Impact of Automated Condition Monitoring Technologies on Railroad Safety and Efficiency

William W. Hay Railroad Engineering Seminar Series
August 27th, 2010

Bryan W. Schlake, Christopher P.L. Barkan, and J. Riley Edwards
University of Illinois at Urbana-Champaign
Railroad Engineering Program

ILLINOIS
RAILROAD ENGINEERING PROGRAM

Presentation Outline

- Objective & Motivation
- Impact of ACMT on Safety
- Impact of ACMT on Efficiency
  - Terminal Performance Using Lean Production Methods
  - Mainline Efficiency Using Dispatch Simulation Software
- Future Work

Research Objective

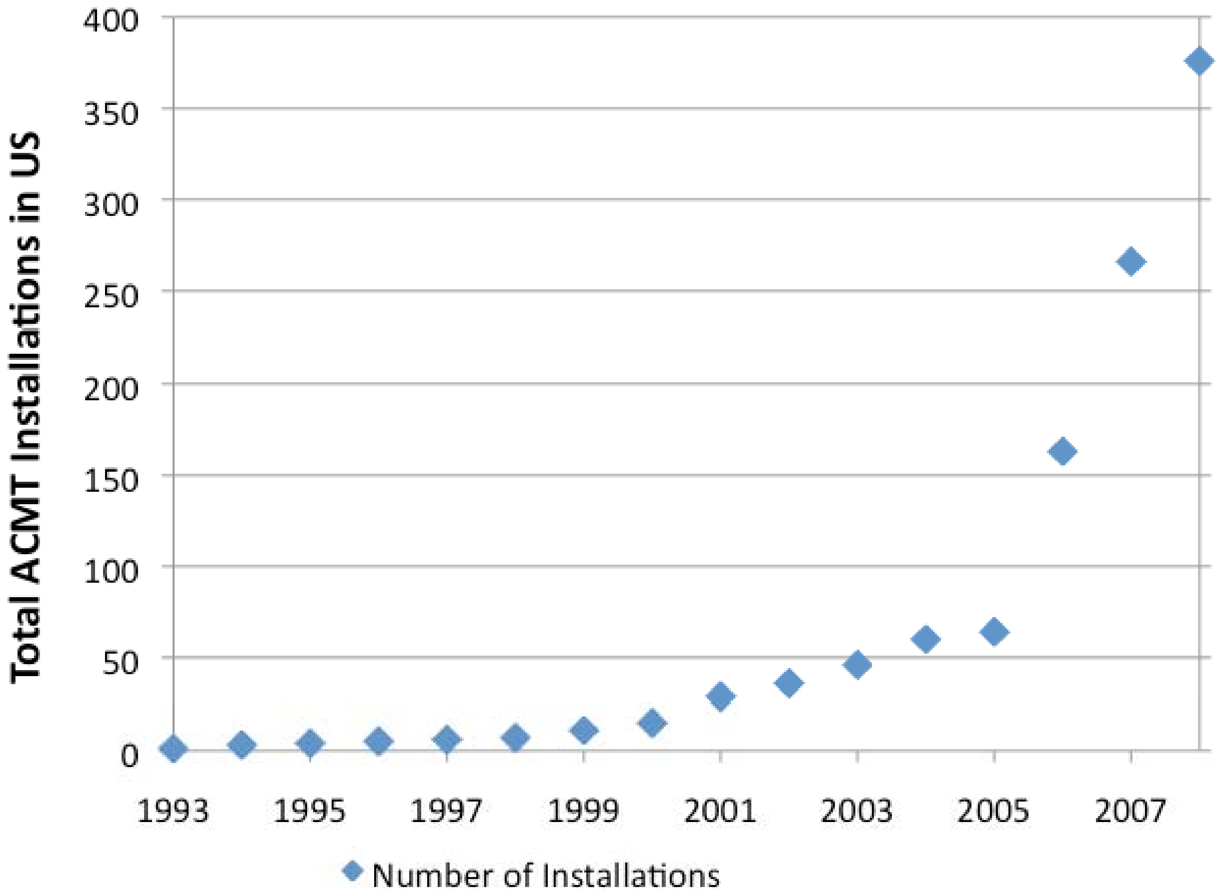
To determine the safety and economic implications of using Automated Condition Monitoring Technology (ACMT) to monitor the condition of freight cars

Automated Condition Monitoring Technology (ACMT)

- Reactive Maintenance:
  - Dragging Equipment Detectors
  - Hot Bearing Detector
- Condition-Based Maintenance:
  - Acoustic Bearing Detectors
  - Wheel Impact Load Detectors
  - Hunting Truck Detectors
  - Truck Performance Detectors
  - Wheel Temperature Trending
  - Wheel Profile Monitoring
  - Warm Bearing Trending
  - Machine Vision (MV) Inspection

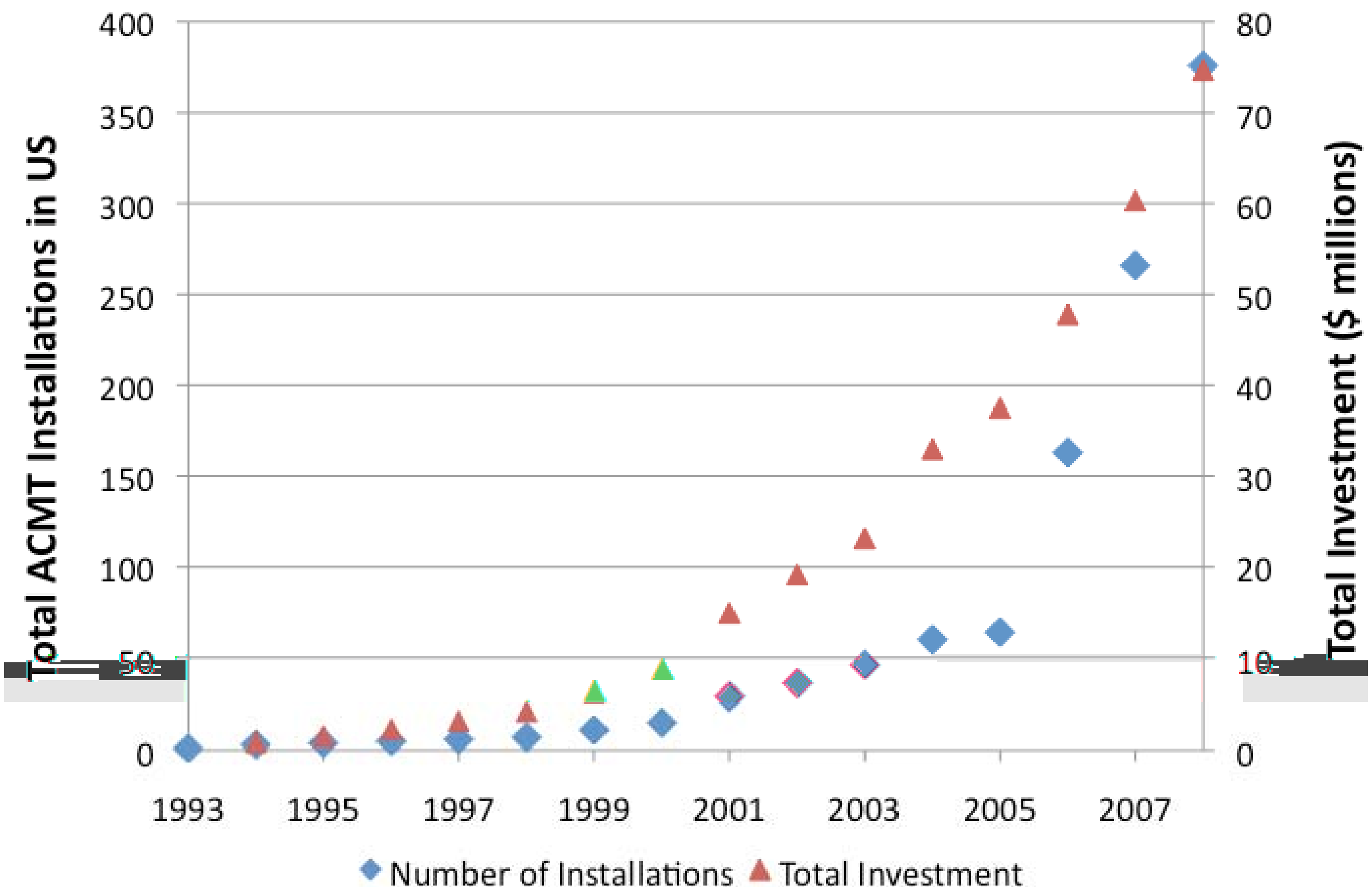
Lagnebäck, R. Evaluation of wayside condition monitoring technologies for condition-based maintenance of railway vehicles, Licentiate Thesis, Luleå University of Technology, Luleå, Sweden, 2007.

