Influence of Mainline Schedule Flexibility and Volume Variability on Railway Classification Yard Performance

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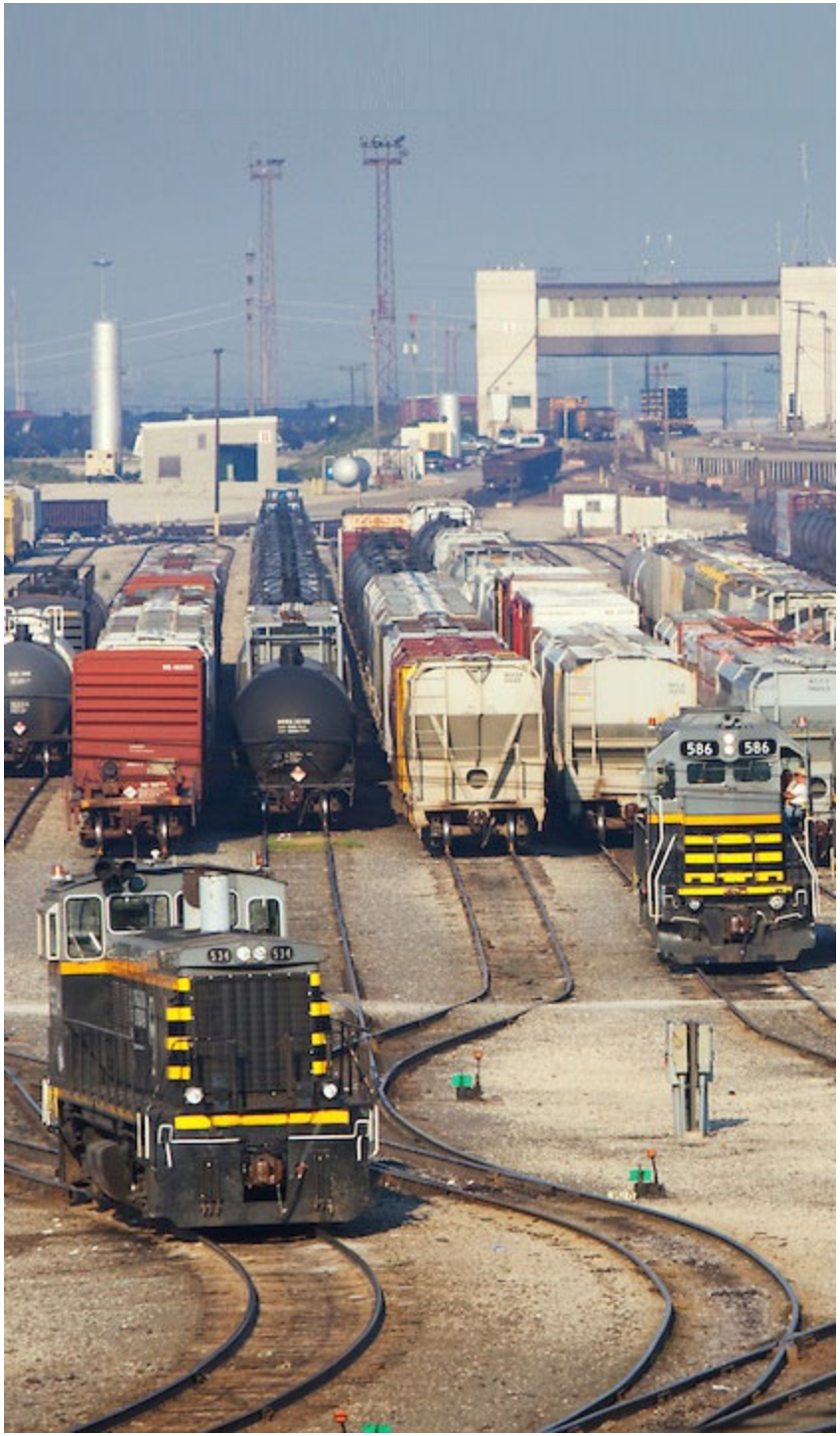
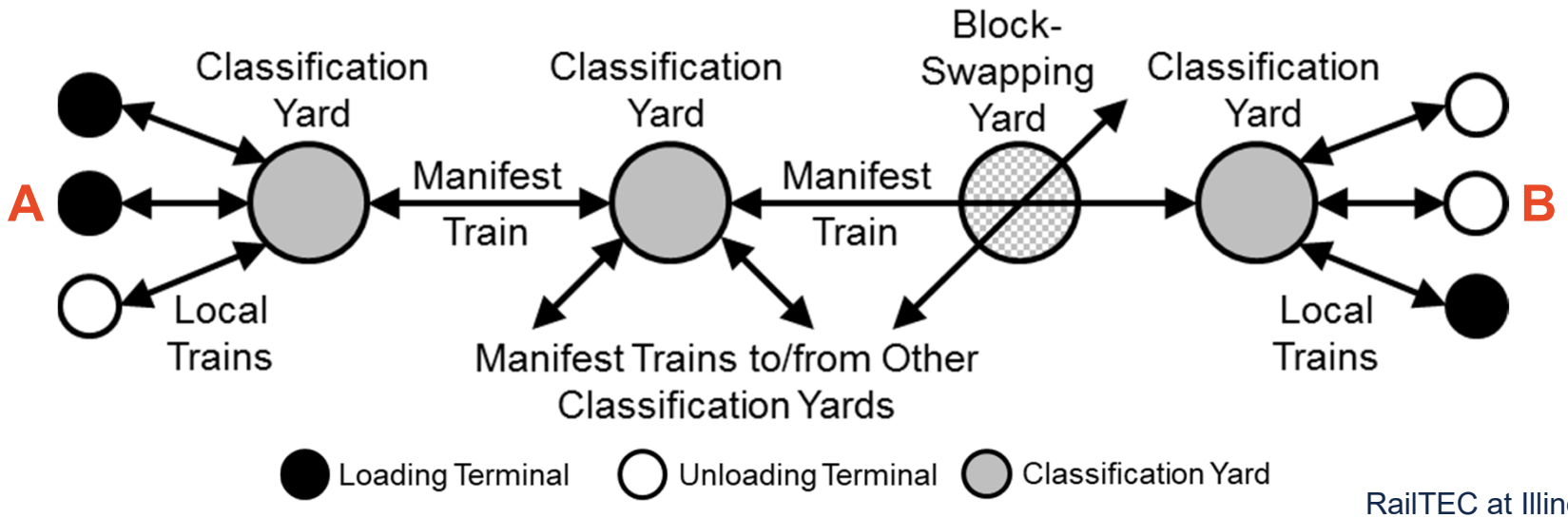


