Optimal Grade Crossing Project Selection for Improved Running Time on Passenger Rail Corridors



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RAILTEC
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Demand for Passenger Service Upgrades

- New Amtrak ridership record 10 of past 11 years… 31.6 million in FY13
- Amtrak ridership is growing faster than any major travel mode
- Continued interest in increasing the frequency and speed of intercity passenger rail service on shared rail corridors
- Increase passenger trains speed and frequency at grade crossings
- Passenger rail corridor development must be supported by investment in grade crossing infrastructure

Track Speed and Grade Crossing Upgrades

40 mph | 60 mph | 80 mph | 90 mph | 110 mph | >125 mph

Passive | Active | Quad gates | Impenetrable Barrier | Grade Separation

~$1,000 | ~$100,000 | ~$1,000,000 | ~$10,000,000


Corridor Improvements

Passenger rail corridor involves a series of integrated systems

TRACK STRUCTURE & GEOMETRY

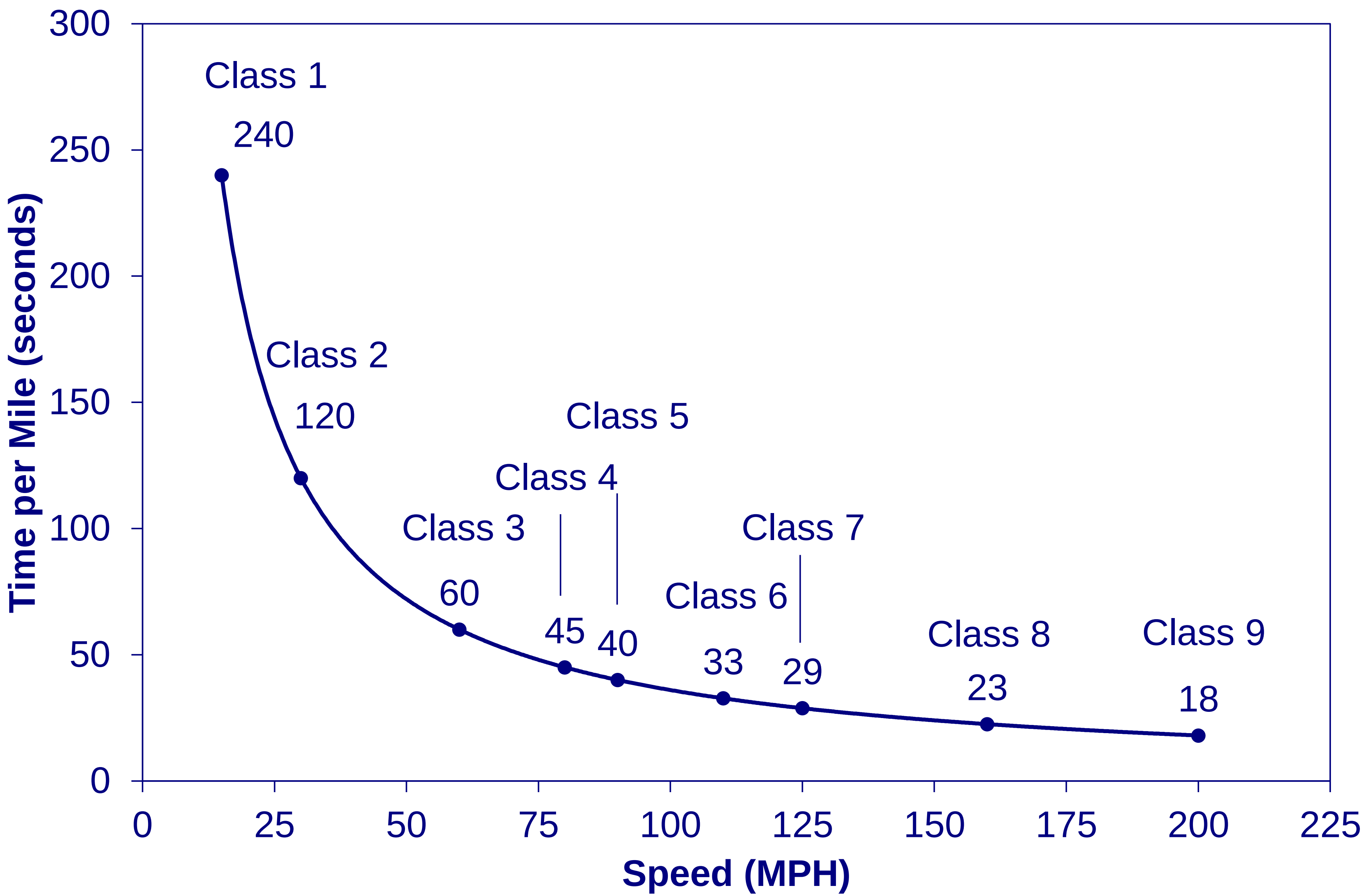
ROLLING STOCK

GRADE CROSSINGS

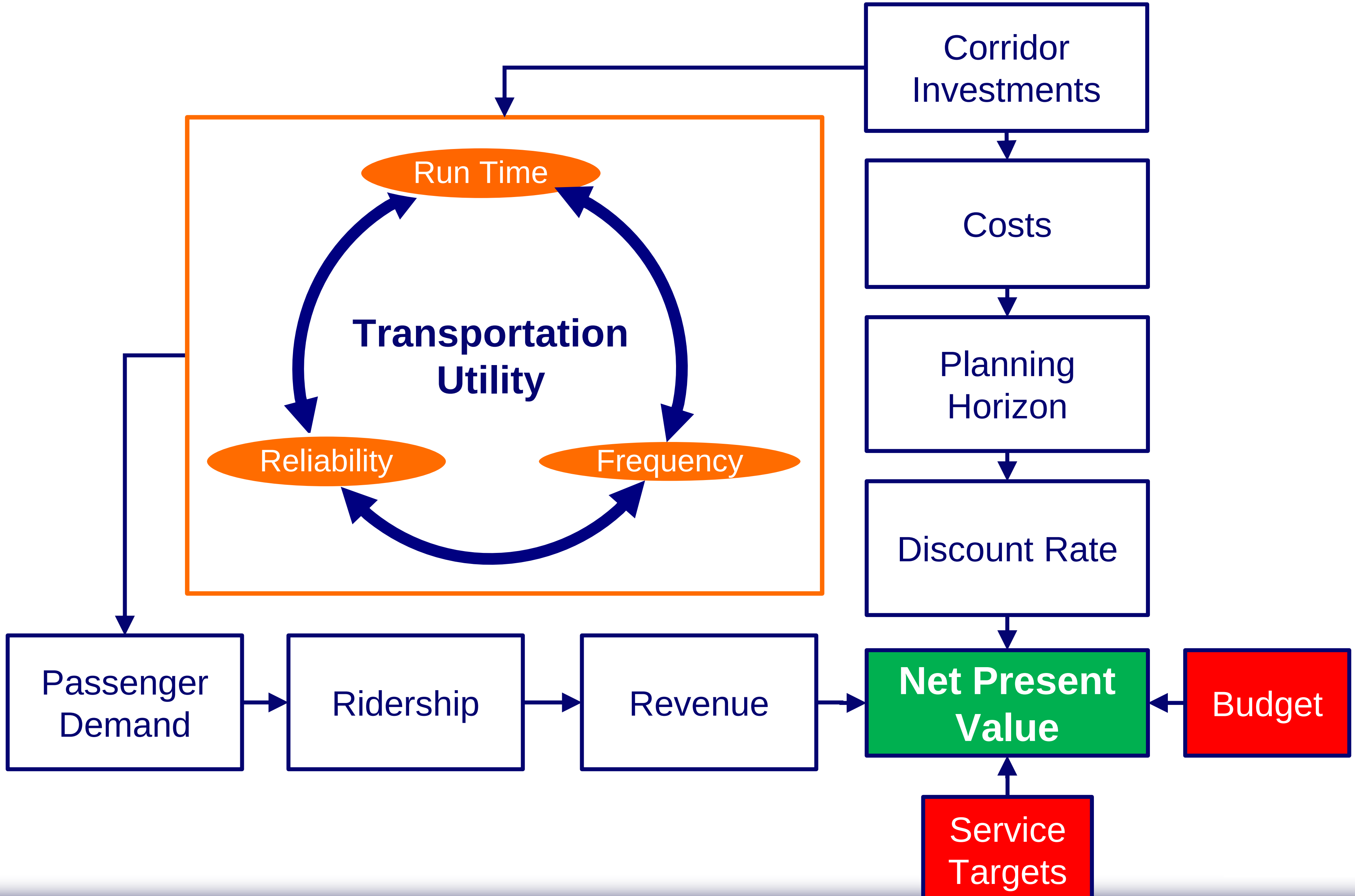
SPECIAL TRACKWORK

SIGNALS & TRAIN CONTROL

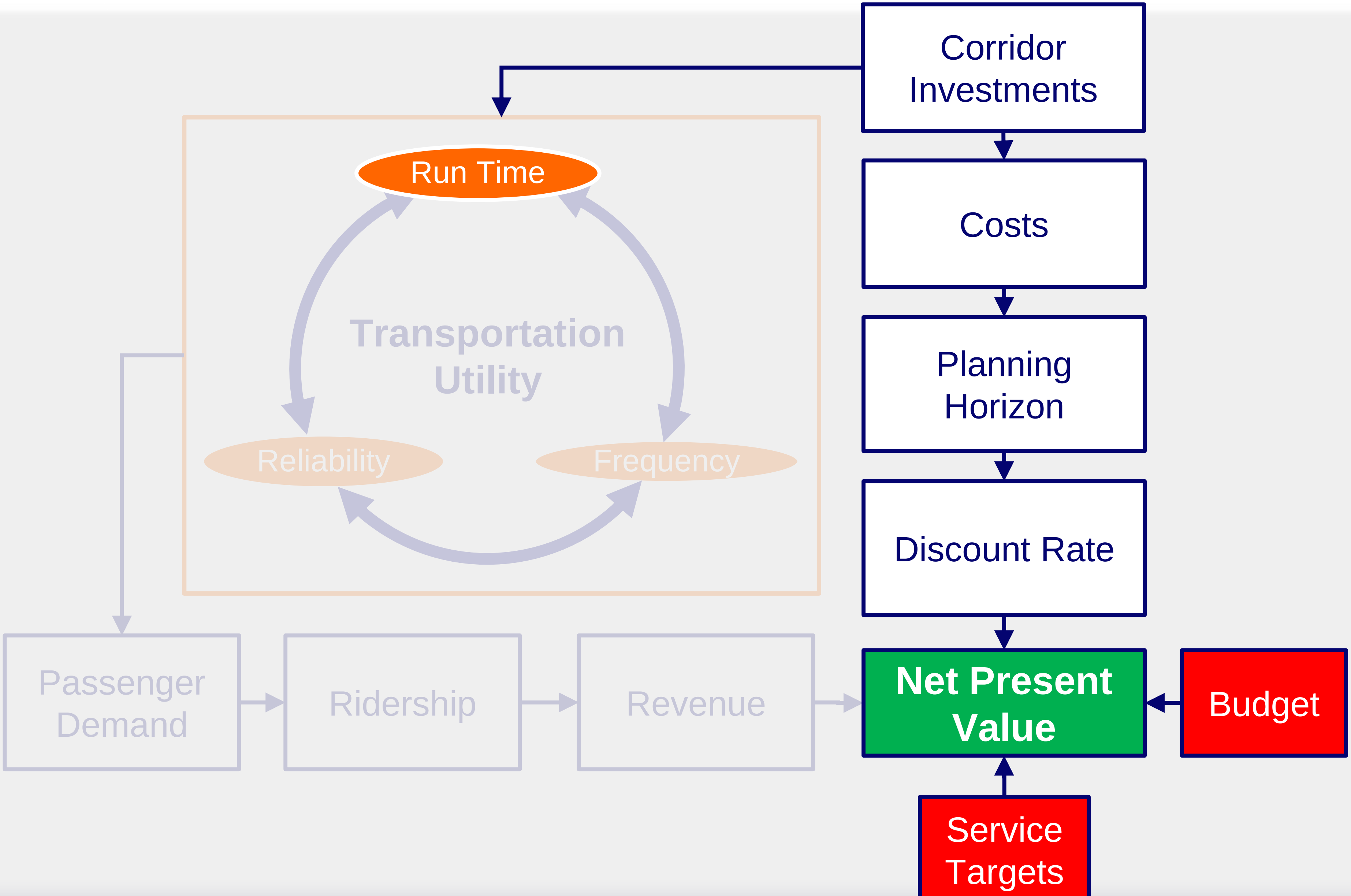
"Go Fast by Not Going Slow…"



