



**Massachusetts Bay  
Transportation Authority**

## **Green Line Transformation Program: Future Capacity Study Update**

**Fiscal & Management Control Board**

**May 7, 2018**



## Green Line Transformation Program

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### Today's Presentations:

#### 1. Future Capacity Study

- Year Long study focused on identifying opportunities to increase Green Line Customer Capacity
- Multiphase program has been identified to modernize and increase capacity of the Green Line

#### 2. Green Line Transformation Program

- Establish a program that integrates safety and reliability needs of today and modernization planning for tomorrow into a single, coordinated capital investment program
- Current \$950m+ of Green Line SGR projects identified in the CIP

#### 3. Award of Program Management & Construction Management team to support this program

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## Green Line Future Capacity Study Overview

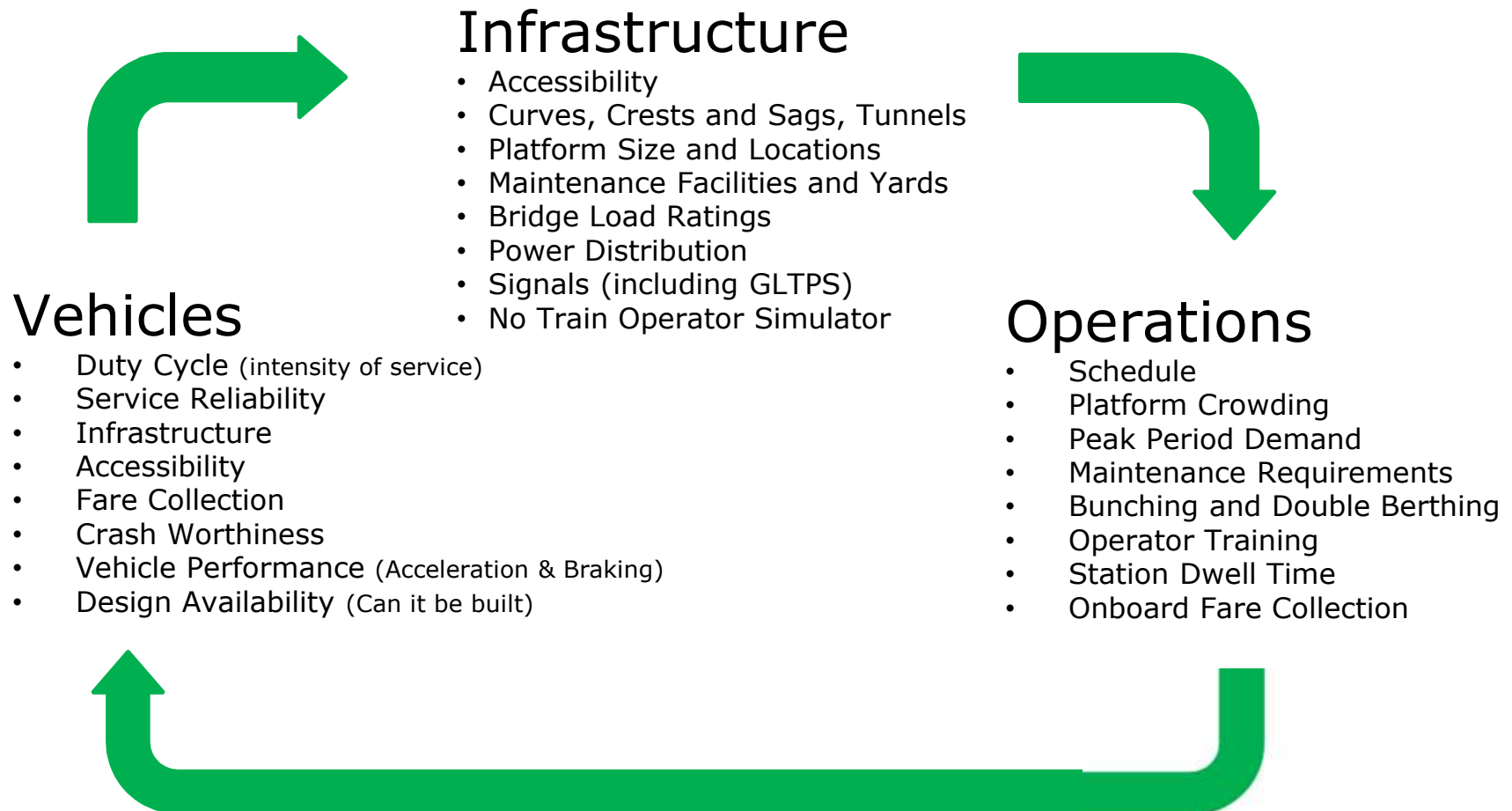
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- Goal: To evaluate practical concepts to increase customer carrying capacity on the Green Line
  - Define Infrastructure Constraints
  - Explore Vehicle Configurations
- Recommended path to achieve greater Green Line capacity
- Next Steps we are taking to get there





## Challenges and Constraints







## Relationship between Infrastructure and Vehicle Design

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- Legacy infrastructure has always influenced vehicle design
  - Lechmere Inner Loop, circa 1920, has been a significant influence on multiple generations of Green Line vehicles and is going away with the GLX
  - The Lechmere Viaduct circa 1905, restricts vehicle loading
  - The diameter of the Park Street Loop defined circa 1895
  - The track spacing and platform layout along Beacon Street in Brookline (C Branch) determined circa 1887
- Front door fare collection constrained door and cab design, going away with AFC 2.0



## Identifying Constraining Infrastructure

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- A comprehensive review of the Green Line was conducted
- All infrastructure constraints that impact vehicle design and capacity have been identified
  - Bridges and Structures
  - Restrictive Curves
    - Lechmere Inner Loop
    - Lake St Yard and Boston College Station
    - Reservoir Yard
  - Park Street Loop
  - Station and Platform Lengths
  - Vehicle Maintenance Facilities and Storage
  - Power & Signals
  - Track State of Good Repair



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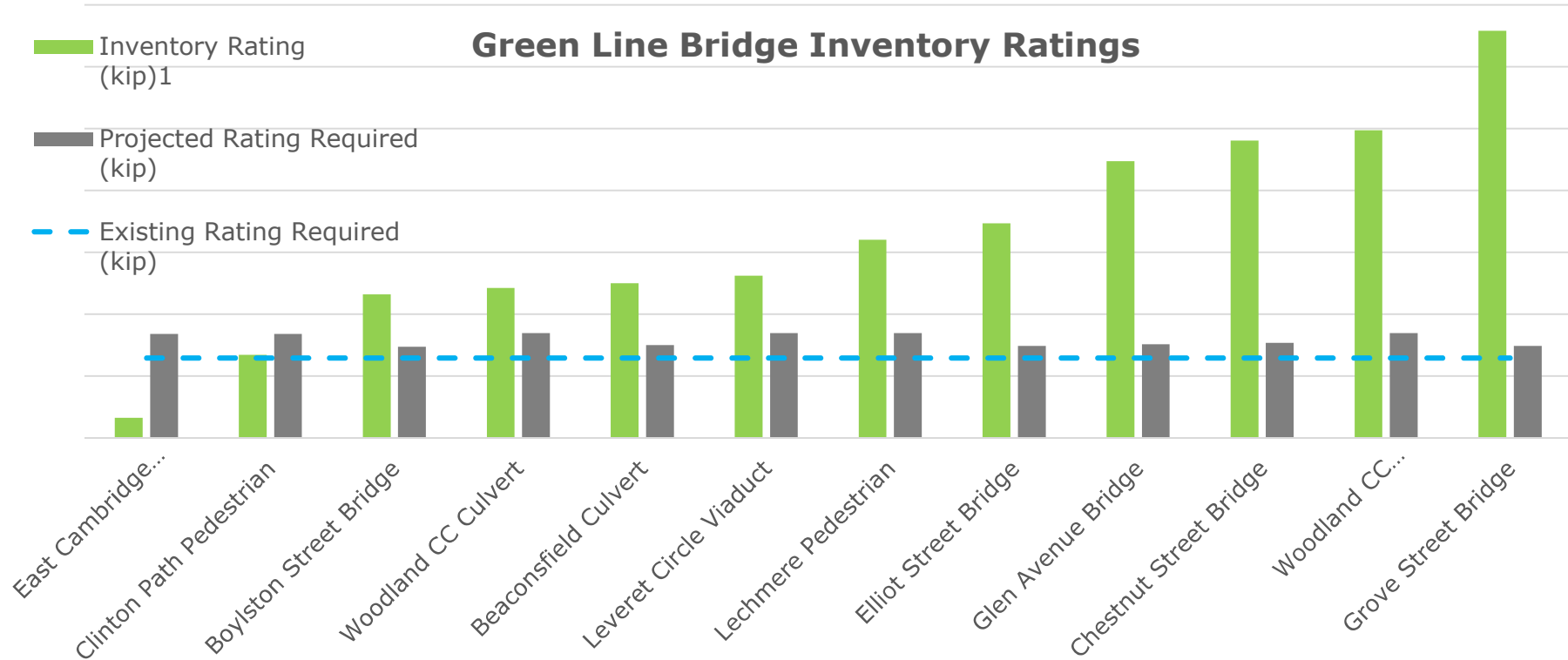
## Bridges and Structures

- Restrictive Curves
  - Lechmere Inner Loop
  - Lake St Yard and Boston College Station
  - Reservoir Yard
- Park Street Loop
- Station and Platform Lengths
- Vehicle Maintenance Facilities and Storage
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- Track State of Good Repair



## Bridges and Structures

- Longer and heavier cars with different axle spacing will load bridges differently than existing cars





## Bridges and Structures - Lechmere Viaduct

- Landmark Bridge between Boston and Cambridge.
- Modernization required because the condition of the bridge restricts current operations to low speeds and limits the number of trains in each direction at any time.

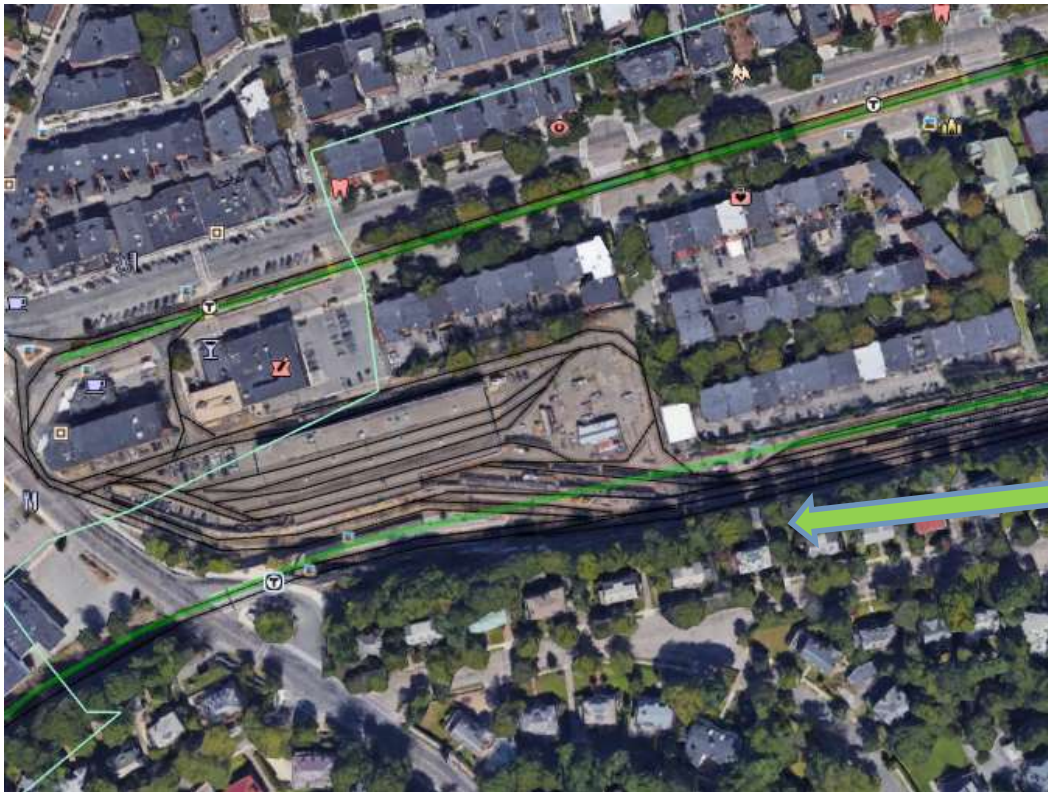






## Bridges and Structures - Clinton Path Underpass

- Pedestrian Underpass near Reservoir Station
- Minor upgrades will be needed to support a longer vehicle





## Identifying Constraining Infrastructure

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  - Bridges and Structures

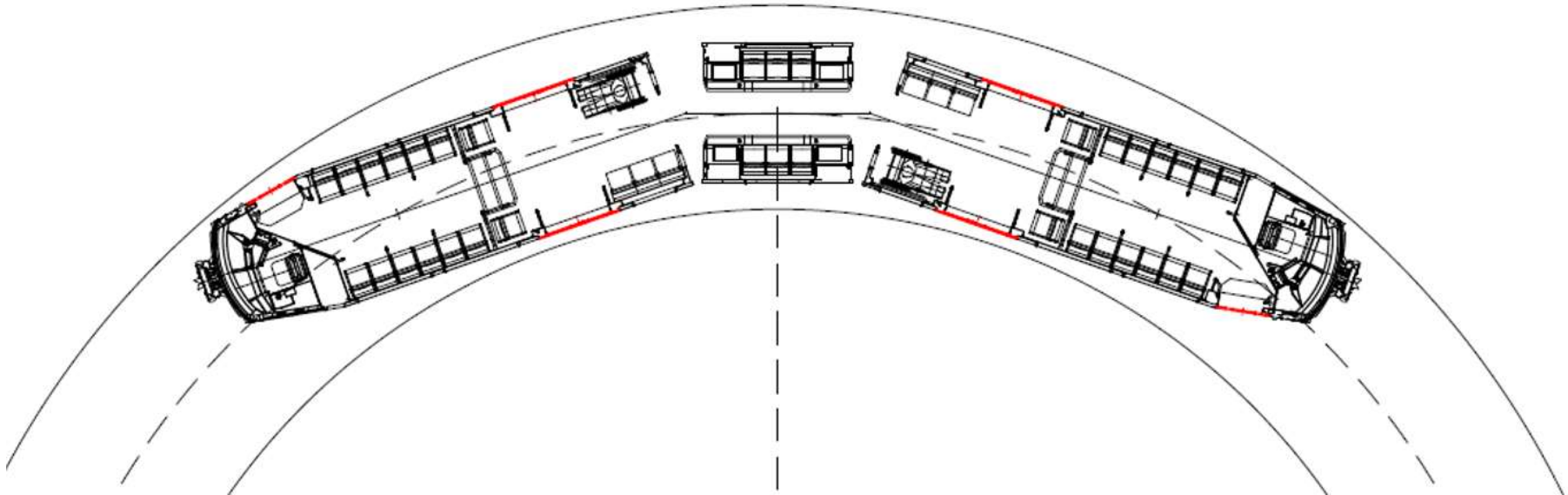
## Restrictive Curves

- Lechmere Inner Loop
  - Lake St Yard and Boston College Station
  - Reservoir Yard
  - Park Street Loop
  - Station and Platform Lengths
  - Vehicle Maintenance Facilities and Storage
  - Power & Signals
  - Track State of Good Repair
-