Freight Rail Transportation Network

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

- Strong financial incentive to match network capacity to demand
  - 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 ← *Yards & Terminals* → 5,000 trains per day



Challenge of Train Planning

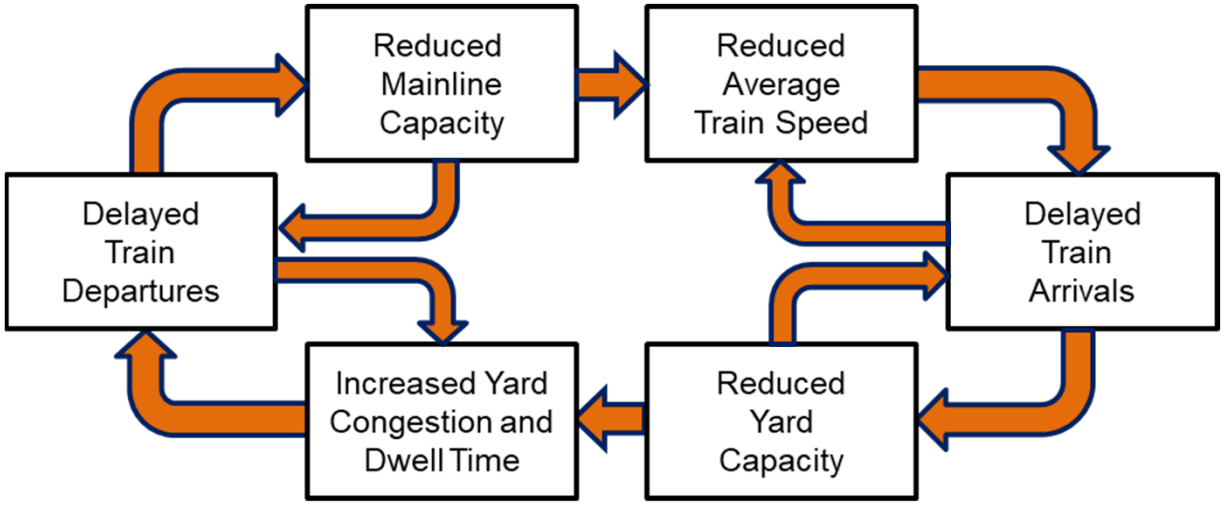
- Manifest train plans must satisfy contradictory design criteria:

Line-Haul Perspective	Classification Yard Perspective
Fewer trains reduce costs	More frequent trains reduce dwell
More small blocks increase routing options	Gain economies with fewer, larger blocks
Multi-block trains reduce line-haul costs	Single-block trains reduce yard handling costs
Bunch trains at yards for short connections	Evenly distribute traffic to better utilize yard resources and avoid queues
Vary train length to match demand cycles	Consistent train and block sizes to match yard layout

- What are the implication of these diverging train timing and size objectives on rail network performance and capacity?

Mainline and Yard Interactions

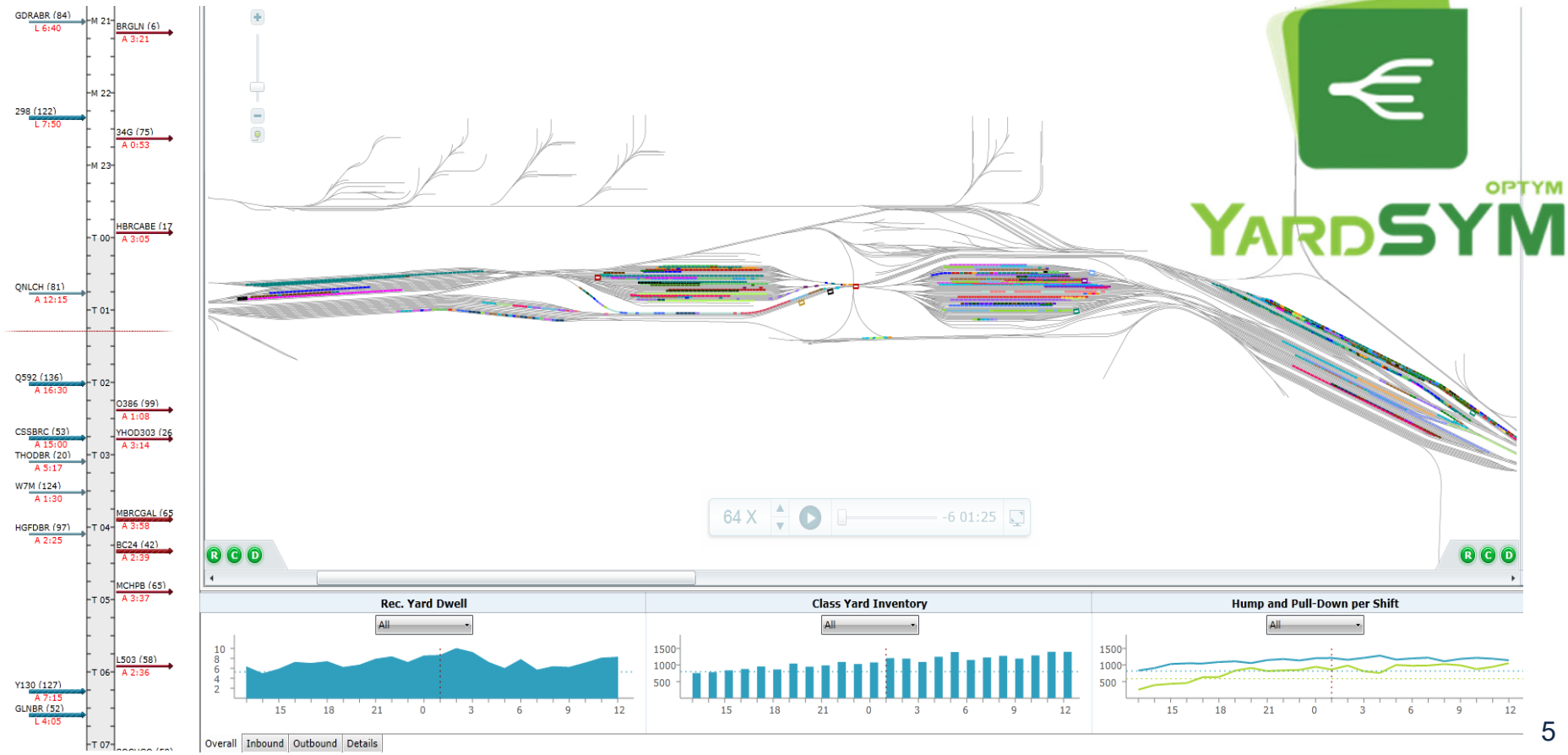
- Mainline, yard and terminal performance all contribute to the quality of railway service through the “network efficiency cycle”