Increased Implementation of ACMT



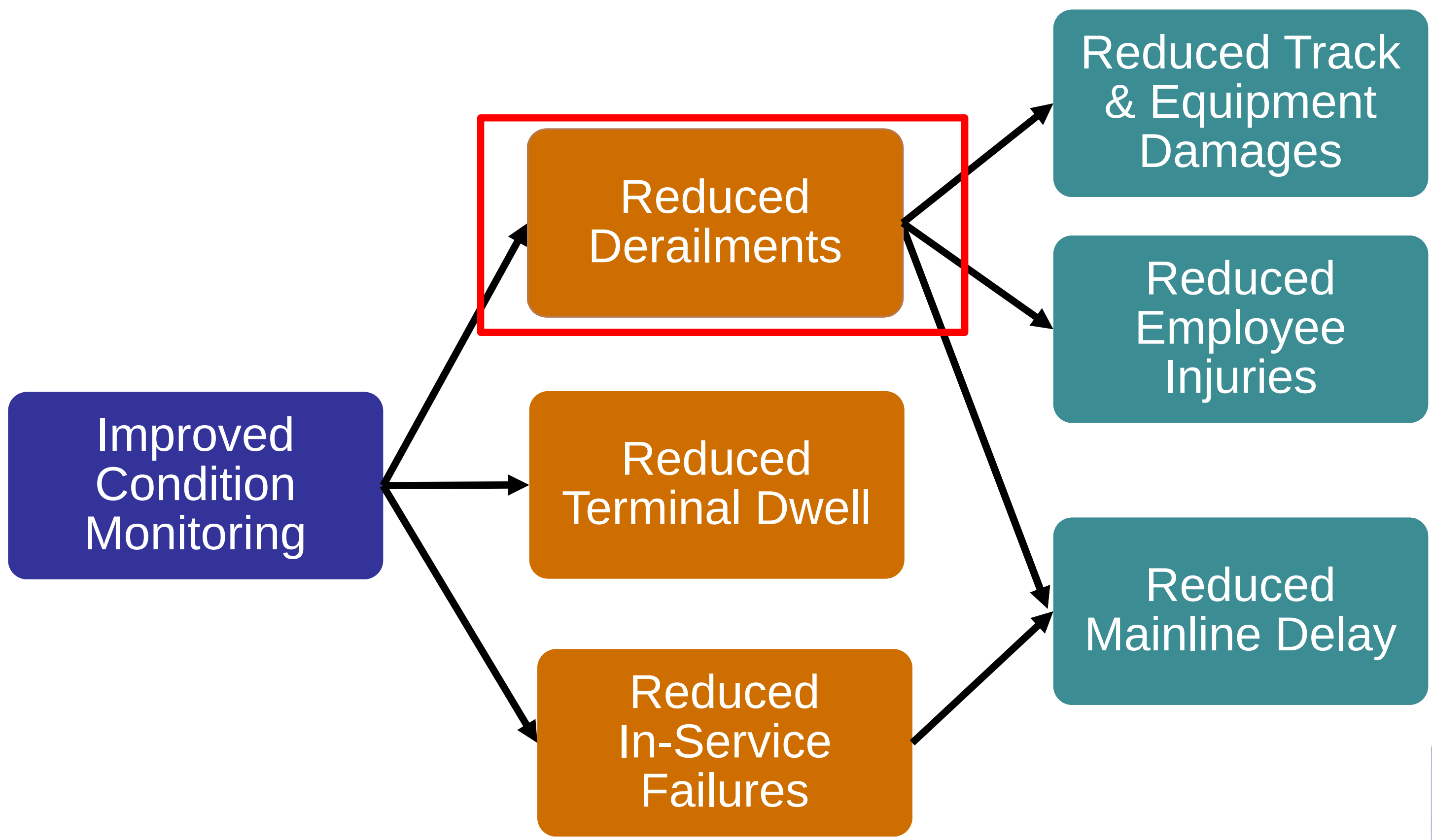
Source: Robert, W., A. Aeppli, and P. Little. Post-Audit of Wayside Detector Costs and Benefits. Cambridge Systematics Inc., 10 September 2009.

Increased Implementation of ACMT



Source: Robert, W., A. Aeppli, and P. Little. Post-Audit of Wayside Detector Costs and Benefits. Cambridge Systematics Inc., 10 September 2009.

Objectives Driving Condition Monitoring Improvements



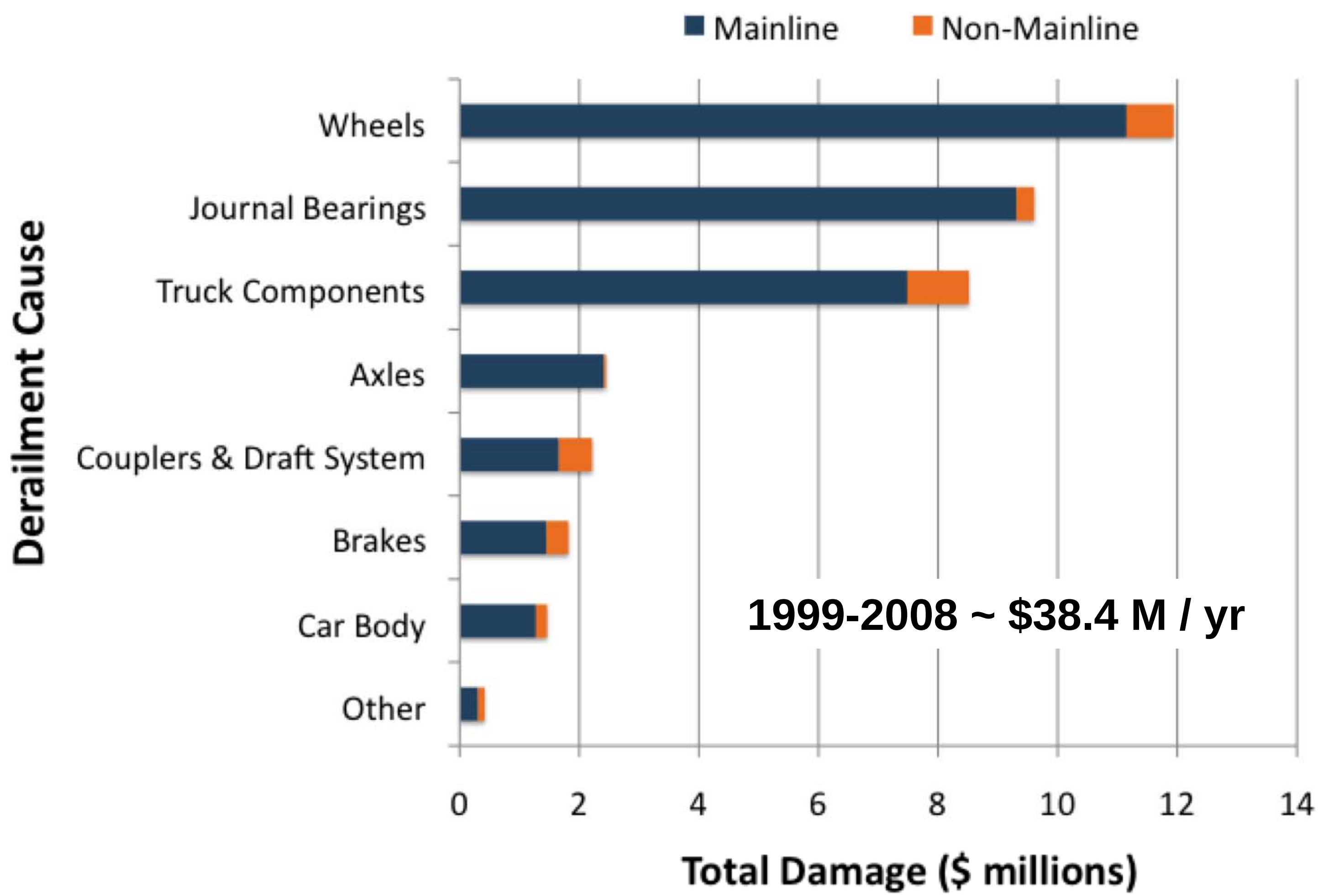
Cost of Equipment-Caused Derailments

- Over 1,340 equipment-caused, reportable mainline derailments from 1999-2008 for four largest US Class I railroads
- $350 million in track and equipment damages
- 78% of all damages resulted from failures to wheels, journal bearings, or truck components
- 49 injuries during this time frame (< 5 per year)

