Network Efficiency Cycle: Quantifying Yard and Mainline Railway Capacity and Performance Connections

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RAILTEC
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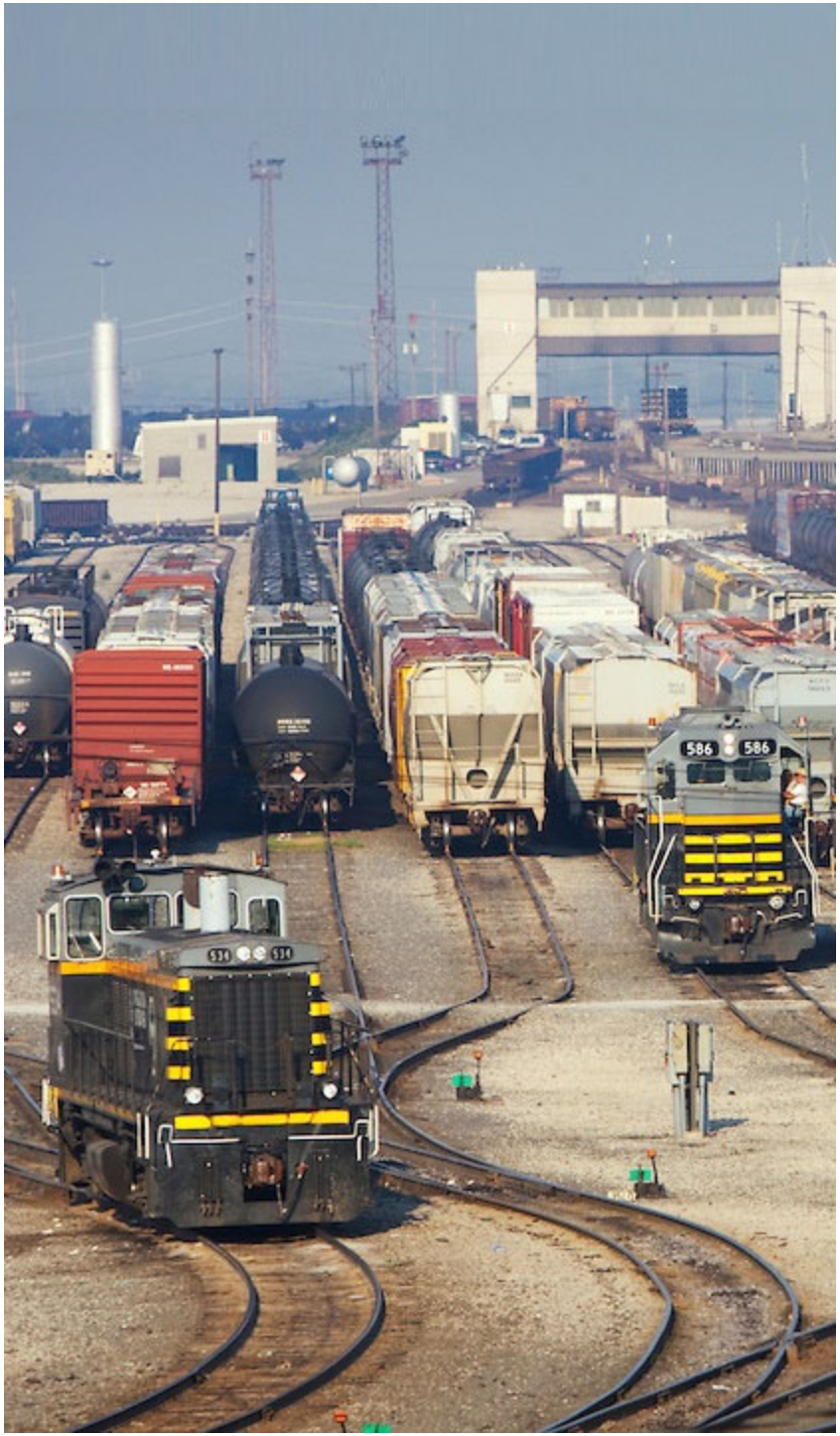


Freight Rail Transportation Network

- In 2018, US Class 1 Railroads transported 1.7 billion tons of freight

- Strong financial incentive to match network capacity to demand

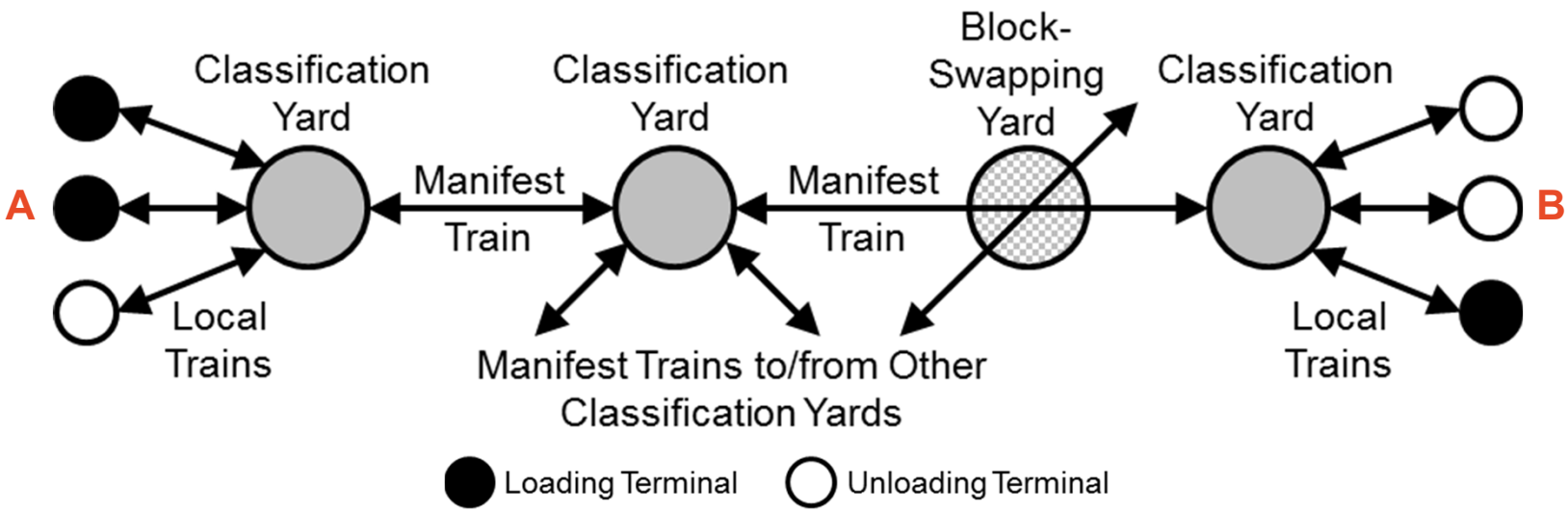
- Freight rail network is an integrated system
  - Links: 161,000 miles of track on 94,000 miles of mainline routes
  - Nodes: hundreds of yards, terminals and junctions

1.5 million railcars + 29,000 locomotives $\xleftrightarrow[\text{Terminals}]{\text{Yards \&}}$ 5,000 trains per day

- Defining the capacity of this network is a challenge

Railway Network Performance

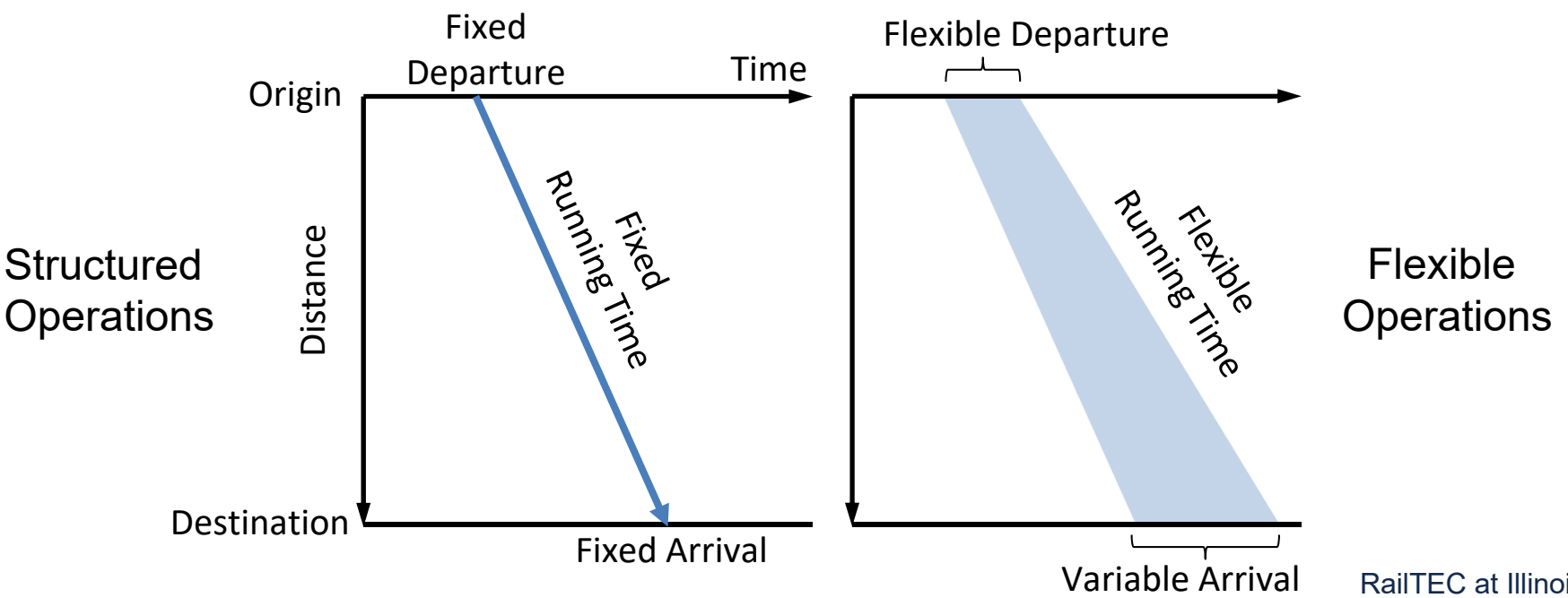
- Mainline, yard and terminal performance all contribute to the quality of railway service



- **Objective:** to develop a stronger fundamental understanding of railway classification yard capacity and performance, and its connection to the capacity and performance of railway mainlines under flexible operations

Structured and Flexible Operations

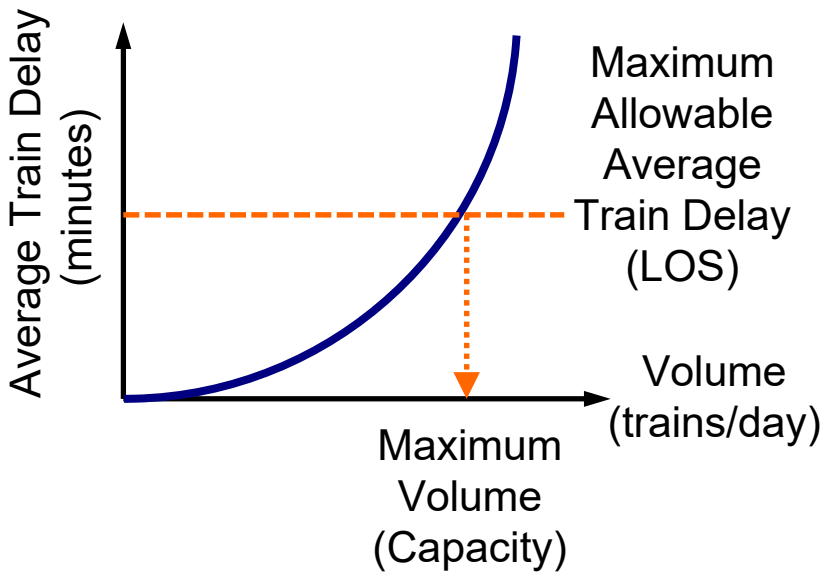
- International research on capacity of "structured operations"
  - Fixed timetable with resolved train conflicts
  - Capacity calculated by UIC Compression Method
  - Predominantly multiple-track mainlines and passenger trains
- Difficult to apply to "flexible operations" in North America
  - Predominantly single-track mainline and freight trains
  - Train plan with target departure times and "schedule flexibility"