## Restrictive Curves

- Tight Curves restrict vehicle design and operations







## Restrictive Curves

- The 42 ft. Lechmere Inner Loop curve has influenced the design of Green Line vehicles for 96 years and is being removed as part of the GLX project.
- The remaining Tightest Curves Shown Below:



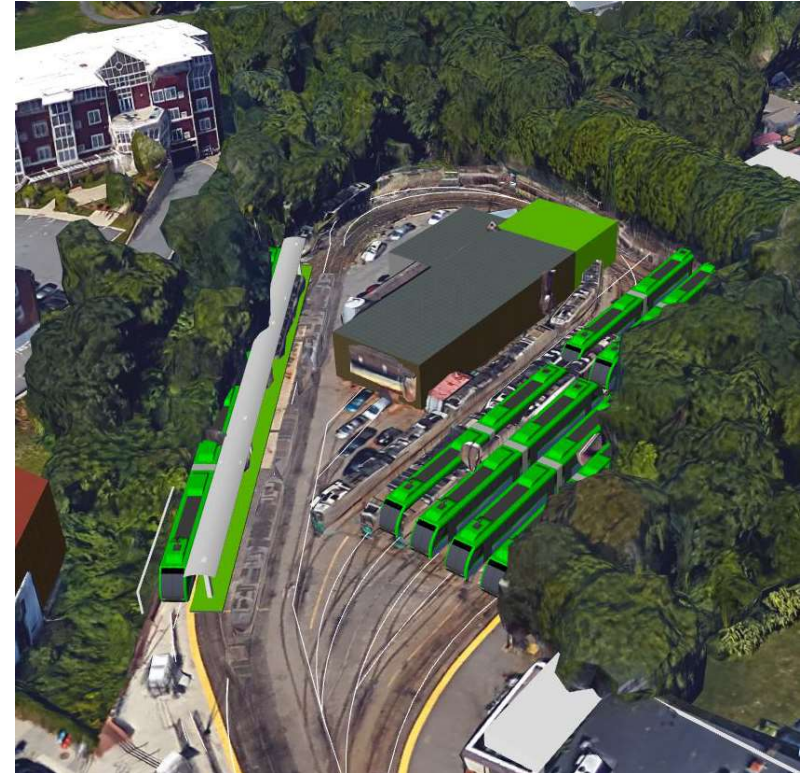
Radius	Location	Name
45	Reservoir Yard	West Wye Curve 97
45	Lake St Yard	Curve 16
45	Lake St Yard	Inner Loop
46	Lake St Yard	Curve 13
47	Park St	Park St Loop
49	Government Center	Brattle Loop



## Restrictive Curves - Lake St Yard & BC Station



- Lake Street Yard Loops are 45ft. curves that will be the tightest curves in the system after GLX opens
- Inbound and Outbound platforms are separated and both platforms are on curves and too short
- Expanding the yard by eliminating the loop will provide more vehicle storage and a better BC Station

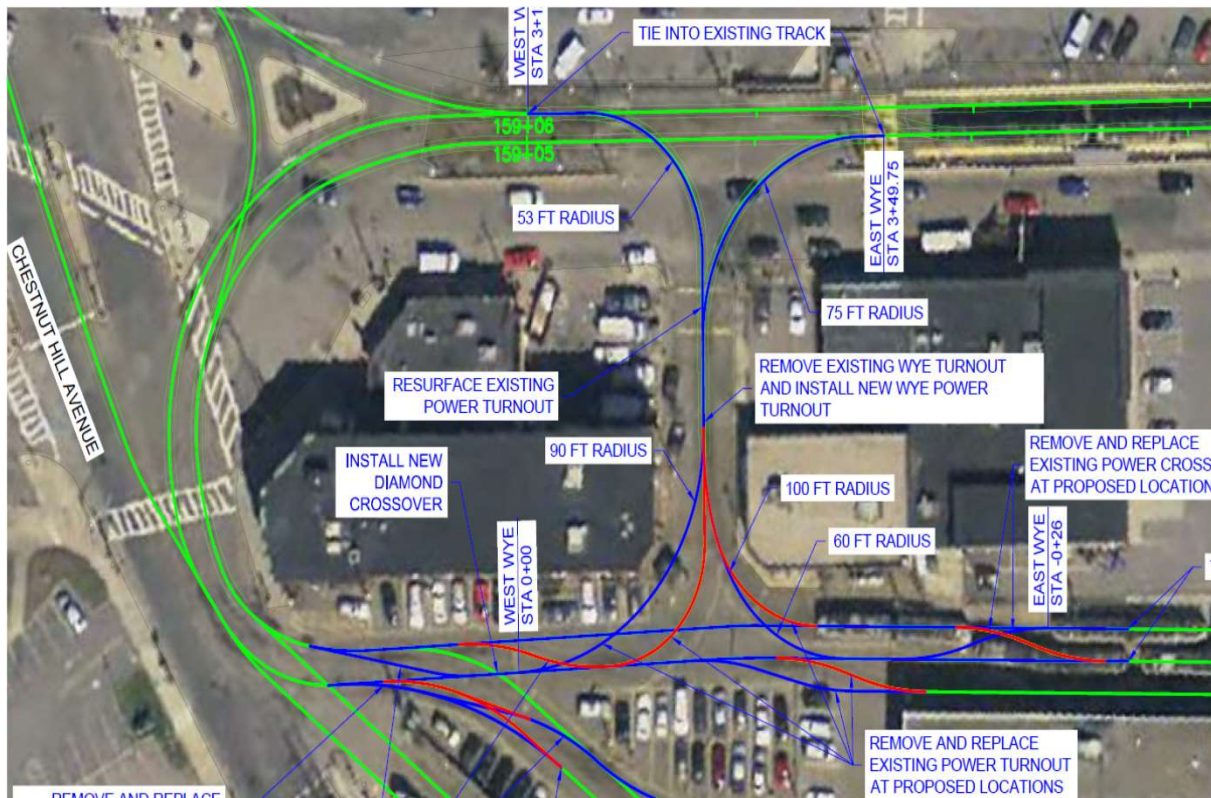






## Restrictive Curves - Reservoir Yard

- Reservoir yard also has 45 foot curve that will be the tightest in the system.
- A proposed plan is shown below.



Existing Track to Remain, Existing Track to be Removed, New Track to be Installed



## Identifying Constraining Infrastructure

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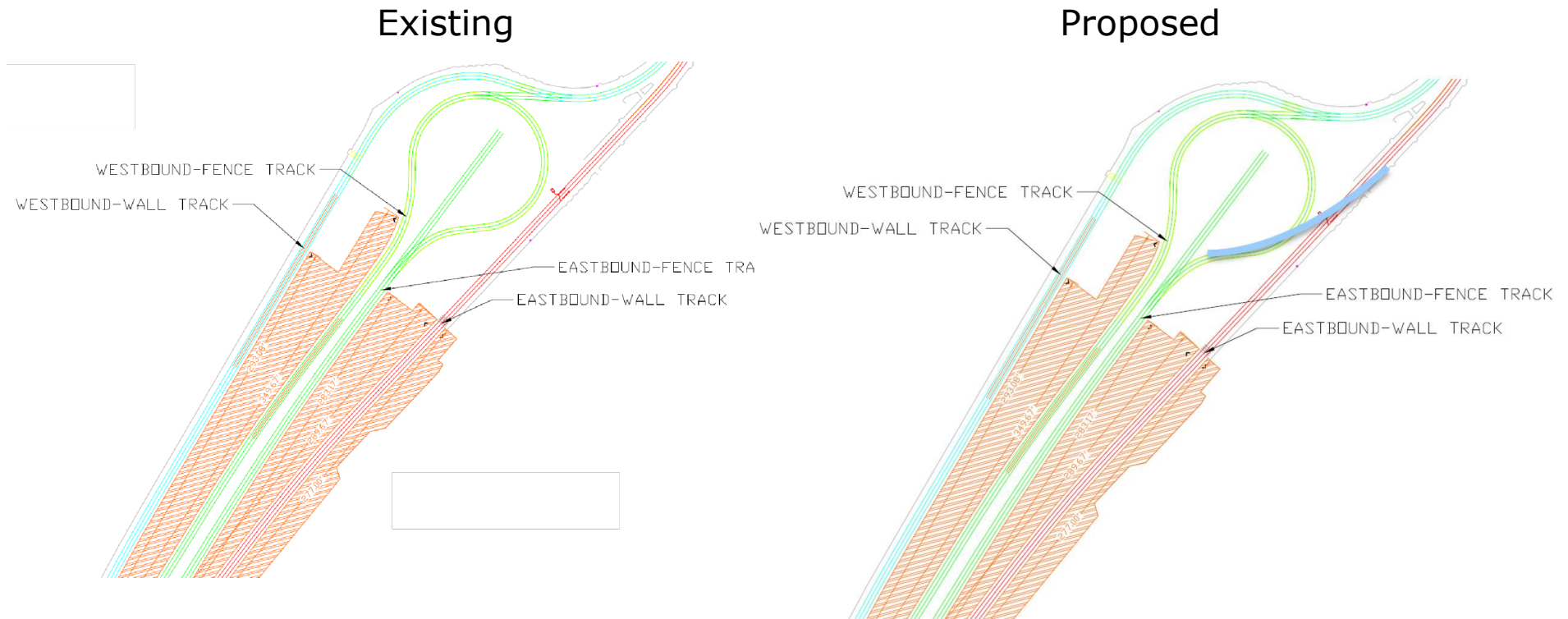
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    - Reservoir Yard

## Park Street Loop

- Station and Platform Lengths
  - Vehicle Maintenance Facilities and Storage
  - Power & Signals
  - Track State of Good Repair
-



## Park Street Loop



- The Park Street Loop at 47 ft. is needed to maintain operational flexibility
- A new cross over will be necessary to efficiently utilize both platforms



## Identifying Constraining Infrastructure

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## Station and Platform Lengths

- Vehicle Maintenance Facilities and Storage
  - Power & Signals
  - Track State of Good Repair
-



## Stations and Platforms

- 34 Platforms are Under 225 Feet
- 225 feet is the length required to fully berth current vehicles as three car trains

Central Subway		C-Line		B-Line	
Platform	(ft.)	Platform	(ft.)	Platform	(ft.)
Boylston (EB)	210	Cleveland Circle (EB)	113	Boston College (EB)	130
Science Park (EB)	220	Cleveland Circle (WB)	136	Boston College (WB)	138
Science Park (WB)	222	St. Paul Street (EB)	195	Blandford Street (EB)	197
<b>D-Line</b>		Washington Square (WB)	200	Sutherland Road (WB)	207
		Englewood Avenue (EB)	204	Blandford Street (WB)	207
		Washington Square (EB)	204	Allston Street (WB)	218
		Dean Road (EB)	206	Allston Street (EB)	219
		Hawes Street (EB)	207	Griggs Street (WB)	220
Platform	(ft.)	St. Mary's Street (EB)	210	Griggs Street (EB)	221
Brookline Hills (EB)	214	St. Mary's Street (WB)	210	Sutherland Road (EB)	224
Fenway (WB)	223	Kent Street (WB)	214		
Reservoir (WB)	223	Kent Street (EB)	216		
<b>E-Line</b>		Brandon Hall (WB)	216		
		Summit Avenue (EB)	219		
		St. Paul Street (WB)	220		
		Hawes Street (WB)	223		
		Brandon Hall (EB)	224		
Platform	(ft.)				
Heath Street (EB)	131				





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  - Park Street Loop
  - Station and Platform Lengths

## Vehicle Maintenance Facilities and Storage

- Power & Signals
  - Track State of Good Repair
-





## Vehicle Maintenance Facilities and Storage

- Shop equipment such as lifts and roof access mezzanines are positioned to maintain the existing fleets of 75 foot cars with three trucks
  - Riverside, Reservoir, Lake Street & GLX
- Longer vehicles with more trucks will require new lifts and new storage strategies





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  - Vehicle Maintenance Facilities and Storage

## Power & Signals

- Track State of Good Repair
-



## Power and Signals

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### Signals: Legacy Signals limit vehicle operations

- Continue our \$350M+ Green Line signals modernization program
- New Vehicles must operate with Green Line Train Protection (GLTP) System

### Power: Running more trains requires more electrical current which puts more stress on our distribution network

- Power Capacity analysis is planned to define what cable and wiring upgrades are needed now and for the future



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## Track State of Good Repair

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## Track State of Good Repair

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- **Track conditions can limit operations of a fully accessible vehicle**
  - Continue investments of \$150M+ currently dedicated to SGR of Green line track
  - Additional track upgrades are anticipated to be need to return all Green Line track to good condition





## Concept Vehicles

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- New Vehicle Goals
- Concept Vehicles Reviewed
- Evaluation Criteria
- Recommended Concept Vehicle
- Detailed Conceptual Analysis Examples
- System Operational Modeling



## Concept Vehicles

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# New Vehicle Goals

- Concept Vehicles Reviewed
- Evaluation Criteria
- Recommended Concept Vehicle
- Detailed Conceptual Analysis Examples
- System Operational Modeling



## New Concept Vehicle Goals

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- Availability from multiple vehicle manufactures
- 100% Low Floor and Accessible
- Provide a full width operating Cab
- Maximize passenger capacity
- Maximize door openings and boarding efficiency
- Ability to negotiate curves, crests, sags, clearances and grades
- Limit axle loads to minimize impacts on track and structures
- Meet duty cycle and operational tempo needed for GL operations
- Minimize operating and maintenance resources





## Concept Vehicles

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- New Vehicle Goals

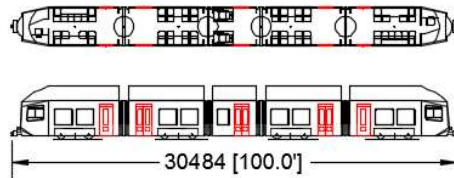
## Concept Vehicles Reviewed

- Evaluation Criteria
- Recommended Concept Vehicle
- Detailed Conceptual Analysis Examples
- System Operational Modeling

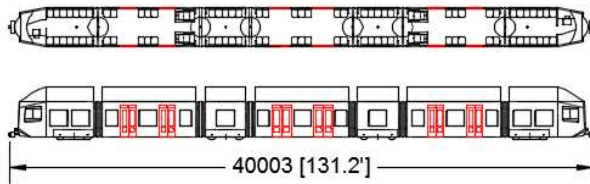


## Concept Vehicles

Concept A



Concept C



Concept D



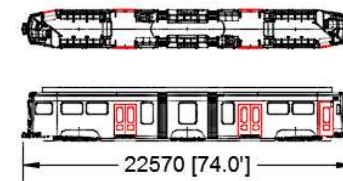
Concept E



Concept F



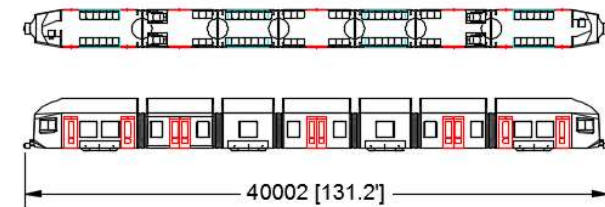
Type 8/9



Concept H



Concept I





## Concept Vehicles

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- New Vehicle Goals
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- Recommended Concept Vehicle

