HEAVY HAUL SEMINAR

JUNE 10-12, 2025

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“TEA Nexus” of Train Control, Energy & Automation

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Motivation

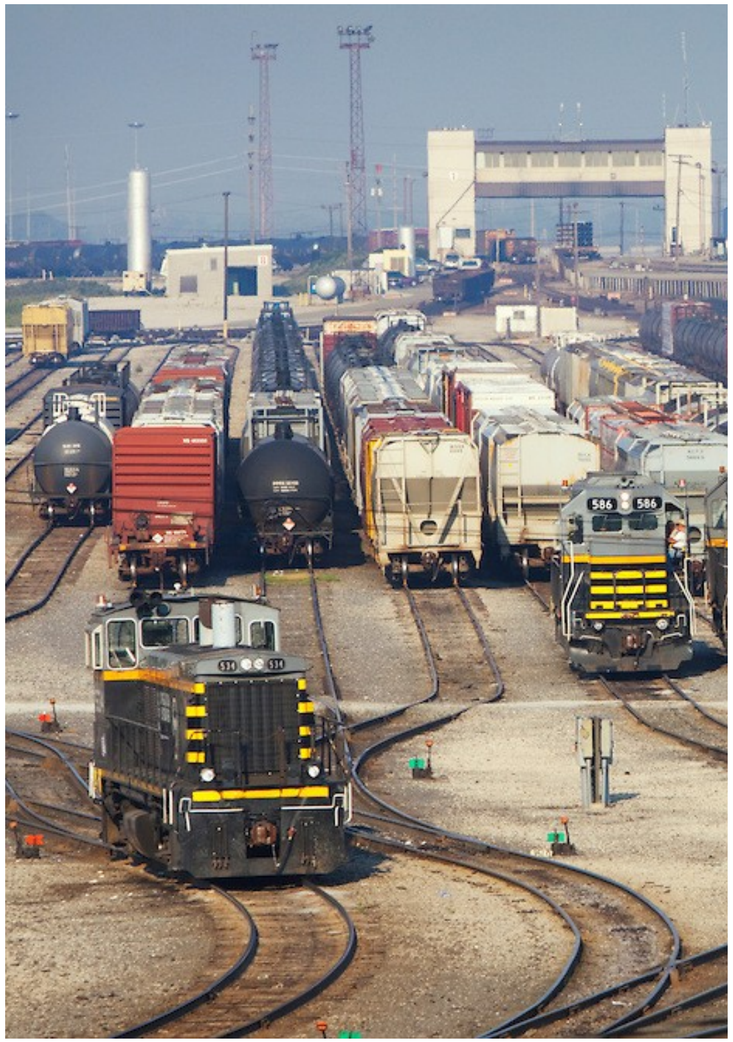
- **Rail** has traditionally been the **most efficient** form of over land transportation
- **Trucks eroding rail efficiency and productivity advantages**
  - Driverless
  - Energy efficiency and alternative powertrains

- Shrinking long-haul bulk commodity “long train” market
- Growth market is **carload** and **short-haul domestic intermodal**
  - Demands **frequent, reliable rail service** with less terminal time

Future Freight Rail Challenges

- Infrastructure and operations designed around **long trains** to **maximize efficiency** and **reduce costs**

- Securing growth by **diverting traffic from trucks** dictates **reliably operating frequent shorter trains**
- Short train **challenges:**
  - Consume **more track capacity for** fixed volume and necessitate costly track infrastructure expansion
  - Less **energy efficient**, increasing **costs**
  - Lower **train crew productivity**, further raising **costs**

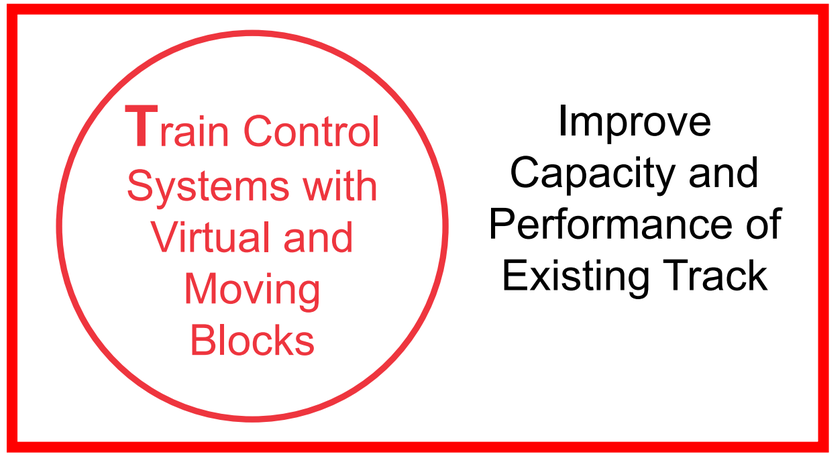


Need for Emerging Technological Solutions

- Mainline track **capacity**
  - Train control systems with flexible or moving blocks
- Energy **efficiency**
  - Electrification and alternative energy sources
- Crew **productivity**
  - Automation and technology-assisted train operations

- Each offers individual benefits when deployed independently
- If **implemented together,** they **help enable each other**
  - Collectively offer **potential compounding benefits… "TEA Nexus"**