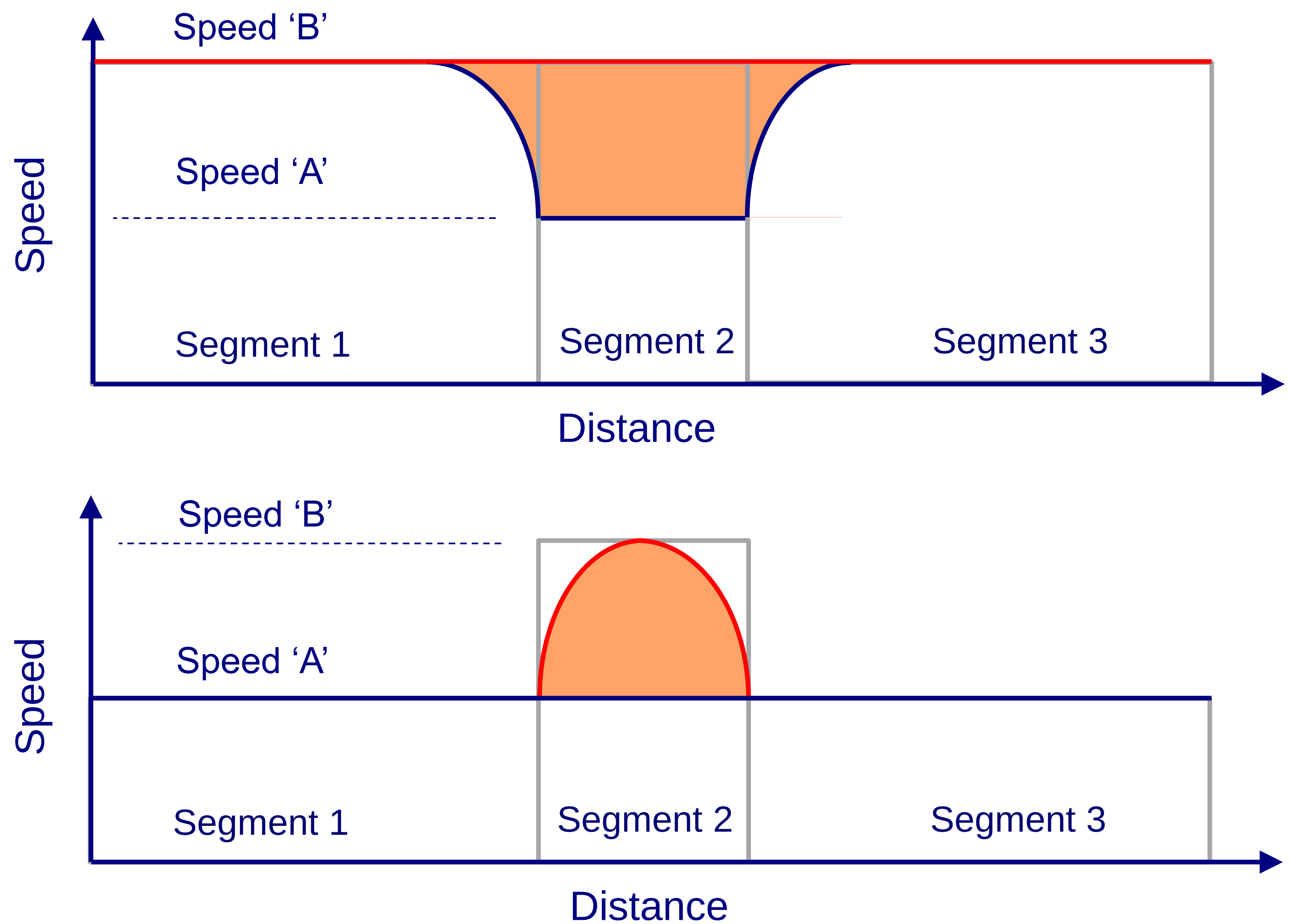
Ultimate Project Selection



Present Model Scope



Project Benefits Depend on Boundary Conditions



Opportunities to Reduce Running Time

- Improvements can be made to address schedule minimum run time and schedule reliability
- Improvement projects have different impacts on both schedule components

Schedule minimum run time

- Infrastructure
  - Track structure
  - Track geometry
  - Signals
  - **Grade crossings**
- Rolling stock
  - Acceleration
  - Top speed
  - Curving performance

Schedule reliability (uncertainty)

- Single vs. double track
- Siding length and spacing
- Capacity utilization
  - Existing capacity
  - Other rail traffic
- Station dwell
- Passenger delays

Model Objective Function

Minimize Total Running Time:

$$\sum_{n=1}^{N}\sum_{s=0}^{S}\sum_{t=1}^{T}\theta_{n,t}\, l_n\, \delta_s\, v_{n,s,s^*,t} + \sum_{n=2}^{N}\sum_{s=0}^{S}\sum_{s^*=0}^{S}\sum_{t=1}^{T}\theta_{n,t}\,\tau_{s,s^*,t}\, z_{n,s,s^*,t}$$

ABD link variable (1,0)

Acceleration/Braking Delay

Segments

Speeds

Trains

Segment specific train time weight factor

Segment length

Unit running time at speed ‘s’

Segment train speed (1,0)

Model Constraints (1 of 2)

$\sum_{n=1}^{N}\sum_{c=0}^{C} x_{n,c}p_{n,c} \leq B$	Budget constraint	(2)
$\sum_{s=0}^{S} v_{n,s,t}\sigma_s \leq \sum_{c=0}^{C} x_{n,c}\nu_c$	Train speed < infrastructure speed	(3)
$z_{n,s,s^*,t} \leq v_{n,s^*,t} \quad \forall\, n, s, s^*, t$	Acceleration and braking link (1)	(4)
$z_{n,s,s^*,t} \leq v_{n-1,s,t}\ \forall\, n, s, s^*, t$	Acceleration and braking link (2)	(5)
$z_{n,s,s^*,t} + 1 \geq V_{n,s^*,t} + V_{n-1,s,t}\ \forall\, n, s, s^*, t$	Acceleration and braking link (3)	(6)
$l_n - a_{n,t} - b_{n+1,t} \geq 0 \quad \forall\, n, t$	Segment acceleration and braking dist.	(7)

Model Constraints (2 of 2)

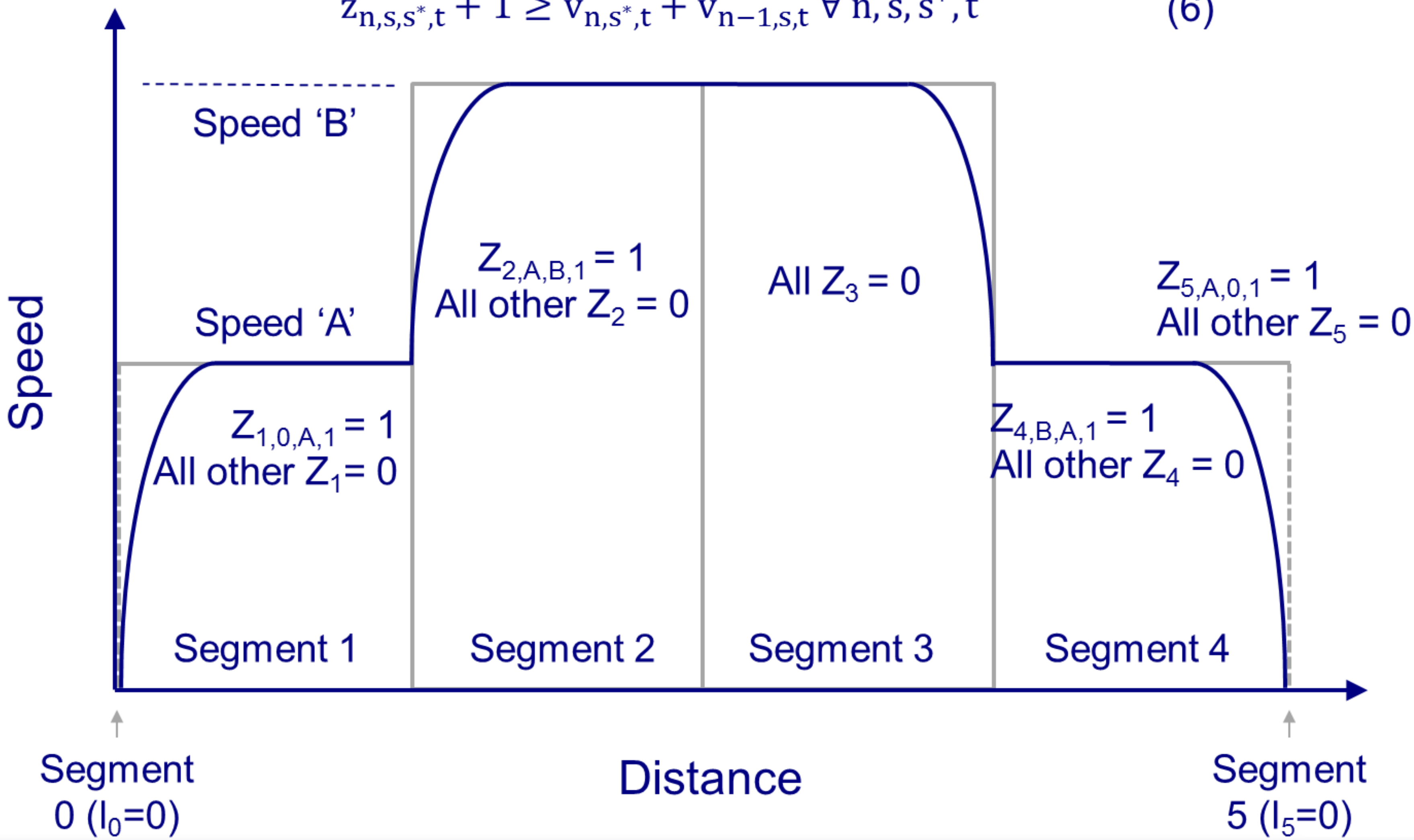
$b_{n,t} \geq \sum_{s=0}^{S} v_{n-1,s,t}\beta_{s,t} - v_{n,s,t}\beta_{s,t} \quad \forall\, 2 \leq n \leq N, t$	Braking distance	(8)
$a_{n,t} \geq \sum_{s=0}^{S} v_{n,s,t}\alpha_{s,t} - v_{n-1,s,t}\alpha_{s,t} \quad \forall\, 2 \leq n \leq N, t$	Acceleration distance	(9)
$\sum_{s=0}^{S} v_{n,s,t}\sigma_s \leq h_{n,t} \quad \forall\, n, t$	Station stopping constraint	(10)
$\sum_{s=0}^{S} v_{n,s,t} = 1 \quad \forall\, n, t$	One operating speed per service on each segment	(11)
$\sum_{c=0}^{C} x_{n,c} = 1 \quad \forall\, n$	One track maximum speed on each segment	(12)