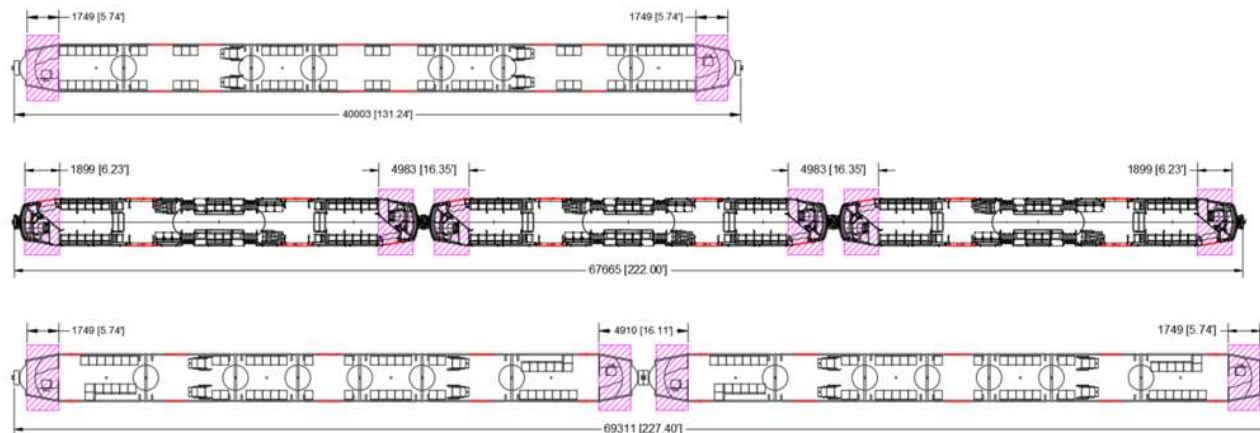
## Evaluation Criteria

- Detailed Conceptual Analysis
- System Operational Modeling



## Evaluation Criteria

- Infrastructure Changes
- Future Capacity
- Dwell Time Impacts
- Fleet Maintenance Costs
- Fleet Operating Costs
- Predicted Reliability
- Operating Impact on Infrastructure
- Fleet Procurement Costs
- Procurement Risk
- Technical Risk
- Industry Standards
- Interoperability





## Concept Vehicles

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- Evaluation Criteria

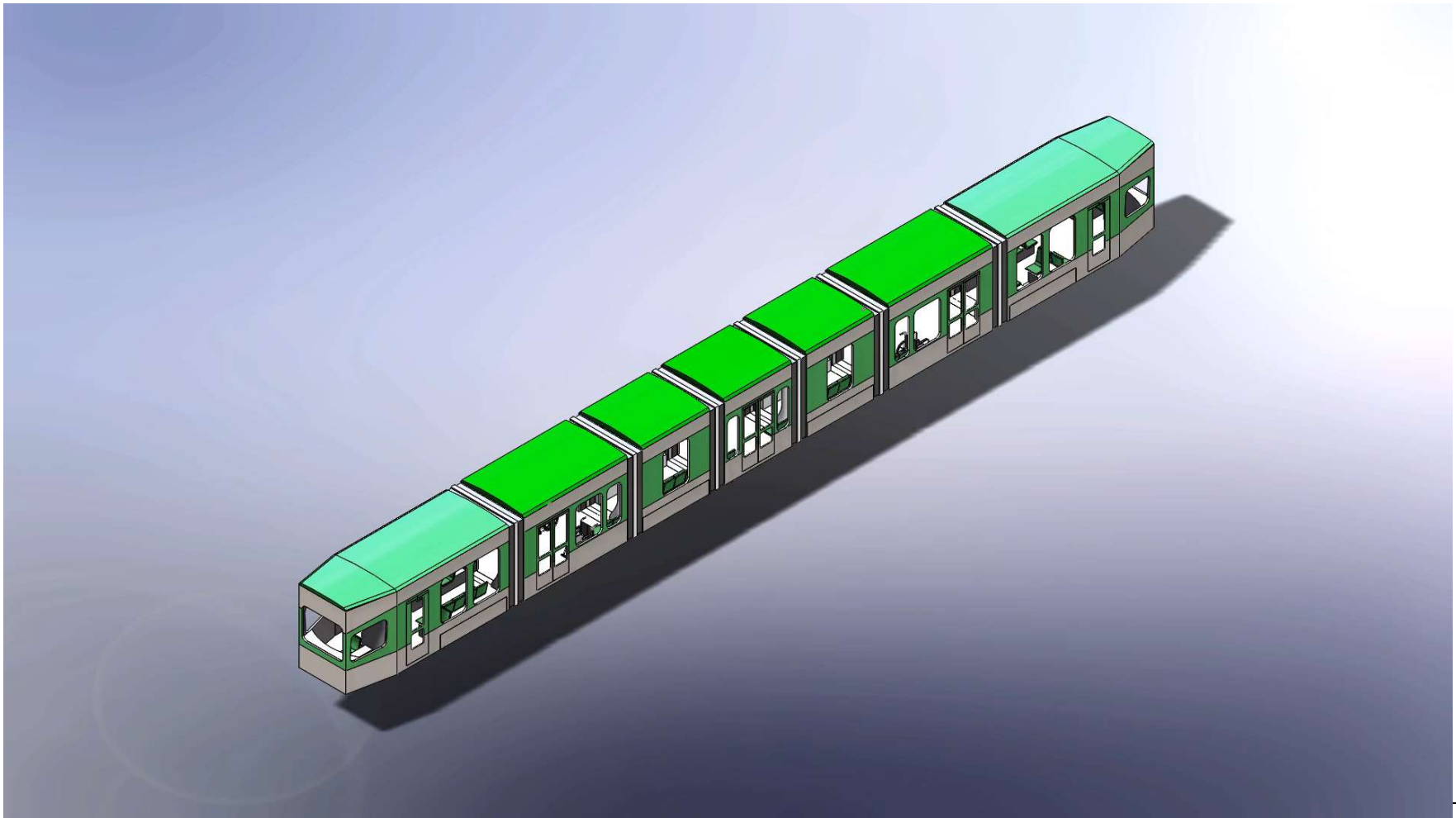
## Recommended Concept Vehicle

- Detailed Conceptual Analysis
- System Operational Modeling



## Recommended Concept Vehicle - Concept D

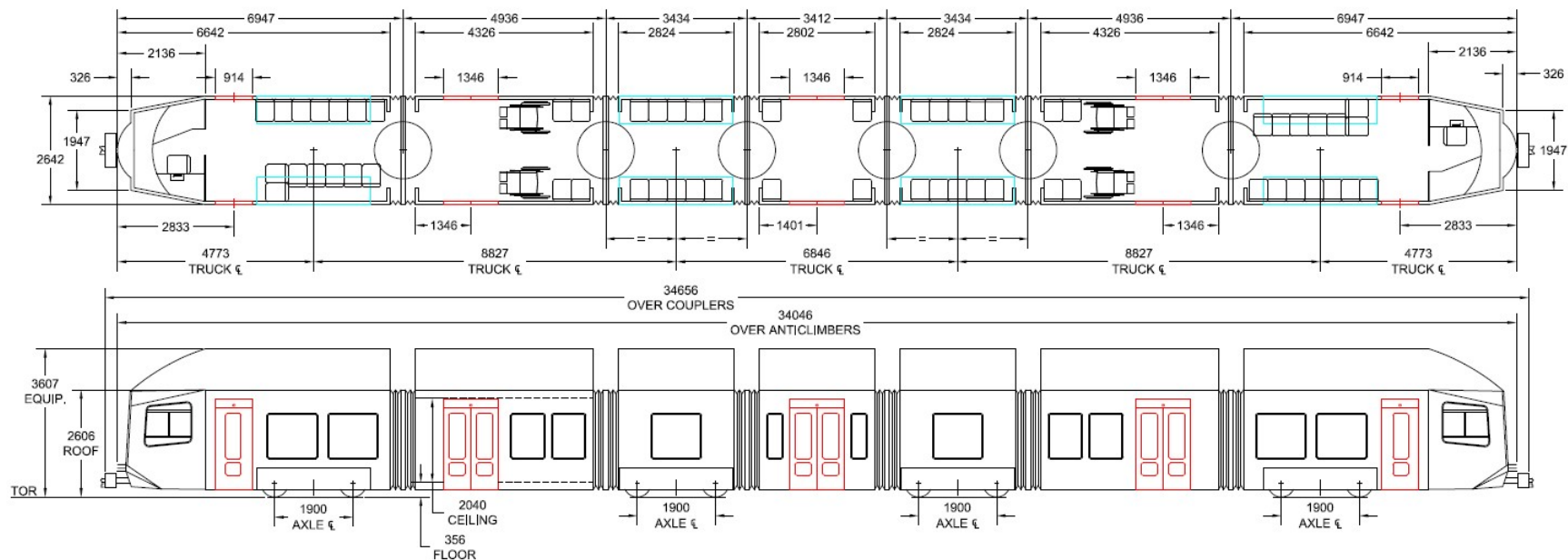
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## Recommended Concept Vehicle - Details

- **Fully Accessible 100% Low Floor, no stairs**
- **Same Passenger Capacity as a two car Type 8/9 train**
- 7 Sections with 4 Powered Trucks
- 5 Door Openings per side
- Full Width Cab at each end

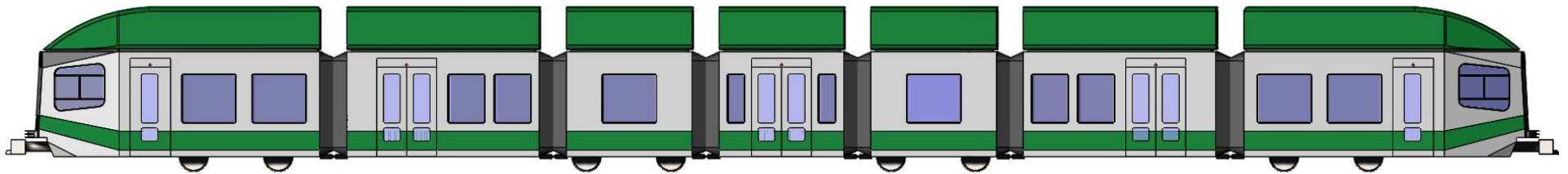






## Recommended Concept Vehicle- Industry Lineage

Rail vehicle manufactures offer modular designs like recommended concept vehicle







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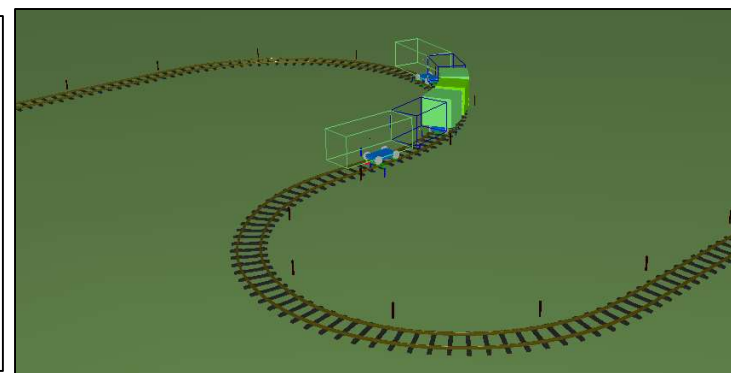
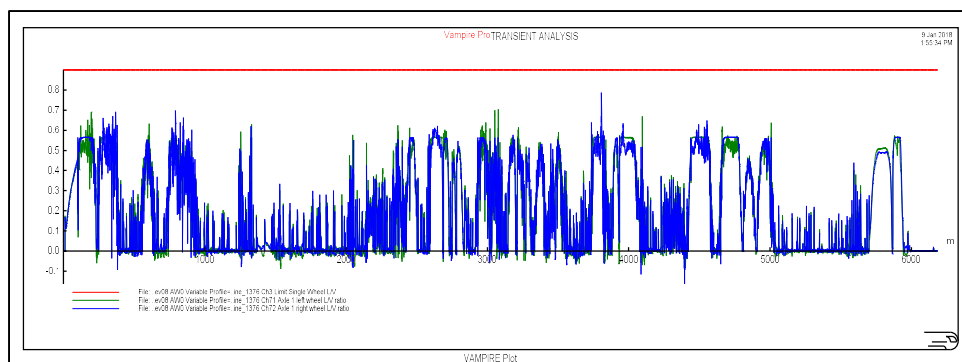
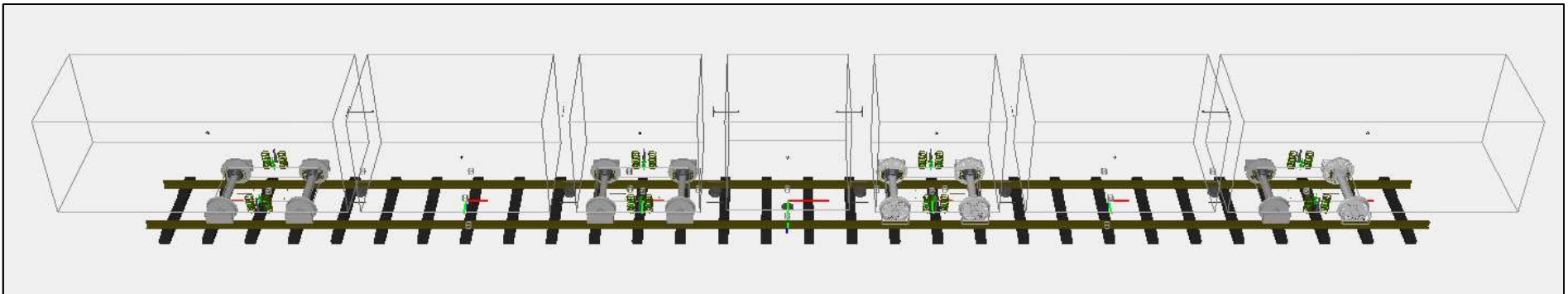
## Detailed Conceptual Analysis Examples