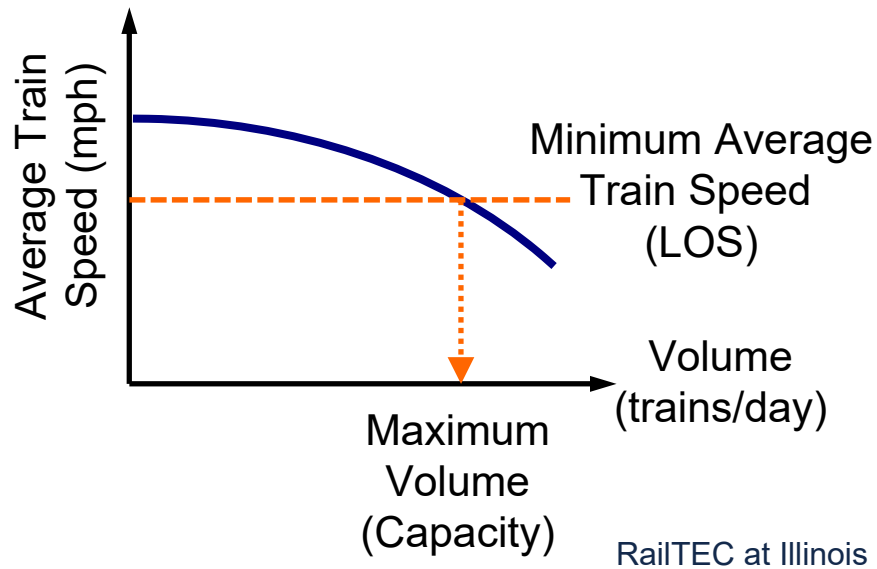


Mainline Performance and Capacity

- Mainline Performance Metrics
  - Train Delay = Actual Train Run Time – Minimum Free Run Time
  - Average Train Speed = Total Train-miles / Total Train-hours (excluding all time in yards and terminals)

- Line capacity is the maximum volume that results in acceptable level of service (LOS) measured by delay or average train speed

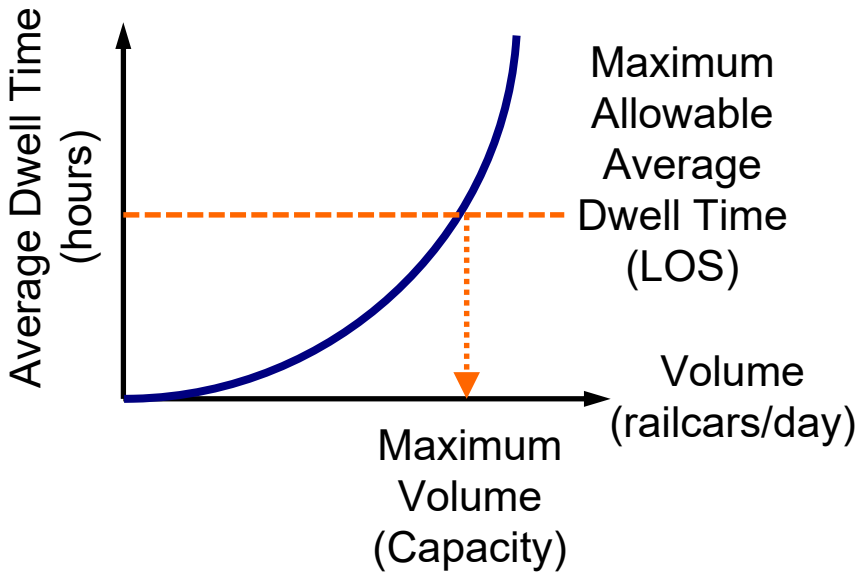


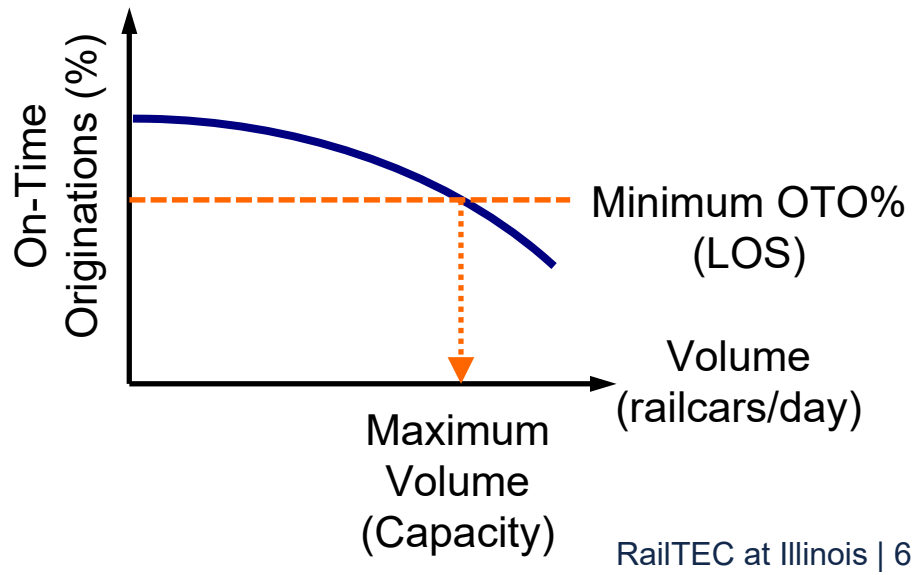


Yard Performance and Capacity

- Yard Performance Metrics
  - Average Railcar Dwell = average time from railcar arrival to departure
  - Connections Achieved = fraction of railcars departing on intended train
  - On-Time Originations = fraction of trains that depart at planned time

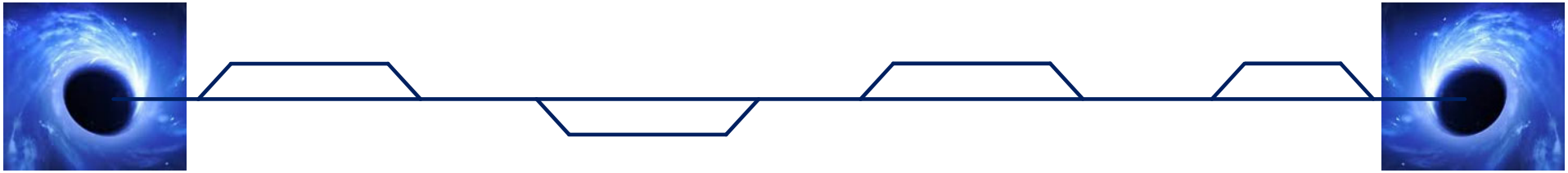
- Yard capacity defined by maximum volume that results in acceptable dwell, connections achieved or on-time originations



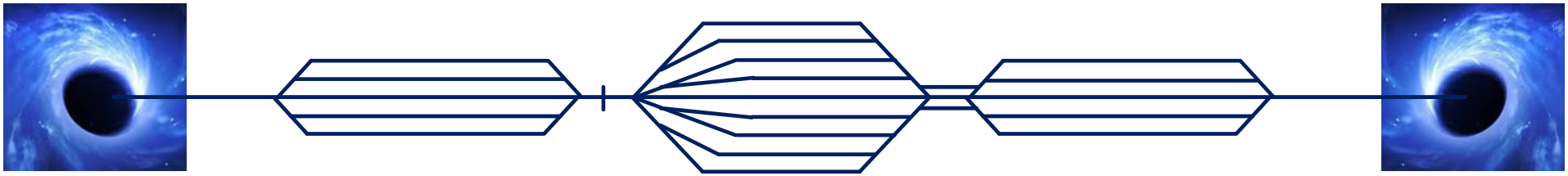


Disconnected Modeling Tools

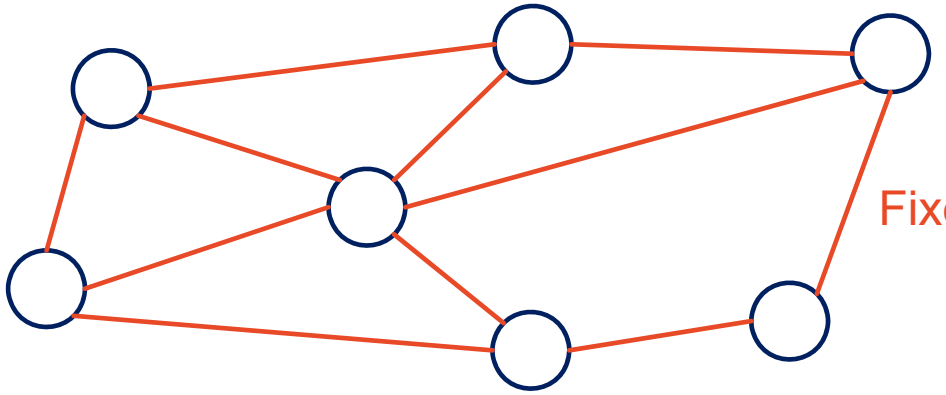
- Mainline



- Yard



- Network



Abstracted to:

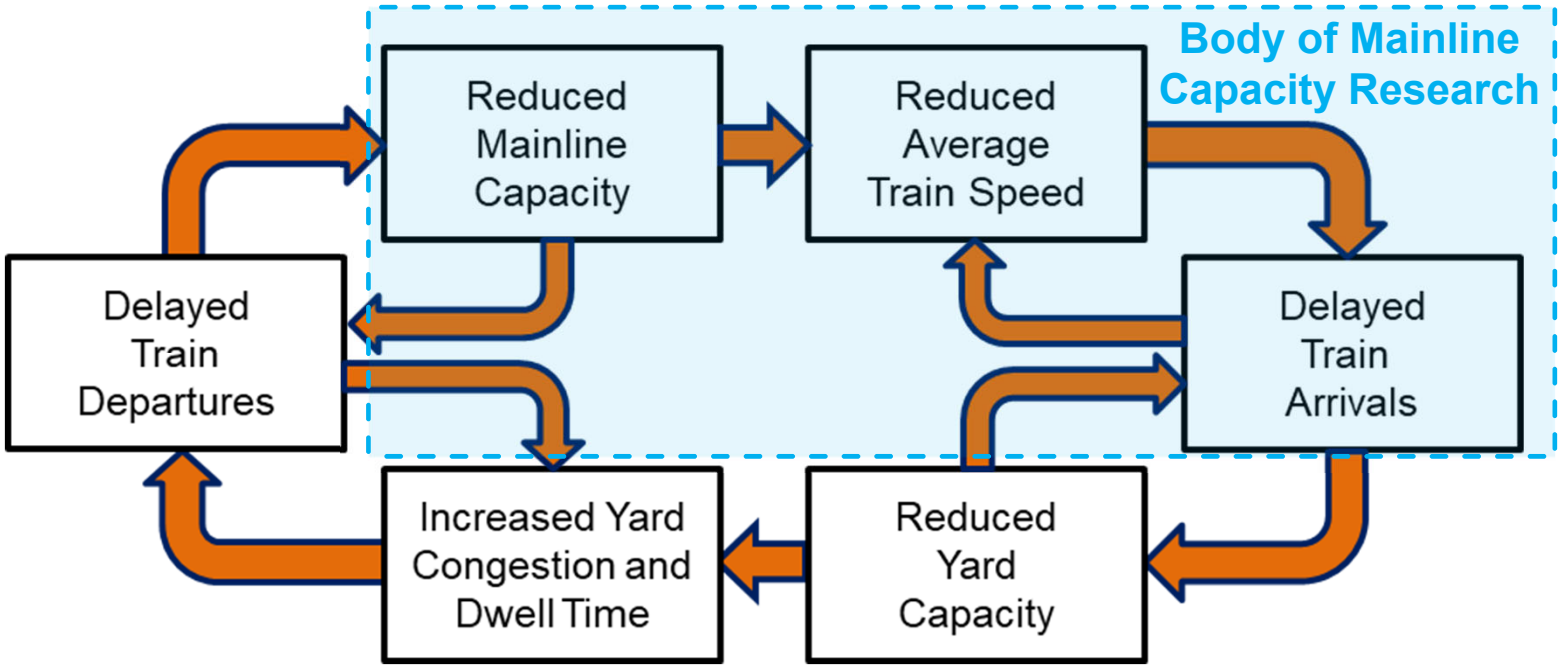
Fixed Node Cost and Capacity

Fixed Link Cost and Capacity

Do not capture interactions!