Slide 9

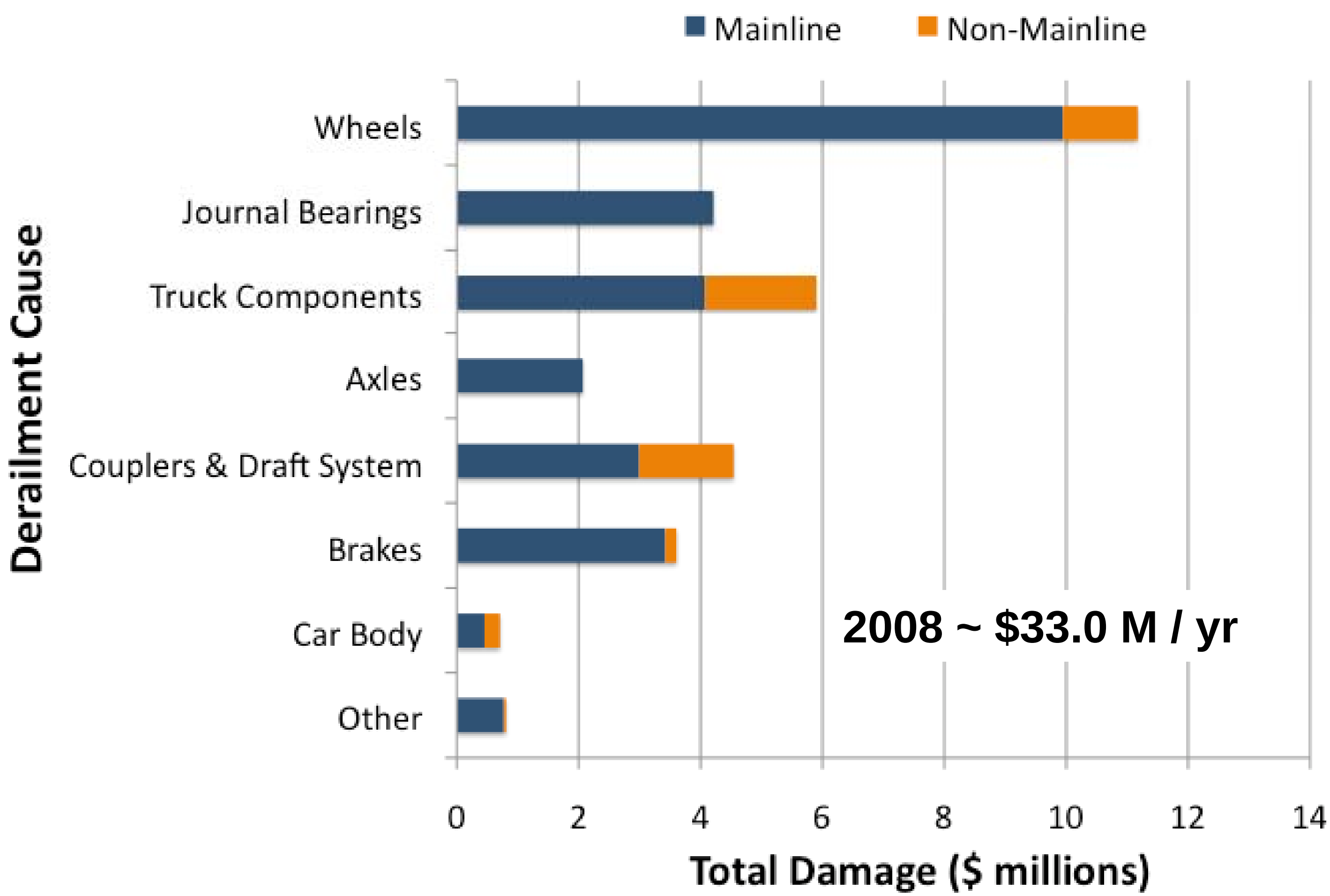
ILLINOIS - RAILROAD ENGINEERING

Cost of Equipment-Caused Derailments



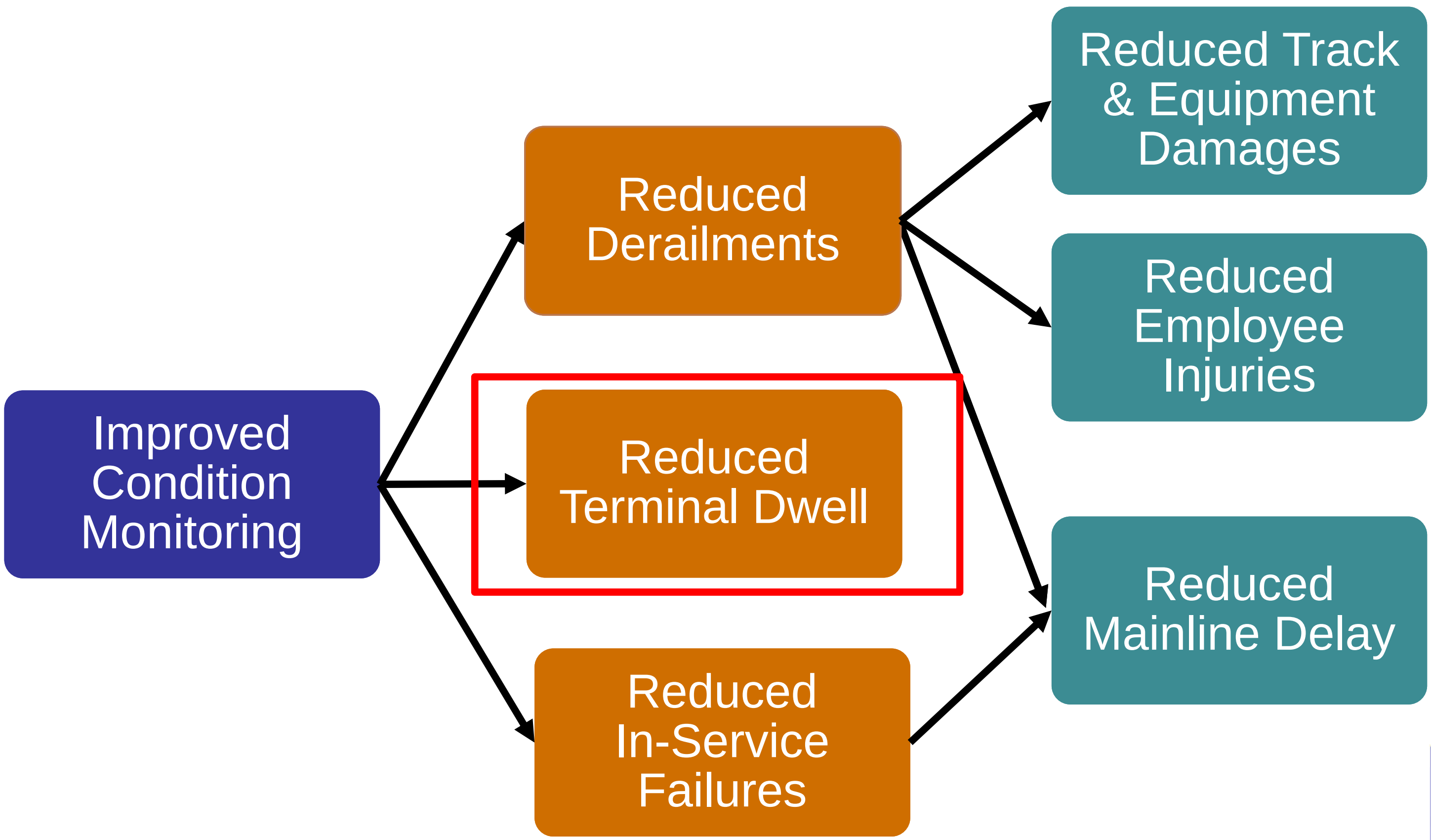
Source: Federal Railroad Administration (FRA) Office of Safety Analysis

Cost of Equipment-Caused Derailments



Source: Federal Railroad Administration (FRA) Office of Safety Analysis

Objectives Driving Condition Monitoring Improvements



Slide 12

ILLINOIS - RAILROAD ENGINEERING

Terminal Performance

- "Cars spend most of their time in terminals, and that's where the service battle is won or lost for carload business"
- Terminal Dwell = the average time a car resides at a specified yard or terminal (measured in hours)
- Terminal Dwell is directly related to average train velocity
- A 15% reduction in systemwide average terminal dwell could result in an increase of 2 mph in carload velocity
- Terminal performance directly affects unit train operations directly due to FRA-required 1,000-mile (Class IA) air brake inspections

Murray, T. Wrong train running. *Trains,* July, 2002, 30-35.

Logan, P. *Role of Yard or Terminal in Operating Performance and Capacity*. Presentation at 85th Annual Meeting of the Transportation Research Board, Washington, D.C.: 2006.

Lean Railroading

- In 1990 “Lean Manufacturing” was first introduced at MIT based on a study of the Toyota Production System
  - *Lean* is defined as the production of goods or services using minimal buffering costs
  - Sources of excessive buffering include *direct waste* and *variability*
- Dirnberger developed steps for applying *lean* to terminals
- Applying Lean Railroading over a one-year period, Canadian Pacific Railway (CPR) saw average terminal dwell drop by over 28%, average terminal capacity increase by 40%, and average train speed increase by 3.6 mph
- CPR, UP, BNSF, NS, Belt Railway of Chicago, and GE Yard Solutions are now applying aspects of Lean Railroading

Dirnberger, J. R. (2006). Development and Application of Lean Railroading to Improve Classification Terminal Performance, M.S. Thesis, University of Illinois at Urbana-Champaign, Urbana, IL.

Lean Railroading (cont.)