Train Performance Calculator Constraints

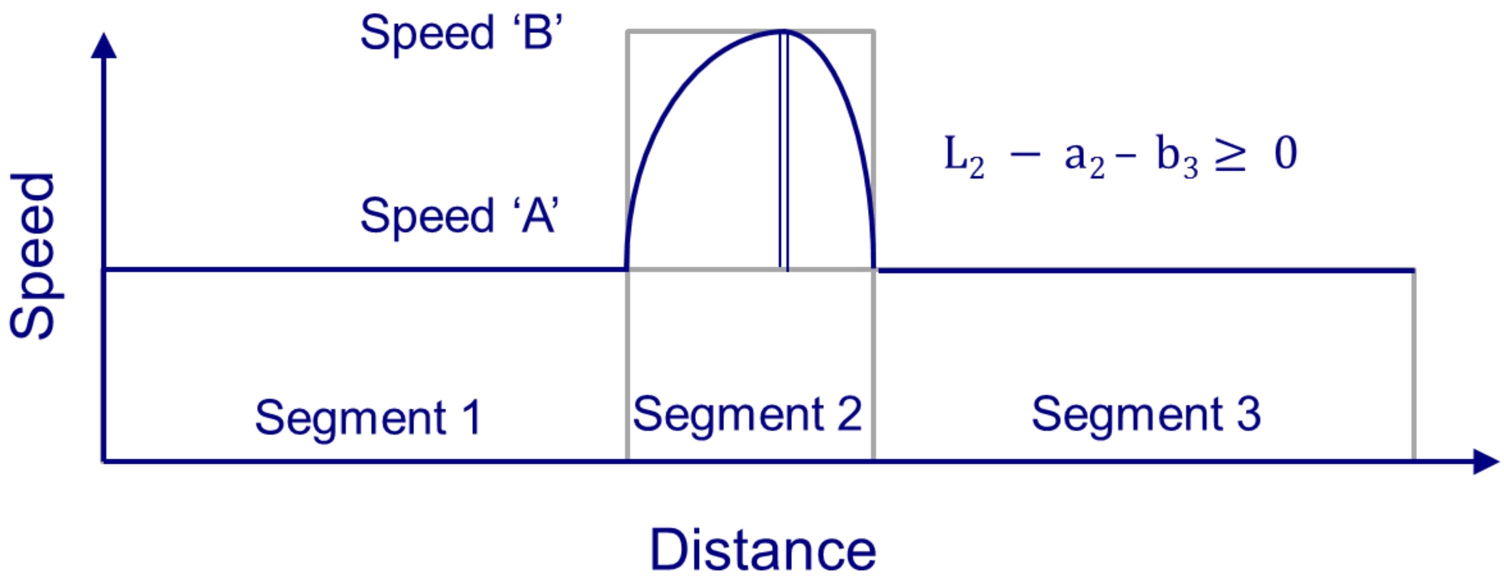
$$z_{n,s,s^*,t} \leq v_{n,s^*,t} \quad \forall\, n, s, s^*, t \tag{4}$$

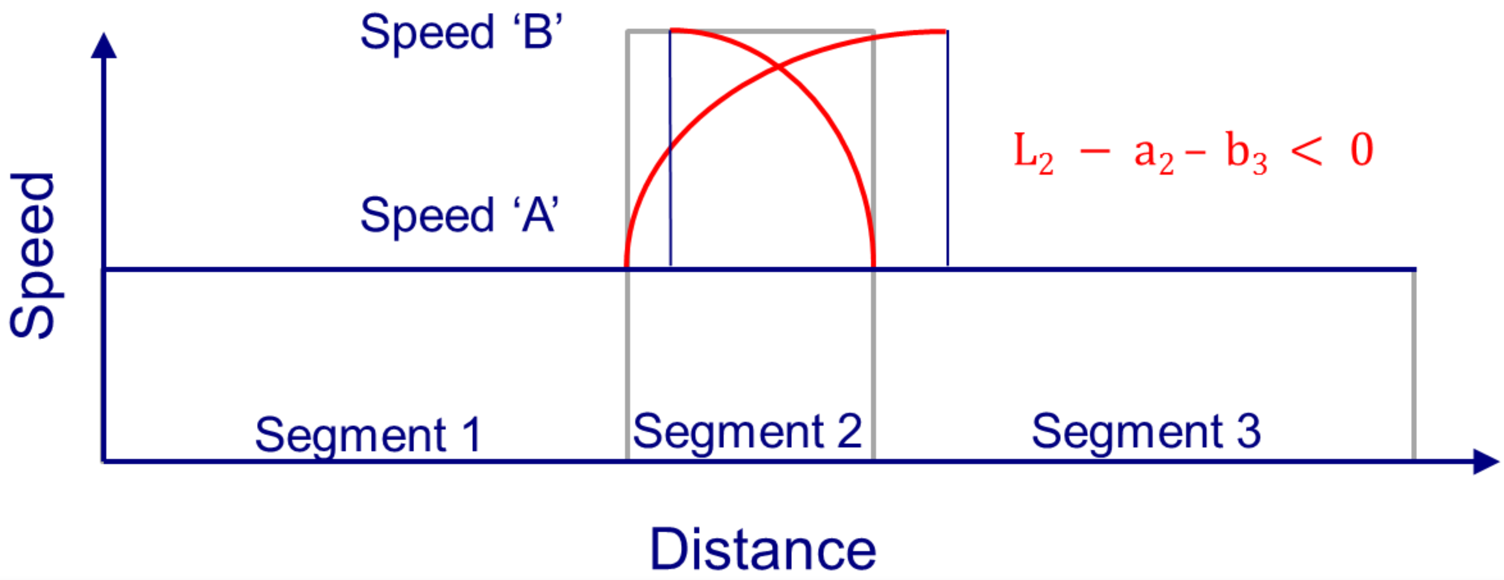
$$z_{n,s,s^*,t} \leq v_{n-1,s,t} \; \forall\, n, s, s^*, t \tag{5}$$

$$z_{n,s,s^*,t} + 1 \geq v_{n,s^*,t} + v_{n-1,s,t} \; \forall\, n, s, s^*, t \tag{6}$$