- Few academic studies of how mainlines and yards interact
- Research questions:
  - How does inbound traffic volume variation and schedule flexibility influence hump classification yard performance and capacity?
  - Does a classification yard amplify, dampen or transform schedule flexibility and volume variability?

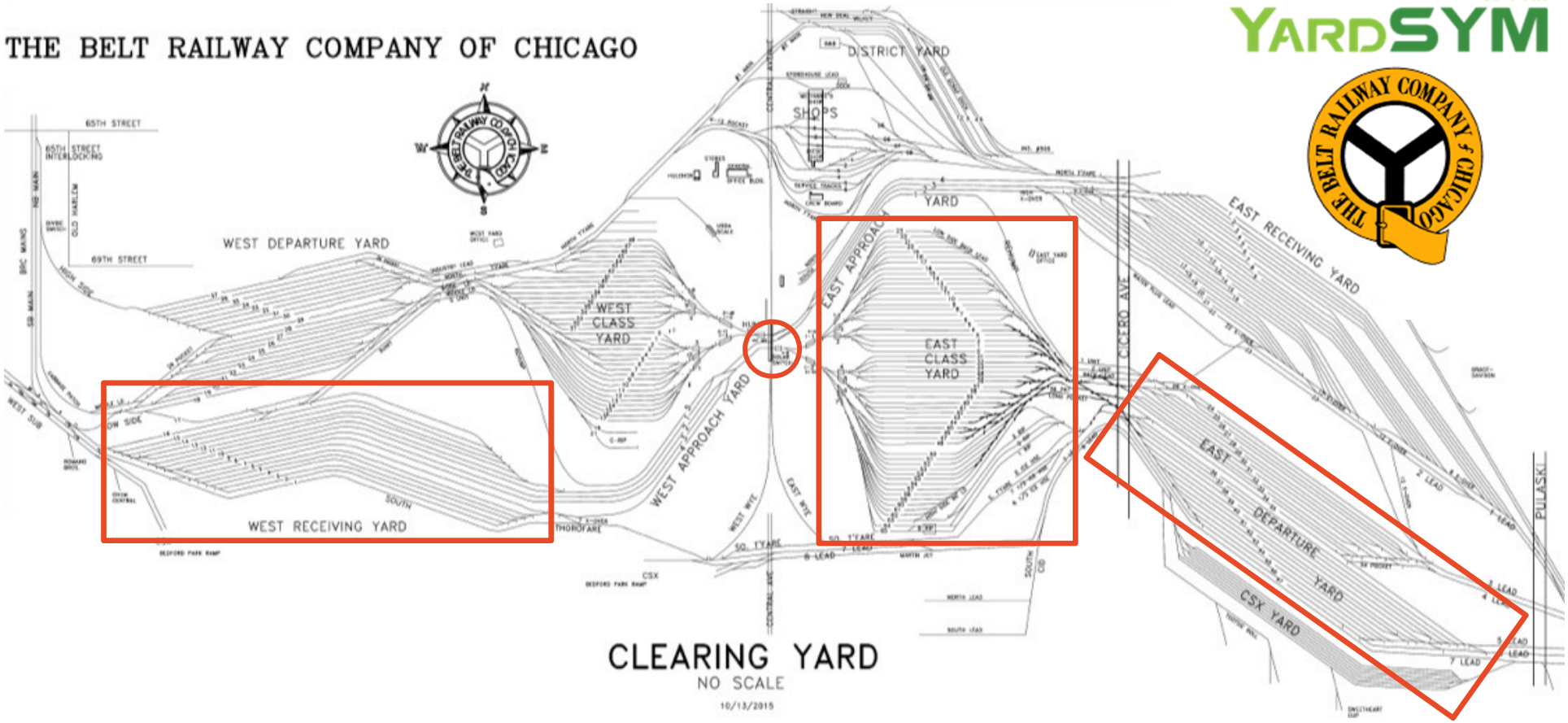
YardSYM by Optym

- 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 traffic complexity



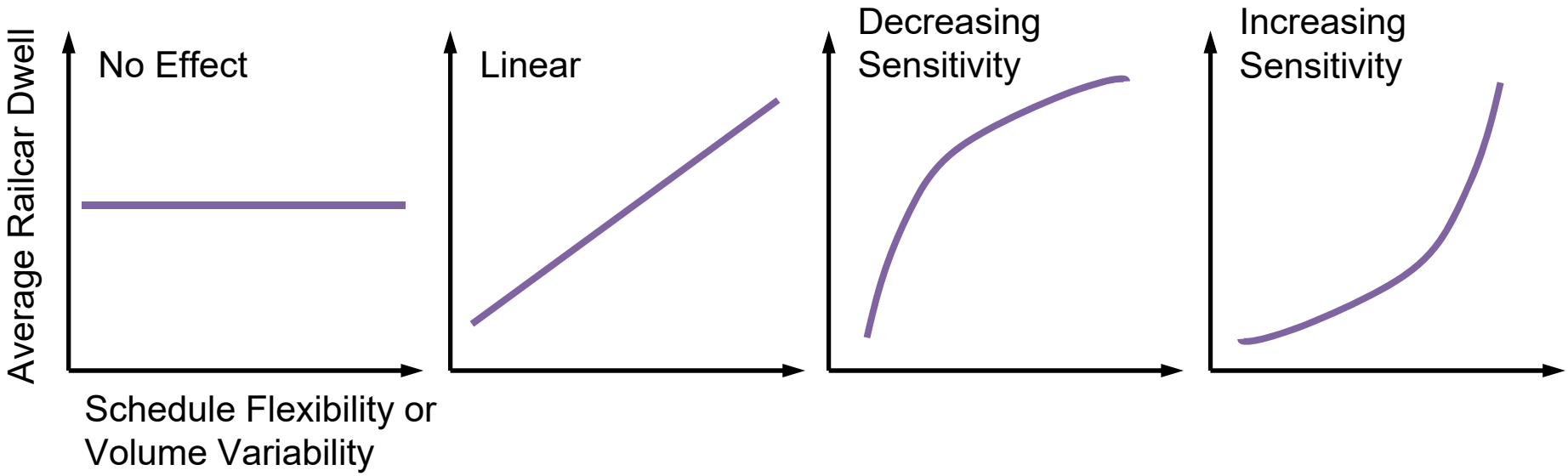
Experimental Design

- 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 and inbound railcar volumes
  - Levels of daily block arrival **volume variability**:
    +/- 0, 83, 100% railcars/outbound block/inbound train/day
  - Levels of train arrival time **schedule flexibility**:
    +/- 0, 5, 60, 180, 360, 720 minutes
- Simulate factors independently and in combination
  - YardSYM randomizes each factor within ranges specified for a particular simulation scenario

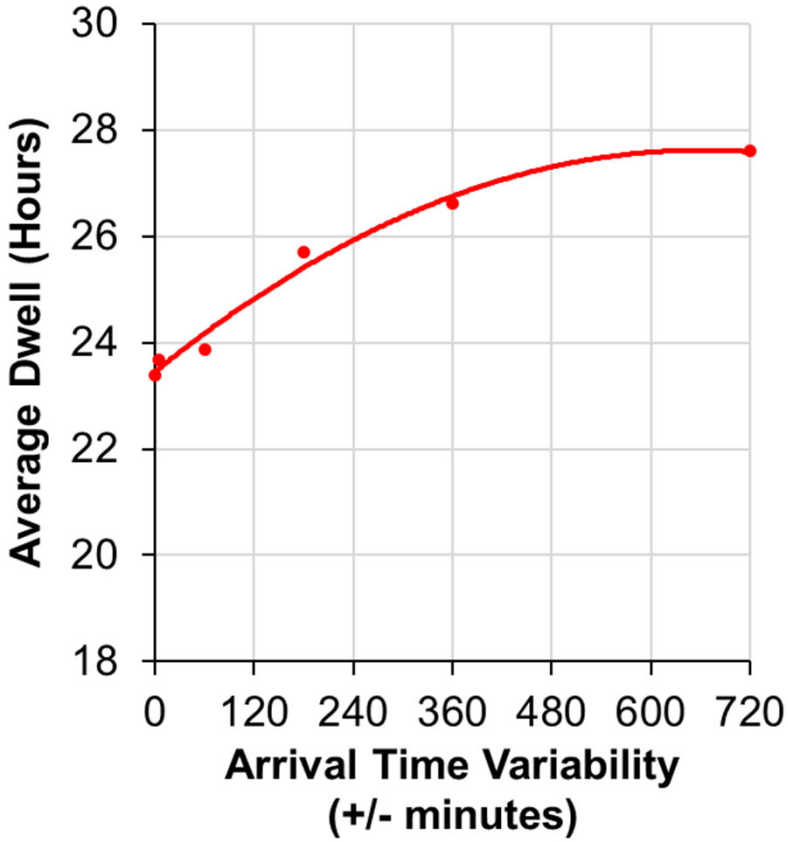
Arrival Time and Volume Variability

- Examine average railcar dwell output from simulation scenarios
  - one factor held constant
  - other factor varies by scenario from low to high levels of variation

- Hypothetical relationships between dwell and either factor:



Results - Arriving Schedule Flexibility

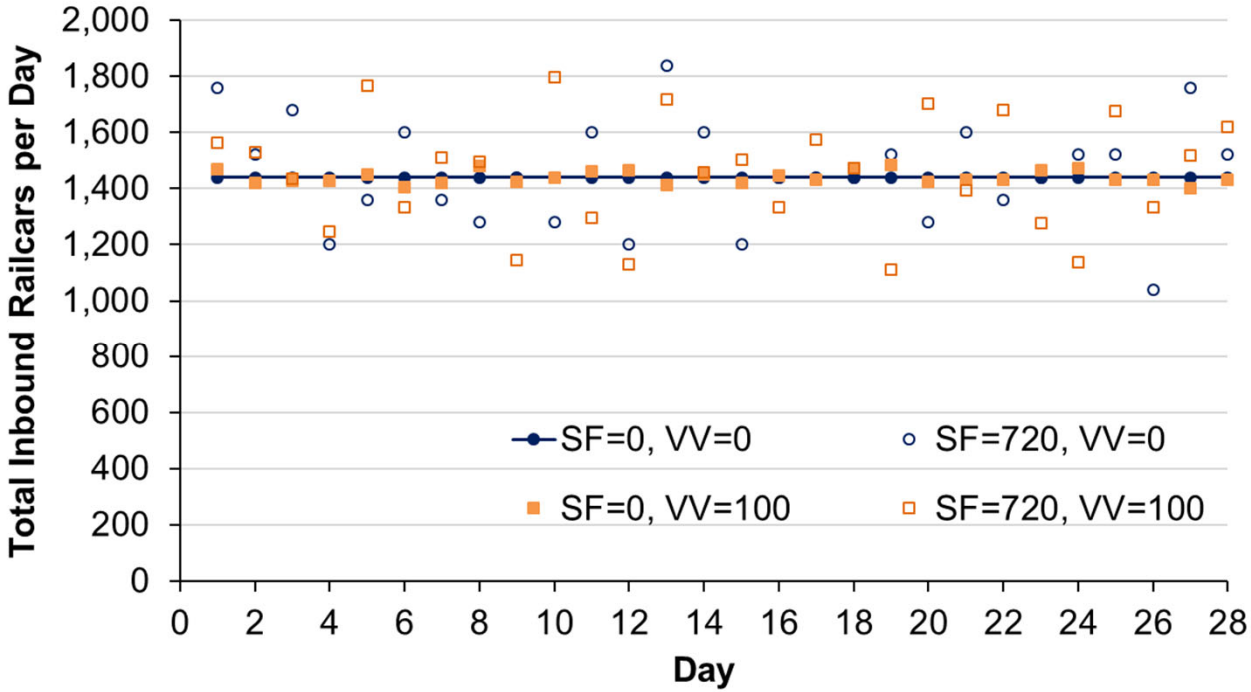


- Railcar dwell has greatest sensitivity to initial increases in arriving train schedule flexibility
- Further increases in schedule flexibility have diminishing effect

Results – Inbound Volume Variability

		Arrival Time Variability (+/- minutes) 0		720	
		Dwell (hours)	Connections Achieved (%)	Dwell (hours)	Connections Achieved (%)
Volume Variability (%)	0	23.39	81.47	27.60	66.17
	100	23.55	80.23	26.33	70.90

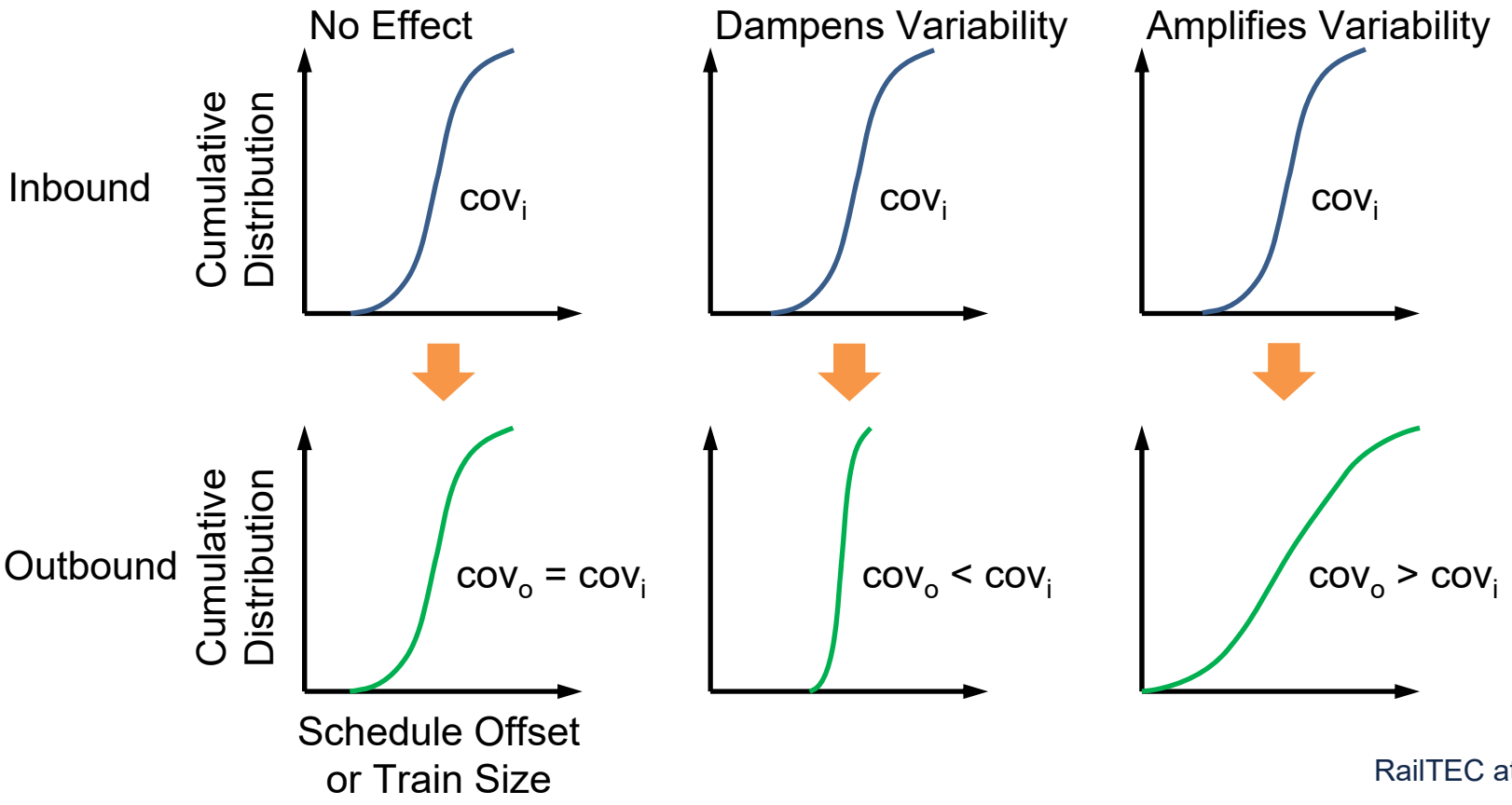
- Increasing volume variability is barely significant at p=0.05 and has less effect compared to arrival time variability