- Steps for Implementing Lean Railroading in Terminals:
  – Eliminate Direct Waste
  – Modify Buffers
  – Reduce Variability
  – Perform Continuous Improvement
- Applied to humping and switching activities to improve efficiency in classification yards
- Lean techniques can also be applied to railcar maintenance practices to improve yard efficiency

Autonomation and Inspection

- Autonomation is “automation with a human touch”
- Train inspection can be likened to quality control in the railyard “production system”
- There are various inspection types used for quality control:

System	Search	Decision
Pure human inspection	H	H
Computer-search human decision	C	H
Human-computer decision-making	C	H + C
Pure automated inspection	C	C

H = Human, C = Computer

*Adapted from Hou et al. (1993)

- Hybrid systems typically perform better than either humans or machines alone

Eliminate Direct Waste

- Direct waste comes from operations that are unnecessary
- Examples include: rework, accidents, in-service failures, injuries, car damage, and unnecessary motion or information collection
- Two Types of Direct Waste:
  - *Type I: Inherent but Unavoidable*
    - Tagging of bad order cars
  - *Type II: Immediately Avoidable*
    - Manual railcar inspection
      - Implementation of Electronically Controlled Pneumatic (ECP) brakes
      - Integration of ACMT

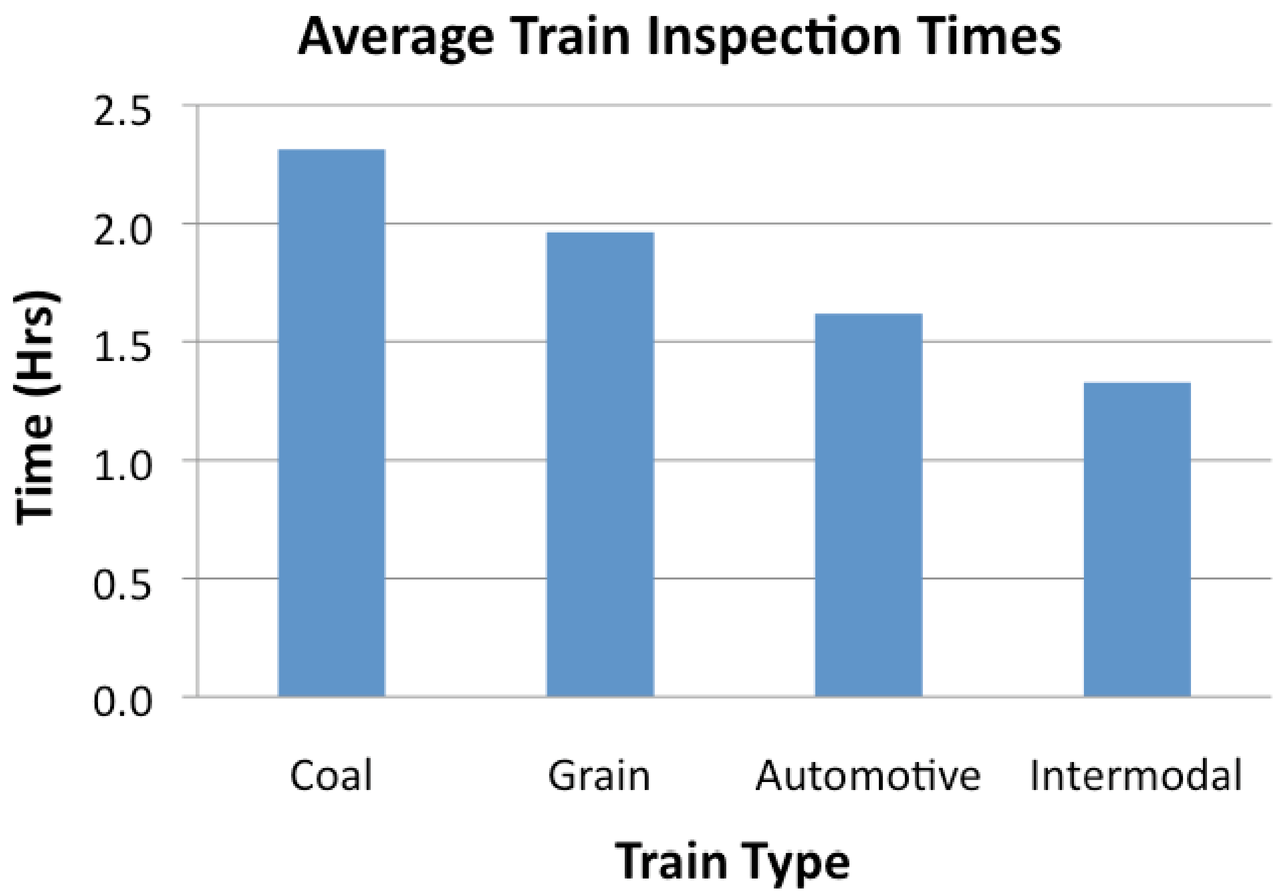
Type I Waste

*Each bad order adds approx. ten minutes of Type I waste

Eliminate Direct Waste

- Direct waste comes from operations that are unnecessary
- Examples include: rework, accidents, in-service failures, injuries, car damage, and unnecessary motion or information collection
- Two Types of Direct Waste:
  - *Type I: Inherent but Unavoidable*
    - Tagging of bad order cars
  - *Type II: Immediately Avoidable*
    - Manual railcar inspection
      - Implementation of Electronically Controlled Pneumatic (ECP) brakes
      - Integration of ACMT

Type II Waste



*Trains equipped with ECP brakes require fewer Class IA inspections

Modify Buffers

- Buffers result from uncertainty and lead to indirect waste
- **Common buffers**
  - **Inventory**: reserve supplies of fuel, railcars, or wheelsets
  - **Capacity**: excess storage tracks, car inspectors, or repair personnel
  - **Time**: "slack time" in the train schedule
- Buffers can be modified, or swapped, to reduce indirect waste
- Example: decrease the time buffer due to excess inspection time and increase the capacity buffer by shifting labor from inspection to repair activities
- ACMT will affect all three types of buffers

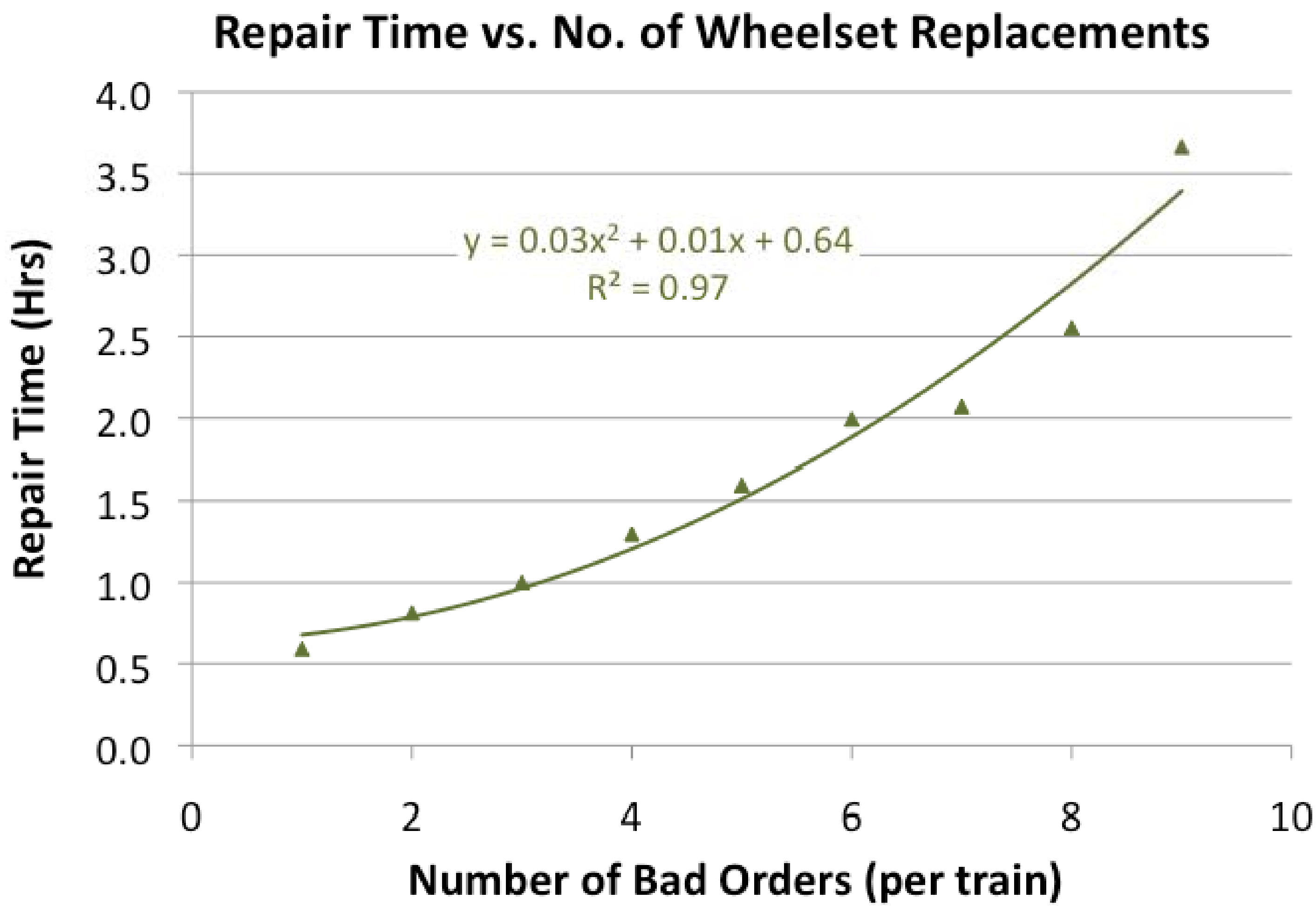
Reduce Variability

- Variability is a fundamental source of waste, as it necessitates buffering in the form of extra inventory, capacity, or time

Buffer	Inventory	Capacity	Time
Type of Variability	• Fueling requirements • Amount of rolling stock requiring maintenance • Severity of required maintenance	• Train arrivals • Amount of rolling stock requiring maintenance • Severity of required maintenance	• Train arrivals • Inspection or repair times • Labor availability

- Variability can be reduced by regulating work-in-process (WIP), or the amount of unfinished product in the system at a given time
- ACMT can help regulate WIP through the use of “windows of opportunity” (e.g. opportunistic wheelset replacement)

Reduce Variability (cont.)