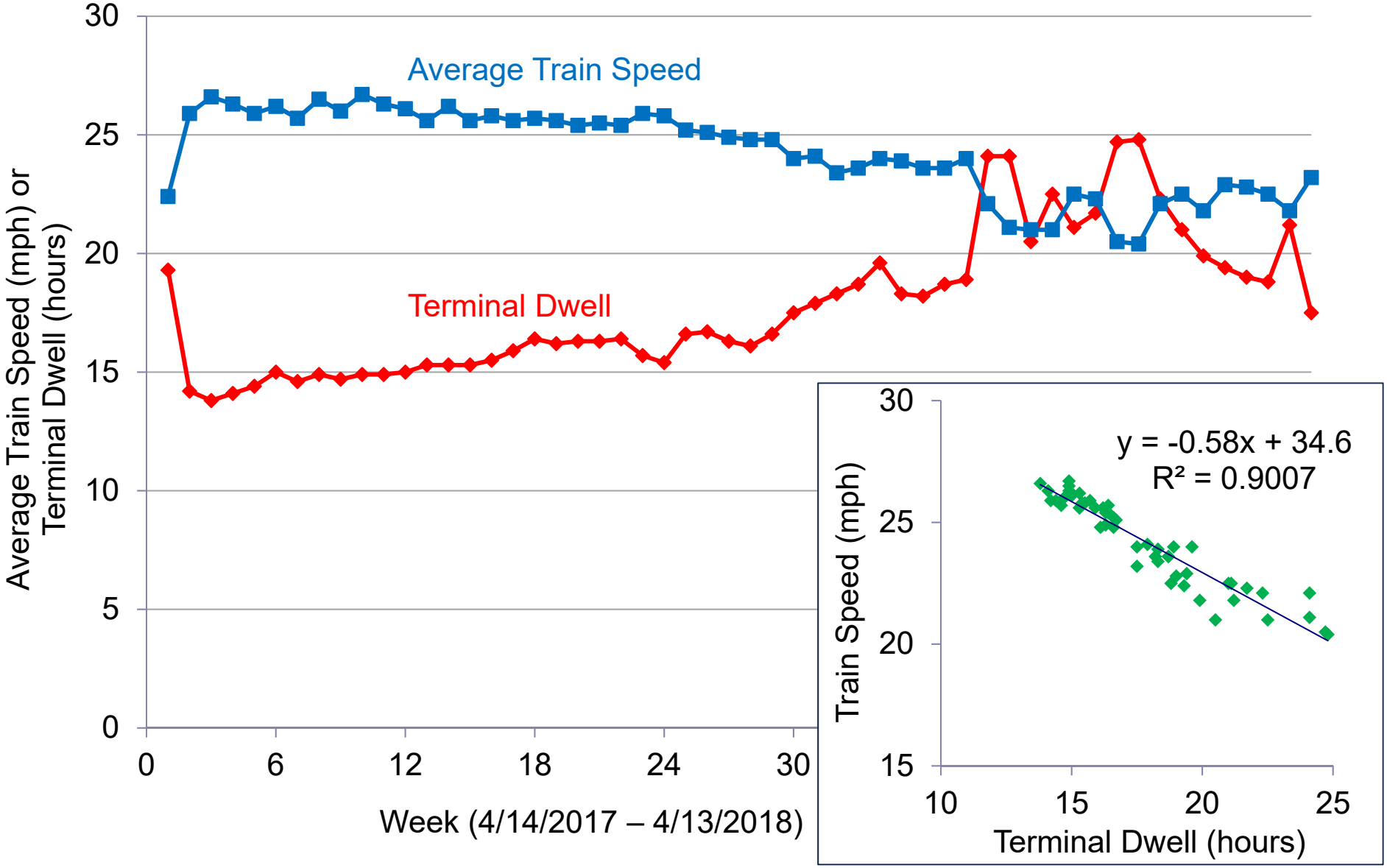
Mainline and Yard Interactions

- Network efficiency cycle (adapted from Dirnberger, 2006)



- Majority of railway industry and academic analytical effort focused on mainline capacity and performance
- Lack of yard capacity knowledge; little research since 1983
- Less academic study of yards and how mainlines and yards interact despite observed interactions

Network Cycle: CN Performance Metrics



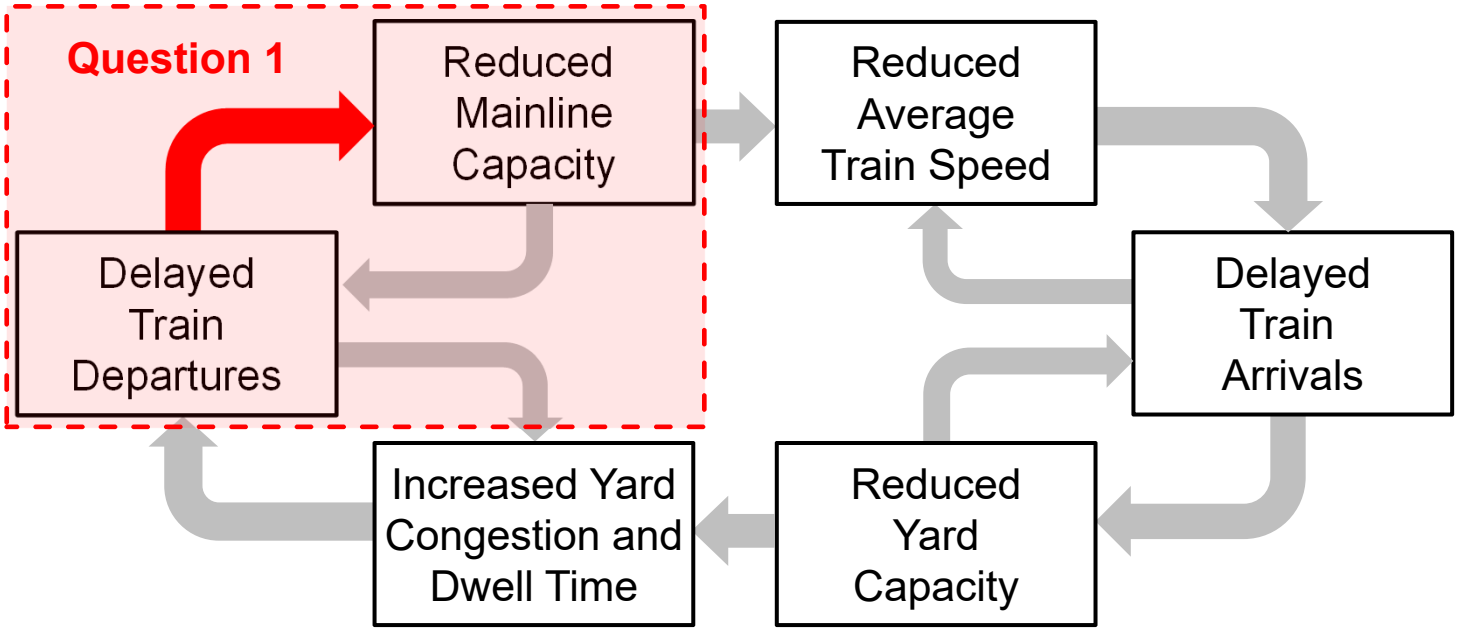
Yard Capacity and Network Disruptions

- Yard and terminal capacity has been the cause of several major network-scale railway service disruptions over the past 20+ years

- Union Pacific (1997)
  - Overestimated capacity of consolidated yards in Houston
- CSX (1999)
  - Overestimated capacity of existing classification yards to support new operating plan after Conrail acquisition
- CSX (2017)
  - Overestimated capacity of remaining yards to support new operating plan after closure of multiple major classification yards

- Continuing recurrence of railway network service disruptions reinforces the need for improved understanding of
  - Mainline and yard capacity interactions
  - How delay and schedule flexibility propagates through the network

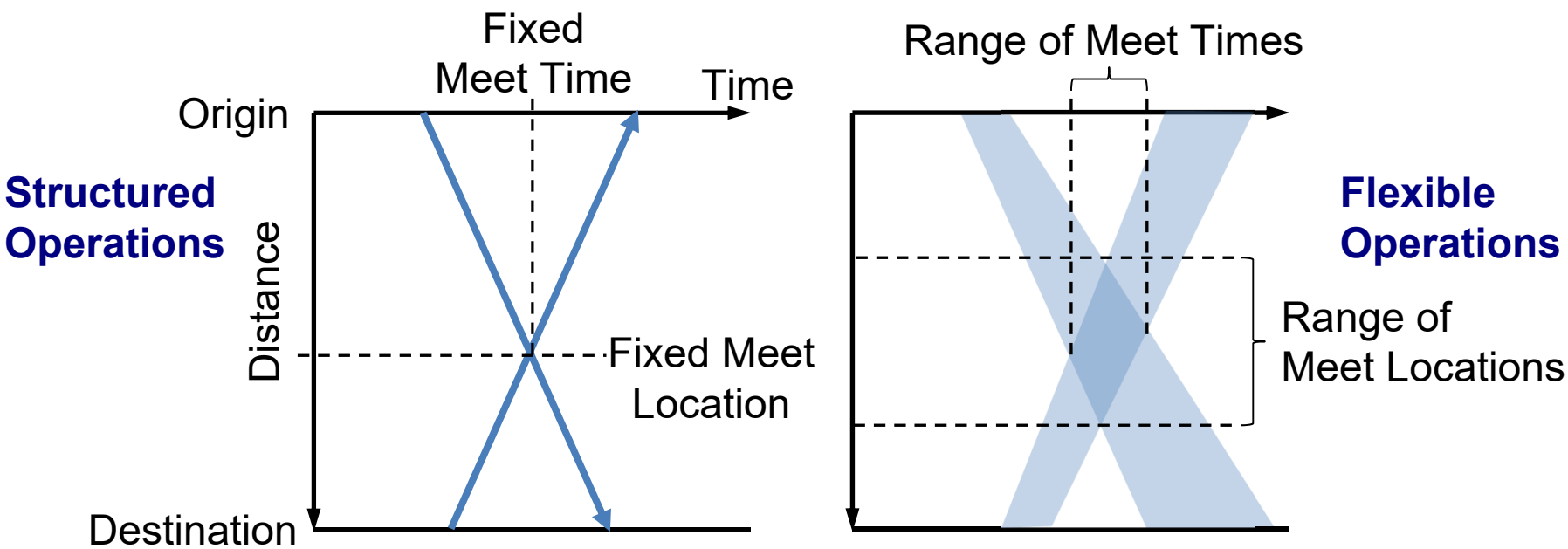
Research Question 1



- What is the relationship between variability in train departure times and the performance and capacity of a given mainline?

Background and Problem

- Schedule flexibility creates uncertainty in the location of train meets on single track



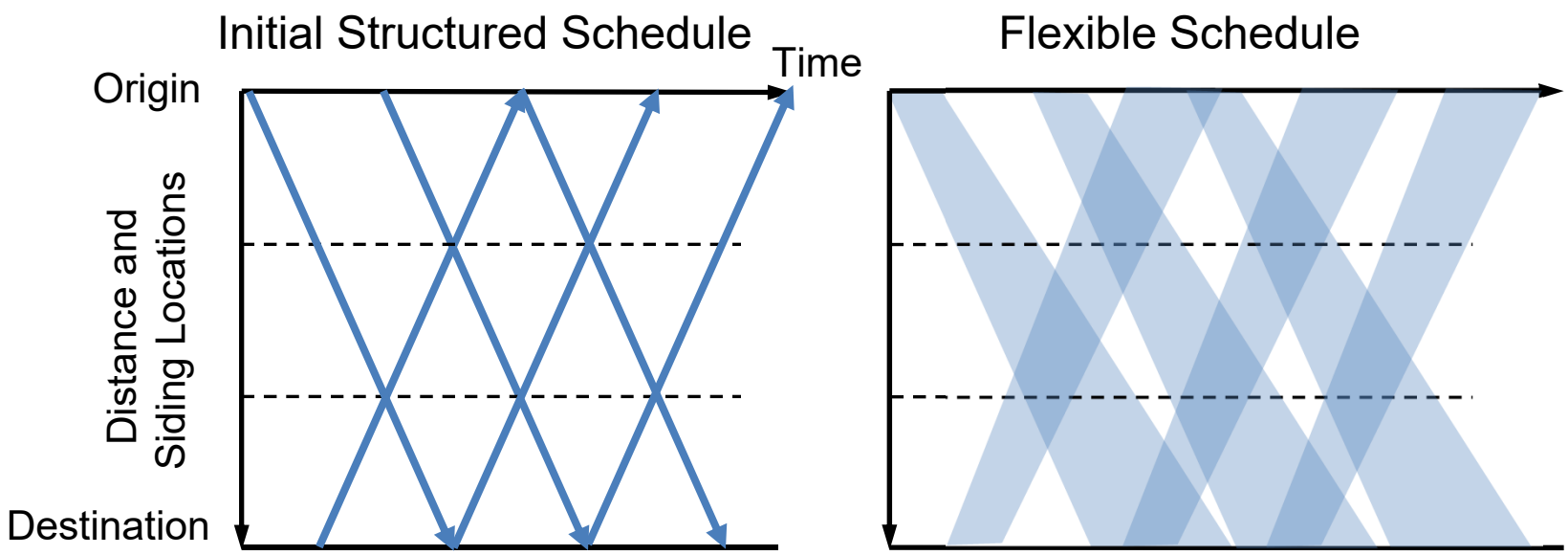
- How does this uncertainty created by schedule flexibility impact mainline train delay and line capacity?