TEA Nexus



Reduce Energy Consumption Cost and Emissions

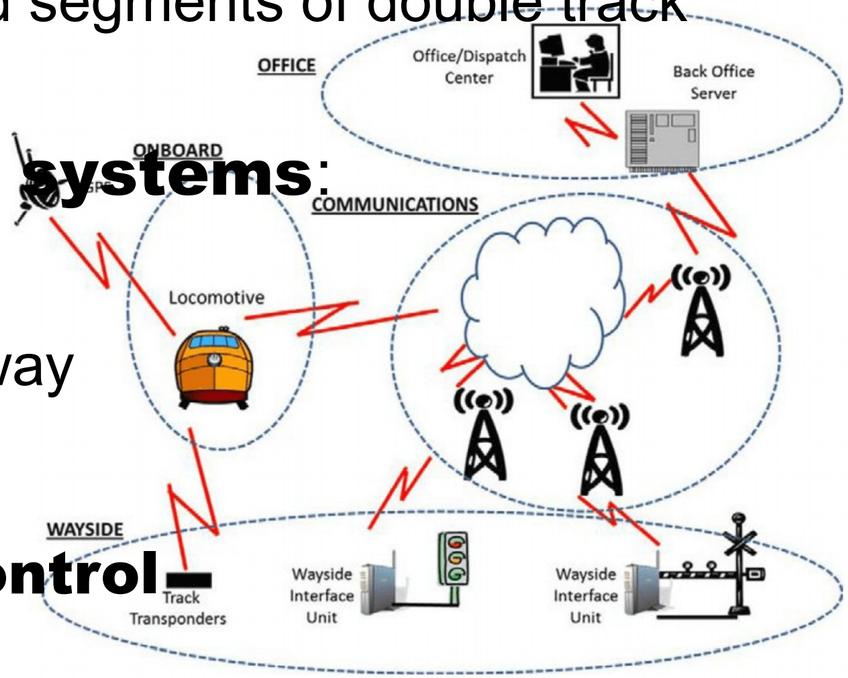
Increase Productivity and Reduce Costs

- How do these emerging technologies yield compounding benefits?

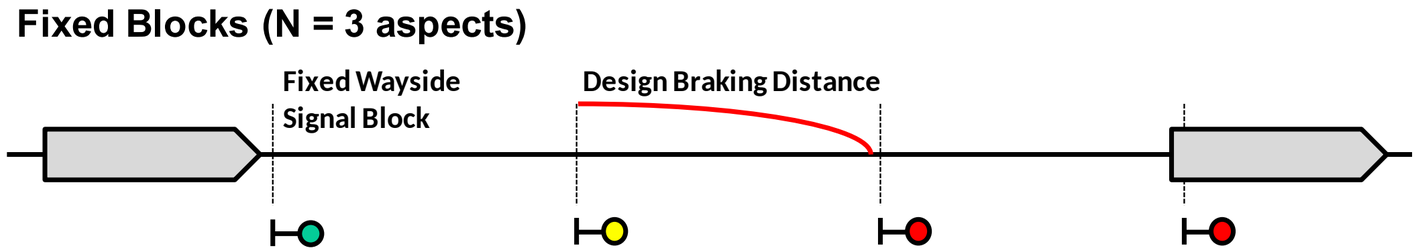
Approaches to Increasing Capacity

- Expensive **infrastructure investment**
  - Upgrade track to increase gross railcar weight and payload capacity
  - Increase number of railcars per train through siding extensions
  - Construct new passing sidings and segments of double track

- **Advanced rail traffic control systems**: a more economical approach?
  - Leverage Positive Train Control (PTC) technology to reduce headway
  - Precise GPS-based train location
  - Robust data communication links
  - Allow **moving/virtual block control**

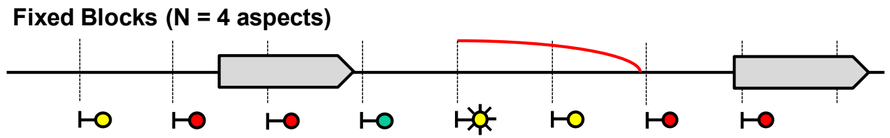


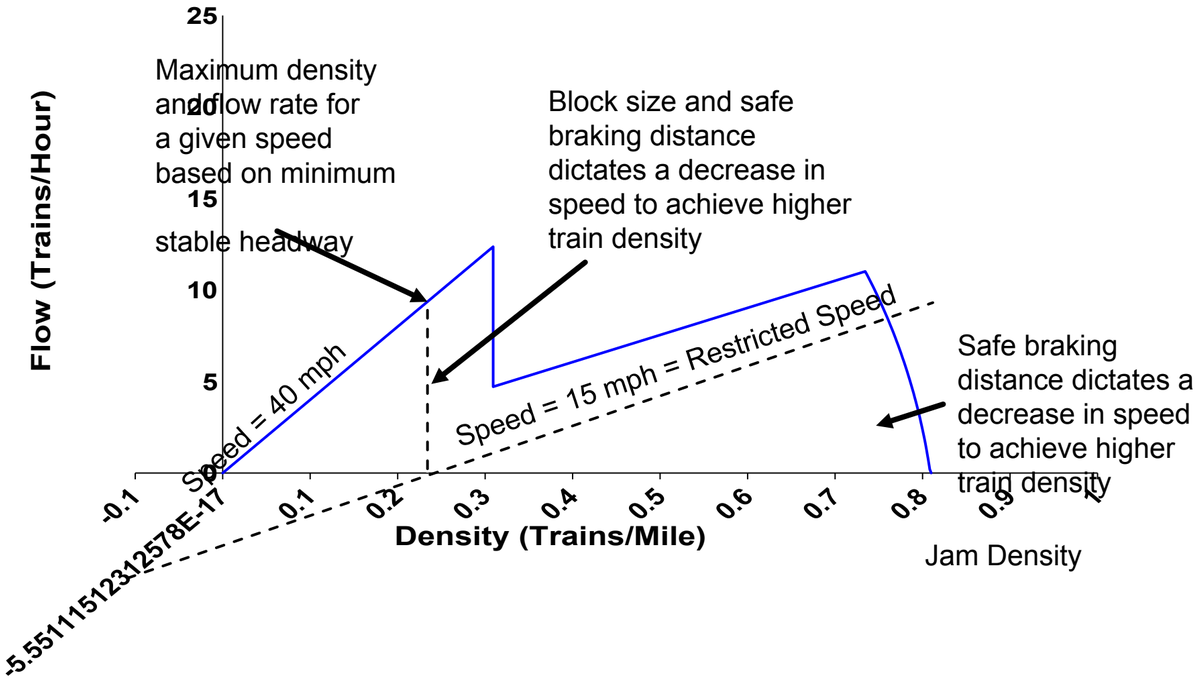
Control System and Train Headway



The Rail Fundamental Diagram (RFD)