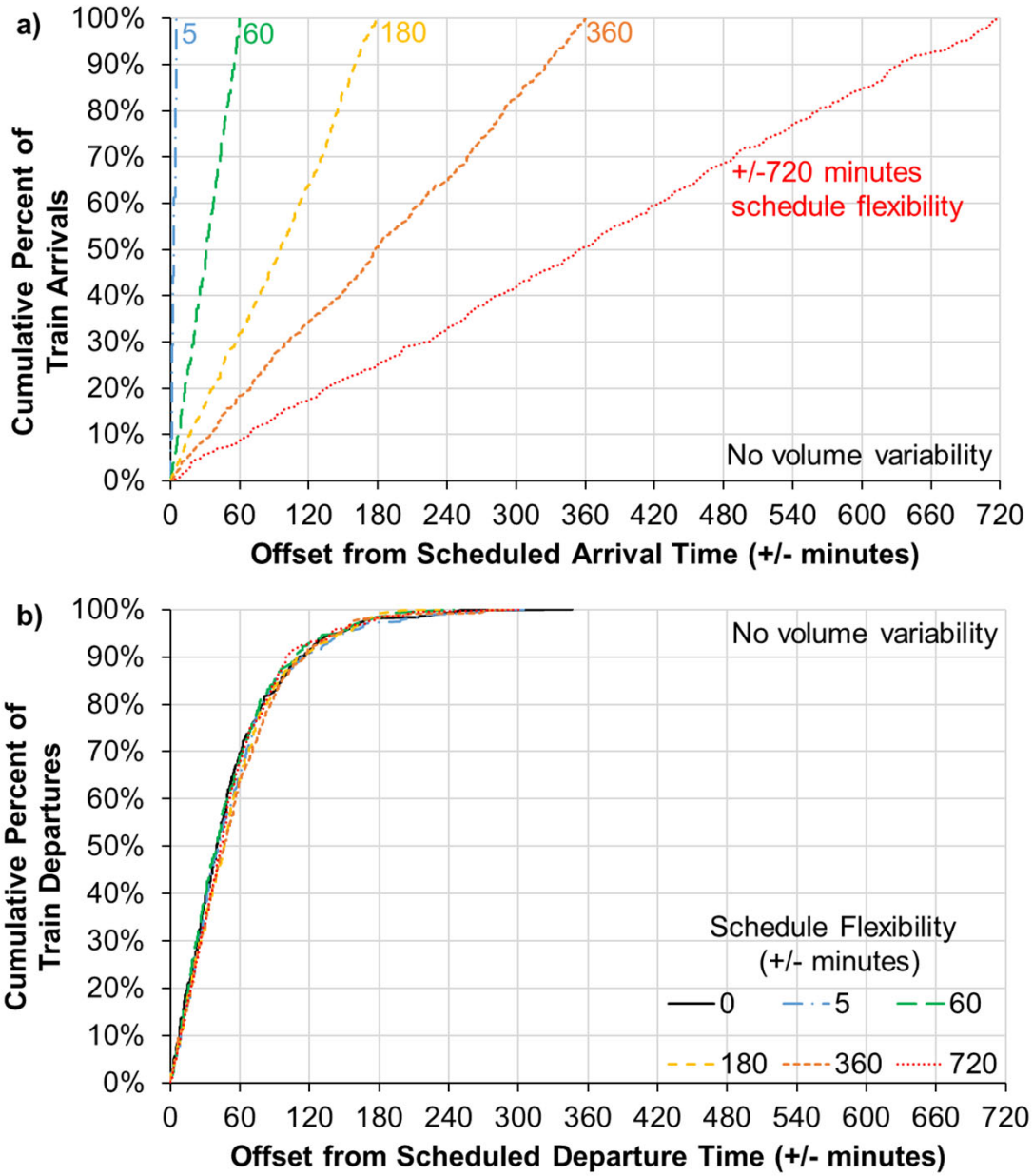
- Varying block arrival volumes has less effect on daily railcar throughput volume than schedule flexibility

Propagation of Variability

- Does a classification yard amplify or dampen schedule flexibility and volume variability?
- Compare inbound and outbound variability for one factor while the other is held constant
- Hypothetical relationships:

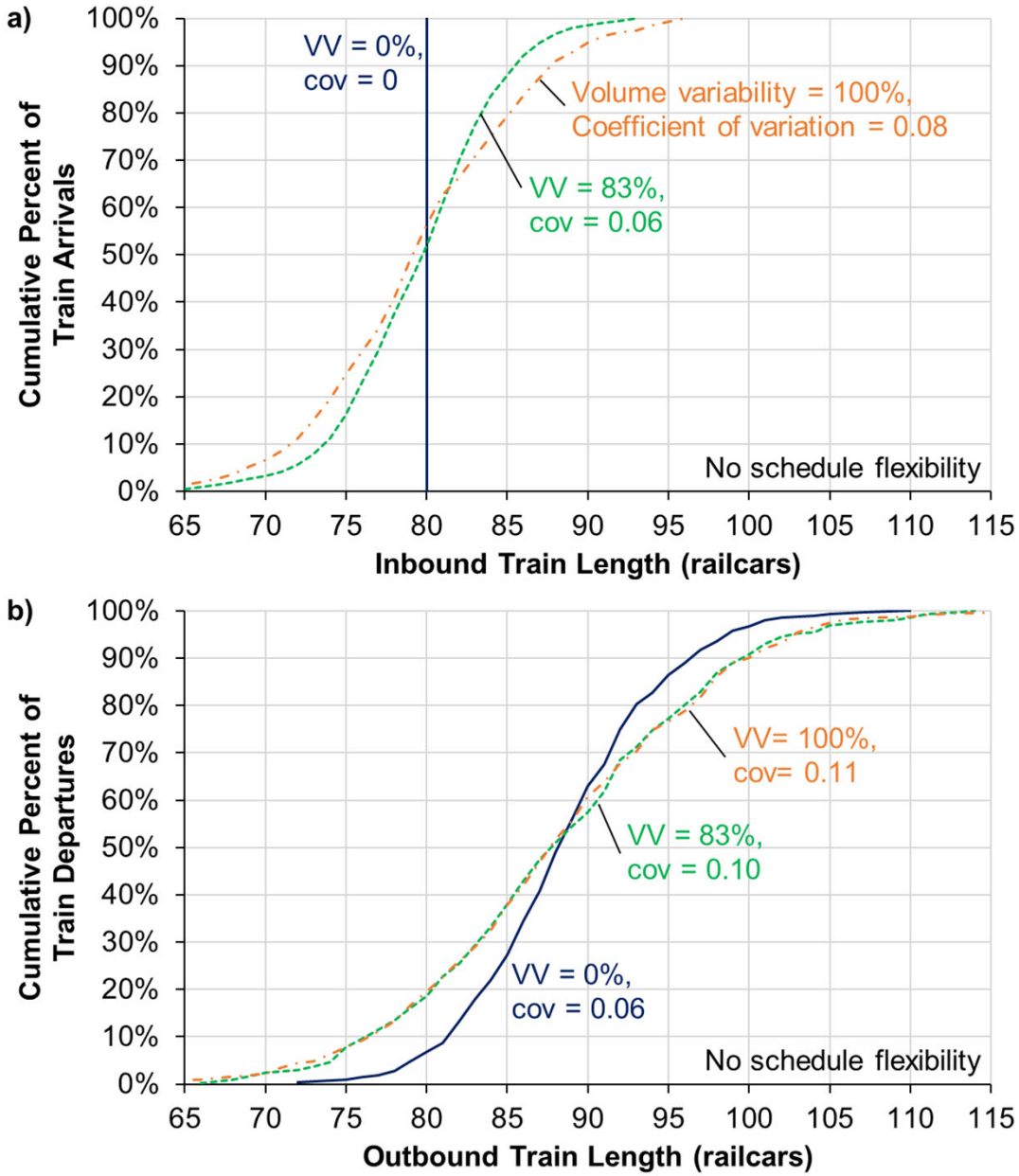


Results – Schedule Flexibility



- 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

Results – Volume Variability



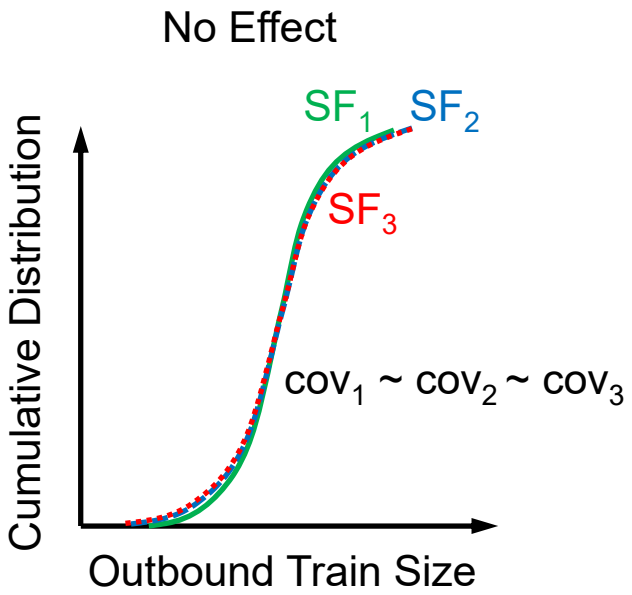
- Departing trains exhibit greater volume variability than arriving trains
  - $cov_o > cov_i$
- Hump classification yards amplify volume variability
- Increasingly hard to maintain minimum and maximum trains sizes as trains move through the network and connect at multiple yards

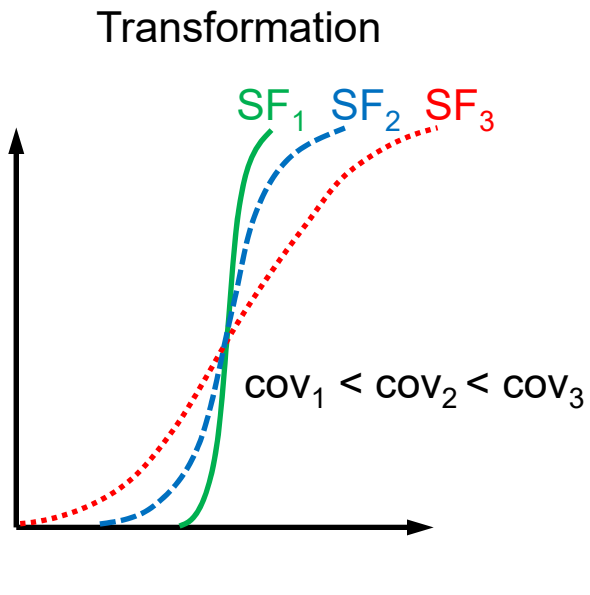