Minimum Upgrade Length Constraints





Case Study – Porter, IN to St. Joseph, MI

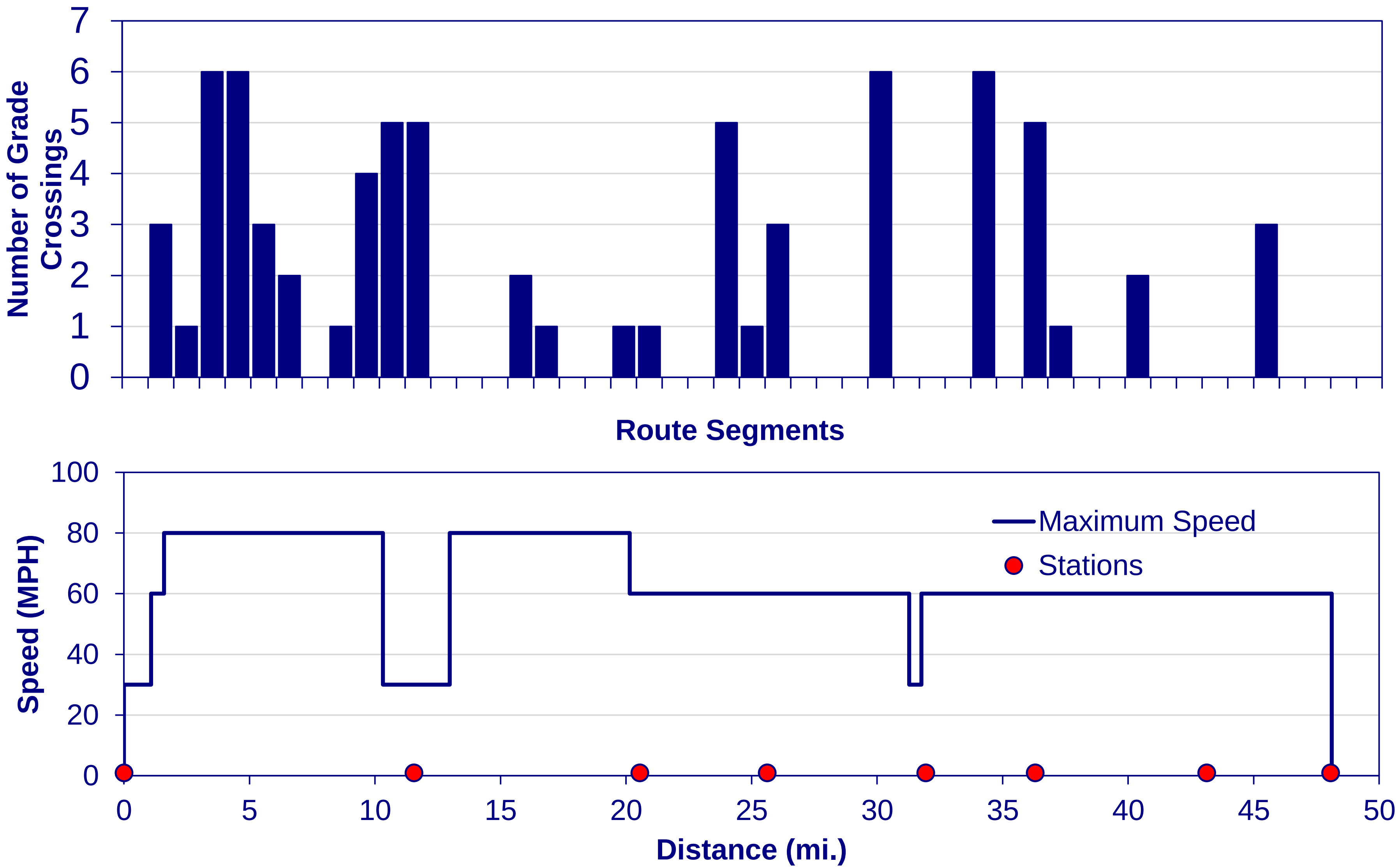
- One round trip frequency per day
- Route length of 176 mi
- 79 MPH maximum speed
- 44 MPH average speed (good case for improvement)
- Annual ridership 106,662 (FY '11)

PERE MARQUETTE

370			◂ Train Number ▸			371
Daily			◂ Normal Days of Operation ▸			Daily
R ☕			◂ On Board Service ▸			R ☕
Read Down	Mile	▼		Symbol	▲	Read Up
4 55P	0	Dp	Chicago, IL–Union Station (CT)	●♿QT	Ar	10 38A
7 38P	89		St. Joseph-Benton Harbor, MI (ET)	○QT		9 44A
8 14P	116		Bangor, MI (South Haven)	○		9 07A
8 56P	151		Holland, MI	○♿QT		8 26A
9 55P	176	Ar	Grand Rapids, MI (ET)	○♿QT	Dp	7 40A

- Selected segment from Porter to St. Joseph for current PSM case study
- Added hypothetical commuter rail service to demonstrate functionality of model

Route Characteristics



Upgrade Treatments

Track Class	Maximum Train Speed (MPH)	Track Structure	Signal System	Grade crossings / Misc.
Class 3	60	Replace 1/3 Cross Ties (wood), 136RE CWR, Surfacing		Curve shift
Class 4	80	Replace 1/3 Cross Ties (wood), 136RE CWR, Surfacing	CTC	Curve shift
Class 5	90	Replace 1/3 Cross Ties (wood), 136RE CWR, Surfacing	CTC/AT S/ATC	Curve shift, Four quad gate crossings
Class 6	110	Replace 2/3 Cross Ties (wood), 136RE CWR, Surfacing	CTC/AT S/ATC	Curve shift, four quad gate crossings with intrusion detection, fenced ROW

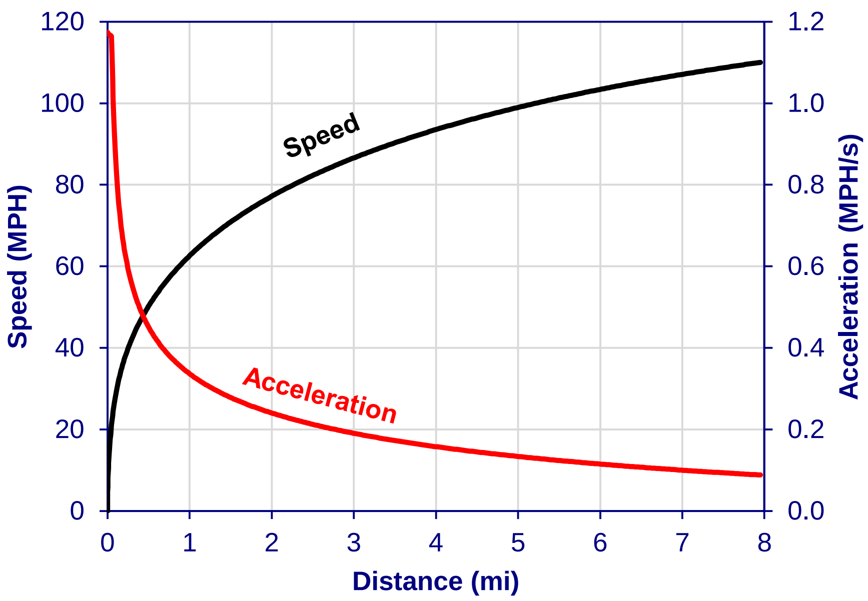
Case Study Input Parameters

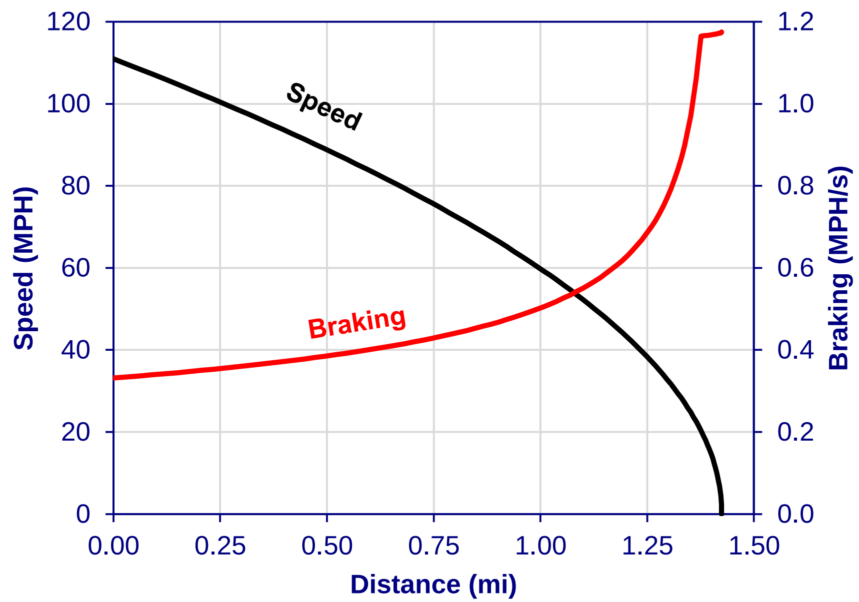
Inputs

- Capital costs from Quandel Consultants (2011)
- Maintenance costs from Zarembski et al (2002)
- Discount rate 5%, 10 year period
- Equal train running time weights (alpha 1 = alpha 2)
- Identical train consists for each service (1 loco, 6 coach, 1 NPCU*)
- Acceleration and braking performance from simplified TPC

