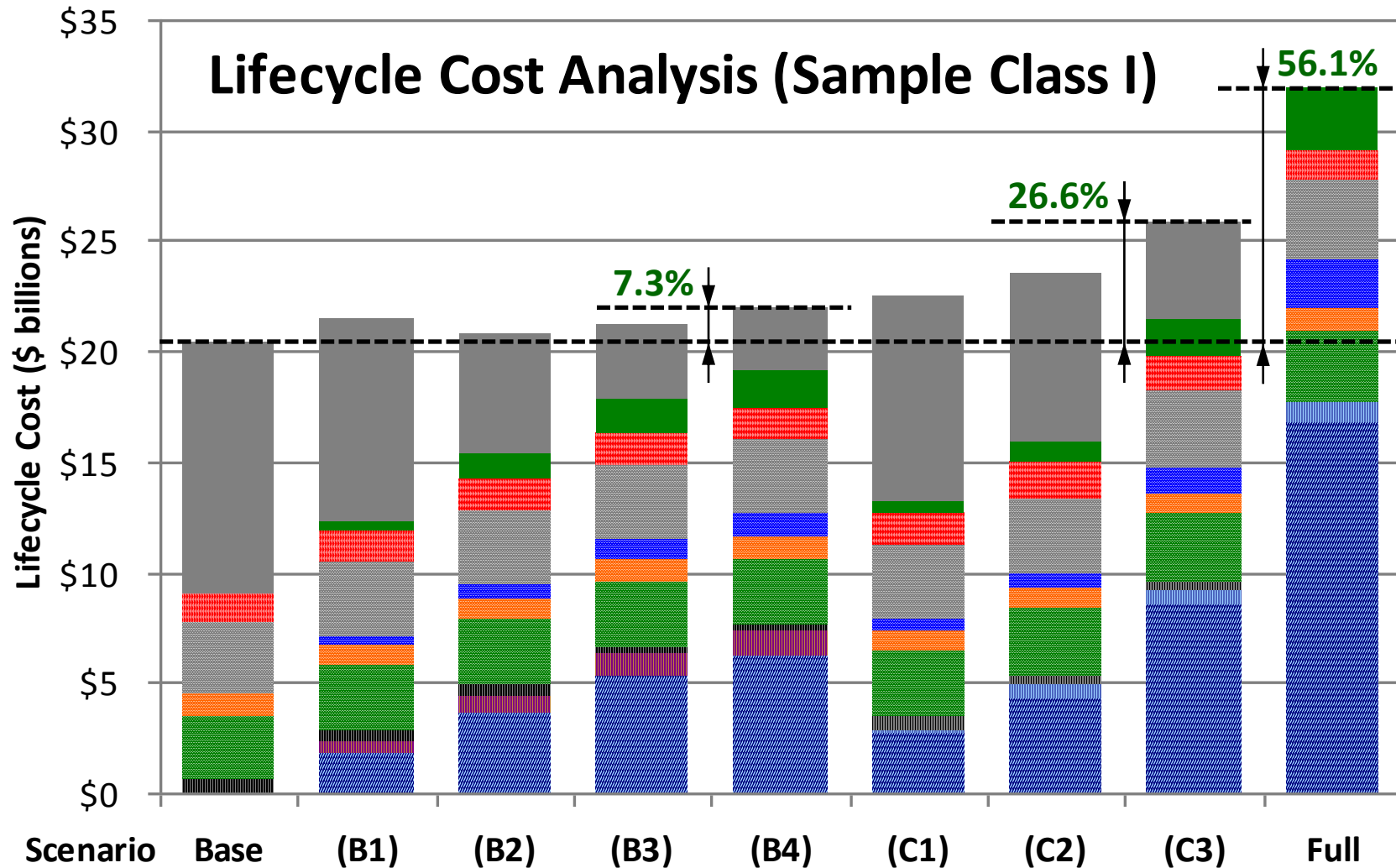


Figure 6(c,d)

LIFE-CYCLE COST ANALYSIS

Lifecycle Cost Analysis (Sample Class I)



- E.T. Infra.
 - Electric Locos
 - Signal MOW
 - E.T. MOW
 - T&E Crews
 - Diesel Fuel
 - Battery Locos
 - Diesel Locos
 - Comms MOW
 - T&S MOW
 - Electric Power
- All Maintenance Costs are NPV.*

Scenarios:

Base Case = Diesel Service Only

B1-B4 = Intermittent + Battery Electric, Phases 1 thru 4

C1-C3 = Continuous Electrification, Phases 1 thru 3

Full = Total Mainline Electrification

Discount Rate = 5%

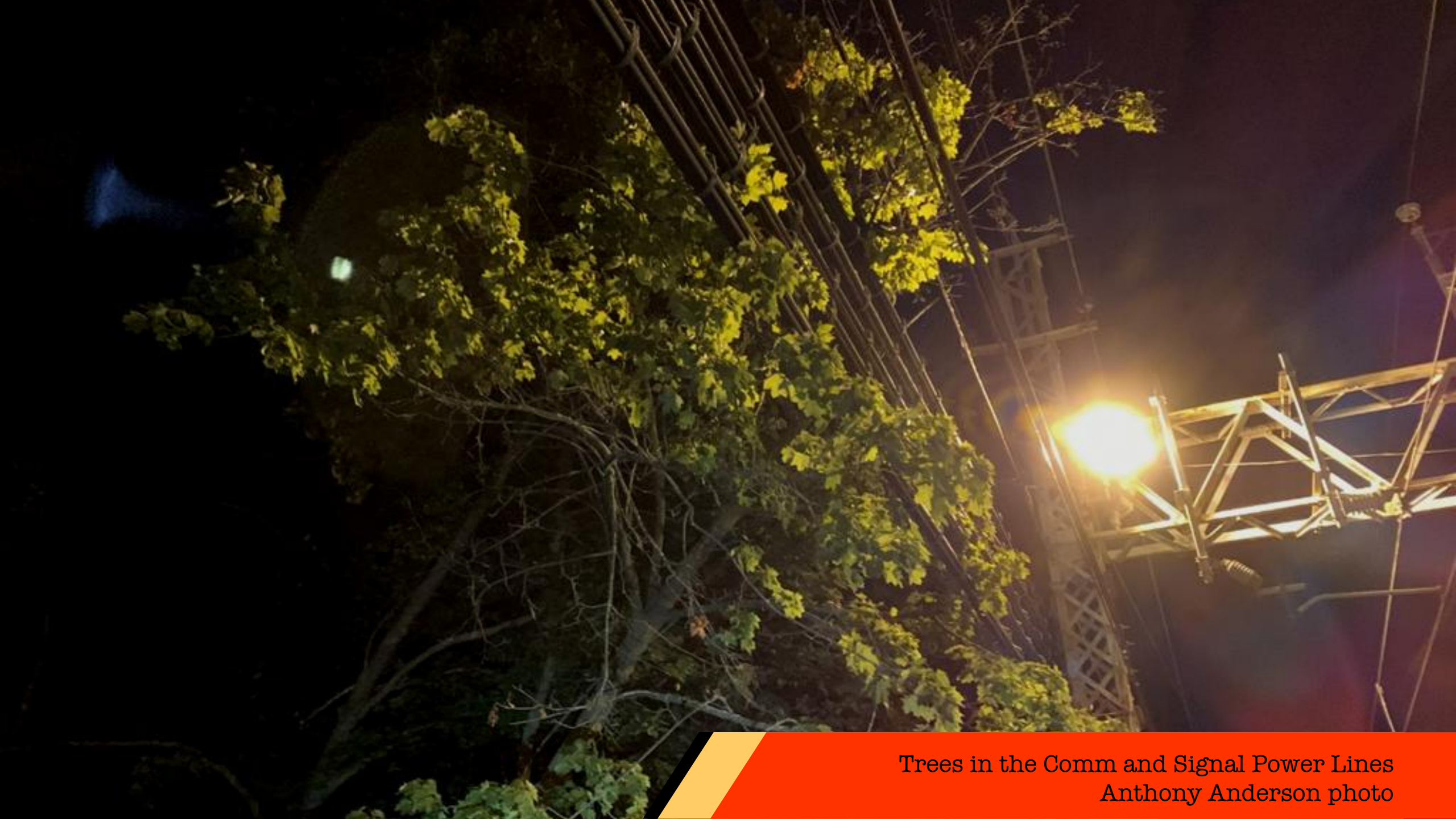
PRACTICAL ISSUES

- Proving high-capacity battery-electric locomotives
- Clearances for double-stack trains
- Non-electrified routes for high/wide loads
- Effects of extreme climate in North America
- Impacts on signal systems and maintenance practices





Indian Western Railways operates a electric double-stack container train from Palanpur to Botad in Gujarat, June 10, 2020; Piyush Goyal photo (India Government Open Data License via indianrailways.gov.in)