Perform Continuous Improvement

- Variability will always exist in the production system
- Managers should work to actively manage buffers:
  - Predictive maintenance can result in reduced inventory buffers
  - Improved railcar maintenance will lead to increased railcar utilization and can result in decreased capacity buffers
  - Time buffers should be closely monitored and appropriately reduced as technology permits
- Improvements in terminal efficiency can impact efficiency across a railroad's entire network

Data Analysis

- Long distance unit trains are required to stop for FRA Class IA, 1,000-mile air brake inspections
- Operational waste was estimated using inspection data for an example Class I railroad terminal

	Train Type				
	Coal	Grain	Automotive	Intermodal	Total
Average Inspection Time (hrs)	2.31	1.96	1.62	1.33	2.16*
Number of Trains Inspected per year	10,600	650	770	1,320	13,340
Percent of Trains Inspected per year (%)	79	5	6	10	100

*Weighted average

- Savings were determined by subtracting the estimated hybrid inspection costs from the current cost of manual inspections

Manual Inspection Cost

$$C_{manual} = 2 \times T_{manual} \times N \times S$$

where,

C_{manual} = total annual labor cost for manual inspections, in $(USD)

T_{manual} = average inspection time (weighted by train type) for manual inspections, in hours

N = number of 1,000-mile inspections per year

S = average hourly compensation for car inspectors, including benefits in $(USD)

$$C_{manual} = 2 \times 2.16 hrs \times 13{,}340 \times \$39.13 / hr$$

Manual Inspection Cost

$$C_{manual} = 2 \times T_{manual} \times N \times S$$

where,

C_{manual} = total annual labor cost for manual inspections, in $(USD)

T_{manual} = average inspection time (weighted by train type) for manual inspections, in hours

N = number of 1,000-mile inspections per year

S = average hourly compensation for car inspectors, including benefits in $(USD)

$$\boxed{C_{manual} = \$2,255,300}$$

Hybrid Inspection Cost

$$C_{hybrid} = (D \times A_{automated} + F_{automated}) \times T_{hybrid} \times N \times S$$

where,

C_{hybrid} = total annual labor cost for hybrid inspections, in US dollars

D = average number of detectable FRA defects per train inspection

$A_{automated}$ = average correct identification percentage for automated wayside detectors (i.e. accuracy)

$F_{automated}$ = average false alarm rate for automated wayside detectors

T_{hybrid} = average inspection time to verify a single component defect, in hours

$$C_{hybrid} = (2 \times 0.95 + 0.10) \times 0.25 hrs \times 13,400 \times \$39.13 / hr$$

Hybrid Inspection Cost

$$C_{hybrid} = (D \times A_{automated} + F_{automated}) \times T_{hybrid} \times N \times S$$

where,

C_{hybrid} = total annual labor cost for hybrid inspections, in US dollars

D = average number of detectable FRA defects per train inspection

$A_{automated}$ = average correct identification percentage for automated wayside detectors (i.e. accuracy)

$F_{automated}$ = average false alarm rate for automated wayside detectors

T_{hybrid} = average inspection time to verify a single component defect, in hours

$$\boxed{C_{hybrid} = \$261{,}000}$$

Results

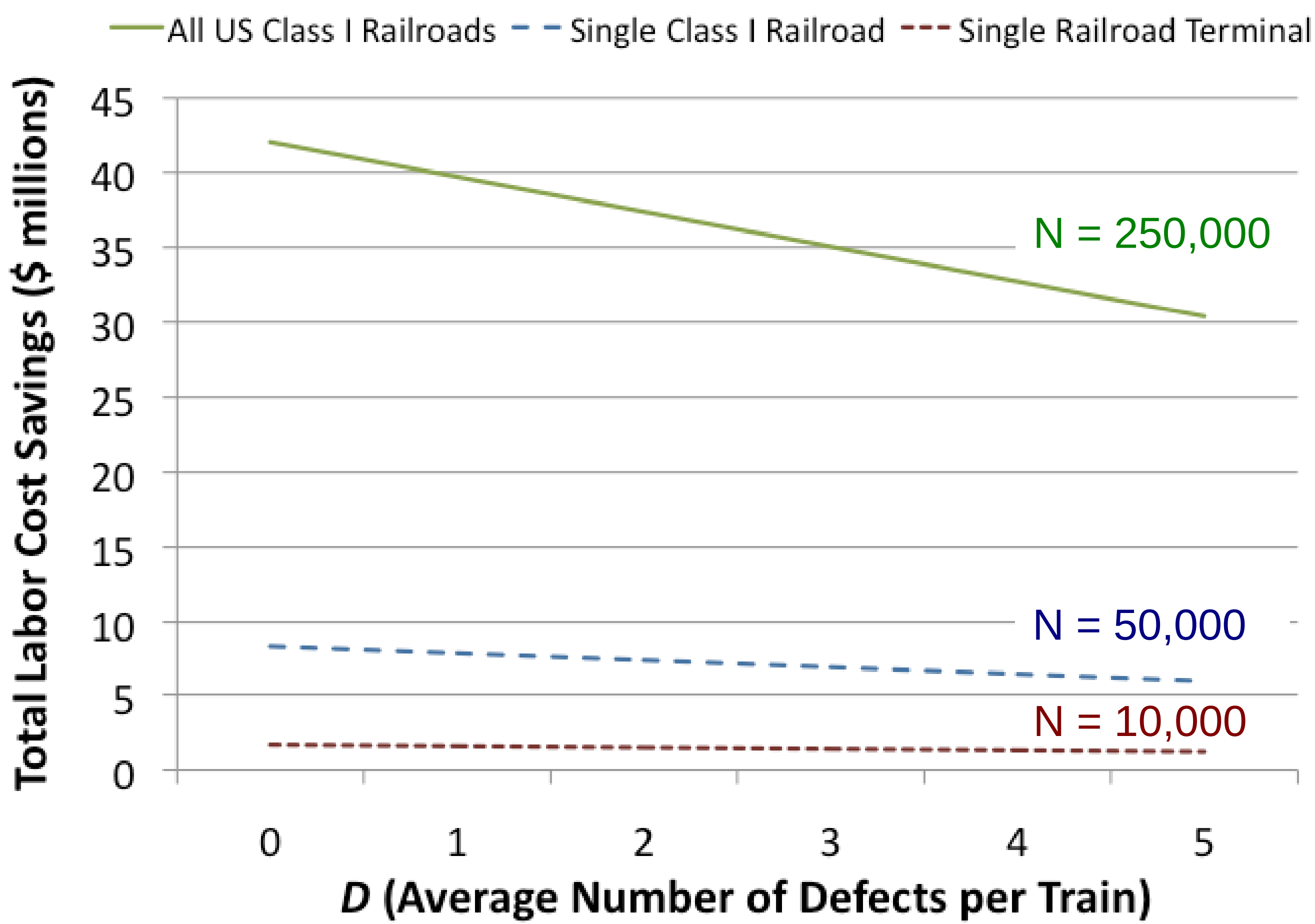
$$\text{Net Savings:} \quad C_{manual} - C_{hybrid} = \$1{,}994{,}300$$

- Results suggest that a single Class I railroad terminal could recover approximately $2 million per year through the use of hybrid inspection practices
- This is a conservative estimate, since only labor costs for Class IA inspections have been included
- Additional savings would result from reducing variability
- These costs are sensitive to both the number of inspections considered, *N*, and the overall condition of the railcar fleet, represented in this model by *D*