- System Operational Modeling



## Detailed Conceptual Analysis – Dynamic Modeling

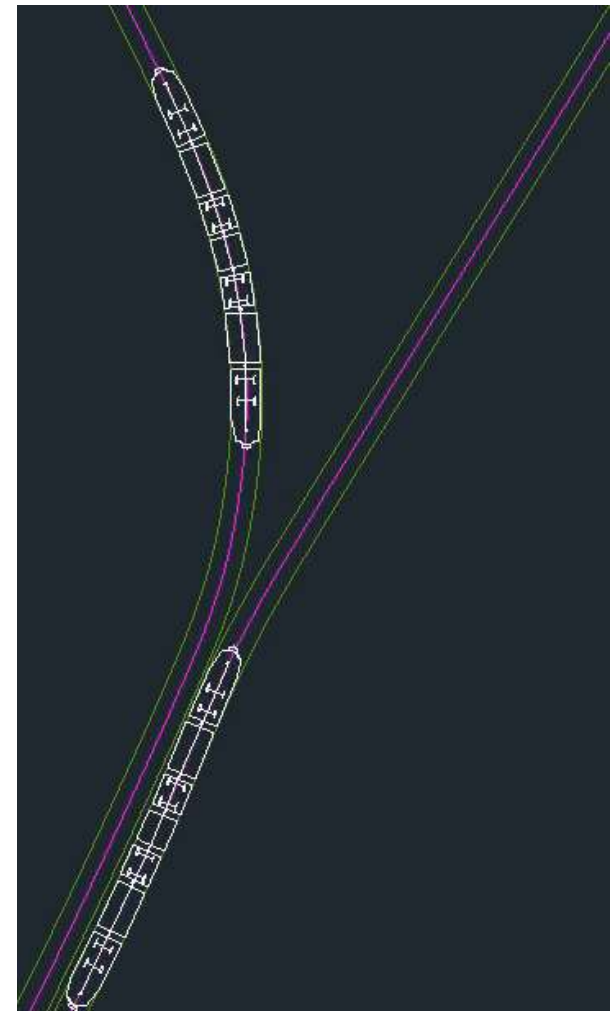
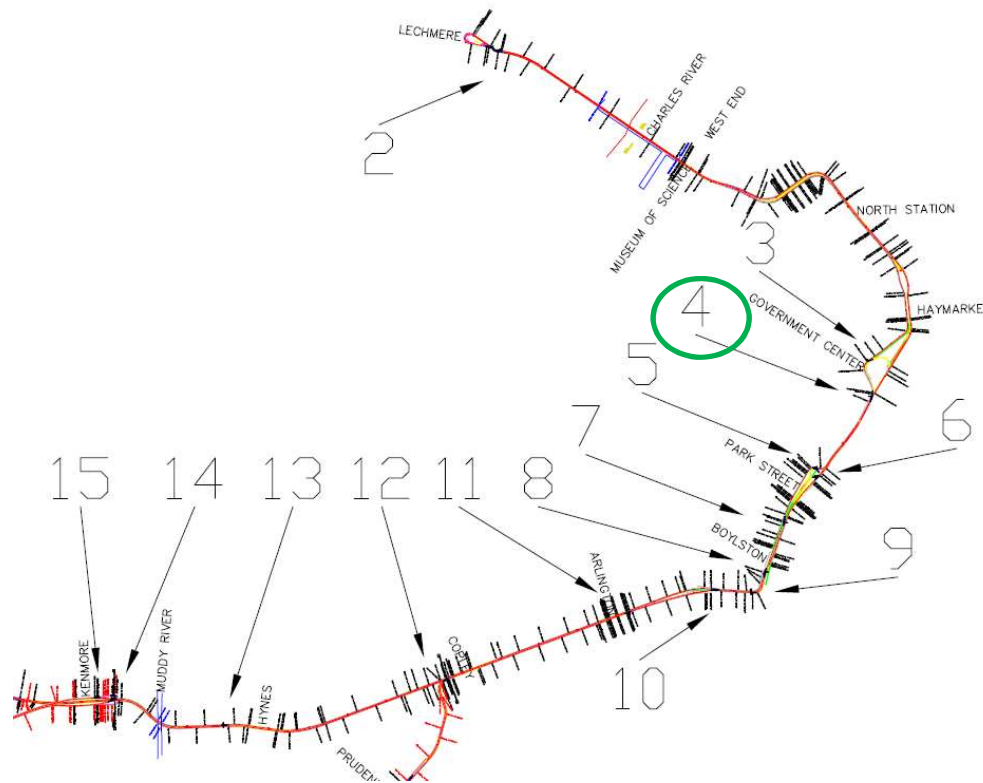
- Dynamic simulations were conducted
- Simulations included various track conditions including curving and stability
- Simulations demonstrated that Concept D is viable in the MBTA Green Line operating environment





## Detailed Conceptual Analysis - Clearance

- Two Concept D vehicles operating west of Government Center through cloud of Park Street

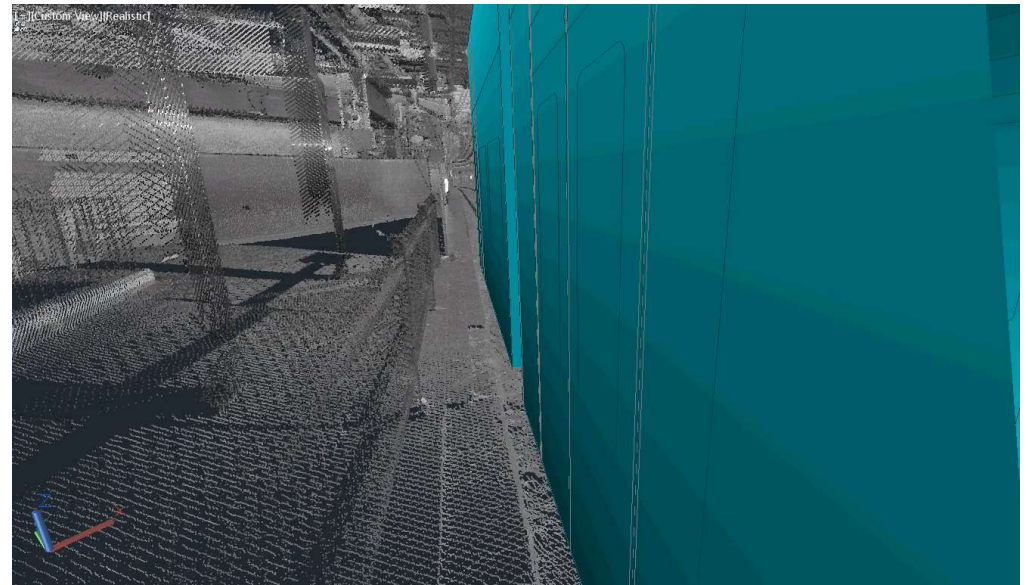
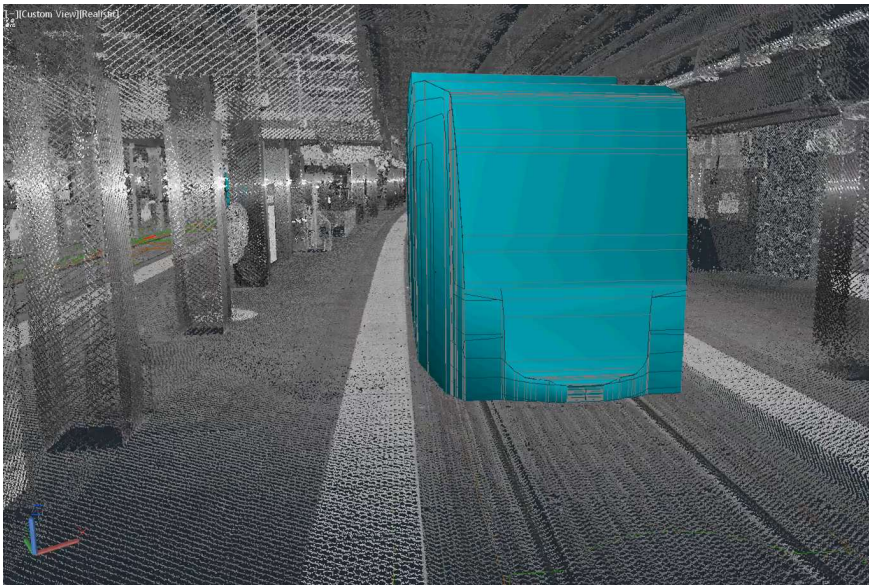


West of Government Center Station  
Location 4



## Detailed Conceptual Analysis - Park Street

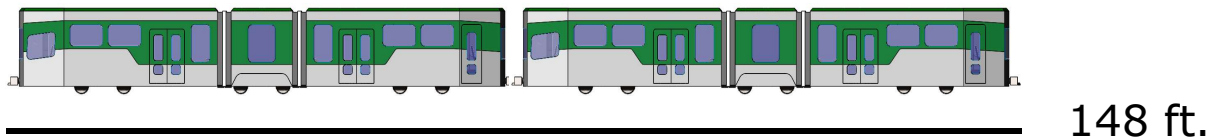
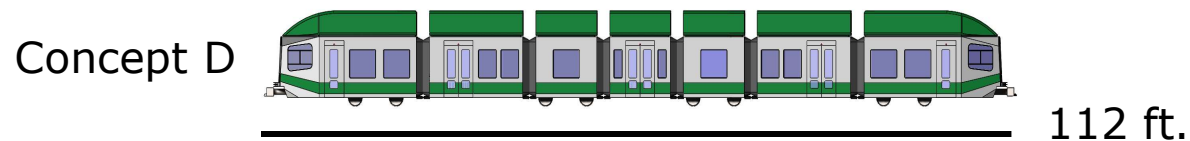
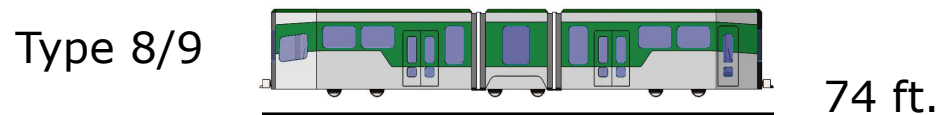
- Concept D operating through actual MBTA collected LIDAR point cloud of Park Street





## Detailed Conceptual Analysis – Platforms

- Analysis of current platforms was conducted to determine impact of concept vehicles on stations







## Detailed Conceptual Analysis - Newton Center Platform



3 car Type 8/9 can berth at platform

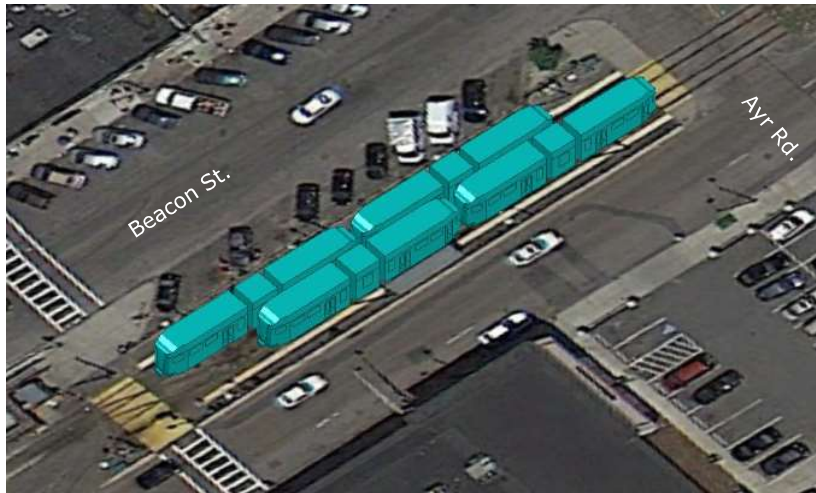
2 Car Concept D can berth at the platform



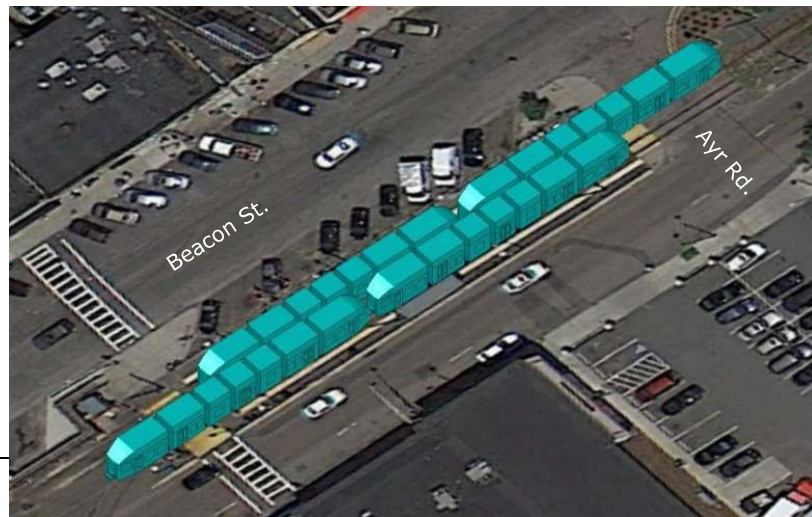
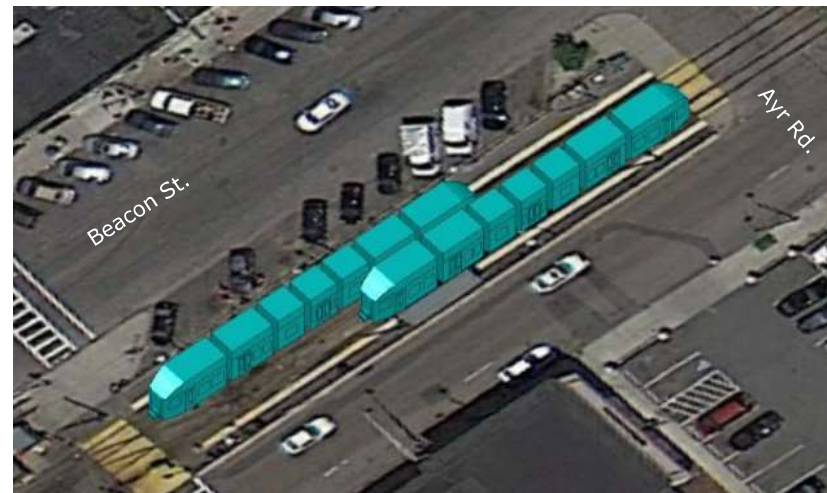


## Detailed Conceptual Analysis – Platforms C Line

2 Type 8/9 can berth at platform



1 Concept D can berth at platform



2 Concept D  
cars cannot

Cleveland Circle





## Detailed Conceptual Analysis – Platforms D & E Lines

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- Three Platforms Require work to run longer trains on the for D & E Lines
- 225 feet is optimally required platform length

D-Line	
Platform	(ft.)
Brookline Hills (EB)	214

E-Line	
Platform	(ft.)
Heath Street	131

Central Subway	
Platform	(ft.)
Boylston (EB)	210



## Detailed Conceptual Analysis – Platforms B & C Lines

27 Platforms listed below must be extended to allow 2 Concept D's to berth the B & C lines

<b>B-Line</b>	
<b>Platform</b>	<b>(ft.)</b>
Boston College (EB)	130*
Boston College (WB)	138*
Blandford Street (EB)	197
Sutherland Road (WB)	207
Blandford Street (WB)	207
Allston Street (WB)	218
Allston Street (EB)	219
Griggs Street (WB)	220
Griggs Street (EB)	221
Sutherland Road (EB)	224

<b>C-Line</b>	
<b>Platform</b>	<b>(ft.)</b>
Cleveland Circle (EB)	113
Cleveland Circle (WB)	136
St. Paul Street (EB)	195
Washington Square (WB)	200
Englewood Avenue (EB)	204
Washington Square (EB)	204
Dean Road (EB)	206
Hawes Street (EB)	207
St. Mary's Street (EB)	210
St. Mary's Street (WB)	210
Kent Street (WB)	214
Kent Street (EB)	216
Brandon Hall (WB)	216
Summit Avenue (EB)	219
St. Paul Street (WB)	220
Hawes Street (WB)	223
Brandon Hall (EB)	224

\* BC Station Requires changes due to Lake street Yard Changes



## Concept Vehicles

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- Evaluation Criteria
- Recommended Concept Vehicle
- Detailed Conceptual Analysis Examples