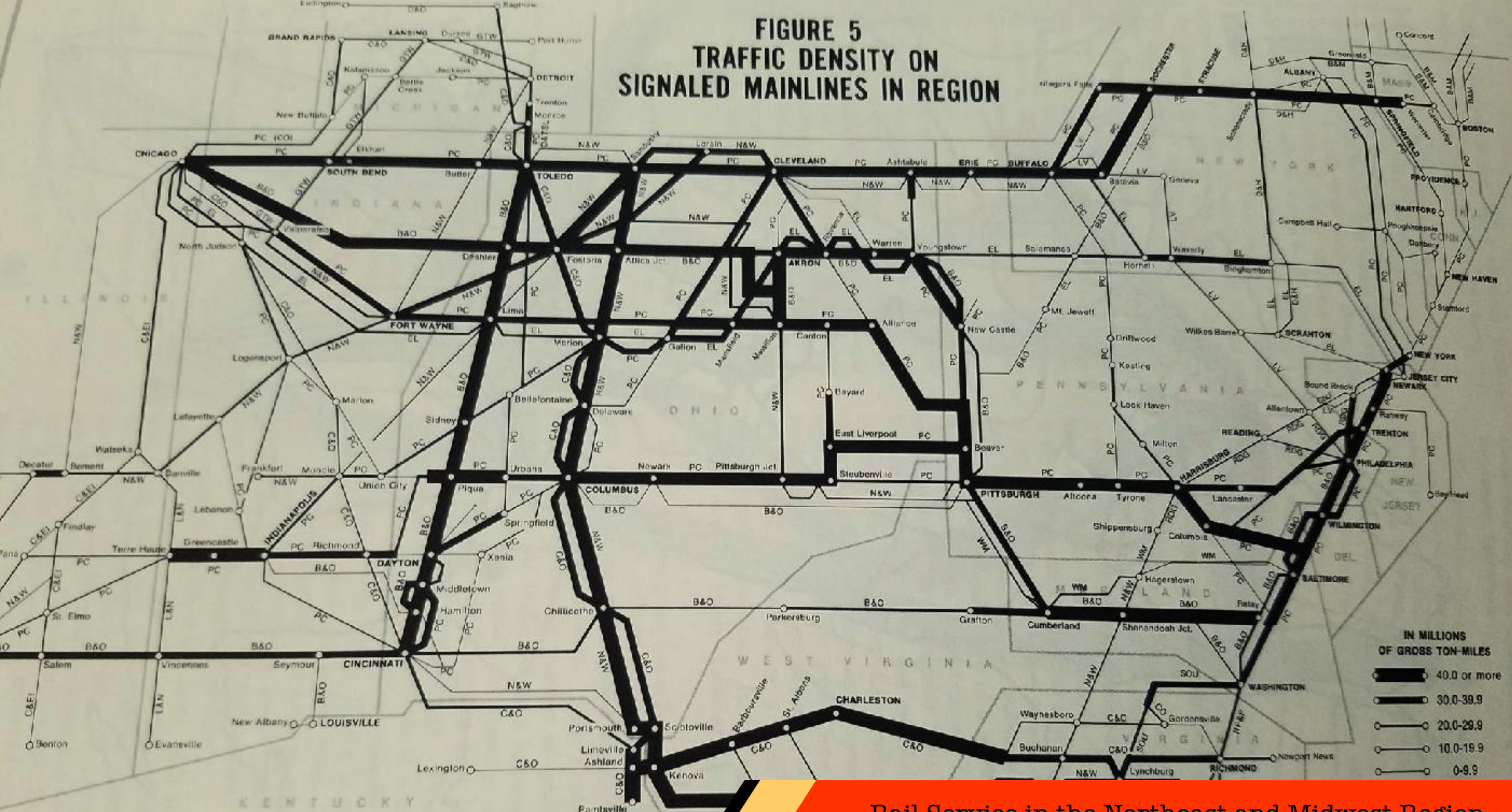
Trees in the Comm and Signal Power Lines
Anthony Anderson photo

NEXT STEPS

- Federal assistance: demonstration programs
- Commodity flow analysis: where to build?
- Business case analysis: what's in it for me?
- Joint network, capacity, and infrastructure planning by railroads with electric utilities



**FIGURE 5
TRAFFIC DENSITY ON
SIGNALLED MAINLINES IN REGION**



Rail Service in the Northeast and Midwest Region
U.S. Department of Transportation (1973)

INSTITUTIONAL MECHANISMS

- Tax credits
- Joint ventures
- Infrastructure improvement grants
- Cap-and-trade
- “Cash for clunkers” for diesel locomotives





Dead Line at Rutherford Yard, Penn.
Tom Beckett/CRHS photo (CC BY-NC-SA)

CONCLUSIONS

- Discontinuous electrification is workable with battery-electric locomotives
- Technology is rapidly developing and should be ready for service within a few years
- Alternating about every 200 miles between electrified and non-electrified