Mainline Simulations

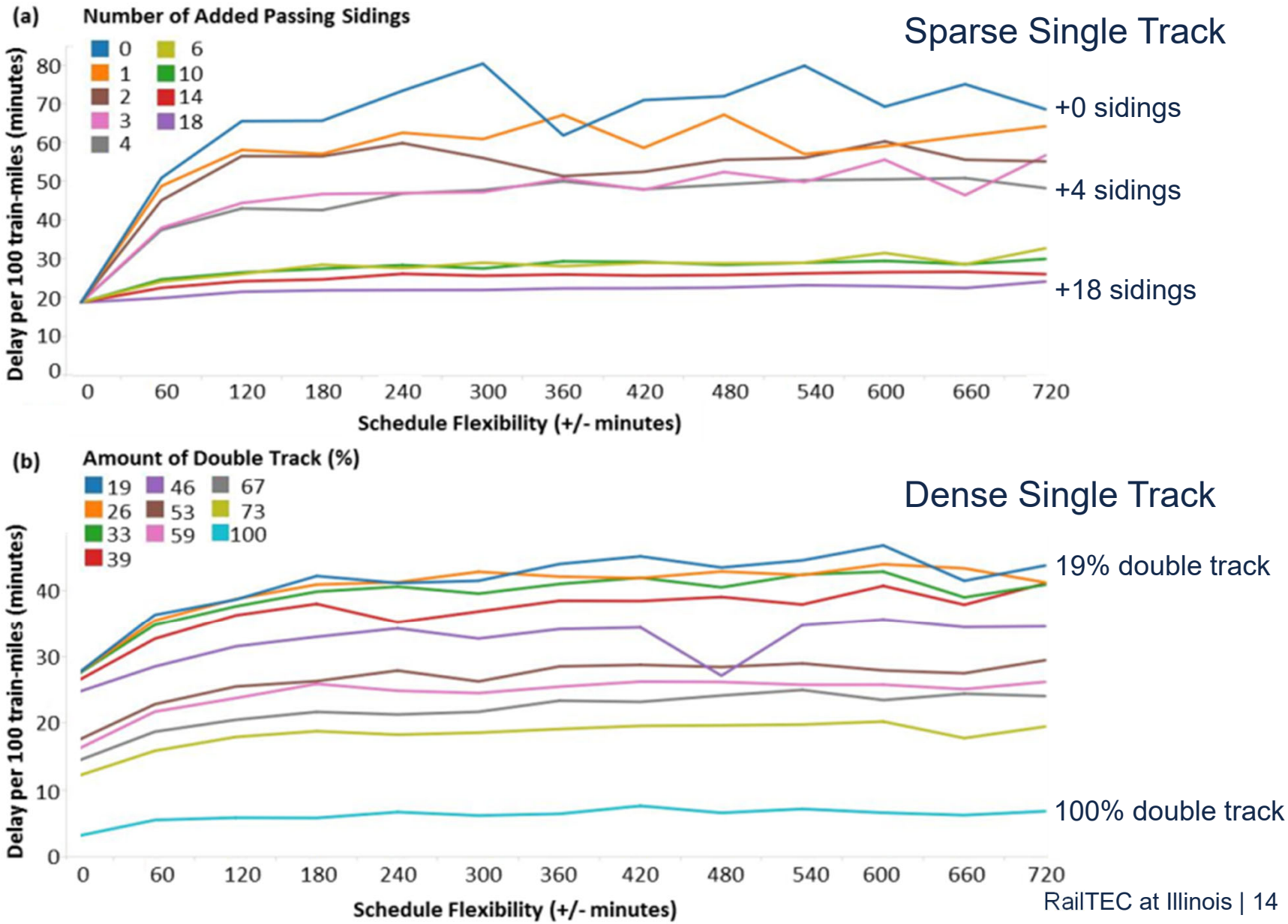
- Study two representative 240-mile single-track routes with Rail Traffic Controller (RTC) simulation software

Rail Traffic Controller™

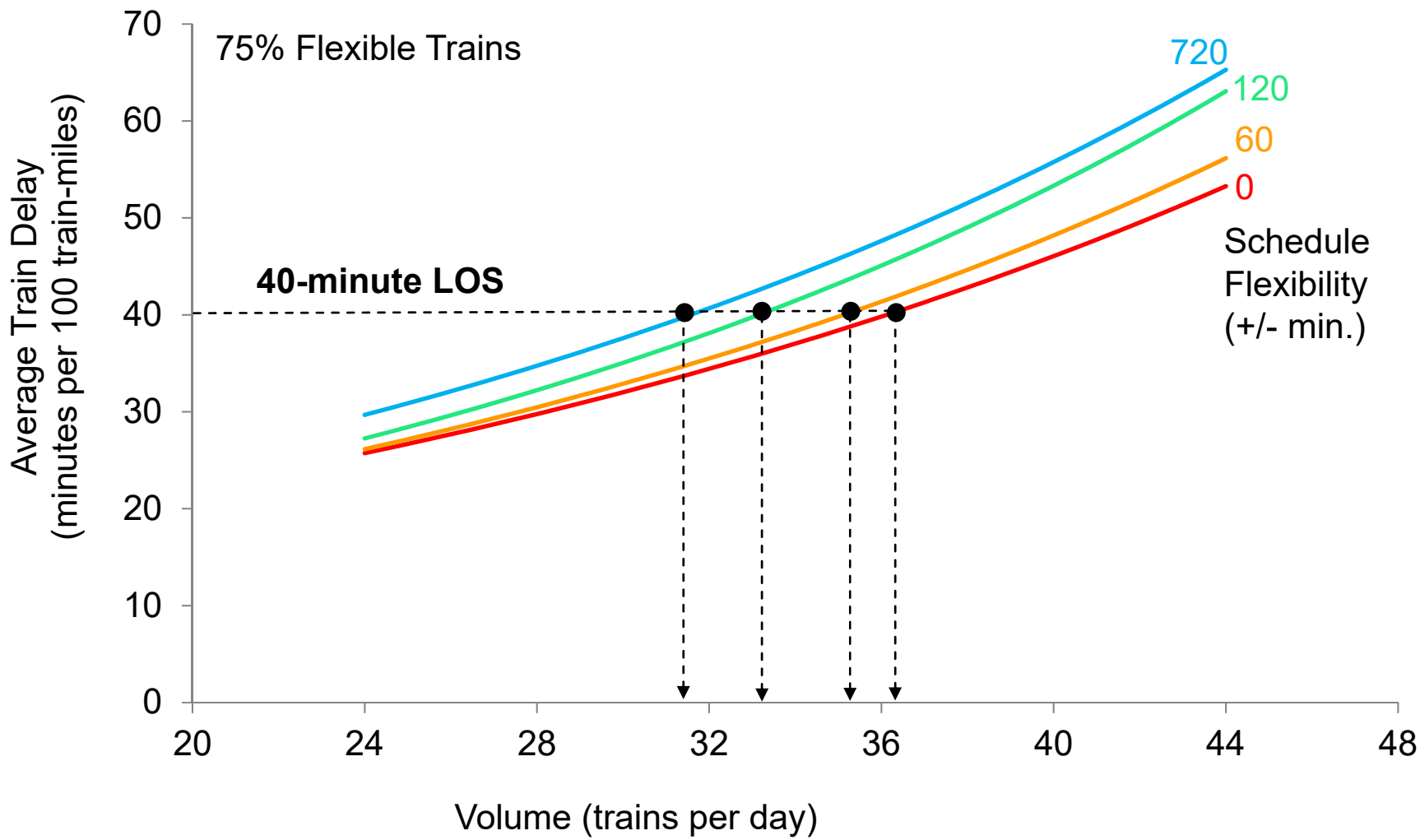
- Initial structured schedule
  - Trains depart at even intervals, meets planned at sidings
- Introduce schedule flexibility to depart trains within window
  - Increment schedule flexibility from +/-0 minutes (fixed) up to +/-720 minutes (fully flexible within each day)