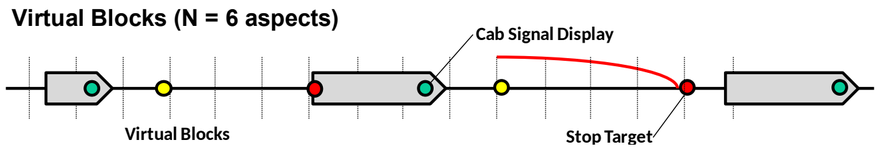
- 4-Aspect Fixed Block (N=4), Maximum Authorized Speed = 40 mph

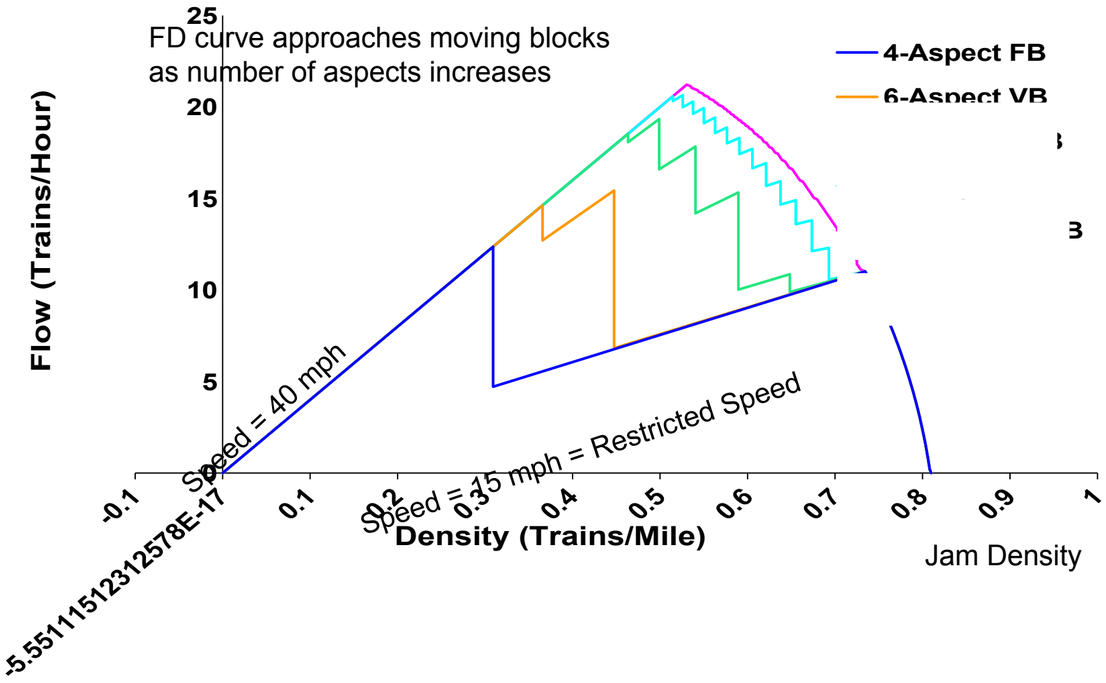




Adding Aspects to Add Capacity

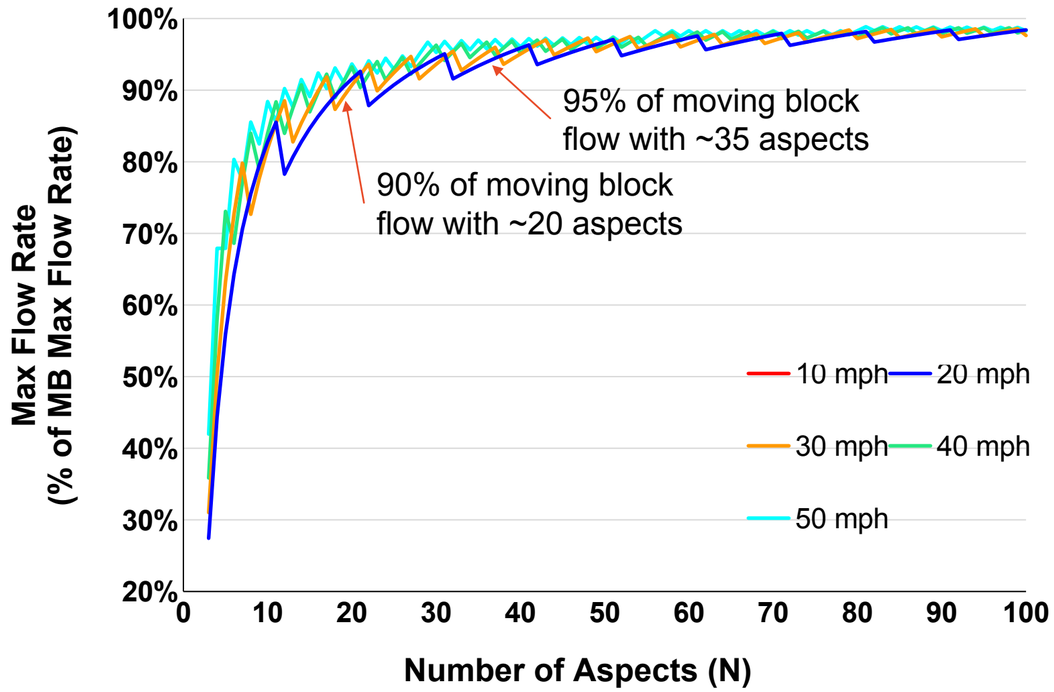
- Peak train flow rate increases with added aspects





How many virtual aspects is enough?