Transformation of Variability

- Does a classification yard transform schedule flexibility into volume variability and vice-versa?
- Effect of different levels of arriving schedule flexibility on observed outbound volume variability
  (while holding inbound volume variability constant)
  - Also opposite effect of volume variability on outbound schedule flexibility
- Hypothetical relationships:

Inbound $SF_1 < SF_2 < SF_3$

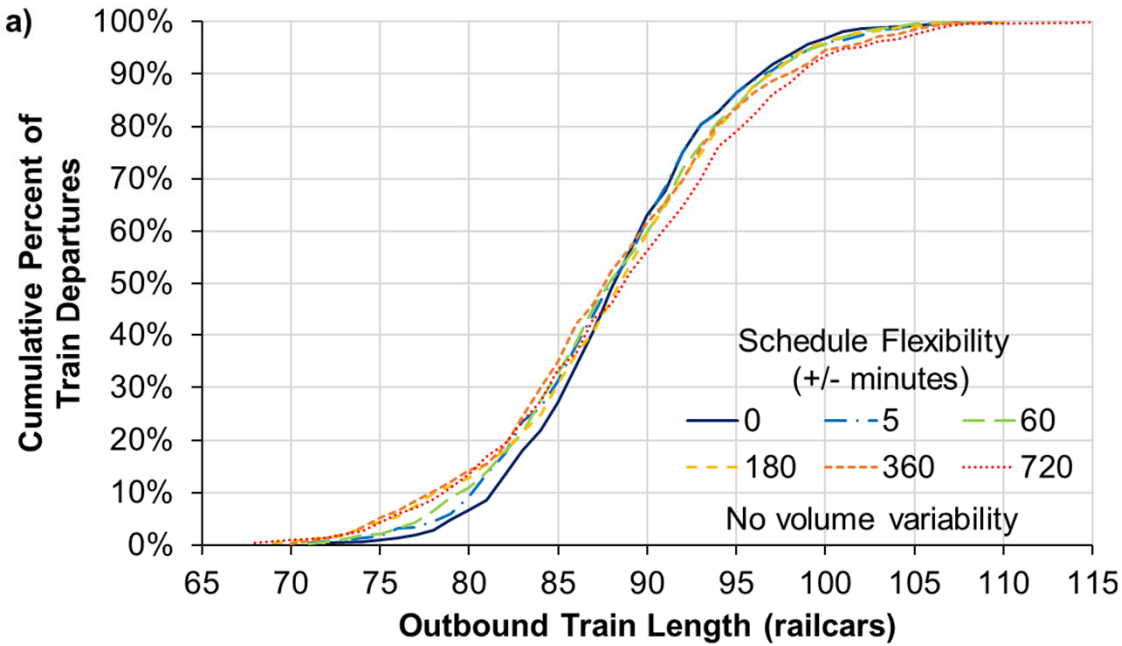
Constant inbound train size (no volume variability)