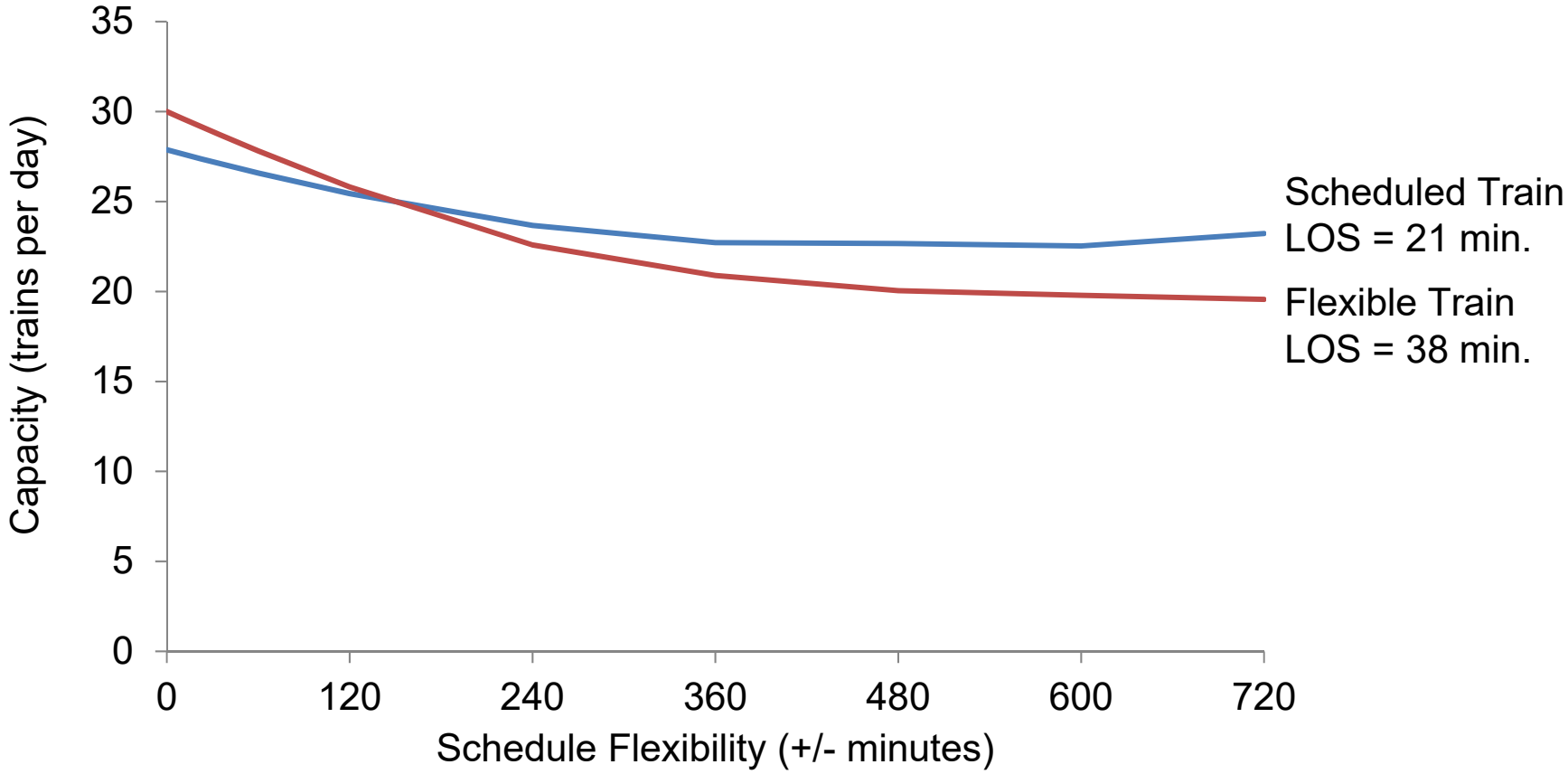
Train Delay and Schedule Flexibility



Delay-Volume Curves

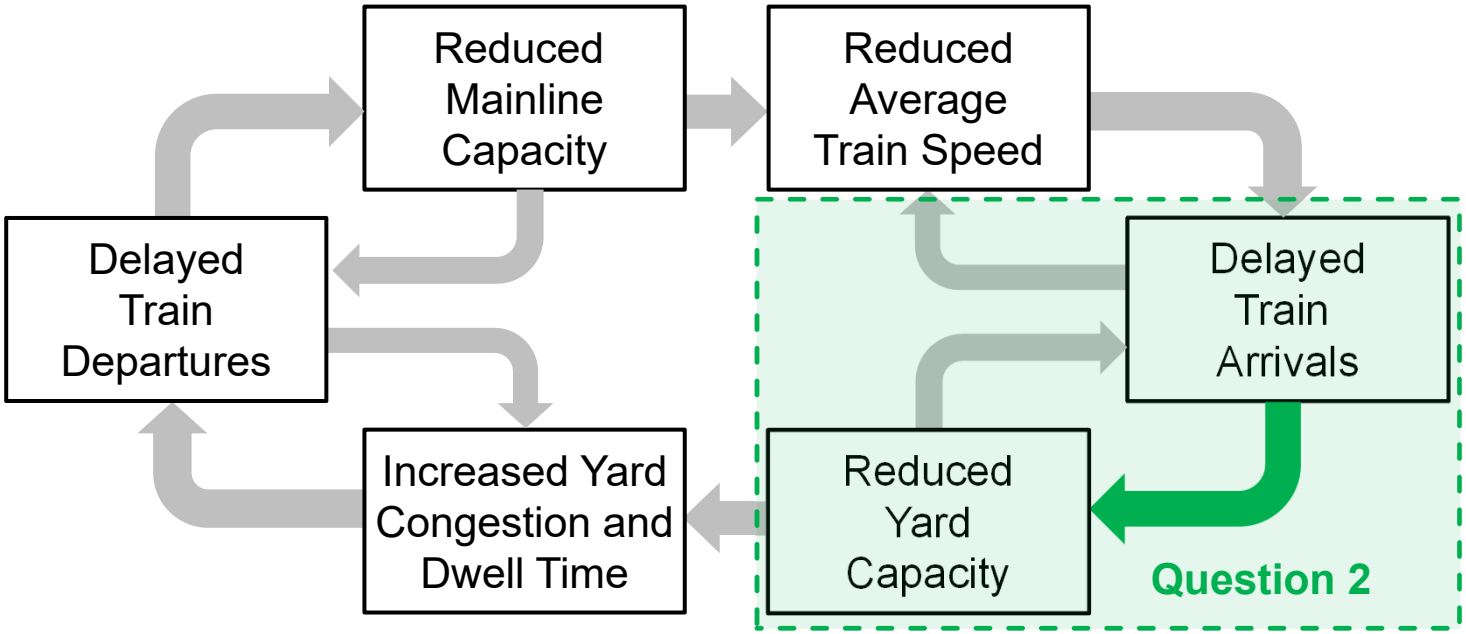


Schedule Flexibility and Capacity



- Variability in train departures decreases mainline capacity
- *What is the impact of these arrival delays on yards*?

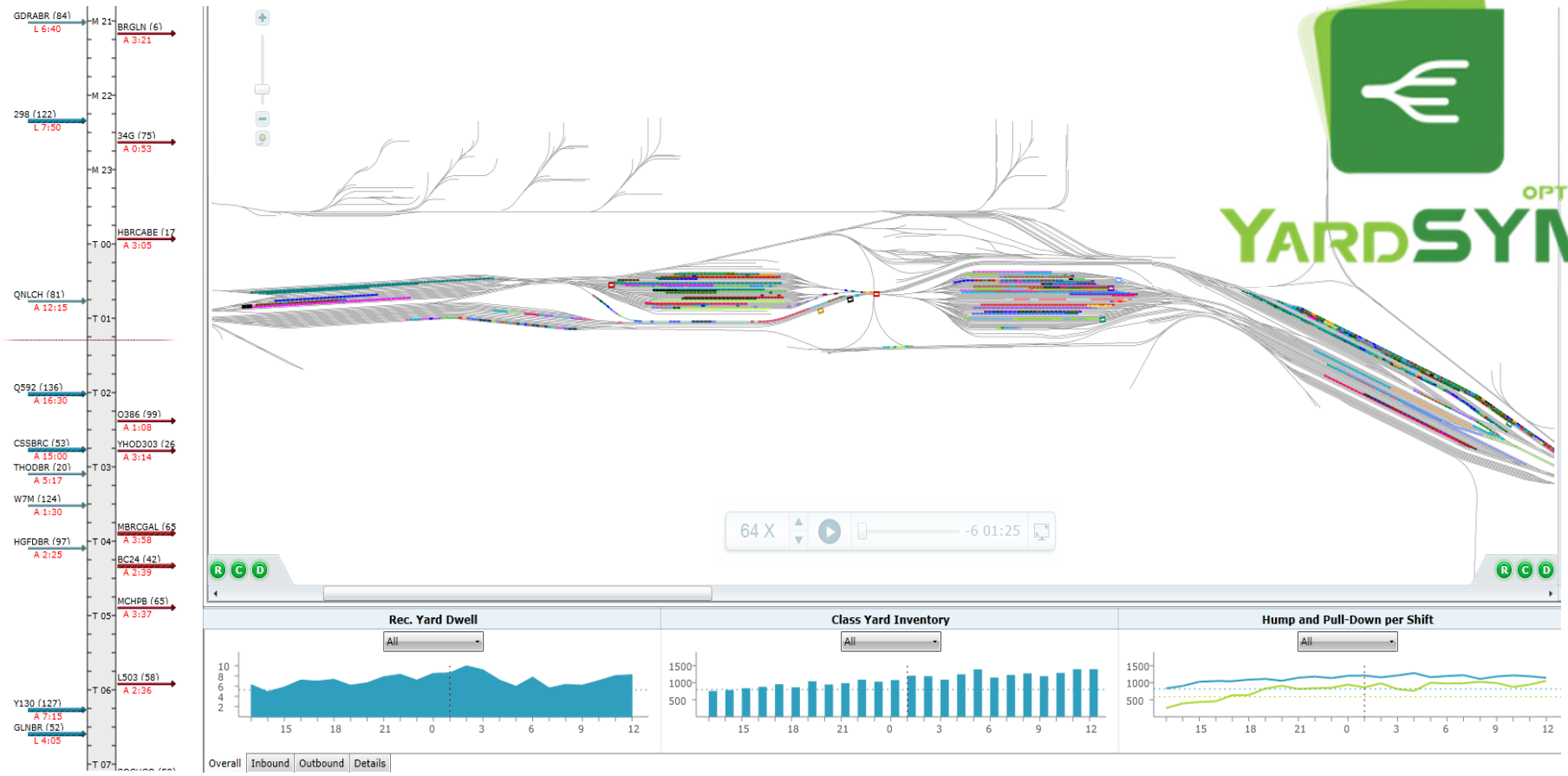
Research Question 2



- What is the relationship between inbound train arrival variation (i.e. mainline schedule flexibility) and hump classification yard performance and capacity?

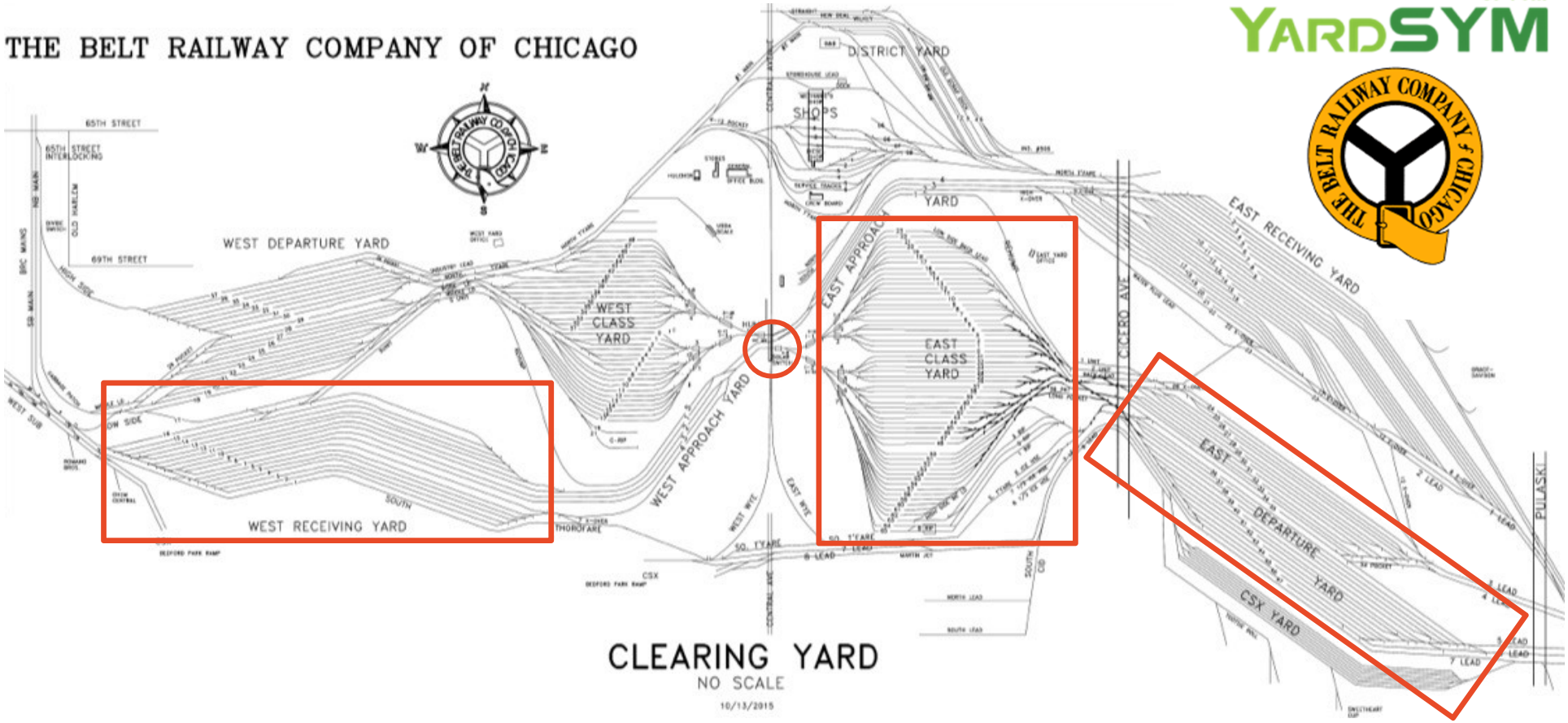
YardSYM by Optym

- Hump classification yard simulation model
  - Specify operating and traffic parameters for yard layout
  - Simulate movement of trains, switch engines and railcars
  - Resolves routing and sorting conflicts
  - Detailed output data with yard animation



Technical Approach

- Belt Railway of Chicago granted access to their YardSYM model
- Clearing Yard model has two directional inline humps
  - Focus on eastbound classification operation
  - Experiments specify varying levels of arrival variability