- Calculated max flow rate for “N” virtual block as a percent of max flow under moving blocks and different track speeds

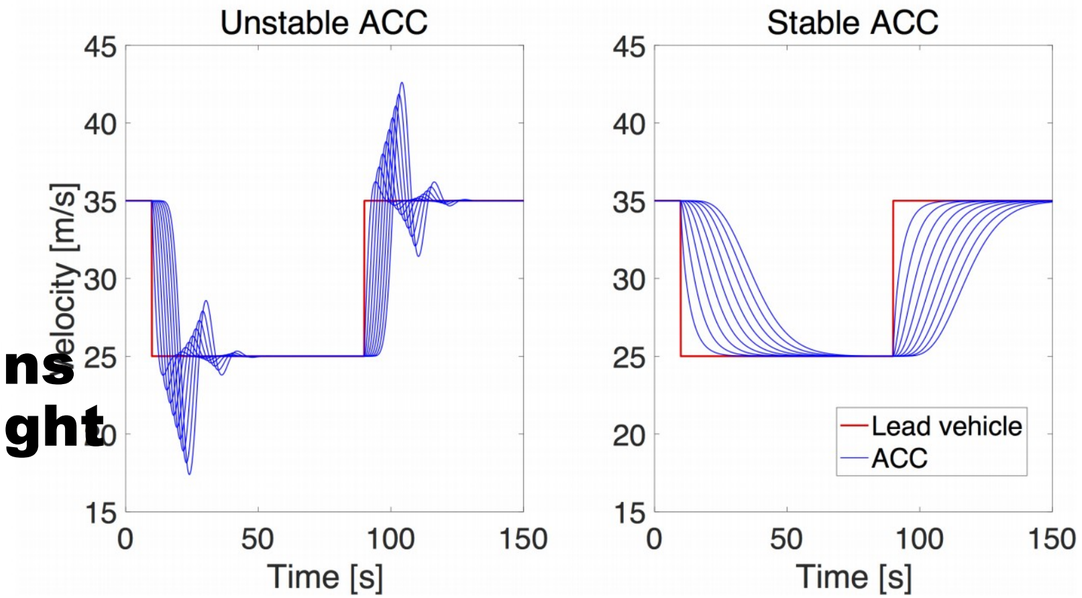


Train Control: Potential Limitations

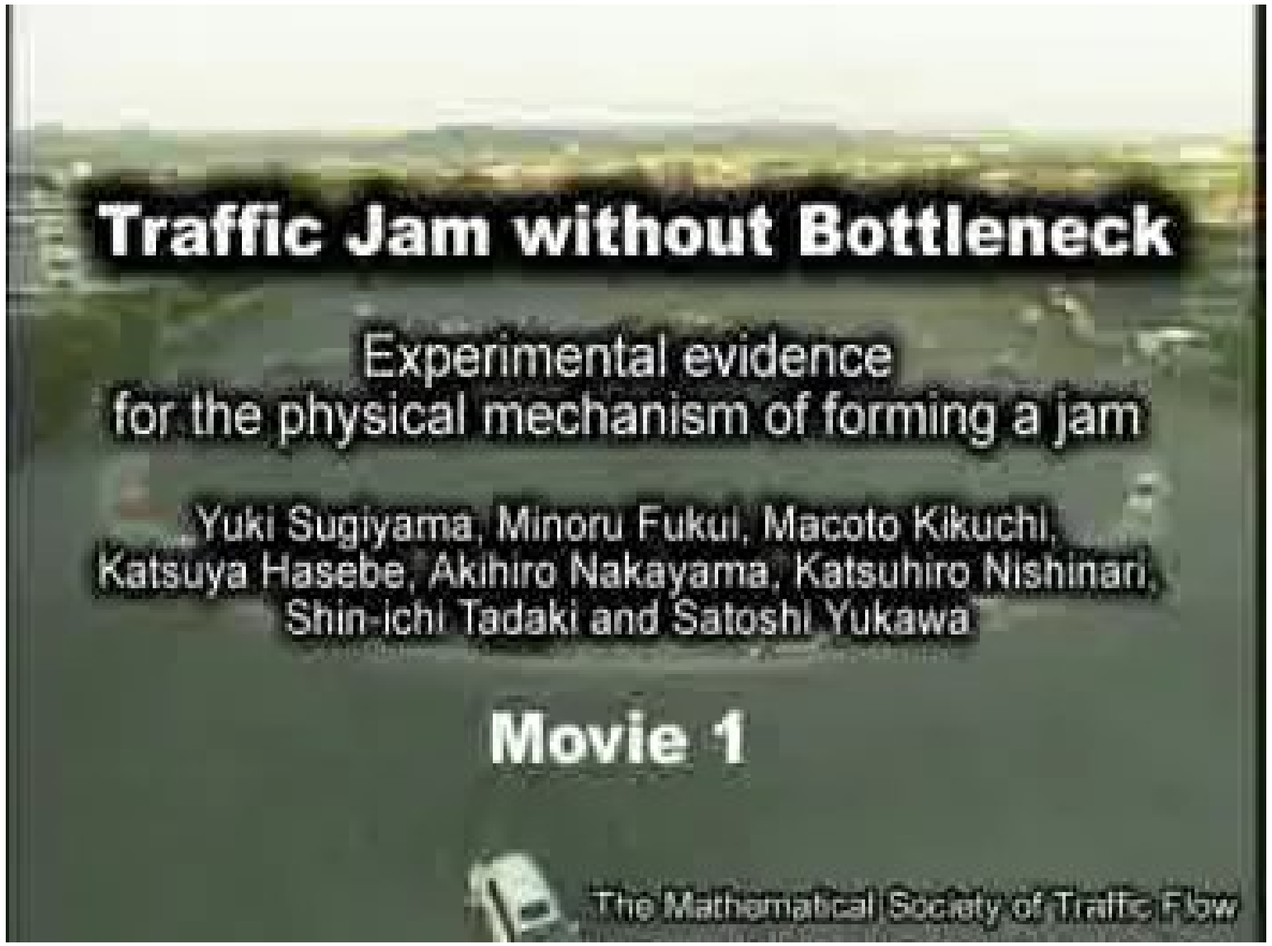
- High-density virtual block system (N~10) likely less complicated than true moving blocks while providing much of the benefit
- Analysis makes simple assumptions about the ability of train “fleets” (platoons) to follow at minimum headways
- **“Train Following Problem”**
  - Need throttle/brake control inputs to follow at safe braking distance
  - Perturbations can ripple through a train fleet if not properly controlled