Solution

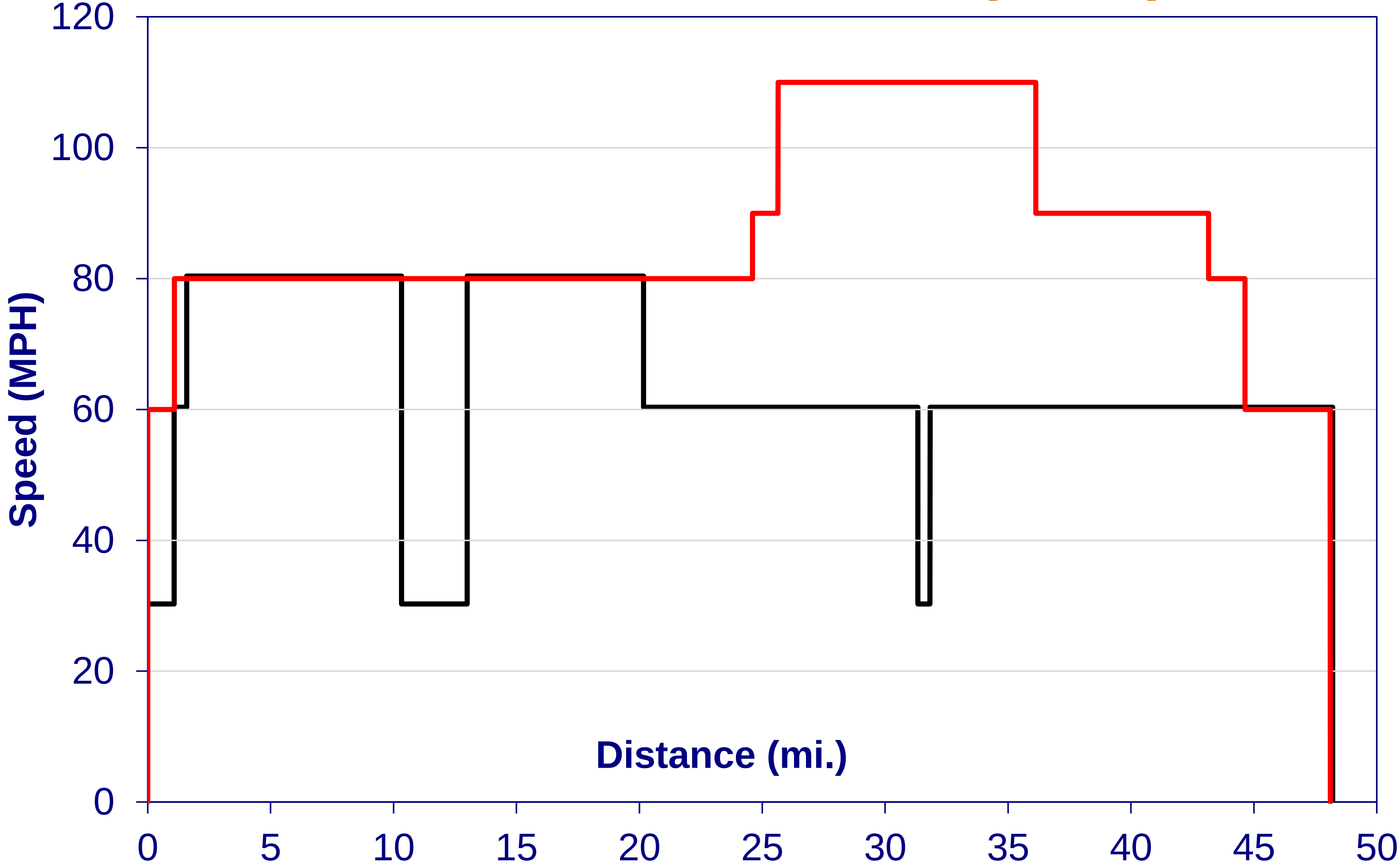
- Mixed Integer Program (MIP) with GUROBI 5.0 solver
- 1-2 minutes to optimal solution for each scenario