## System Operational Modeling



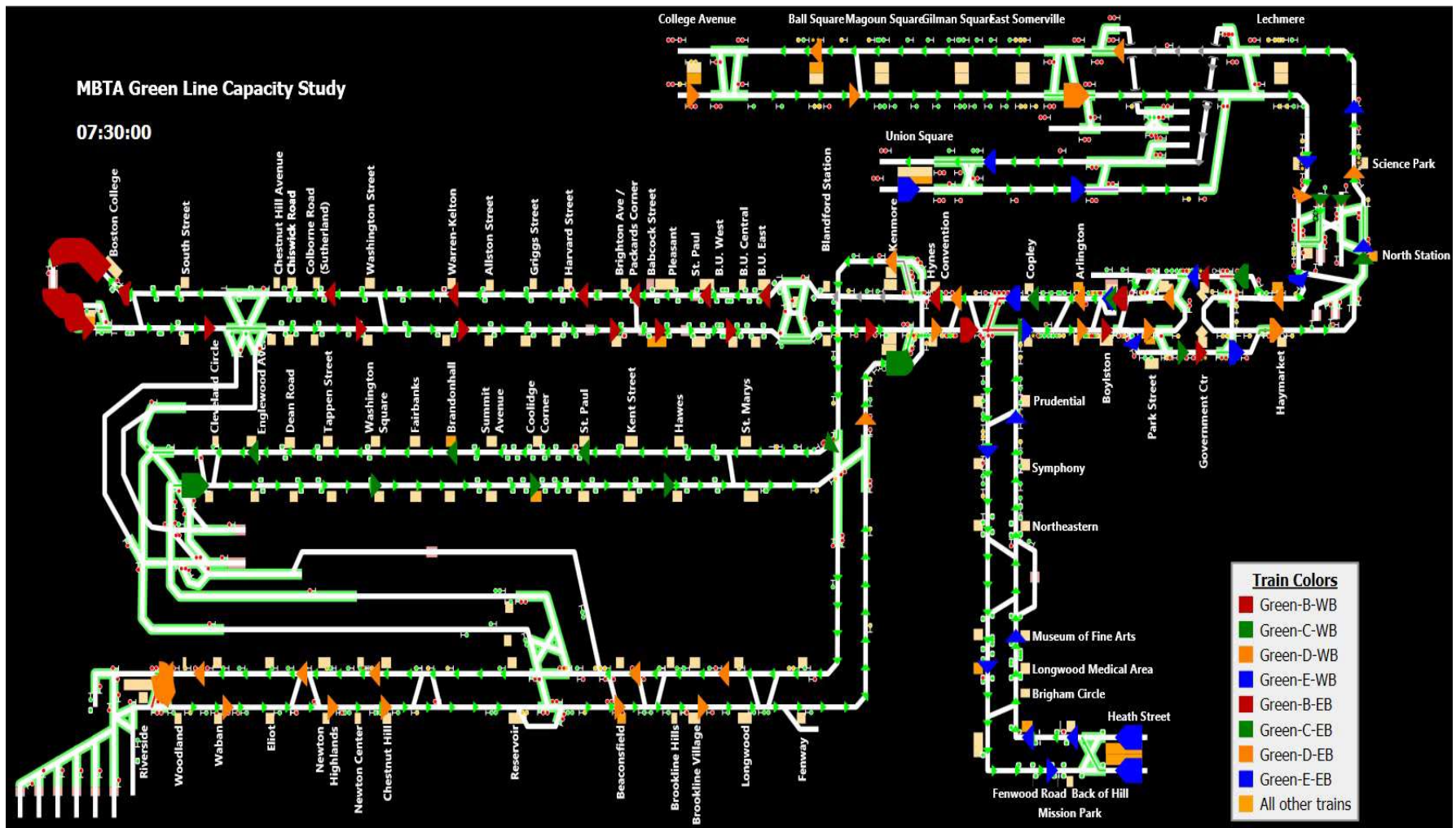
## Detailed Conceptual Analysis – Operational Modeling

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- A complete operational model of the Green Line was developed
- Multiple operational simulations were run to identify the best combination of concept vehicles and infrastructure needs.
- The model confirms recommended Concept D will improve Green Line operations



# Detailed Conceptual Analysis - Operational Simulation





## Phased Implementation

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- Multi-phased program proposed that will transition the Authority to a modern 100% accessible high capacity car and necessary system improvements
  - Phase I: Near term projects currently identified in FY19-23 Draft CIP totaling \$950M+
  - Phase II: Procurement of a new modern fleet of Green Line vehicles and completion of necessary infrastructure changes to operate them as single units
  - Phase III: Completion of necessary infrastructure changes to operate new vehicles as 2 car units on the D & E Lines.
  - Phase IV: Long term possibility, completion of infrastructure changes to operate new vehicles as 2 car units on B & C Lines.



## Phased Implementation – Phase I

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- Projects Currently Identified in draft FY19-23 CIP \$963.7M
    - \$739.9M Programmed in current draft CIP
    - The remaining program costs will be programmed in the outlying years of the CIP
    - Many Projects identified are currently underway
  - Projects address urgent SGR needs and necessary system reliability improvements
    - Track
    - Power
    - Signals
    - Current Vehicles
    - Infrastructure
  - Will be discussed further in following presentation
  - Continue project funding of \$223.8M will be programmed in next CIPs
-





## Phased Implementation – Phase II

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- Operate New Trains as Single Cars on the Green Line – All Lines
  - Increase weekday peak trains operating
    - Current: 73 Trains
    - Proposed: 94 Trains
    - **Capacity Gain: 15%**
  - Necessary Projects
    - Complete Phase I Programs
    - Vehicle Procurement
    - Reconditioning of Lechmere Viaduct
    - Installation of a Park Street Loop Crossover
    - Expand Vehicle Maintenance Facilities
    - Reconfigure Lake St. and Reservoir Yards
    - Reconfigure BC Station
  - Rough estimated cost: \$1.5-\$2 Billion
-



## Phased Implementation – Phase III

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- Operate New Trains as Single Cars on the B & C and Operate New Trains as two car trains on the D & E lines
  - Increase weekday peak trains operating
    - Current: 73 Trains
    - Proposed: 94 Trains
    - **Capacity Gain: 50%+**
  - Necessary Projects
    - Complete Phase I Programs
    - Complete Phase II Programs
    - Reconfigure Heath Street Station
    - Extend Brookline Hills- East Bound Platform
    - Clear obstruction on Boylston Station East Bound
    - Upgrade Power Distribution
    - Retirement of the Type 7 & 8 Cars
  - Rough estimated cost: \$500 million
-



## Phased Implementation – Phase IV (Long Term Possibility)

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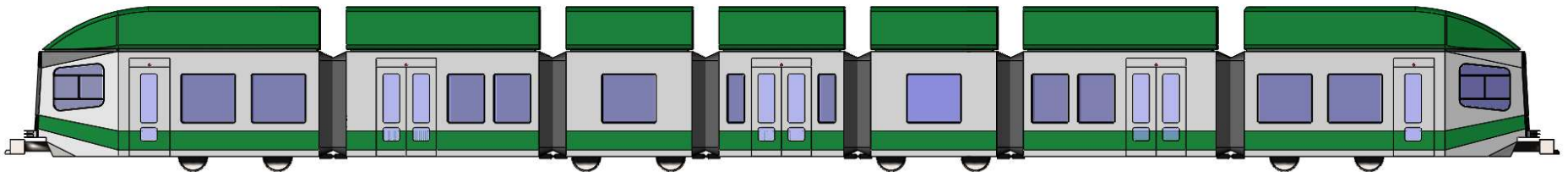
- Operate New Trains as two car trains on all lines
    - If ridership growth requires more capacity than programmed two car trains could be operated on all lines
  - Increase weekday peak trains operating
    - Current: 73 Trains
    - Proposed: 94 Trains
    - **Capacity Gain: 100%+**
  - Necessary Projects
    - Complete Phase I Programs
    - Complete Phase II Programs
    - Complete Phase III Program
    - Extend or reconfigure 27 stations on the B & C Lines
    - Procure additional Type 10 vehicles
    - Expand vehicle storage to accommodate a larger fleet
  - Rough estimated cost: TBD
-



## Program Next Steps

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- Award PM/CM Team For Green Line Transition – Today
- Finalize Concept Vehicle Design Specifications & Award Vehicle Engineering & PM Contract
- Prepare detailed cost estimates for Phase II & III
- Complete Alternative program funding analysis

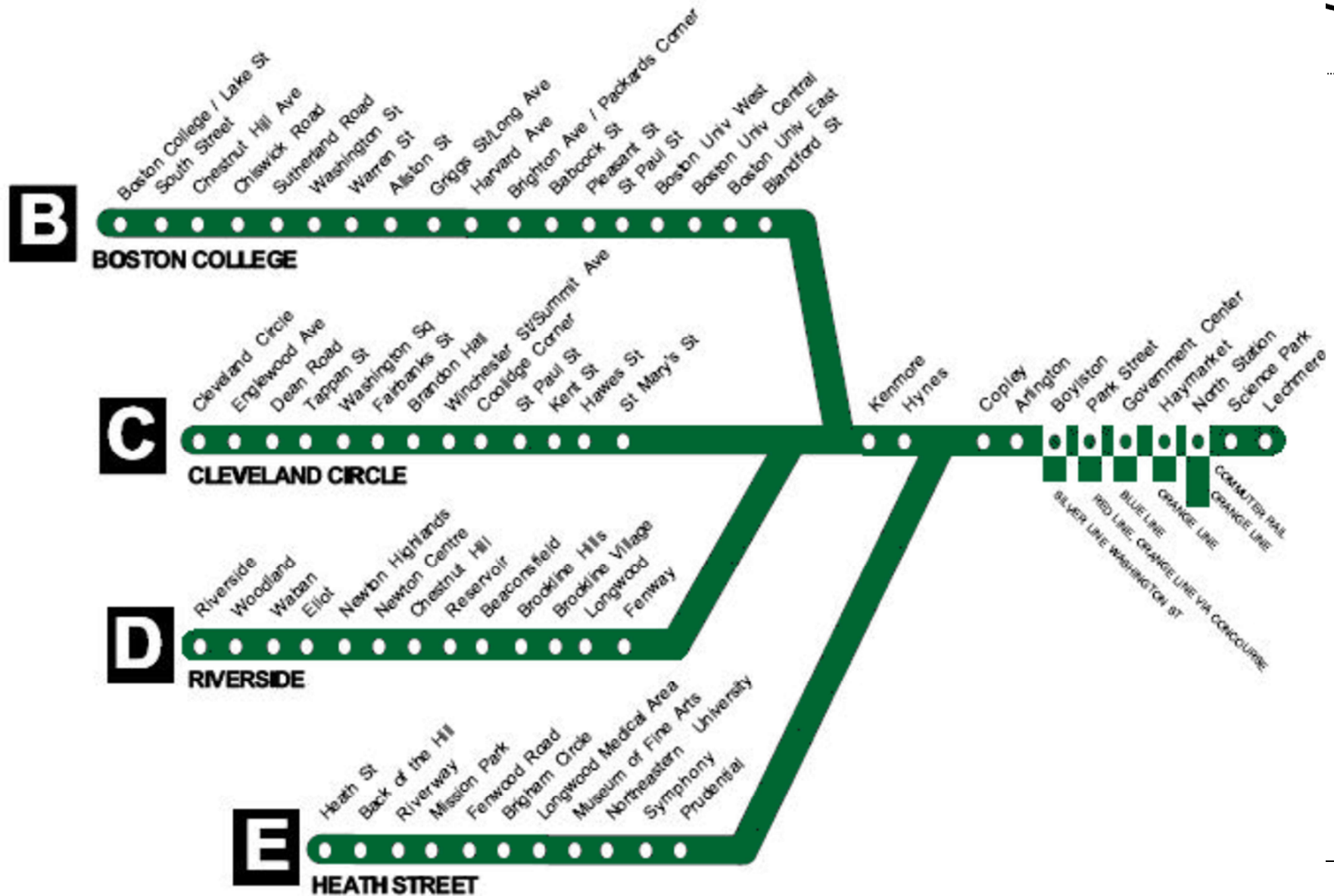




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# Thank you

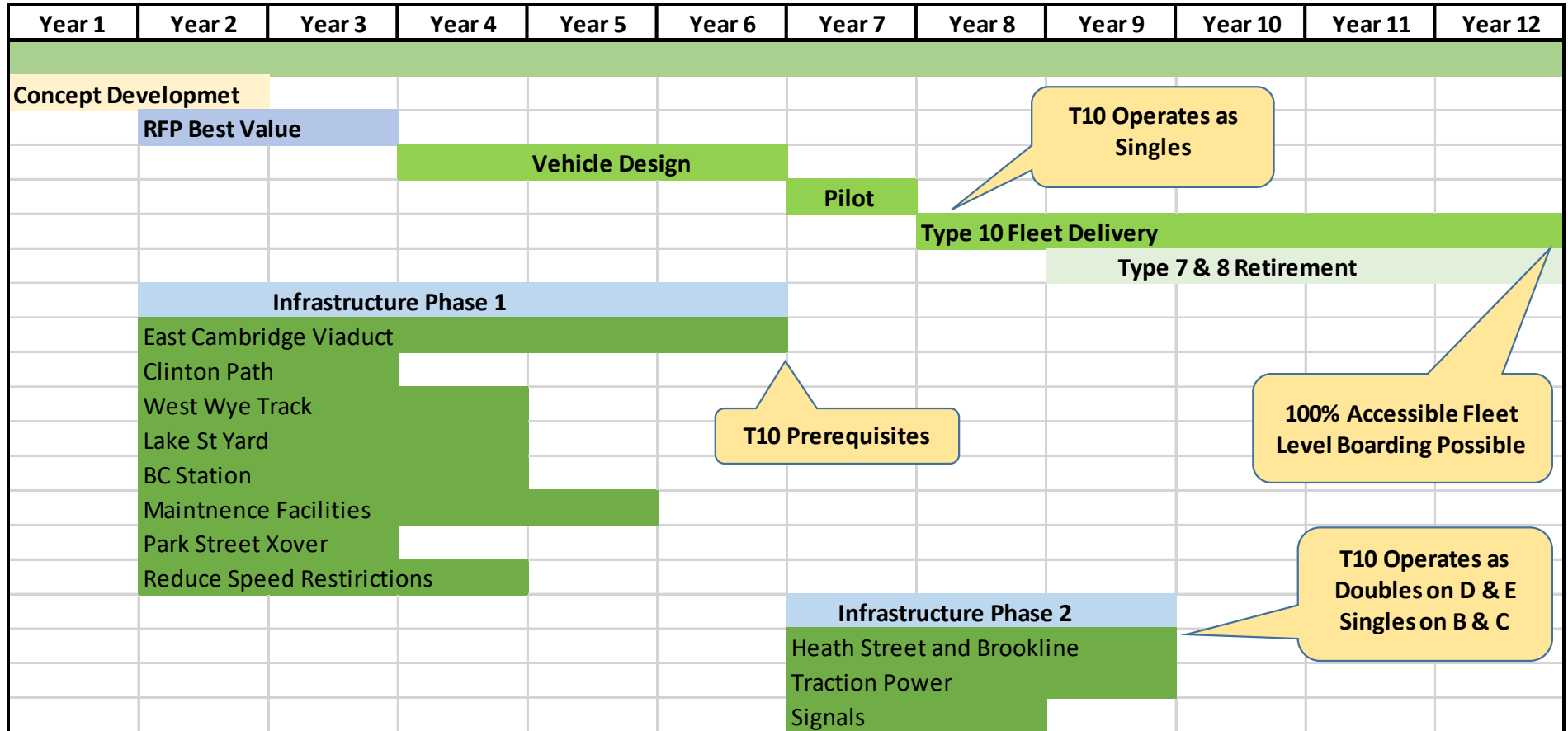
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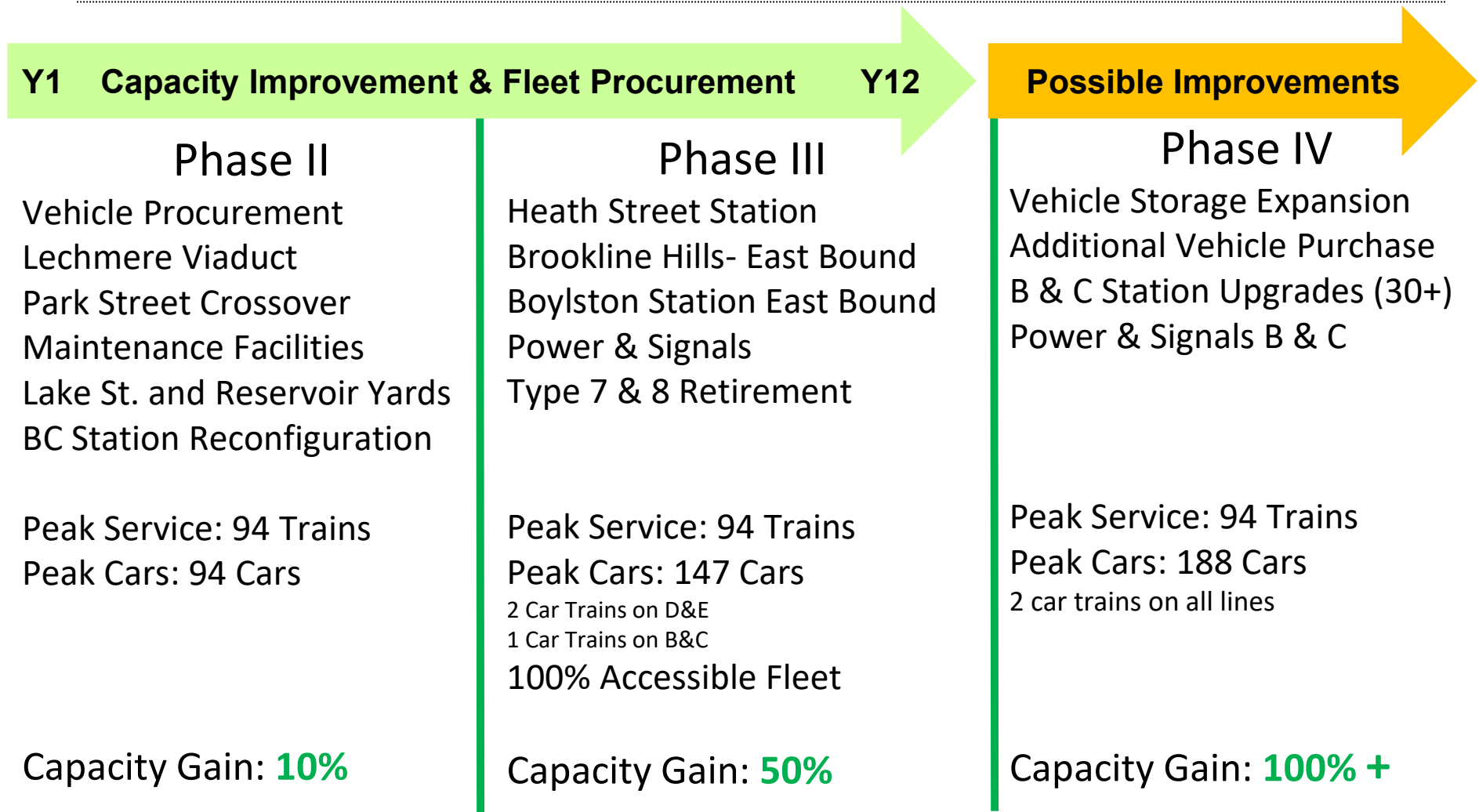