Need Train Following Stability

- Following trains in a platoon need to **maintain headway without using more aggressive throttle and braking** than lead train → "string stable"
- Eliminating unnecessary braking and throttle action helps **reduce energy consumption**
- Reduces likelihood of following train **PTC braking enforcement**
- **Challenge: Freight trains have low power-to-weight ratio → unresponsive!**



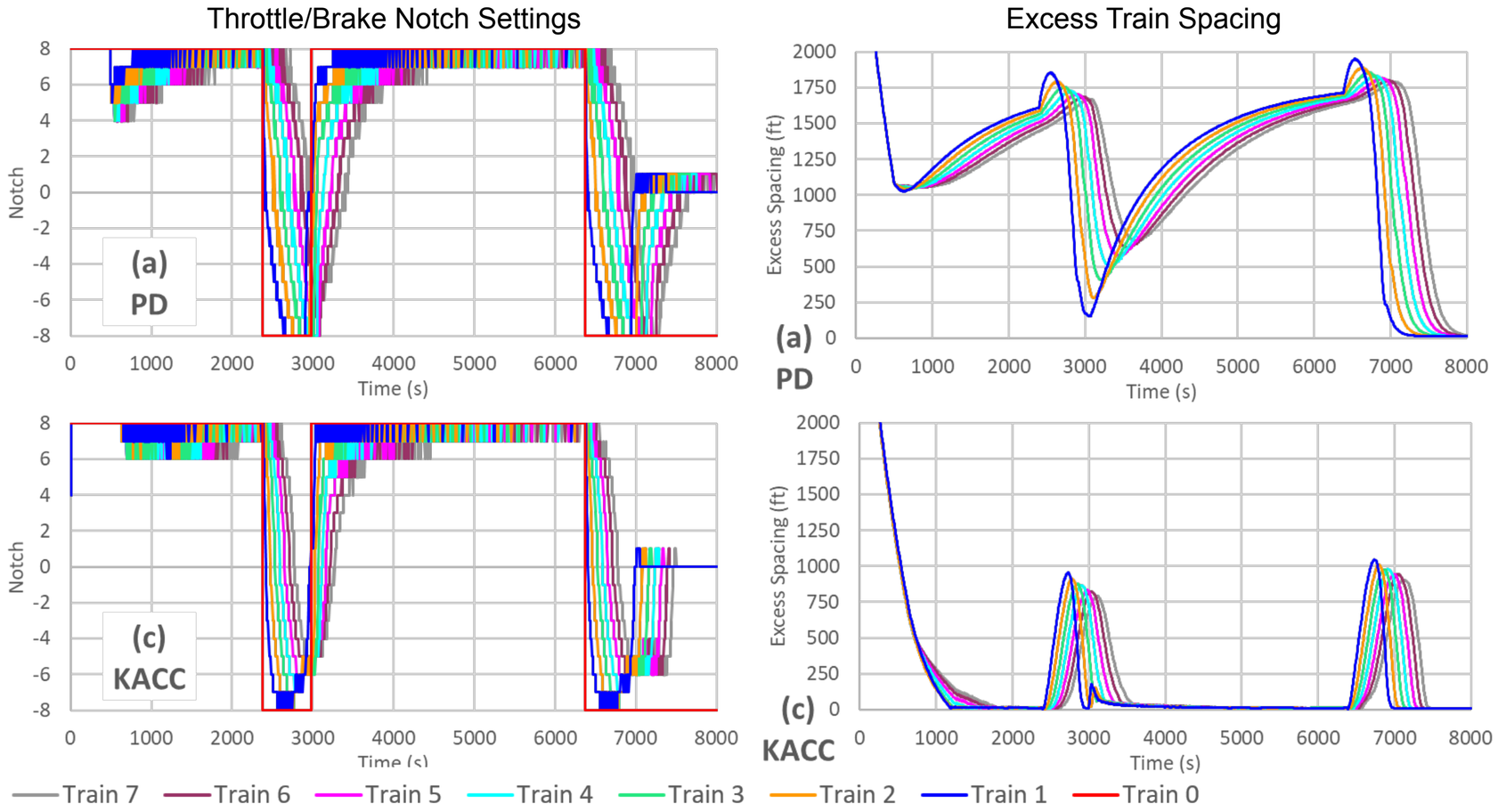
Manual Control: Not String Stable!