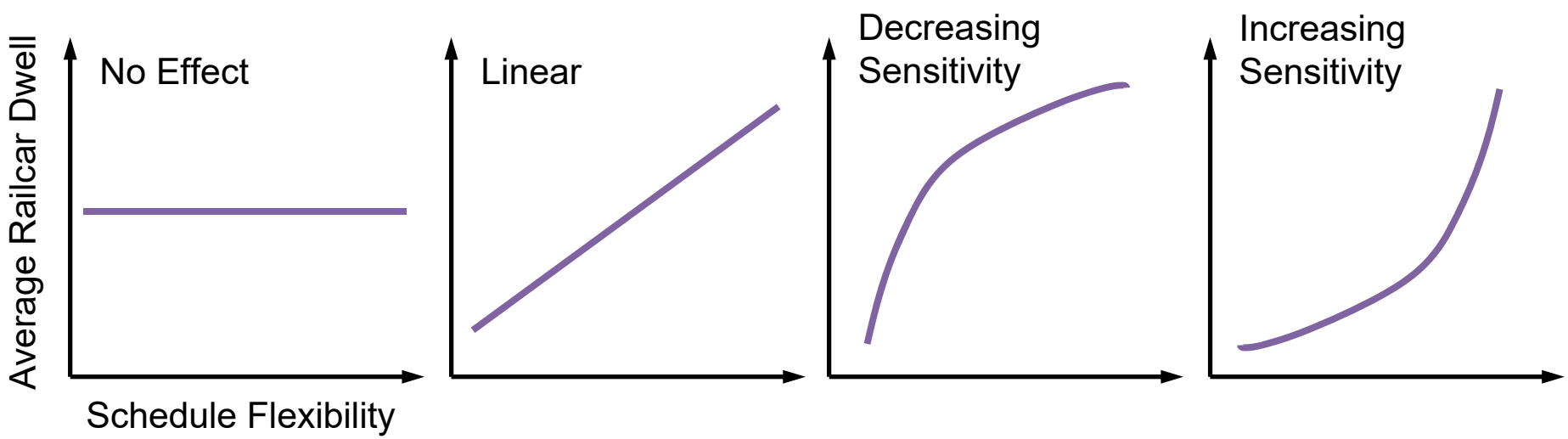


Arrival Time Experimental Design

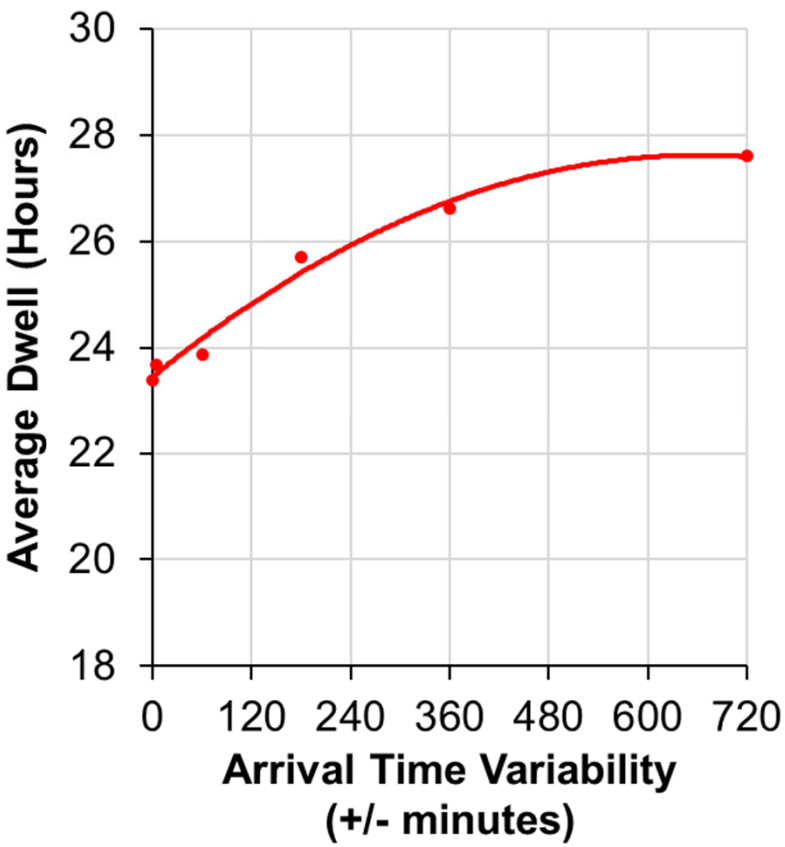
- Throughput volume of 1,440 railcars/day
  - 32 blocks, 18 inbound trains/day, 16 outbound trains/day
  - Trains evenly spaced during the day
  - Inbound trains connect equal number of railcars to every outbound block

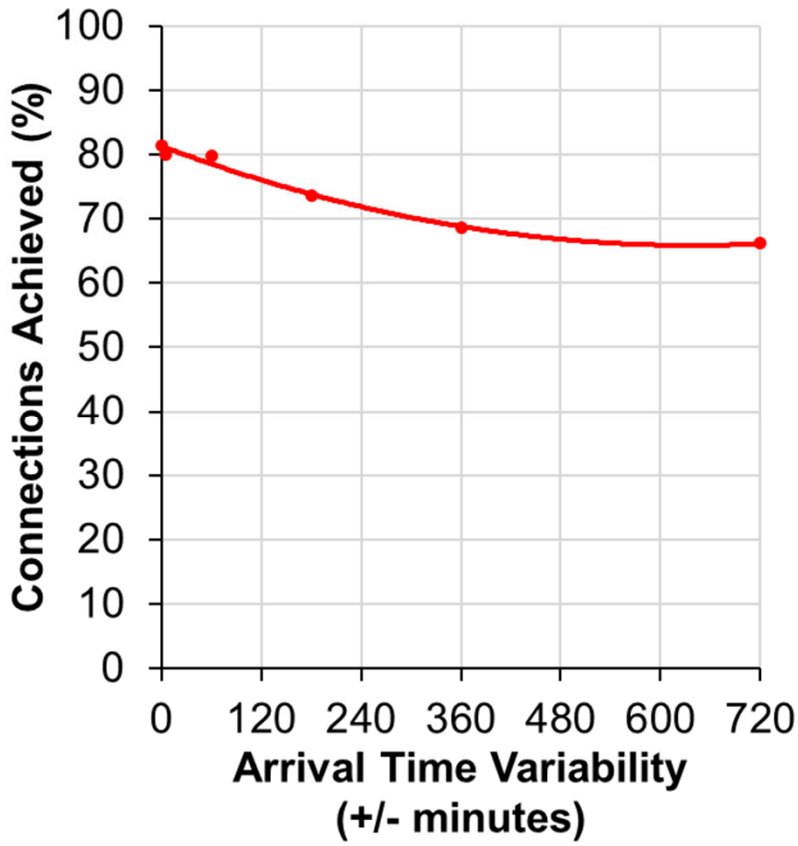
- Introduce variation in arrival times
  - Levels of train arrival time **schedule flexibility**:
    +/- 0, 5, 60, 180, 360, 720 minutes

- Hypothetical relationships between dwell and schedule flexibility:



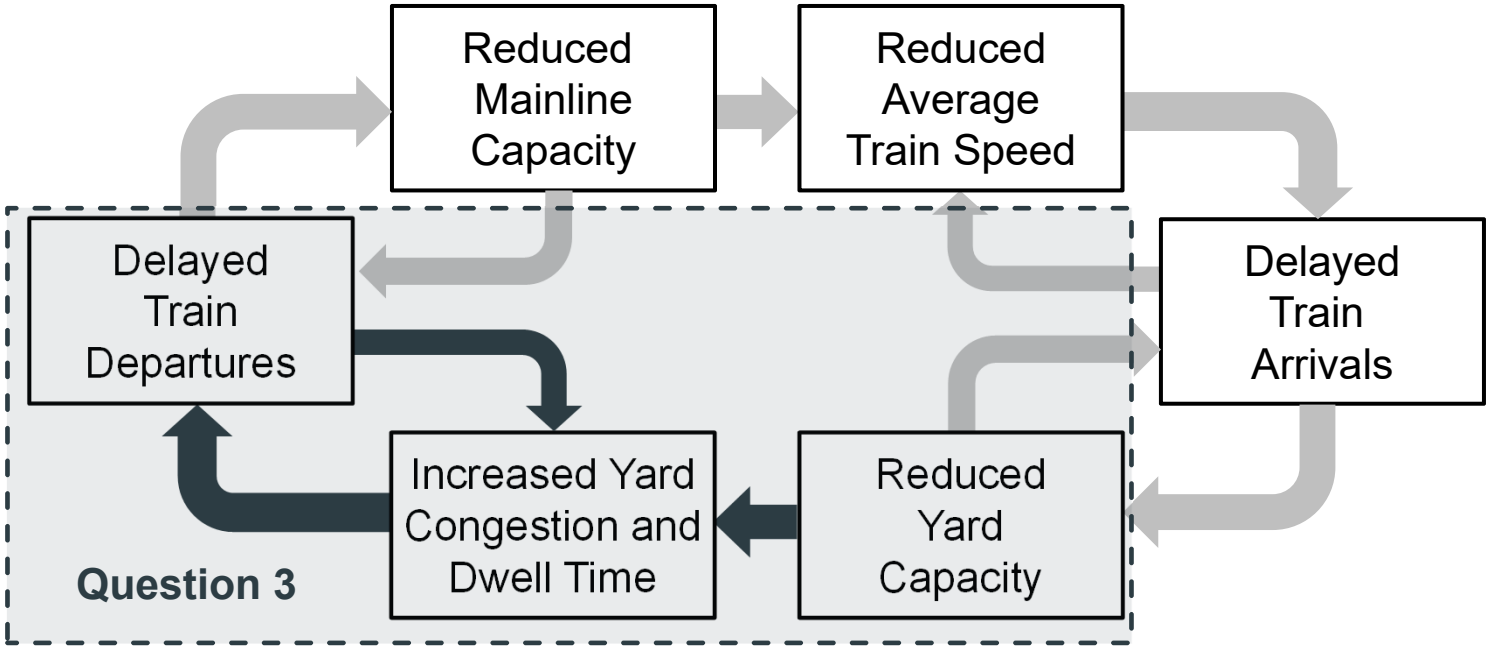
Results - Arriving Schedule Flexibility





- Dwell and RCRT both have greatest sensitivity to initial increases in arriving train schedule flexibility
- Further increases in schedule flexibility have diminishing effect