# Conceptual Implementation Plan





## Phased Implementation Potential

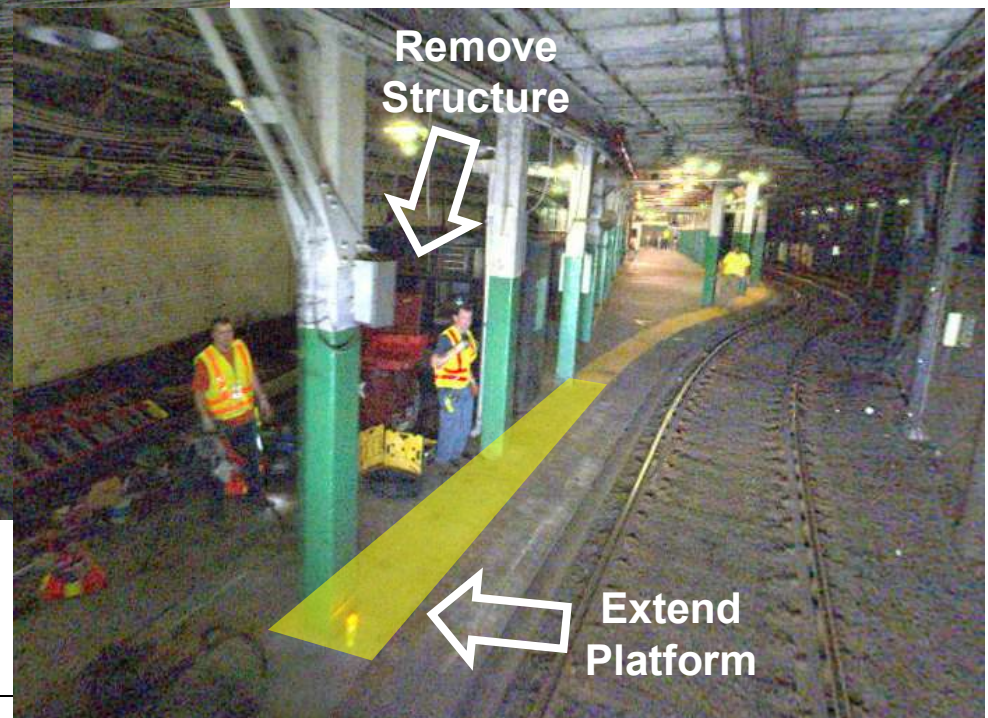
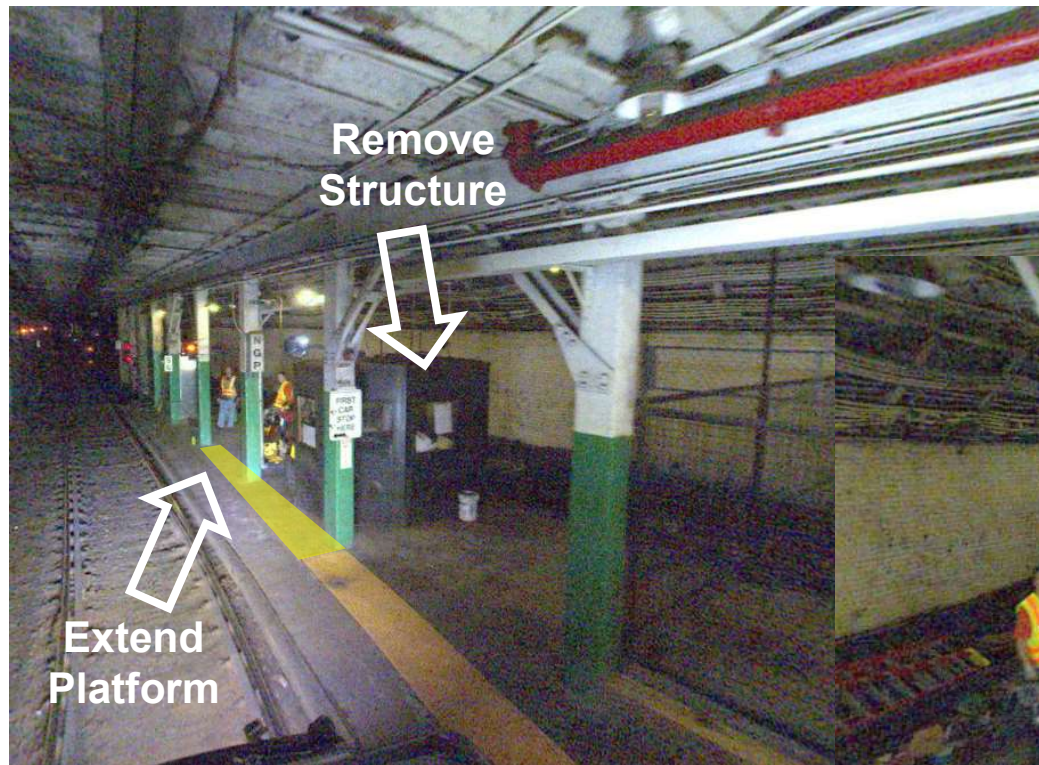




## Boylston EB – A Line

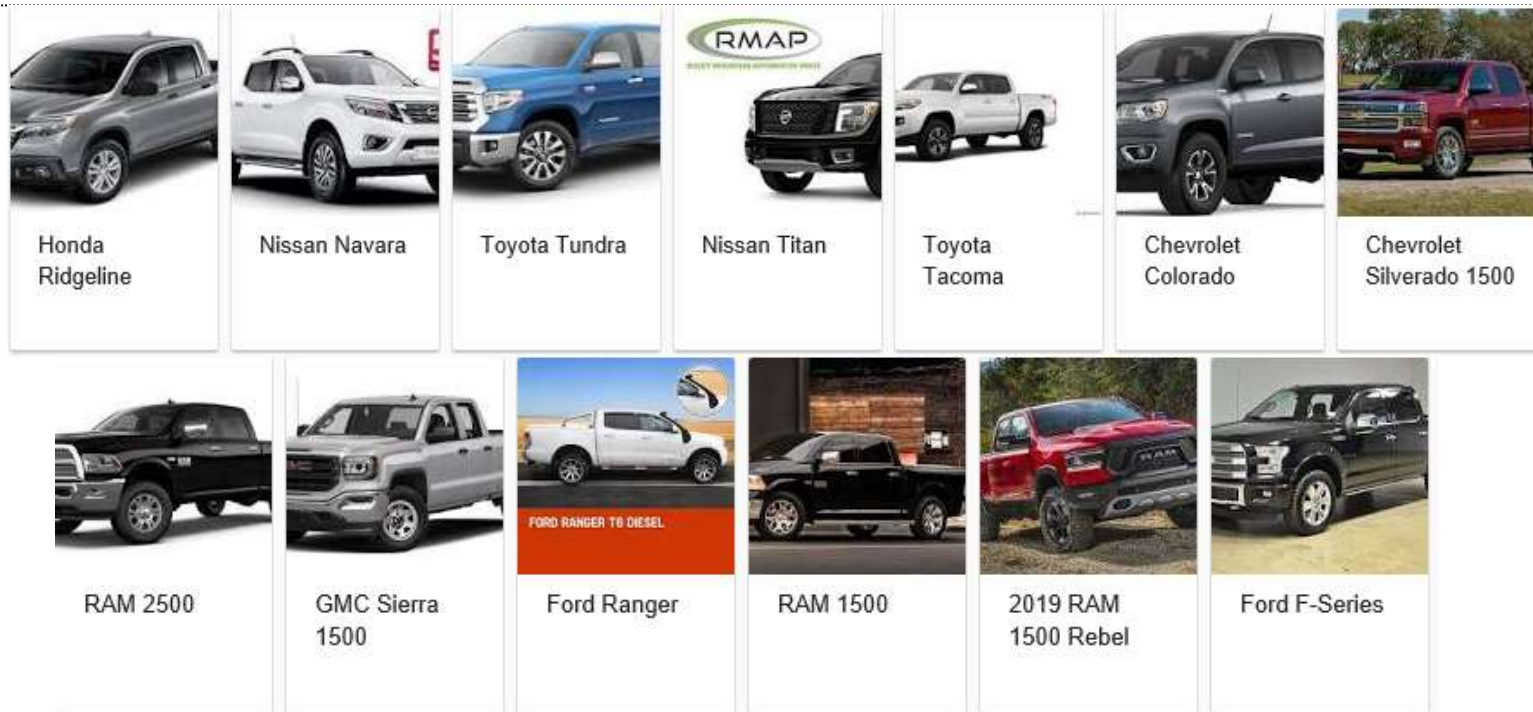
Existing Platform Length: 210 ft. (All Low)

Extended Platform Length: 225 ft. (All Low)





## Are these the same truck ?



Yes - they are all pickup trucks. No - they are all designed and manufactured based on the unique goals, traditions and experiences of each manufacturer.

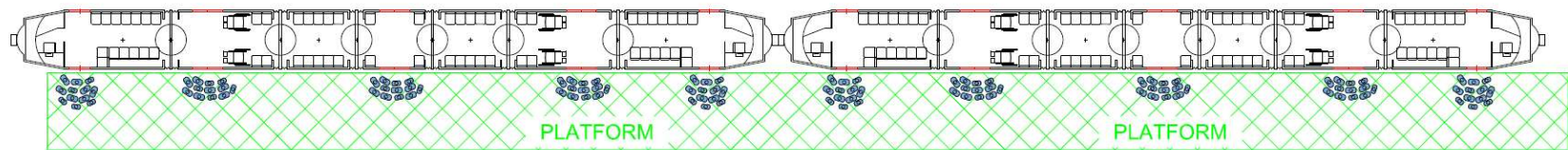
They have different supply chains, components, performance and nearly limitless variations, especially when aftermarket modifications are considered.



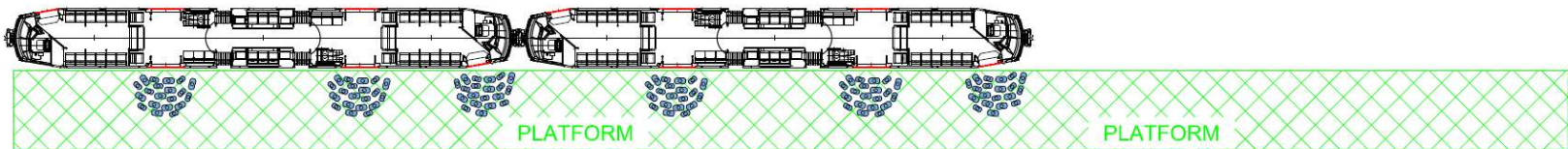


## Dwell Time and Car Length

Type X Concept D

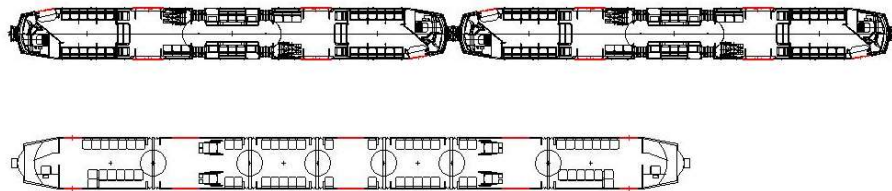


Type 9 (Concept G)

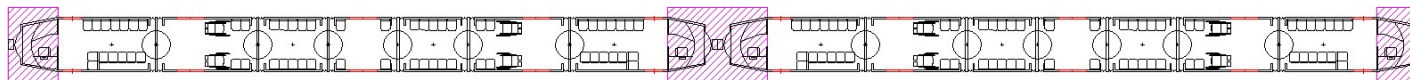
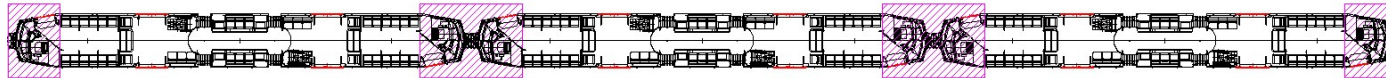




## Concept D vs Concept G



Operations			Maintenance			
Passengers (8/m <sup>2</sup> )	Operators	Current Draw	Cabs	Trucks	Couplers	Articulations
396	2	2700	4	6	4	4
388	1	1850	2	4	2	6



	Passengers Carried (8/m <sup>2</sup> )	Train Operators	Unused Space	Cabs	Trucks	Couplers	Articulations
Three Car Train	594	3	22%	6	9	6	6
Two Car Train	776	2	14%	4	8	4	12





## Tapered Noses are common for LRVs around the world





## Example Solution 1

- Increasing front overhang requires additional clearance on outside of curves.
- Green Line clearance constraints prevent sufficient increase in front overhang for existing three-segment vehicle configurations.
- Moving to a seven-segment vehicle configuration (Concept D) allows increased front overhang without requiring additional clearance.