- https://www.youtube.com/watch?v=7wm-pZp_mi0

Train Following Simulation Experiment

- Eight-train platoon with fixed lead train throttle/brake pattern

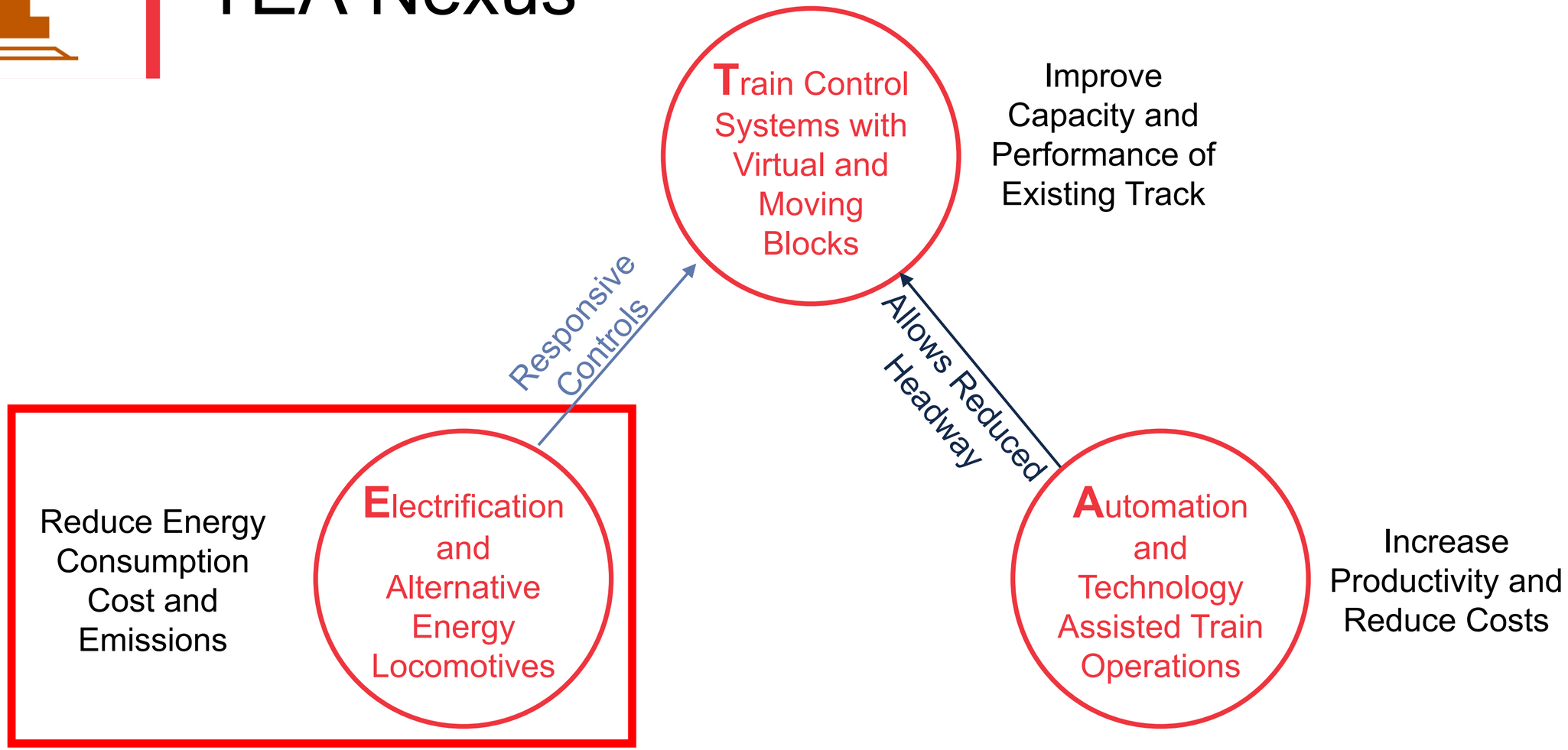


Implications for Capacity Benefits

- **Excess spacing is required** to account for train control actions
  - Manual control of large diesel engine is slow!
  - Results in **~5% less capacity** than theoretical moving block

- Train platoons under virtual and moving blocks can **benefit from increased control responsiveness** provided by replacing:
  - Diesel-electric → **Electrification** or **alternative energy** locomotives
  - Manual control → **Automation** or **technology-assisted train operations**

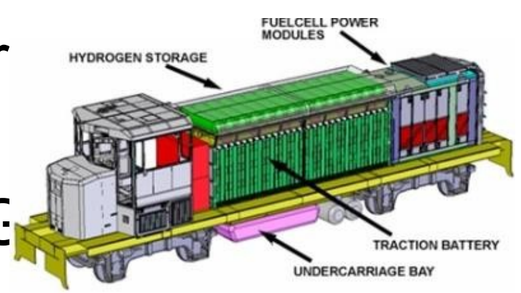
TEA Nexus

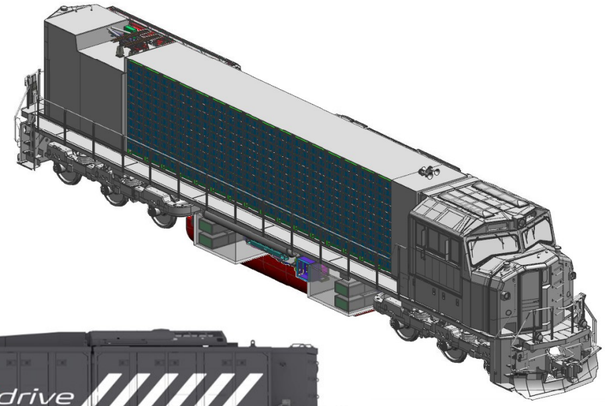


- Electrification and automation help enable capacity benefits

Alternative Energy for Rail Applications

- Alternatives to diesel-electr
  - Biodiesel
  - Natural Gas (LNG, CNG
  - Hydrogen Fuel Cells
  - Batteries
  - Electrification