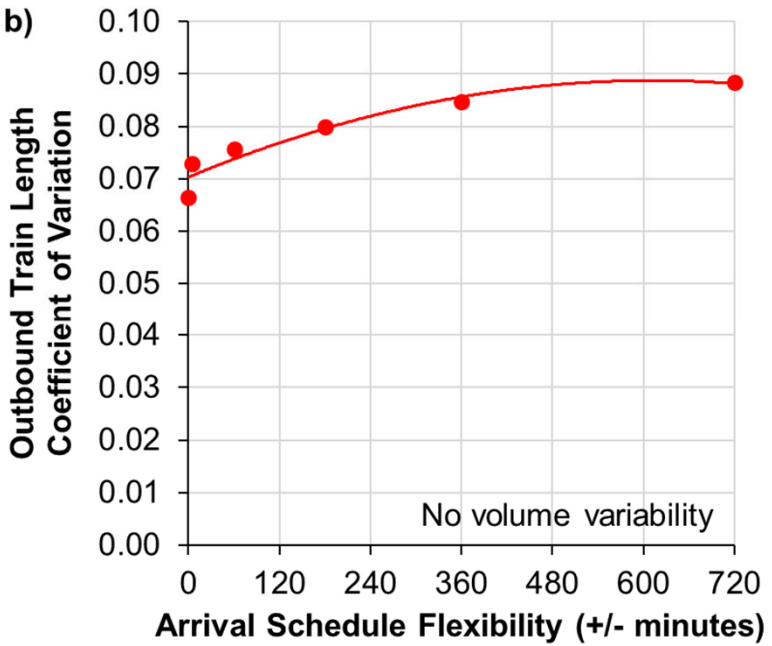




Results – Transformation of Variability

- Schedule Flexibility into Volume Variability

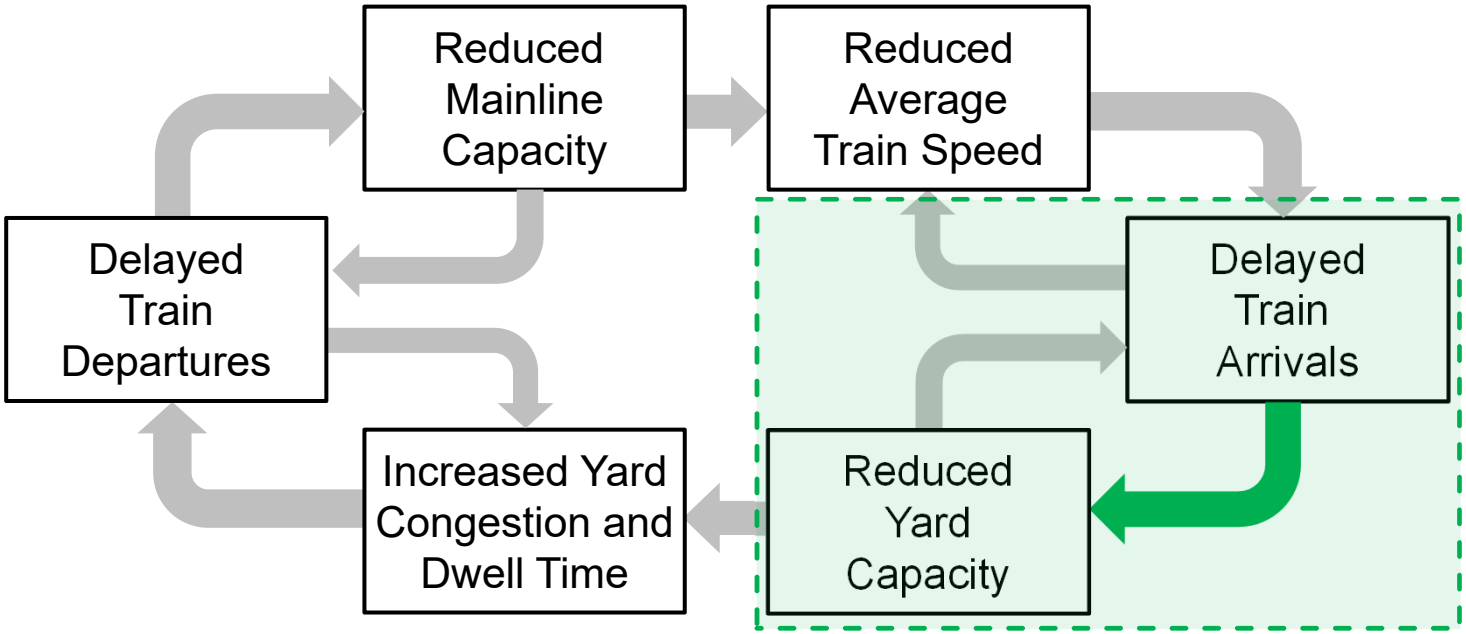




- Volume Variability into Schedule Flexibility
  - Does not alter average or distribution of train departure times
  - Trains dispatched on time but with greater variability in train length and fewer connections achieved

Summary and Conclusions

- Arriving train schedule flexibility and volume variability have a detrimental effect on hump classification yard performance
- Yards propagate variability
  - Amplify or dampen arrival time variability into a consistent outbound schedule flexibility of 120 to 180 minutes
  - Amplify volume variability
  - Transform arrival time variability into outbound volume variability
- Quantify yard response to mainline effects in network efficiency cycle



Thank you for your attention!

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