Slide 30

ILLINOIS - RAILROAD ENGINEERING

Sensitivity Analysis



*N = annual Class IA inspections

Summary of Terminal Performance Analysis

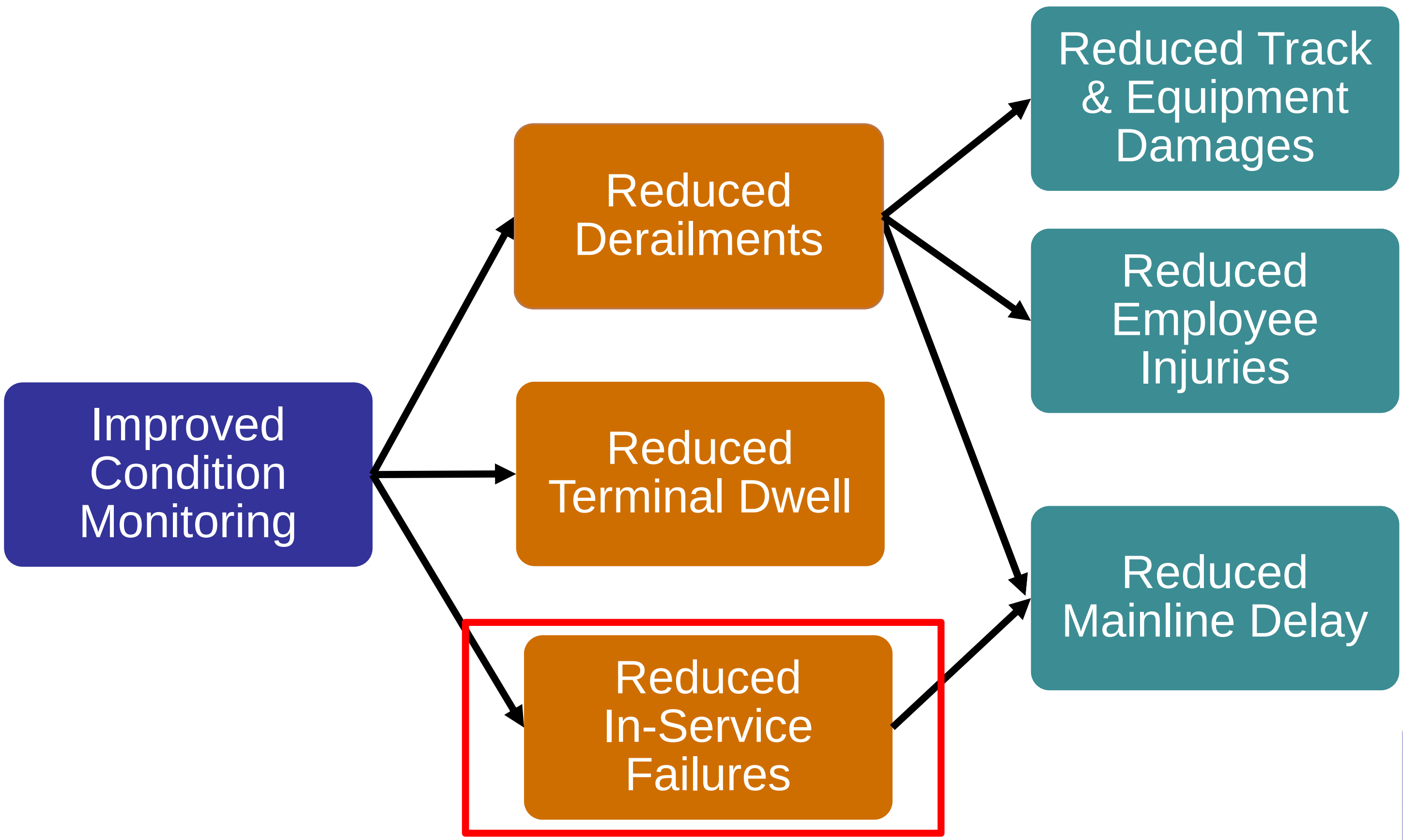
- Railroad terminals can benefit substantially from lean principles
- A methodology has been presented for the application of Lean Railroading to railcar inspection and maintenance practices
- Results from this analysis:
  - Single Terminal: ~$2 million estimated annual savings
  - US Railroad Industry: ~$35 million estimated annual savings
- To realize these benefits:
  - ACMT capable of monitoring all safety-critical railcar components must be fully developed and integrated
  - New operational practices must be approved and adopted
- As technology integration advances, the distances between inspections may be increased, resulting in additional savings

Future Terminal Related Research

- Evaluate the entire railcar maintenance process to understand additional sources of waste (e.g. value stream mapping)
- Examine sources of variability and develop techniques to better quantify variability
- Apply lean production methods to other areas such as intermodal terminals

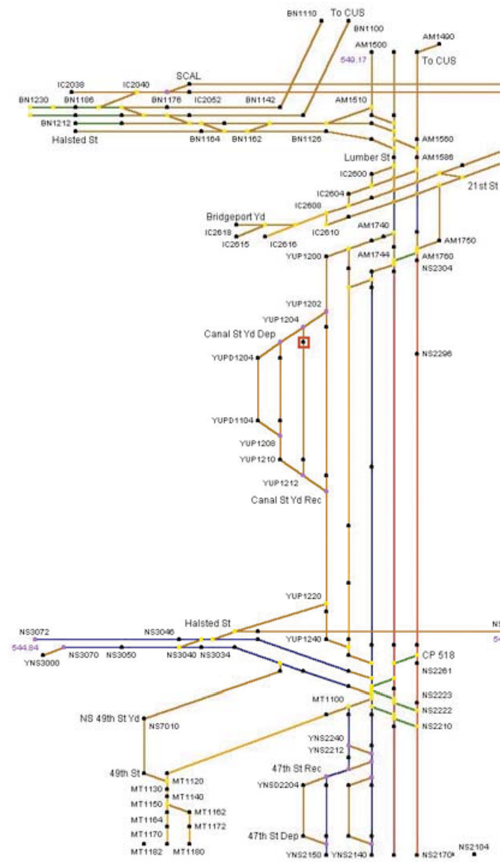
http://assets.bizjournals.com/story_image/111314-600-0-2.jpg

Objectives Driving Condition Monitoring Improvements



Analysis of Train Delay

- Train delay is a metric often used for mainline capacity
- Rail Traffic Controller (RTC) from Berkeley Simulation Software is the de facto industry standard for measuring train delay
- The University of Illinois at Urbana-Champaign (UIUC) recently used RTC to analyze effects of train type heterogeneity
- In the current study, we assess the effects of equipment-caused mainline in-service failures (ISFs)
- We consider the amount and variability of train delay for various lengths of ISF and traffic volumes



http://www.berkeleysimulation.com/rtc/loca_
nter.html

RTC Dispatch Simulations

Route Characteristics	Train Characteristics
260 miles long	Unit coal trains
10 miles between control points	115 cars, 6,325 ft. long
8,000 ft. signaled sidings	16,445 tons per train (loaded)
2.5-mile signal spacing	3,795 tons per train (empty)
3-block, 4-aspect signaling	0.78 HP / trailing ton
0% grade and curvature	3 SD70 4,300 HP locomotives
	Maximum speed: 50 mph

- Simulations consisted of unit coal traffic on single and double-track routes
- 1, 3, and 5-hour train stops were initiated to represent equipment-caused in-service failures (ISFs)
- Train delay was determined by subtracting delay time for the base case from the delay time for an ISF

Delay Cost Calculation

$$\boxed{\text{Total Cost} = \text{Total Delay Time} \times \text{Delay Cost}}$$

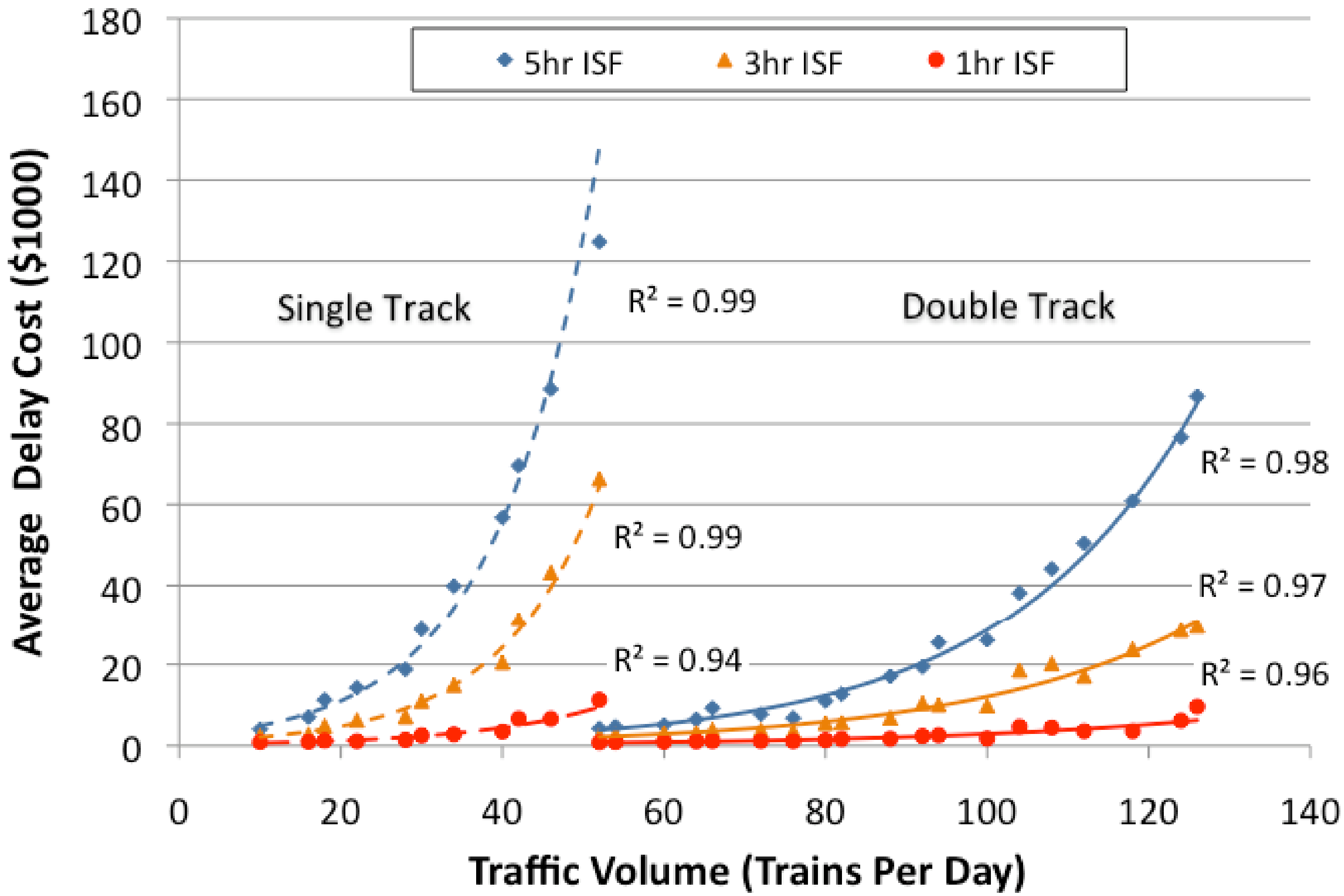
- Delay cost figure involves five components:
  - freight car ownership cost
  - locomotive ownership cost
  - fuel idling cost
  - crew labor cost
  - lading delay cost
- For the current study, we assume a delay cost of $662 per train-hour
- The lading delay cost was estimated at $430 per train hour

Dingler, M. H. Understanding the Impact of Operations and New Technologies on Railroad Capacity, (In Press) M.S. Thesis, University of Illinois at Urbana-Champaign, Urbana, IL, 2010.