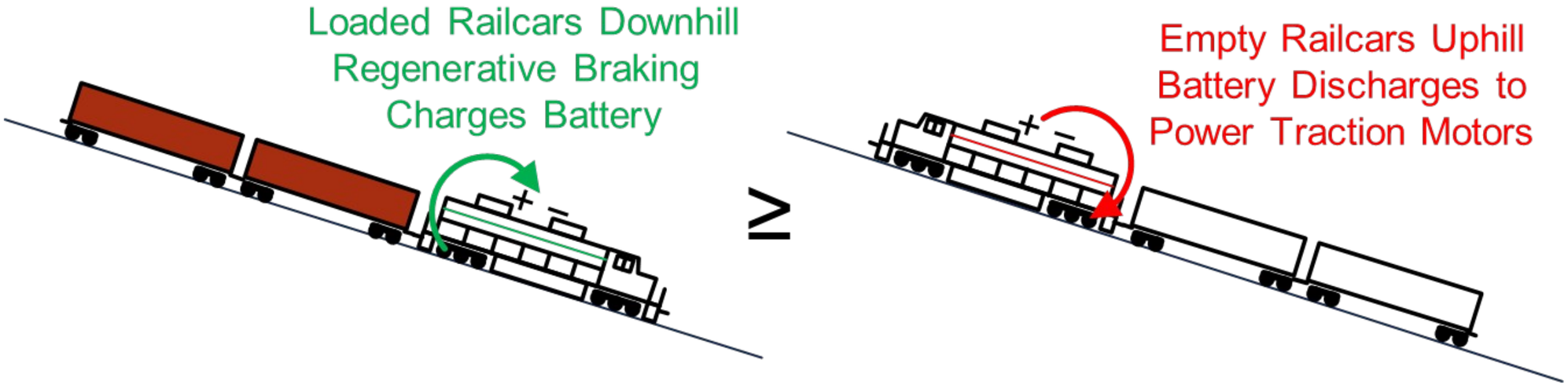


- Advantages of “non-combustion” alternatives
  - More responsive and finite throttle and braking controls
  - Improved energy efficiency and use of regenerative braking

Gravity Battery-Electric Train (GBET)

- 14.5 MWh 8-axle Battery Electric Locomotive (BEL)

- Downhill mine-to-port railway in Australia

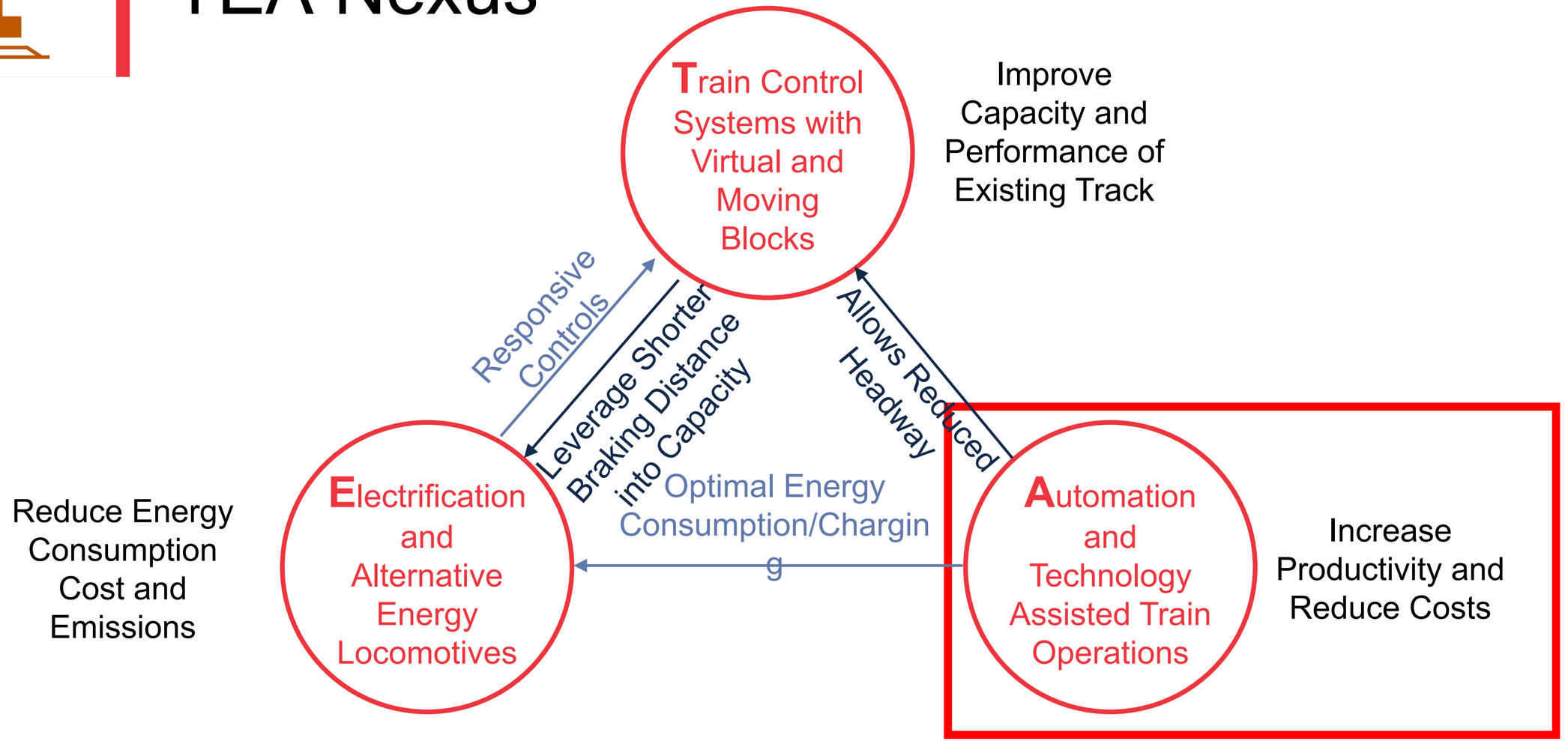


- Zero-emissions and no charging required!