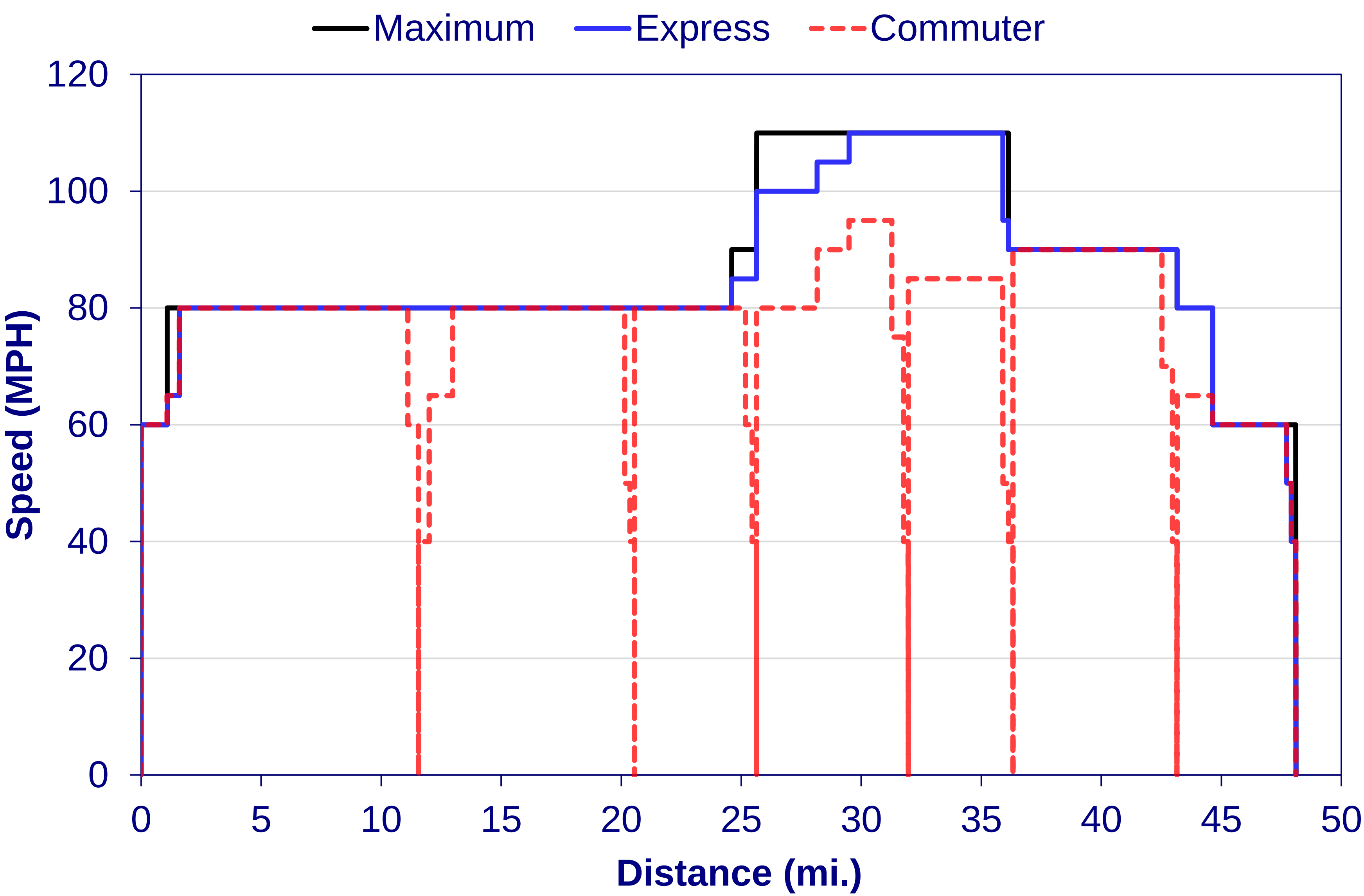


* NPCU = Non-Powered Cab Unit

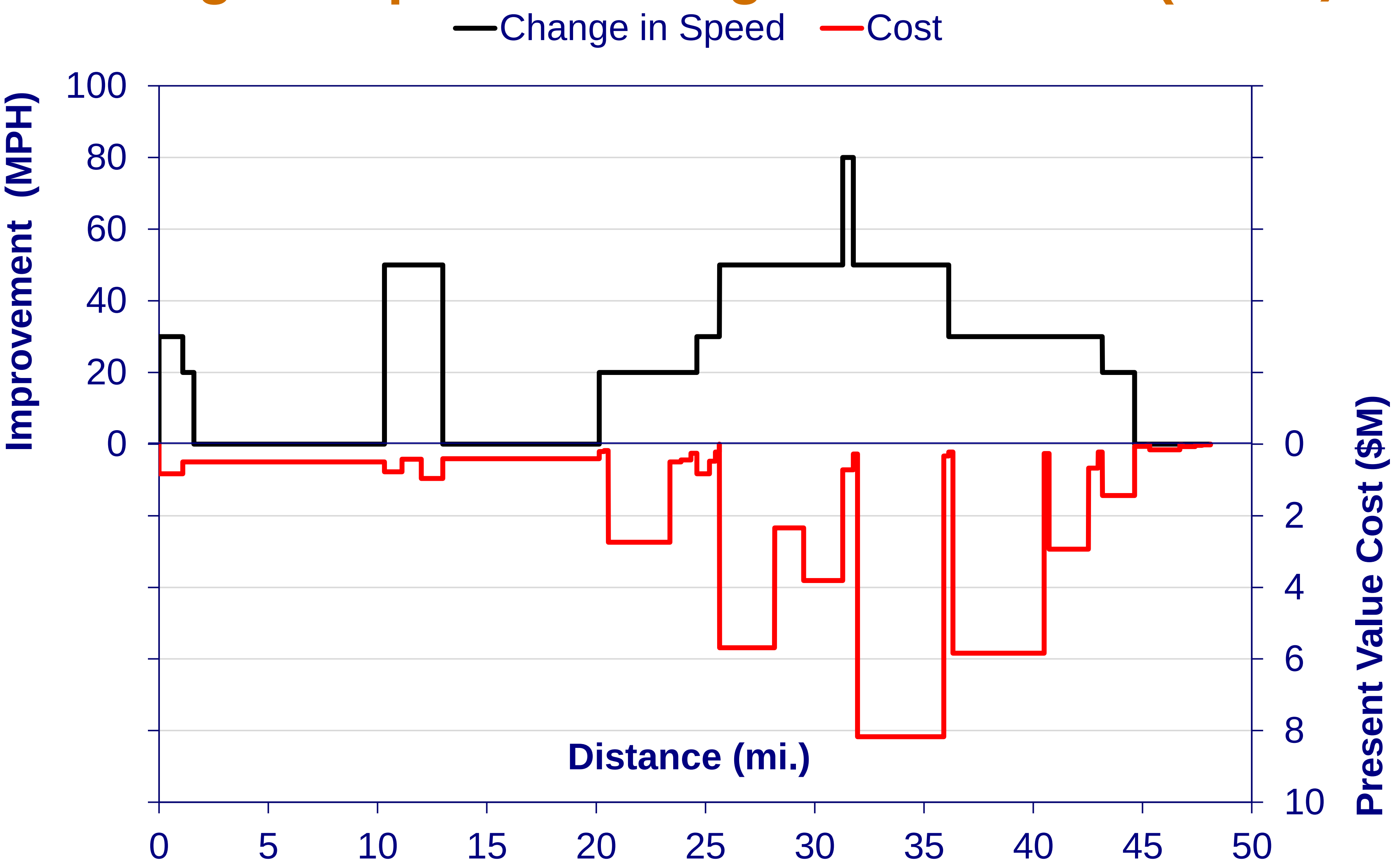
Initial vs. Final Condition ($45M)



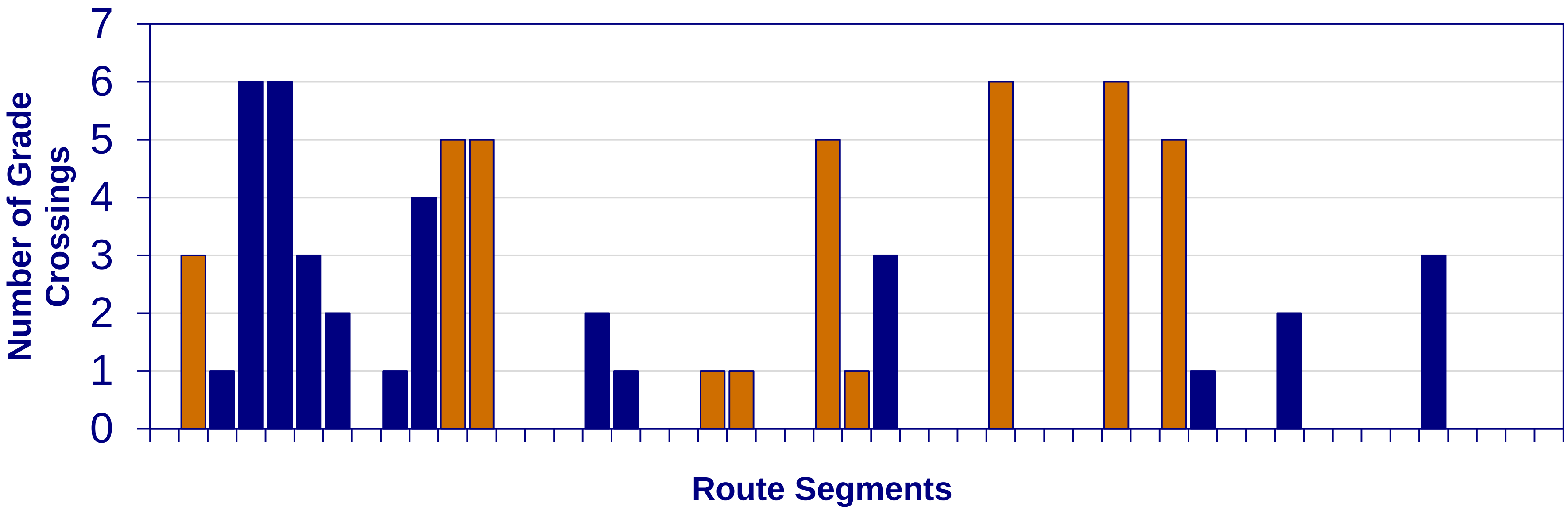
Service Speeds ($45M)



Change in Speed and Segment PV Cost ($45M)