Slide 37

ILLINOIS - RAILROAD ENGINEERING

Train Delay Costs



Estimation of Industry-Wide Costs

	Single-Track		Double-Track	
Average ANMGT	Delay Cost ($)	Ton-Miles (%)	Delay Cost ($)	Ton-Miles (%)
<40 (~37)	1,250	31.3	990	0.9
40-60	1,600	17.9	1,000	2.3
60-100	2,190	18.7	1,040	6.2
>100 (~110)	4,640	5.5	1,160	16.3
Total	--	73.5	--	25.6

- Assumptions:
  - 15,000 to 20,000 ISFs on US class I mainlines per year
  - Average delay time of 1.5 hours per ISF
  - Delay costs are negligible for routes with more than two main tracks
- Results:
  - Annual failure costs range from $24 million to $33 million for US Class I railroads

Bureau of Transportation Statistics (BTS), Research and Innovative Technology Administration, U.S. Department of Transportation. National Transportation Atlas Database. 2006.

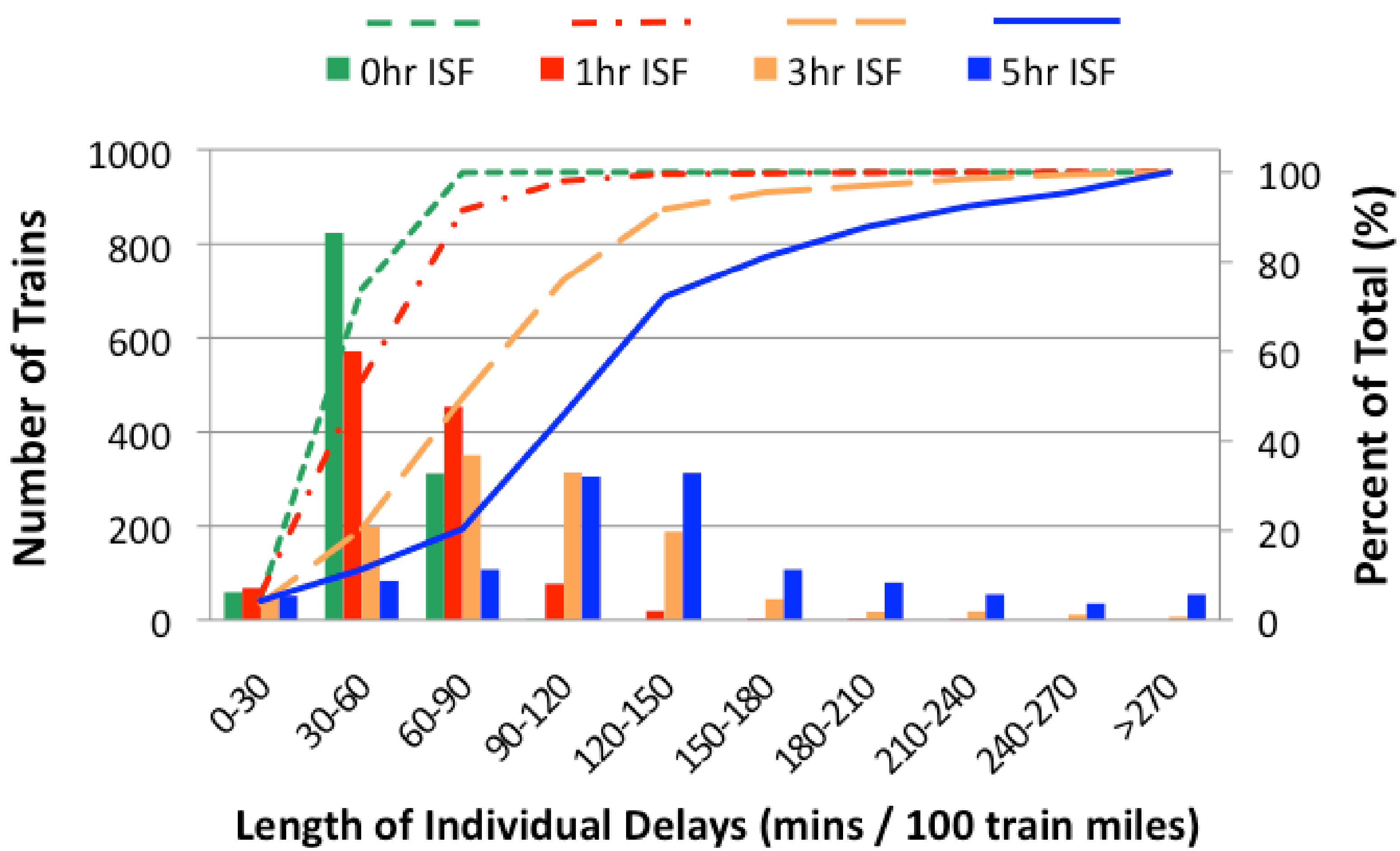
Train Delay Variability

- Variability is a fundamental source of operational waste because it necessitates buffering (e.g. added slack time in train schedules)
- Based on RTC simulations, train delay variability increases with both traffic volume and length of ISF
- Length of ISF ranged from 0 to 5 hours
- Traffic volumes ranged from 16 to 52 trains per day (T/D) on single-track (ST) and from 64 to 126 T/D on double-track (DT)
- Frequency diagrams were created for both single and double-track routes

Slide 40

ILLINOIS - RAILROAD ENGINEERING

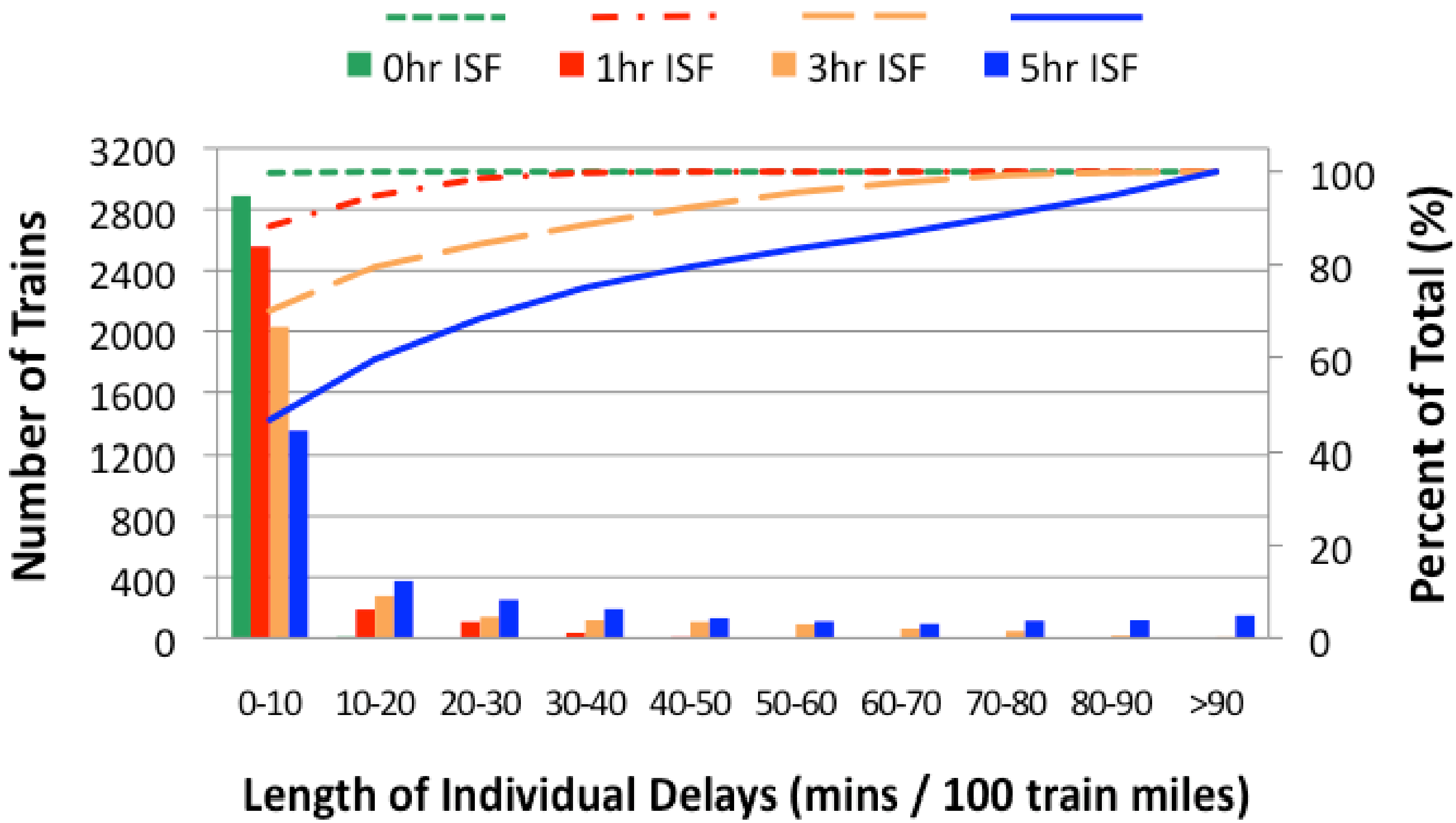
Various Lengths of ISF (ST, 52 T/D)