Energy: Potential Limitations

- Alternative energy benefits require **optimal throttle and brake use**
  - Potentially **decrease braking distances** → **Train traffic control with virtual/moving blocks**
- **Energy benefits** of regenerative braking limited by in-train forces
  - Use **multiple distributed power groups** to meet maximum dynamic brake force limits and avoid wasting energy
  - Use **independent controls** for multiple DP loco groups to maximize regeneration (multi-fence mode)
- Demanding conditions for train crew → **Automation** or **technology-assisted train operations**

TEA Nexus



- Automation and train control can maximize energy efficiency

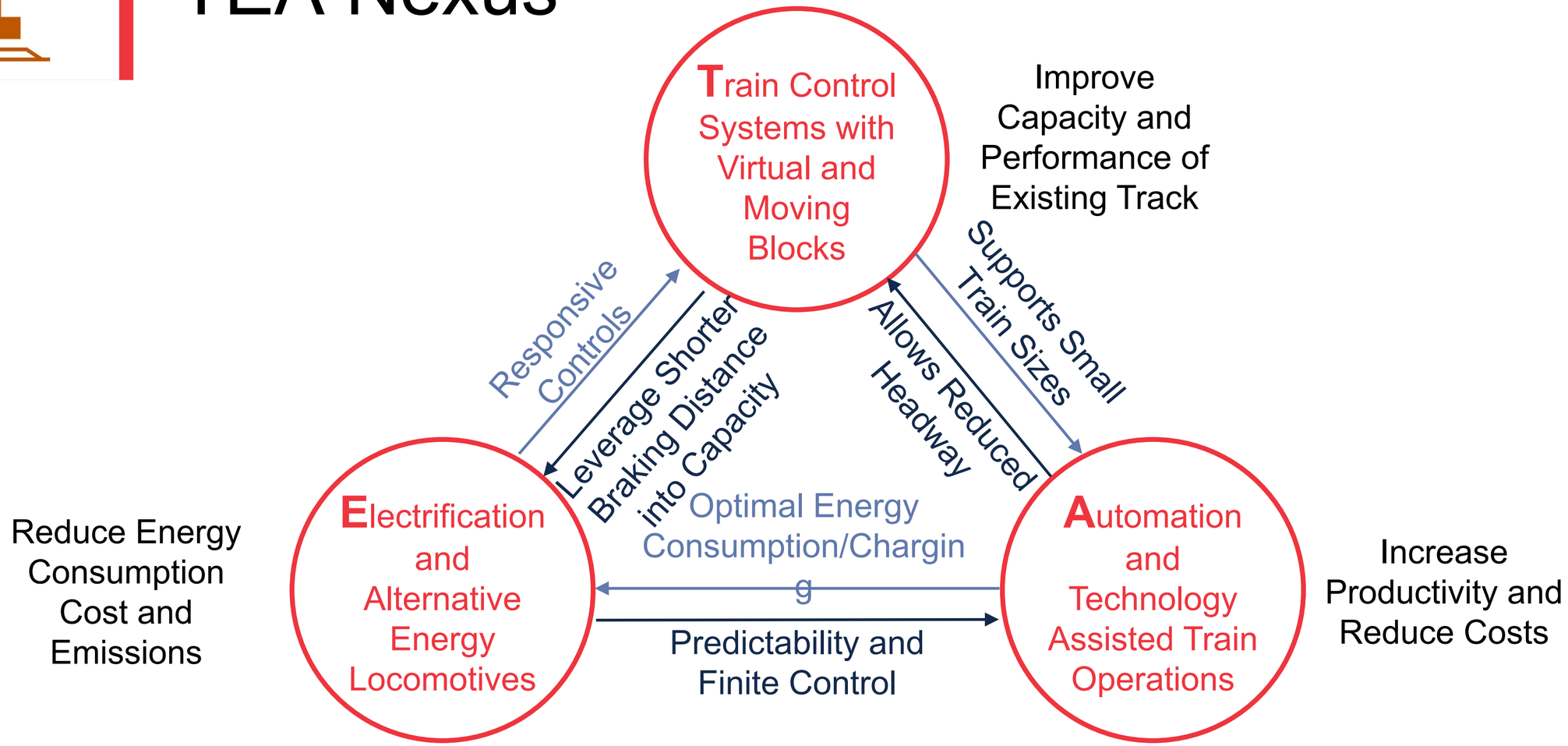
Automation

- **Fully automated** heavy-haul train operations in **Australia since 2019**
- 500-mile isolated mine-to-port iron ore railway
- “World’s largest robot”
  - 240 railcars/train
  - 31,000 tons/train
- **Increased capacity and efficiency** through consistent train speed
and reduced headway

Technology Assisted Train Operations

- In North America, existing **driver advisory systems** suggest optimal throttle/brake control inputs
- Fully automated freight train **demonstrations under test conditions**
  - Many **technical, regulatory and institutional barriers**
- Improve feasibility with:
  - **Shorter trains**
  - Predictable controls and **responsive motive power**

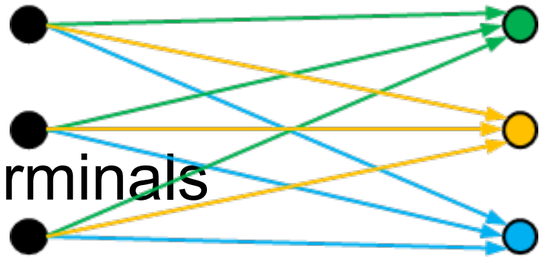
TEA Nexus



- Alternative energy and virtual blocks can facilitate automation

TEA Implications for Freight Rail Service

- **TEA Nexus facilitates more flexibility in efficient sizing of trains and motive power while effectively using existing track infrastructure**
- Smaller train sizes may become economical
- Directly connect more origin-destination pairs
- **More frequent departures** that by-pass terminals
- **Shorter connection and transit times**
- *Revolution in railway service design and network planning?*
  - ***Win traffic from trucks by acting more like a truck!***



Takeaways

- New **train control** technologies with virtual and moving blocks have
the potential to increase railway capacity and performance

- Benefits enhanced by emerging **energy** and **automation** technology

- **Compounding benefits** of Train control, Energy and Automation may disrupt railway operating paradigms

- **Need to evaluate the joint economics of these technologies**
and through the lens of improved service and traffic growth

Thank you for your attention!

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