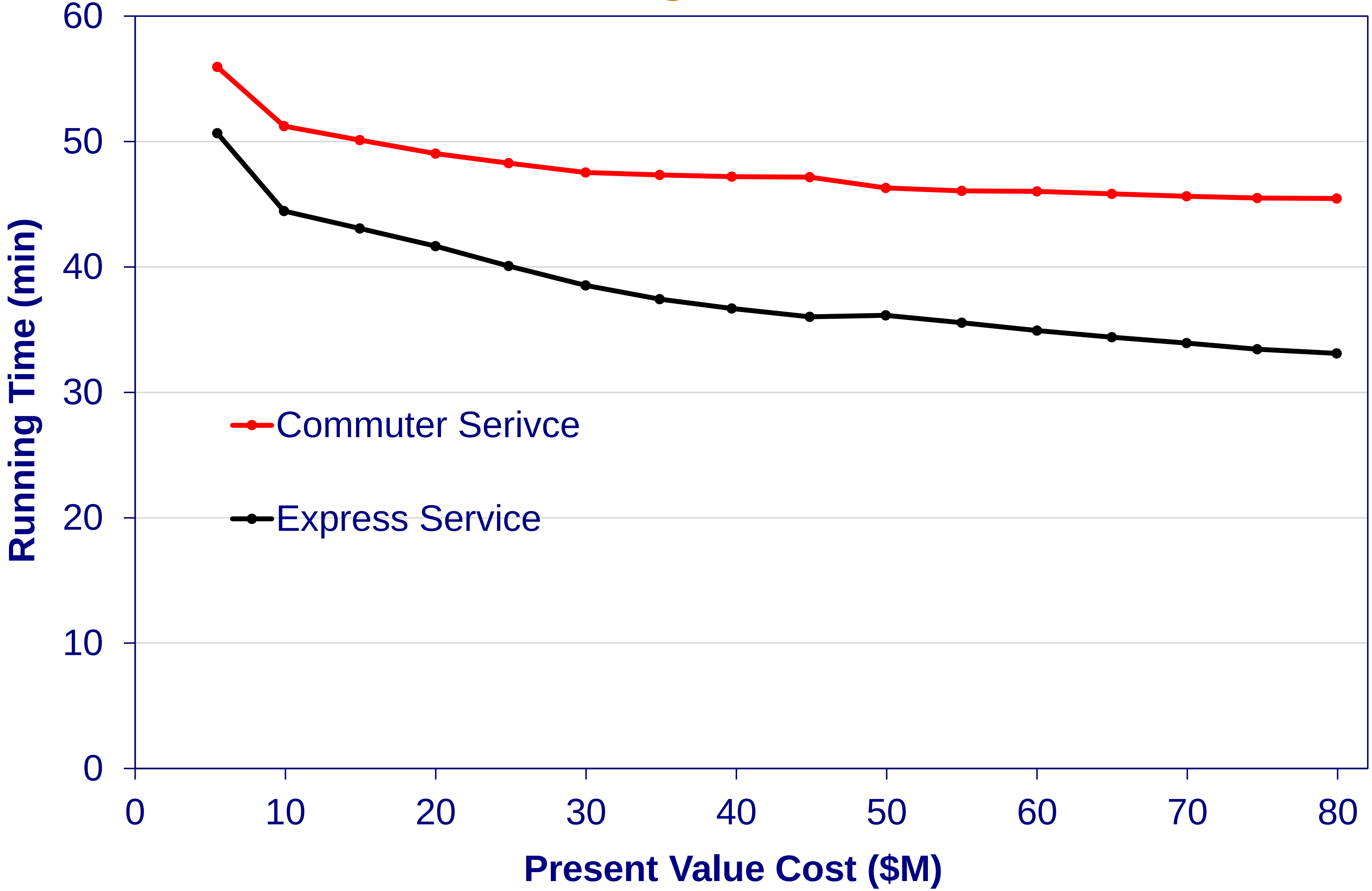


Grade Crossing Improvements

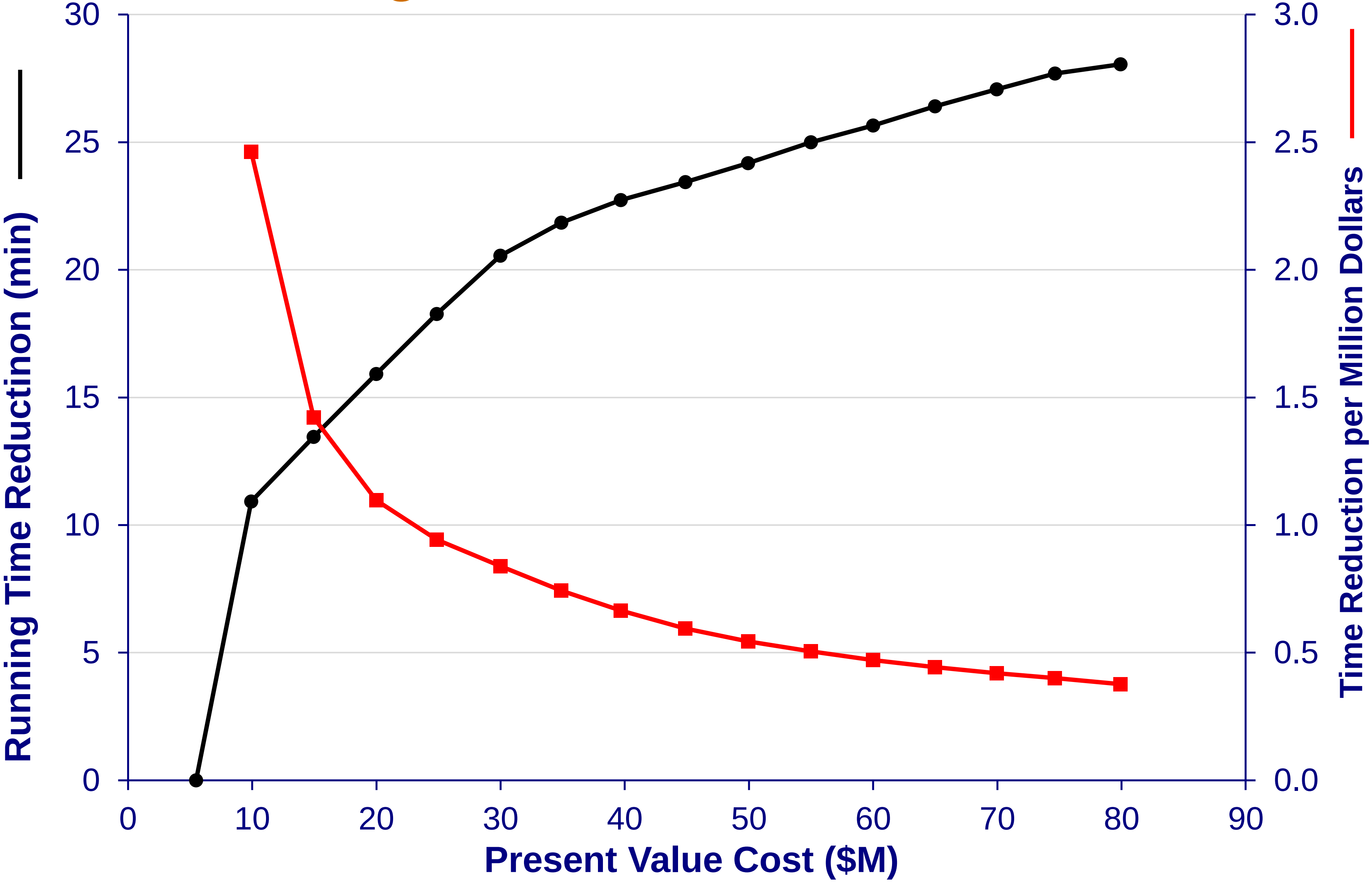


- Improved crossings shown in orange
- Only a subset of crossings are improved corresponding to segments with speed improvement
- Crossings near speed restrictions and unimproved segments do not need to be upgraded, minimizing investment

Service Running Time vs. PV Cost



Running Time Reduction vs. PV Cost



Summary

- Grade crossings and protection devices are one part of the integrated passenger rail corridor system
- Can't view in isolation due to interactions and train performance
- Requires a corridor approach to evaluate benefit of projects
- Optimization can prioritize and target investment for maximum return and suggest appropriate budgets for corridor upgrades

Thank you for your attention!

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