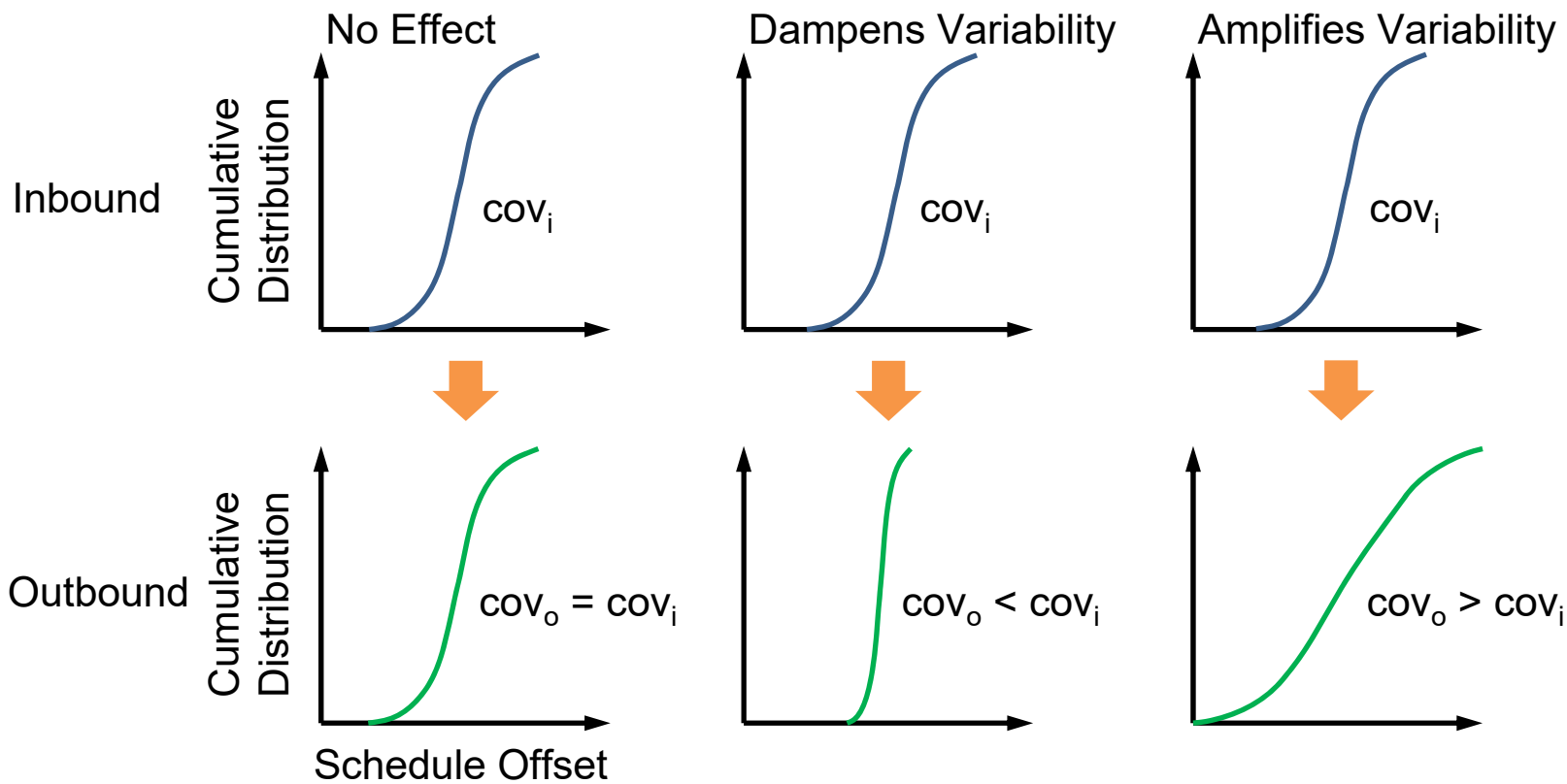
Research Question 3



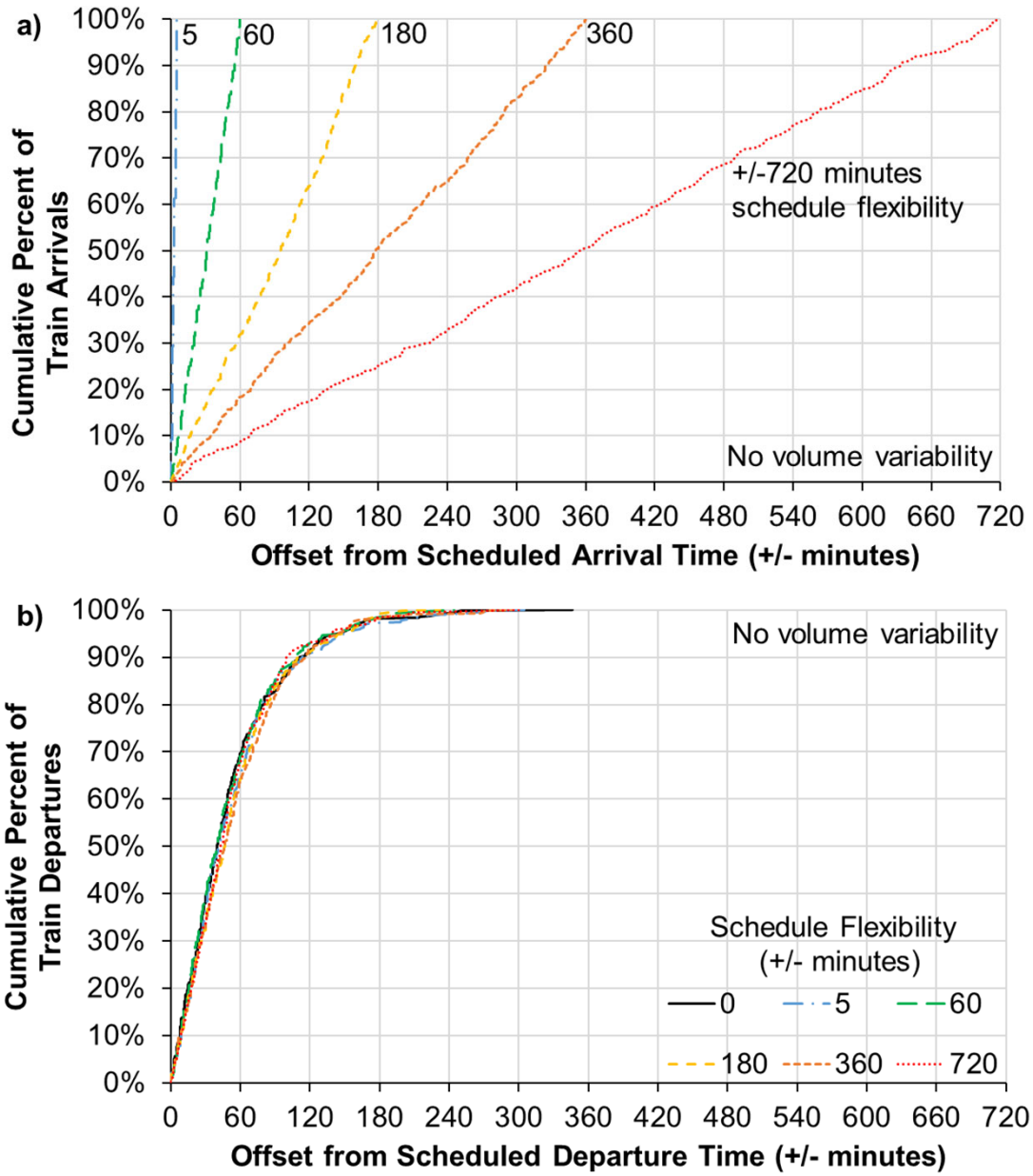
- Does a classification yard amplify or dampen schedule flexibility?
- Does a classification yard transform arriving train schedule flexibility into outbound train volume variability?

Propagation of Variability

- Does a classification yard amplify or dampen schedule flexibility?
- Compare inbound and outbound train time variability for scenarios in previous experiment
- Hypothetical relationships:



Results – Schedule Flexibility



- Departing trains exhibit 120 to 180 minutes of schedule flexibility independent of arriving train schedule flexibility
- Hump classification yards act to both amplify and dampen inbound schedule flexibility to a consistent outbound schedule flexibility

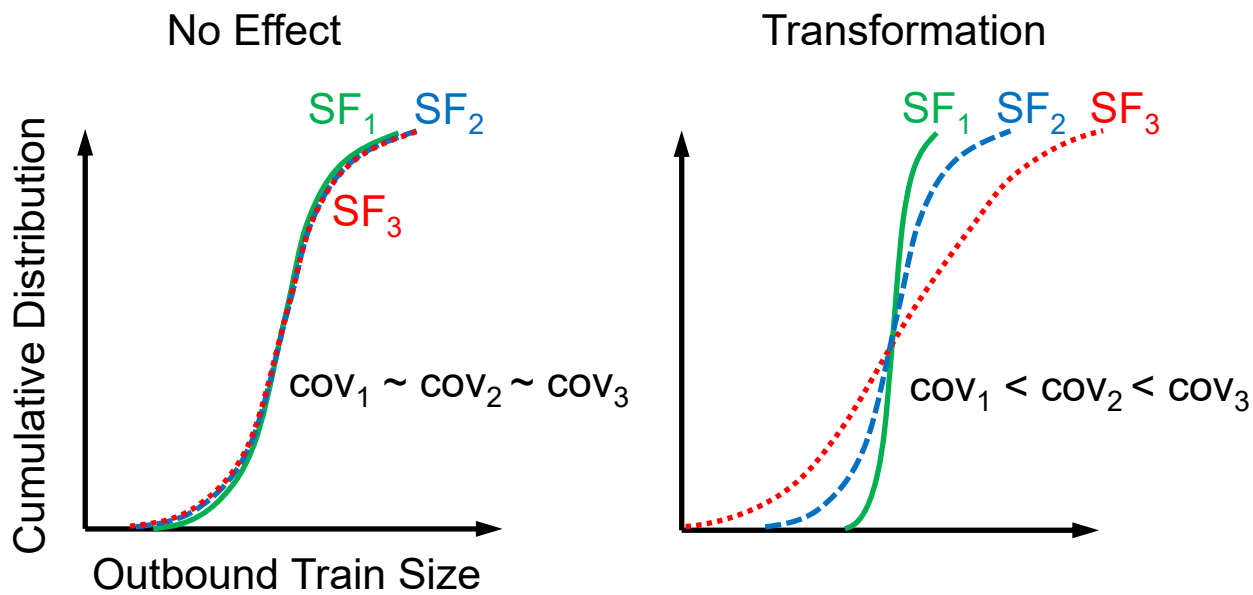
Transformation of Variability

- Does a classification yard transform schedule flexibility into outbound train volume (size) variability?
- Effect of different levels of arriving schedule flexibility on observed outbound volume variability

- Hypothetical relationships:

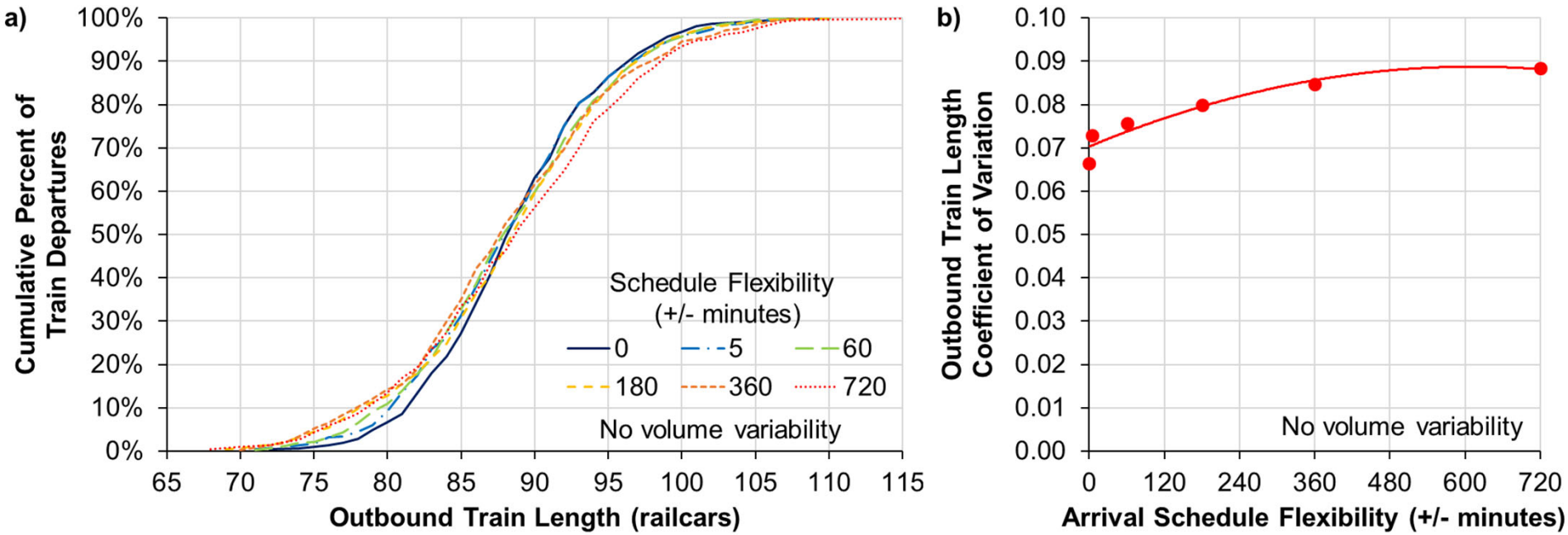
Inbound $SF_1 < SF_2 < SF_3$

Constant inbound train size (no inbound volume variability)



Results – Transformation of Variability

- Schedule Flexibility into Volume Variability

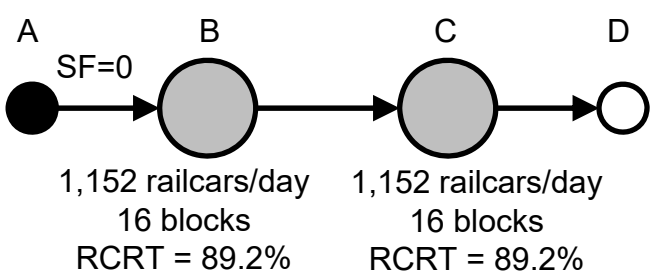


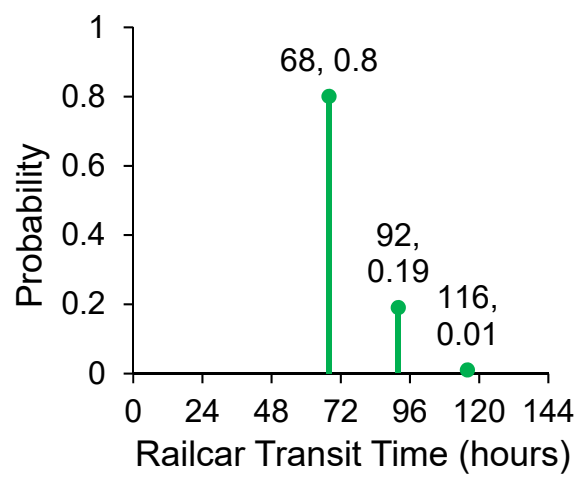
- Transform arriving train variability into increased variation in outbound train sizes
- Introduces additional source of variation for mainline operation
  - Documented mainline delay and capacity impact of over-length trains
- Additional inbound variation to other yards and terminals

Implications: Railcar Transit Time

- Combine mainline and yard results into hypothetical railcar trip plan
- Mainline delay, dwell and RCRT from previous experiments

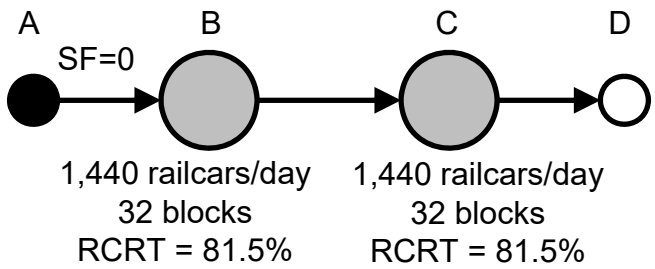
- Ideal case with no schedule flexibility and low yard traffic complexity