## Example Solution 2

- Increasing rear overhang requires additional clearance on inside of curves.
- Green Line clearance constraints prevent sufficient increase in the rear overhang.
- Requires high floors at vehicle ends.

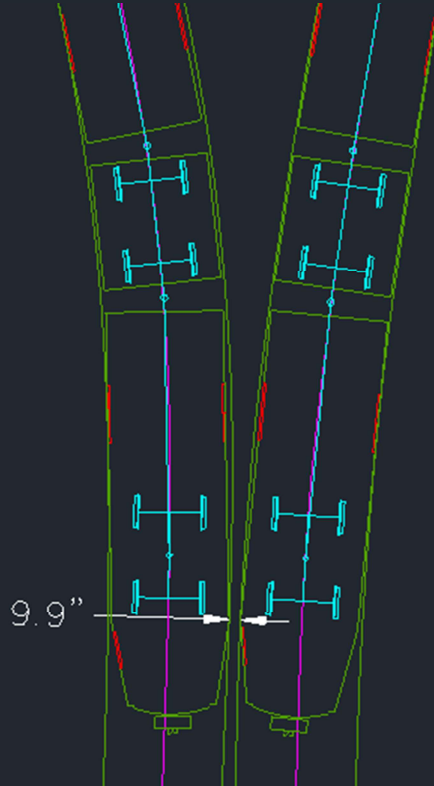




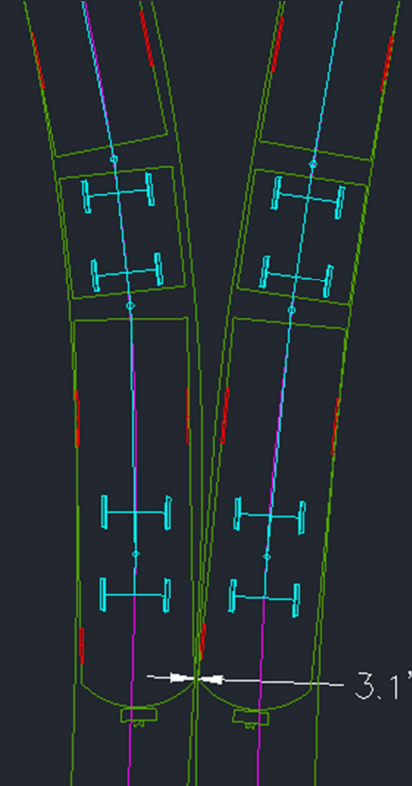
## Tapered Nose Explanation

- Existing Green Line Vehicles are designed with tapered noses to reduce overhang when traversing tight curves.

**Type 9 – As Built**



**Blunt Nose Vehicle**



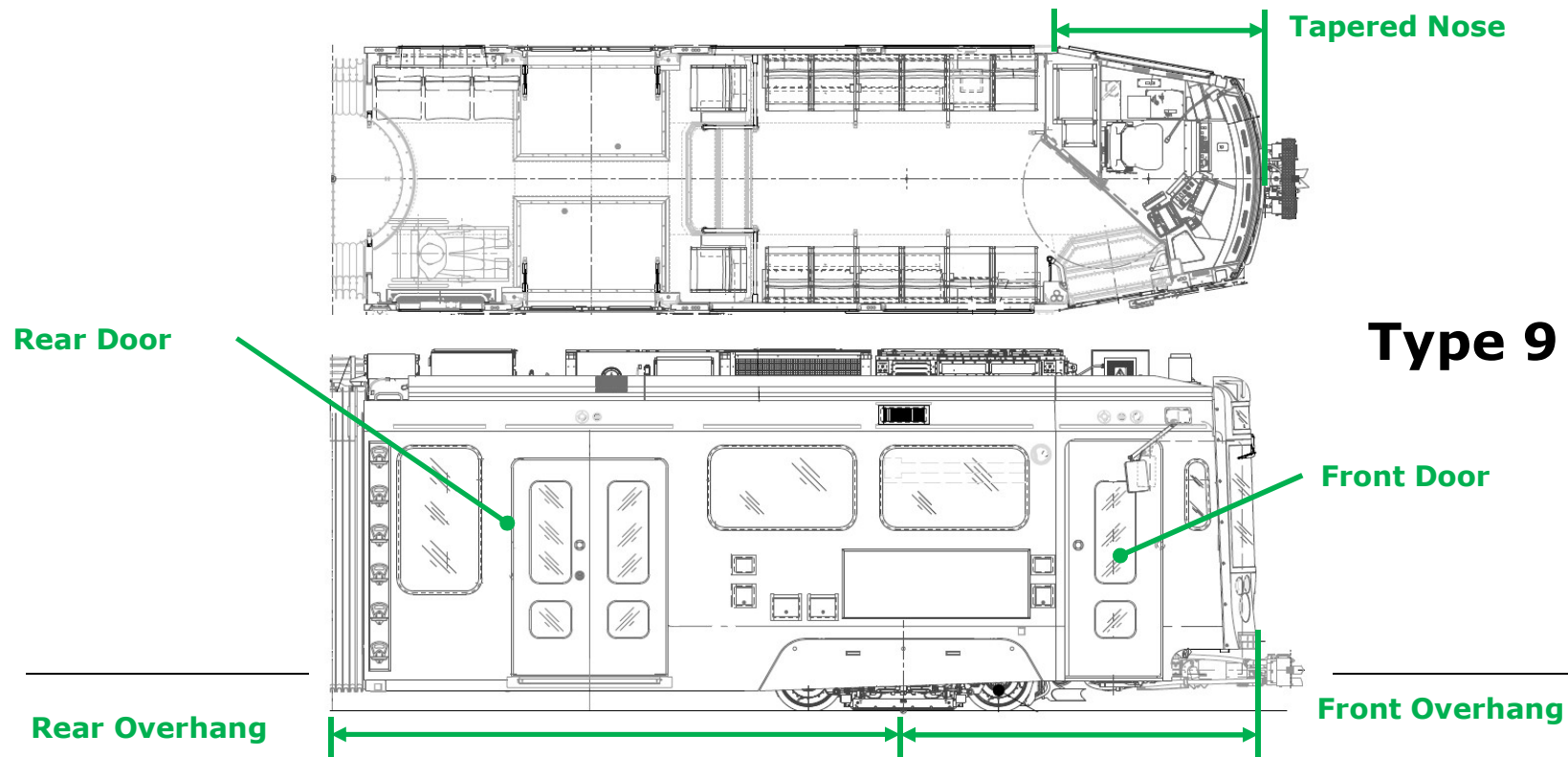
**Government Center**



## Tapered Nose Explanation

It is less common to have a door built into the tapered nose:

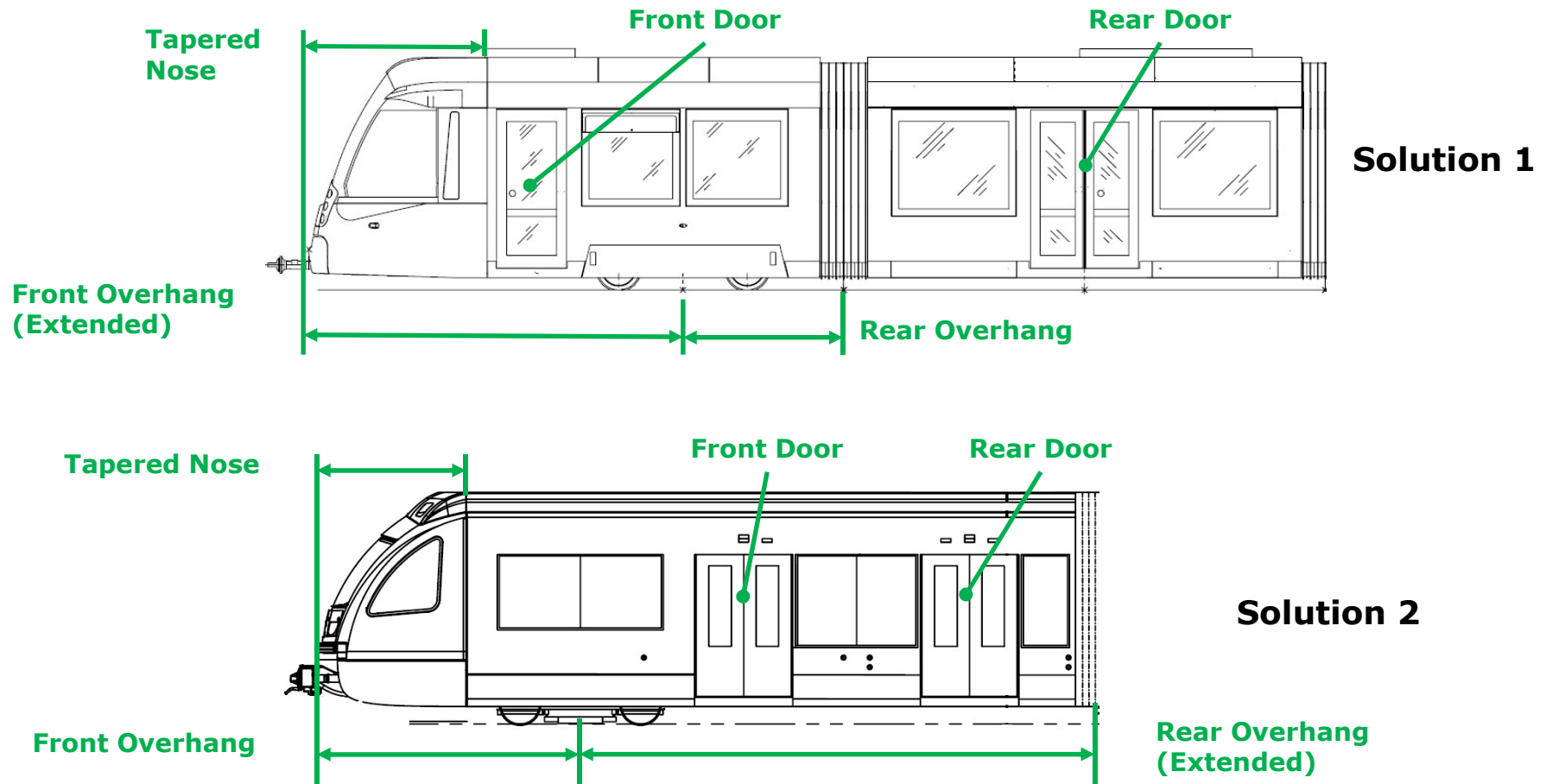
1. Partial-width cab.
2. Door on one side only.
3. Increases door-to-platform gap on tangent track.
4. Challenging to obtain required carbody strength.





## Tapered Nose Explanation

- Two solutions are common throughout industry:







## Example Solution 1

- Increasing front overhang requires additional clearance on outside of curves.
- Green Line clearance constraints prevent sufficient increase in front overhang for existing three-segment vehicle configurations.
- Moving to a seven-segment vehicle configuration (Concept D) allows increased front overhang without requiring additional clearance.





## Example Solution 2

- Increasing rear overhang requires additional clearance on inside of curves.
- Green Line clearance constraints prevent sufficient increase in the rear overhang.
- Requires high floors at vehicle ends.





## Kinkisharyo/Mitsubishi

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# Kinkisharyo

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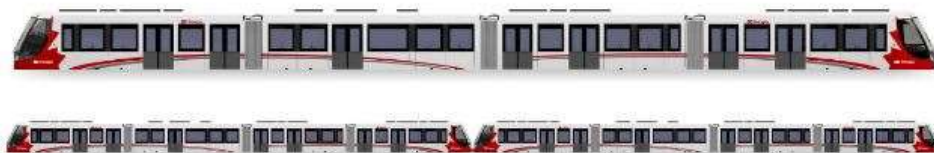
## CAF Urbos

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## Alstom Citadis







## Bombardier Flexity





## Siemens Avenio

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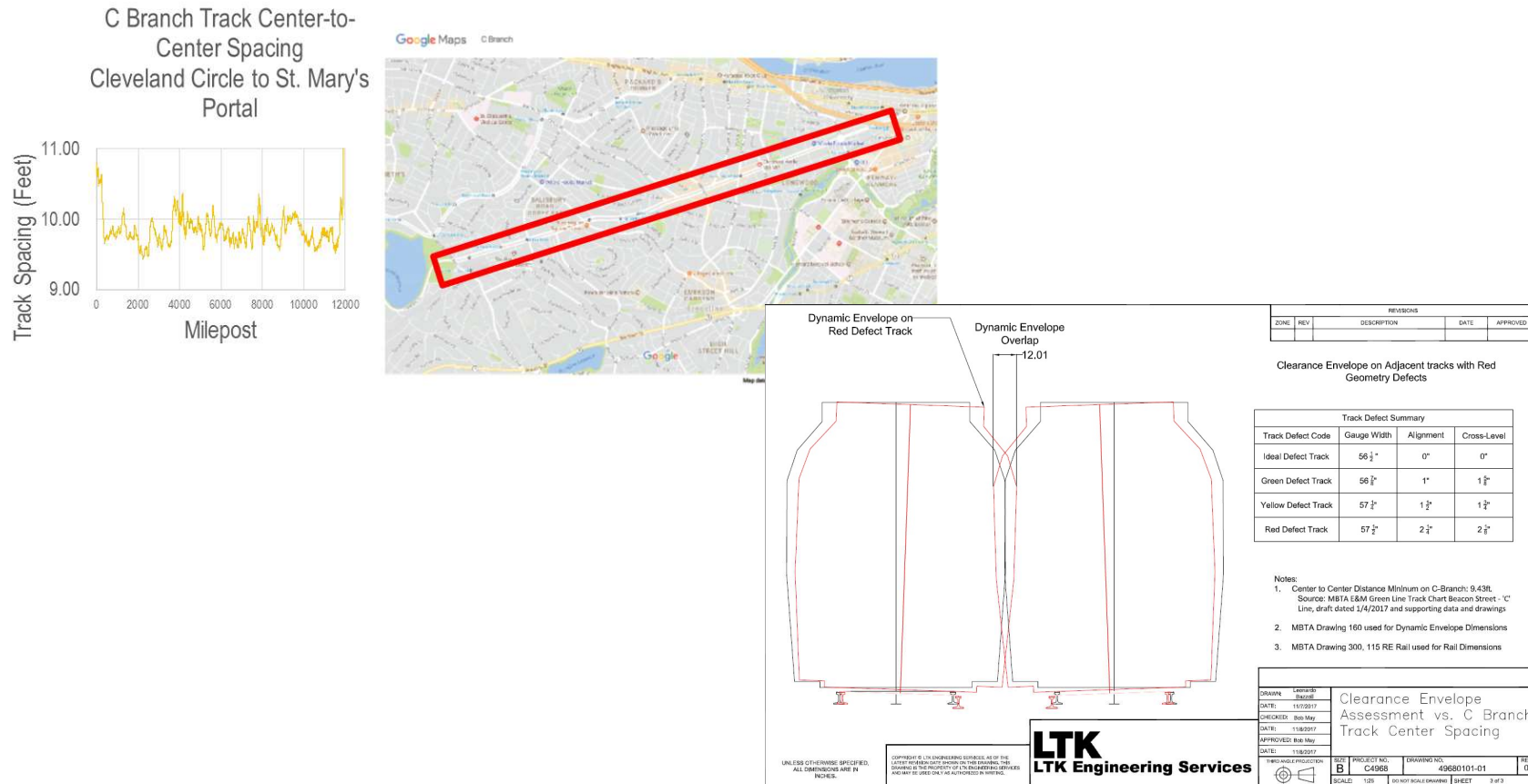
# C- Line