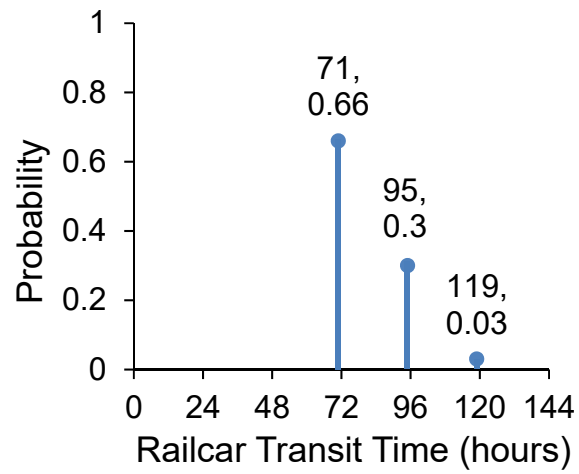




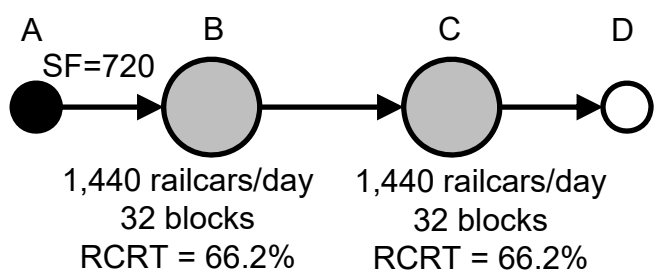
Railcar Transit Time (continued)

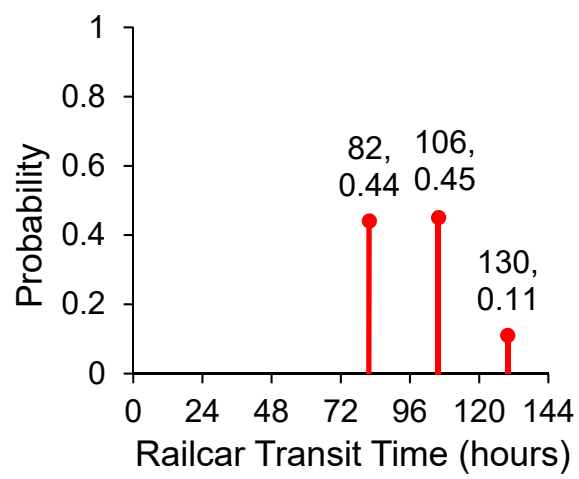
- No schedule flexibility but higher yard traffic complexity





- With schedule flexibility and higher yard traffic complexity

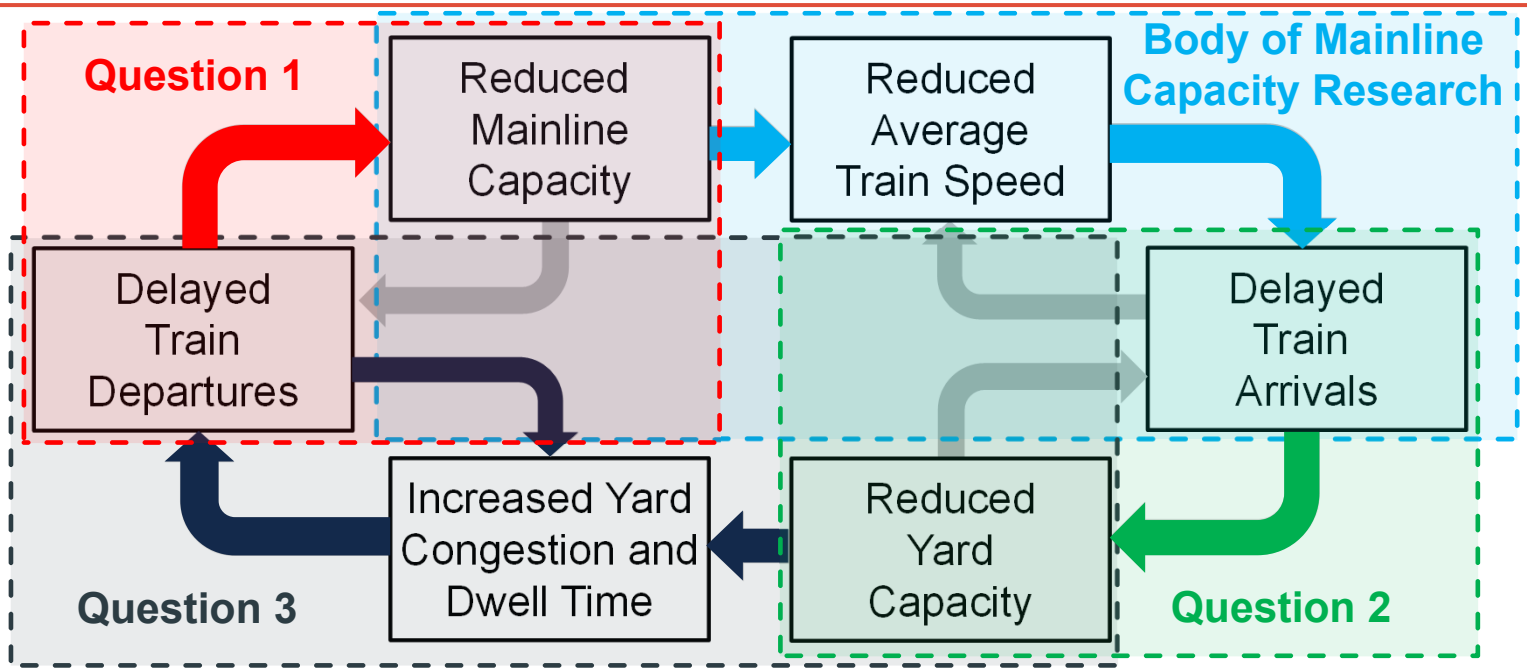




Summary of Experimental Results

- Starting from a structured operation, small amounts of schedule flexibility rapidly lead to increasing mainline train delay and decreases in mainline capacity
- Arriving train schedule flexibility is detrimental to yard performance
- Yards propagate variability
  - Amplify or dampen arrival time variability into a consistent outbound schedule flexibility of 120 to 180 minutes
  - Transform arrival time variability into outbound volume variability
- Schedule flexibility impacts both mainline and yard performance with compounding effects on railcar transit time
- Railway capacity is a network concept
  - Mainlines and yards interact to propagate congestion and poor LOS throughout the network

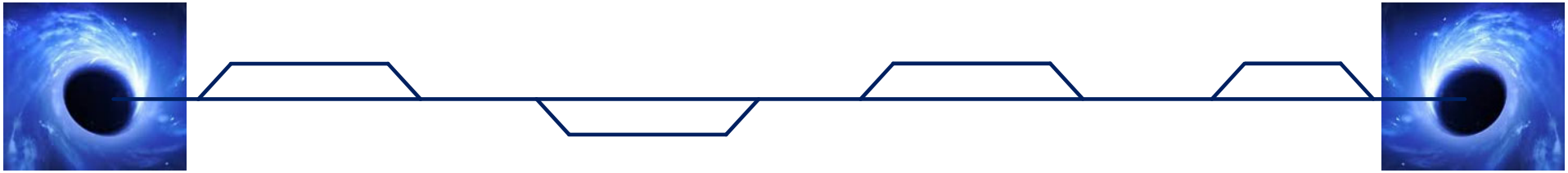
Implications for Rail Network Operations



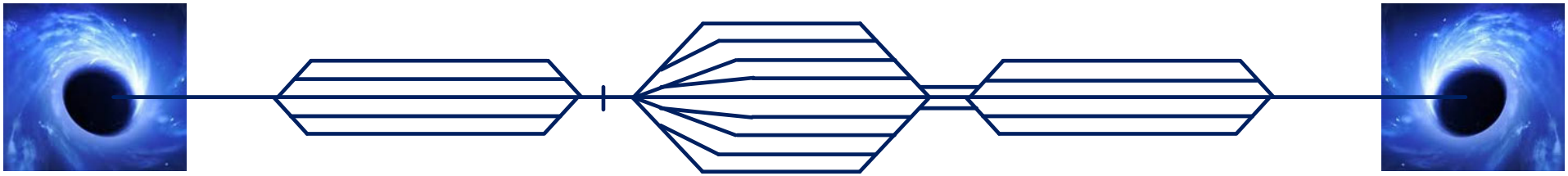
- Understanding influence of schedule flexibility on capacity and performance of classification yards and mainlines is critical to understanding how the railway network responds to service disruptions and changes to rail traffic patterns
- Schedule flexibility can help quantify yard response to mainline effects, and mainline response to yard effects in the network efficiency cycle
- Classification yards act to disrupt structured operations by amplifying schedule flexibility and volume variability

The Future: Holistic Modeling Tools

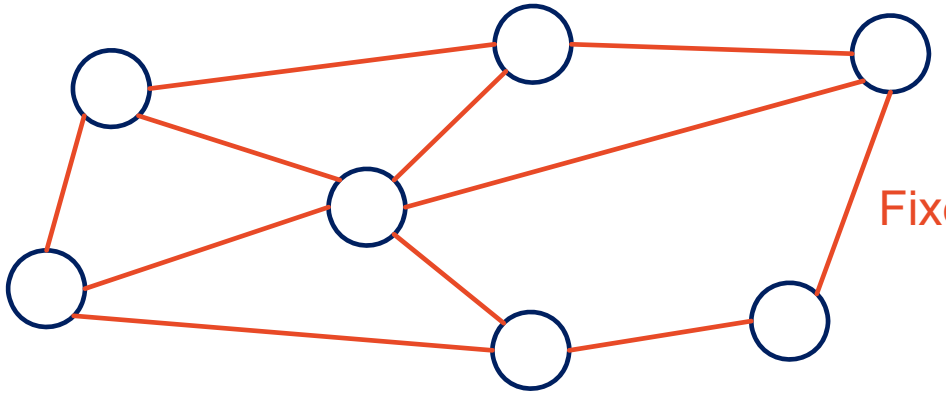
- Mainline



- Yard



- Network



Abstracted to:

Fixed Node Cost and Capacity

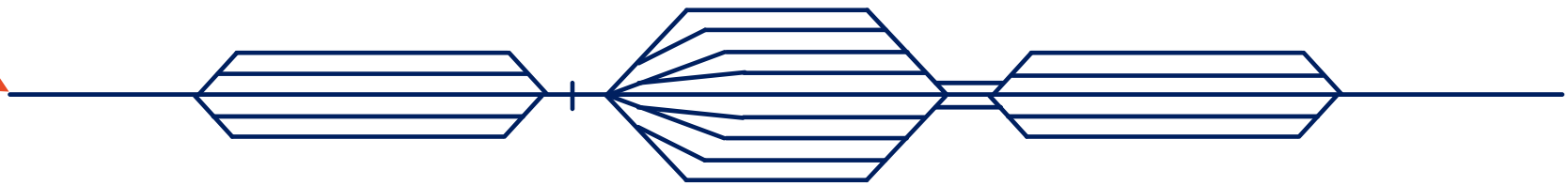
Fixed Link Cost and Capacity

Do not capture interactions!

The Future: Holistic Modeling Tools

- Mainline

- Yard



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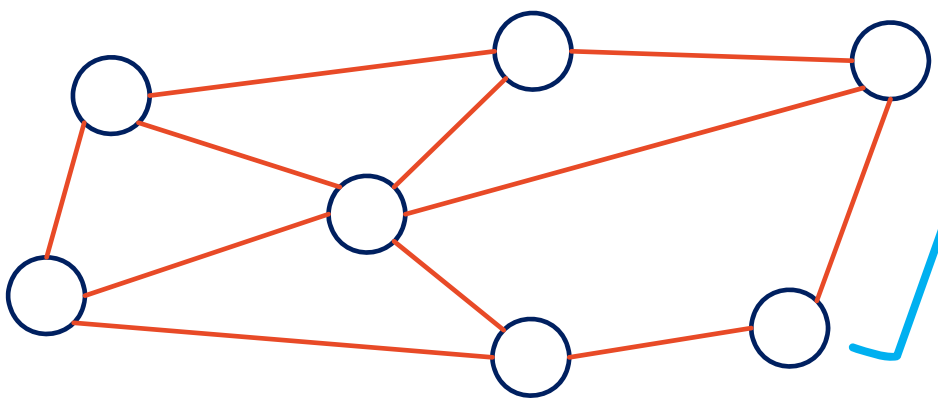

Role of Academic Research

- Always seeking opportunities for addressing specific real-world railway operational challenges and problems

- Latitude to conduct more basic research into fundamental railway capacity and performance relationships and phenomena

- Industry partnerships are essential to rail research
  - Unlike many engineering applications, difficult to capture in a “lab”
  - Can only go so far with representative networks and corridors
  - Intricacies of actual networks and operations

- Pathways for involvement
  - Posing real-world operational problems to academia
  - Considering requests for anonymized data for analysis and validation
  - Internships in network planning and operations
    - Students return with better understanding of real-world problems, constraints and application of tools
    - Typically leads to better research questions and results

Thank you for your attention!

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