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# C Branch Spacing

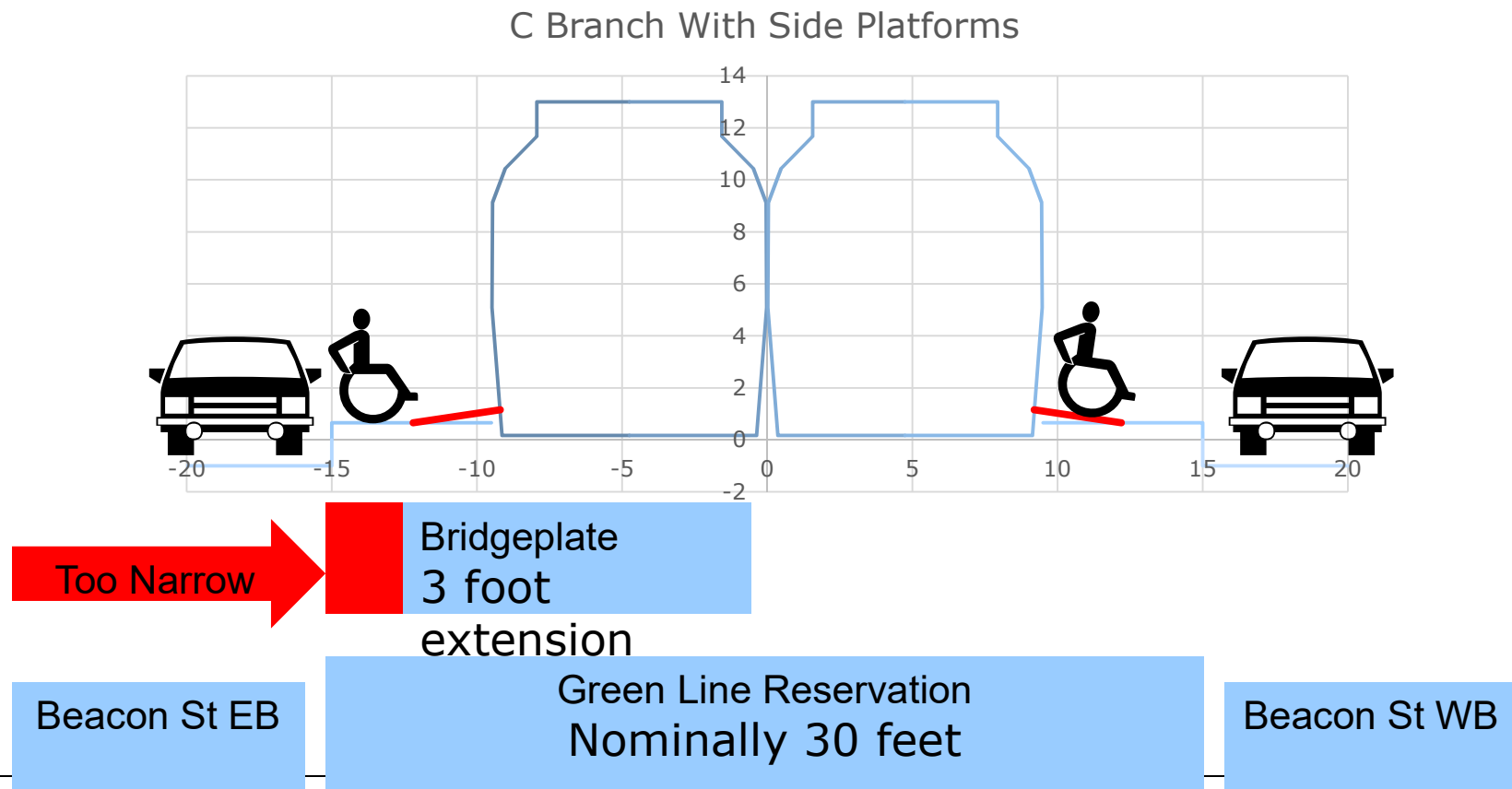
- Almost the entire C Branch has track spacing less then 10 feet.





## C Branch Accessibility Challenge

Many Stations are not wide enough for accessibility

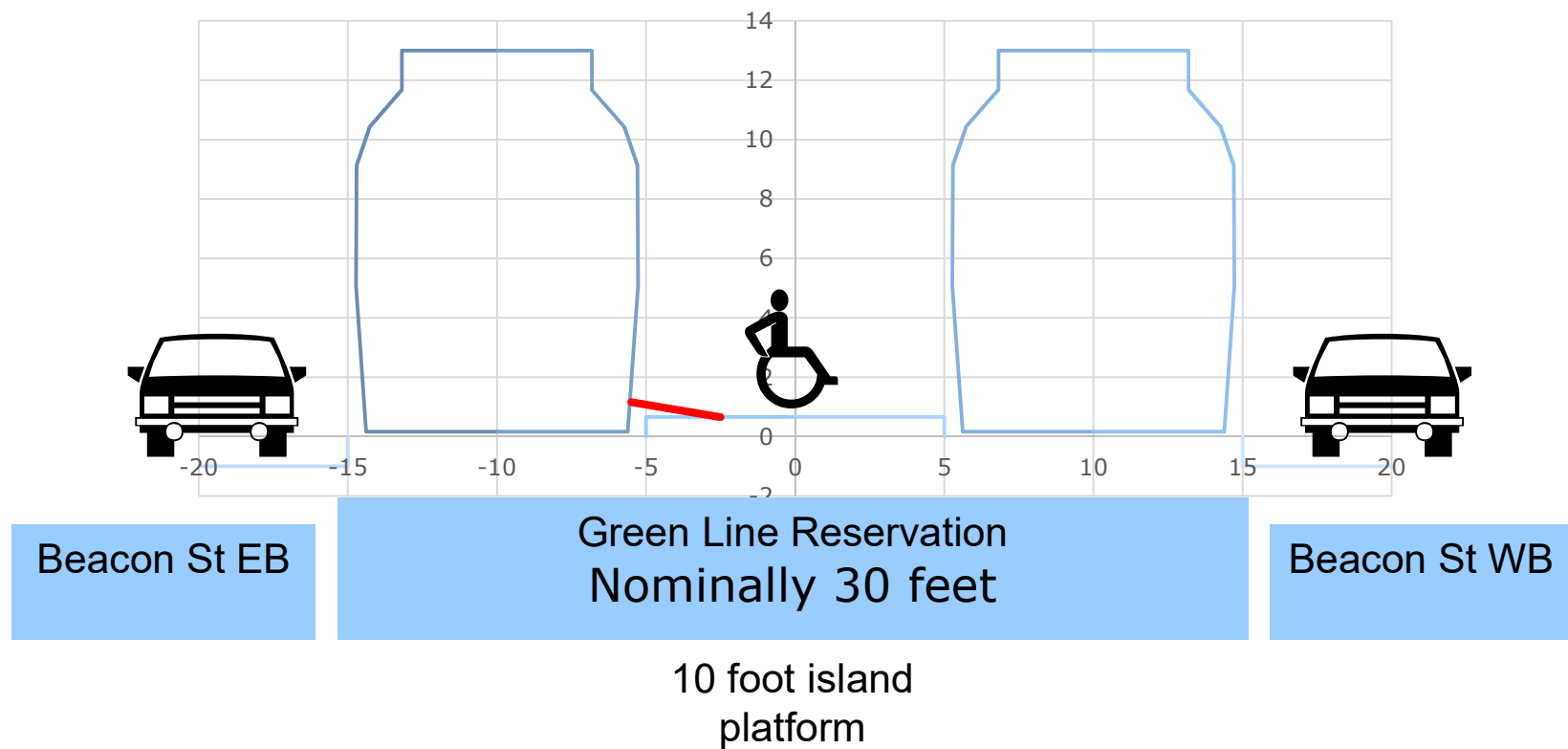




## Accessibility Study Suggests Center Platforms

Provide a Path to Full Accessibility and Resolve Track Center Spacing

C Branch With Center Island Platforms

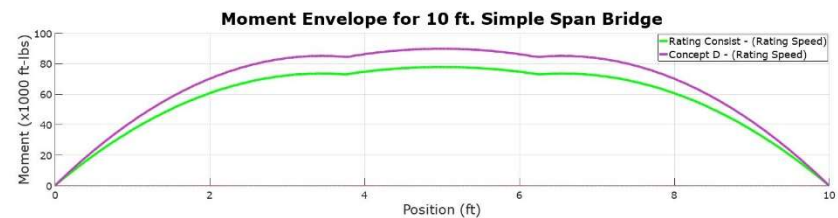
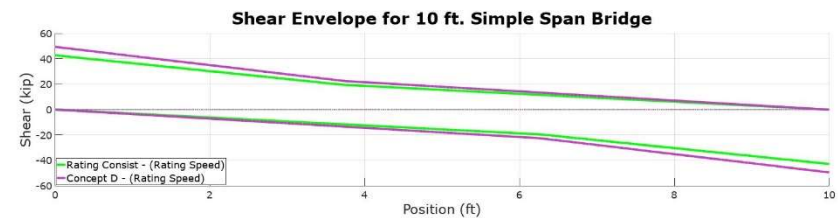
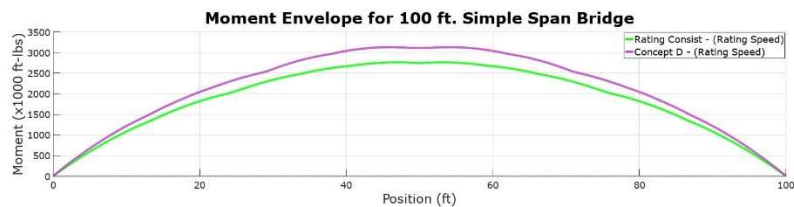
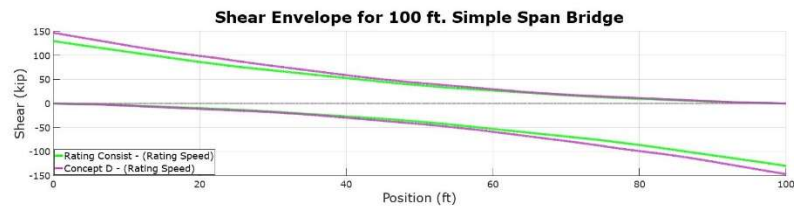






## Load Rating of Bridges

- Longer and heavier cars with different axle spacing will load bridges differently than existing cars (Moment and Shear both increase)
- All bridges will require “re-rating” analysis for a new car design because MBTA ratings and design standards are based on existing vehicles. The East Cambridge viaduct and Clinton Path underpass need strengthening.





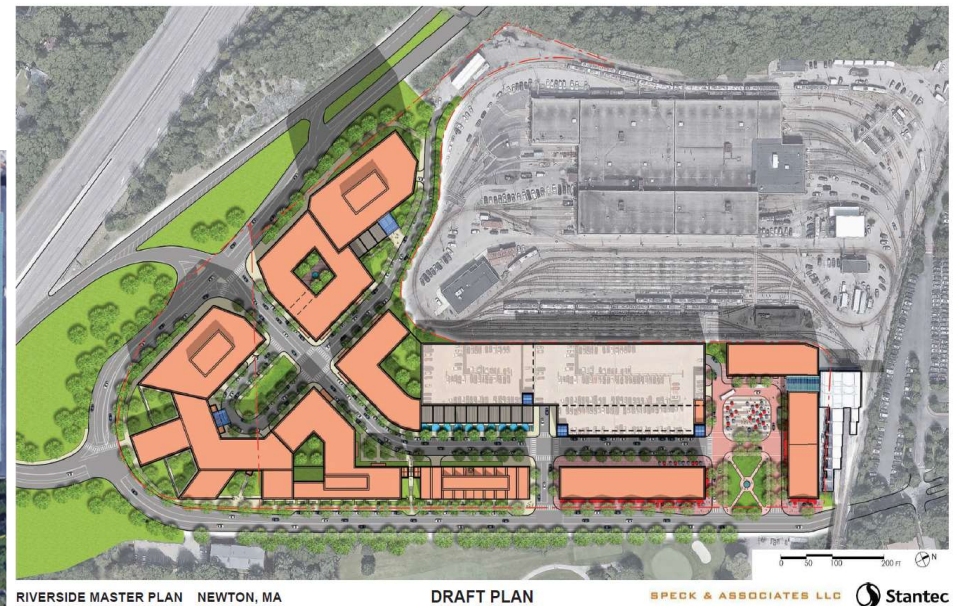
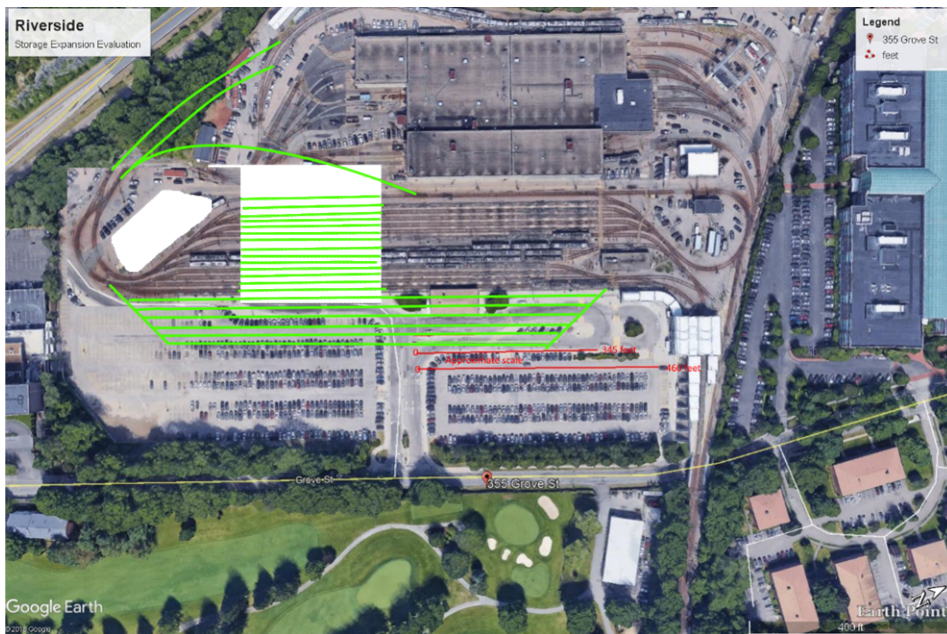
## Operational Constraints for Simulations

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- All operational constraints that impact vehicle design and operations have been identified
  - Fare Collection – Front door collection drives dwell time on surface stations, AFC 2.0 will eliminate this.
  - Park Street Lacks a crossover
  - GLX – adds more passengers and trains
  - Track Condition – Limits speeds and adds complexity to operations
  - Lake Street and reservoir Yard curves
  - Chicken farm (D Line Waban and Newton)
  - North Station X-over (toilet)
  - Double Berthing – Dynamic Double Berthing needed
  - Station Consolidation – Helpful
  - Traffic Signal Priority – Helpful



## Expanding Storage at Riverside ?







# Heath St