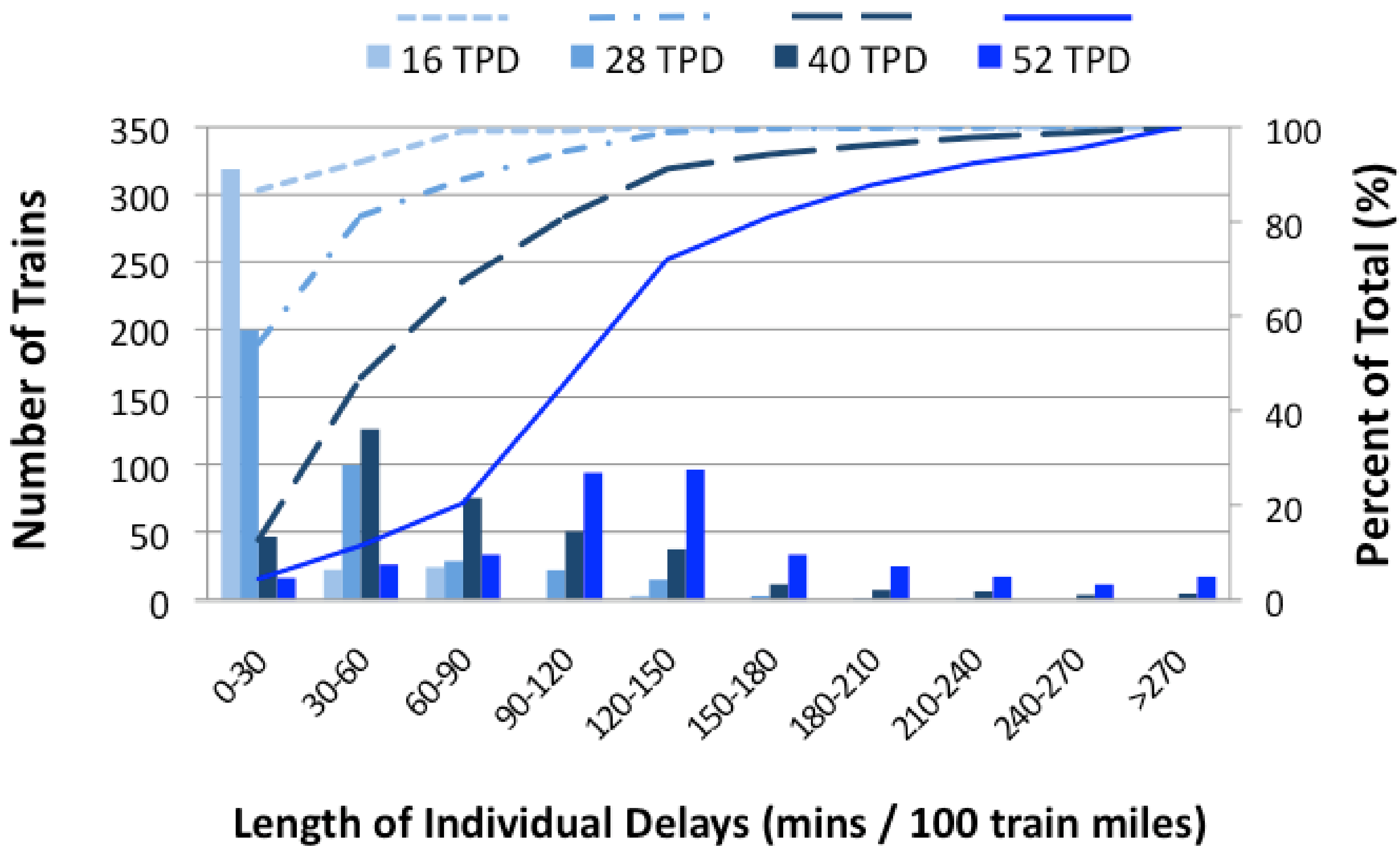
Slide 41

ILLINOIS - RAILROAD ENGINEERING

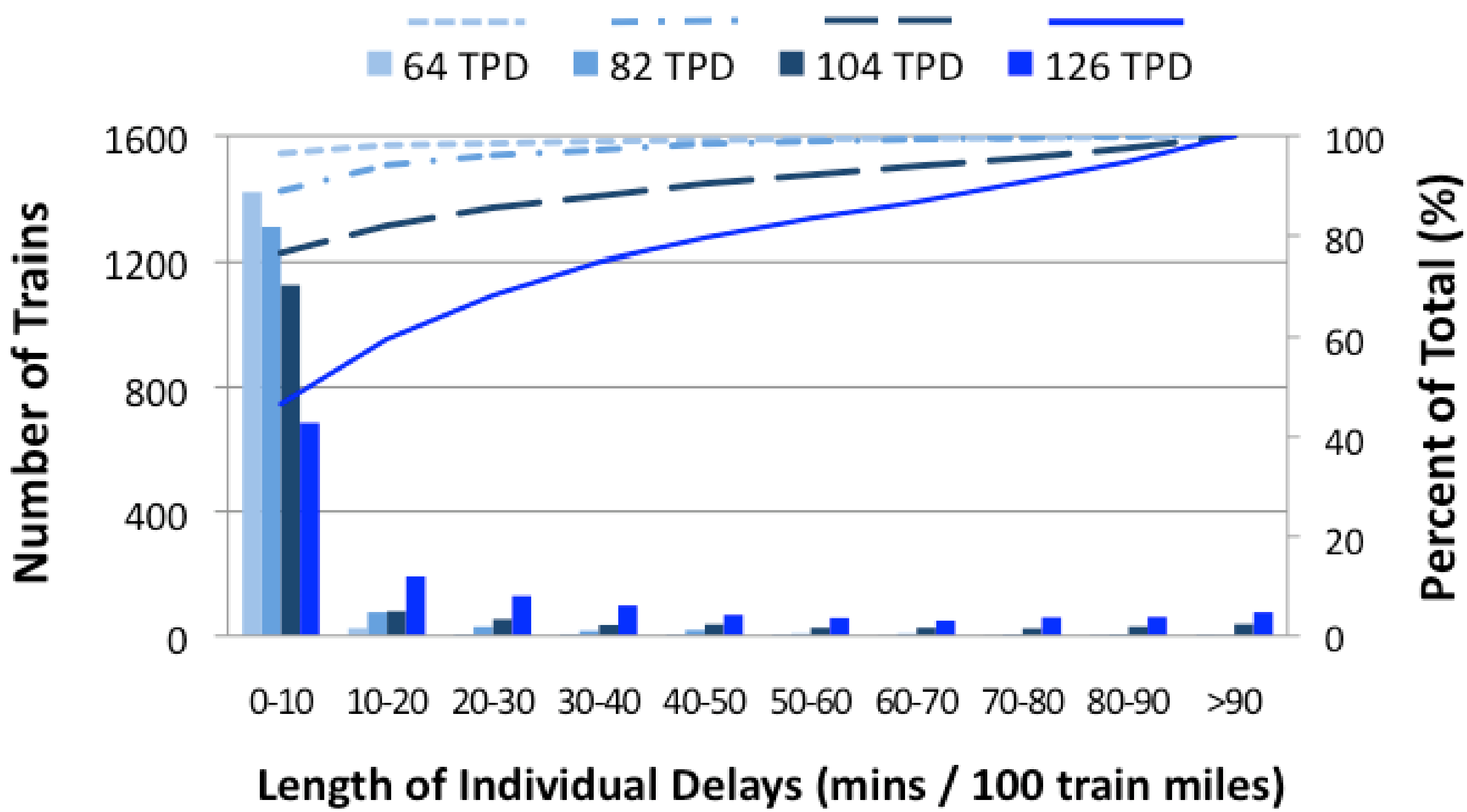
Various Lengths of ISF (DT, 126 T/D)



Various Traffic Volumes (ST, 5 hr ISF)



Various Traffic Volumes (DT, 5 hr ISF)



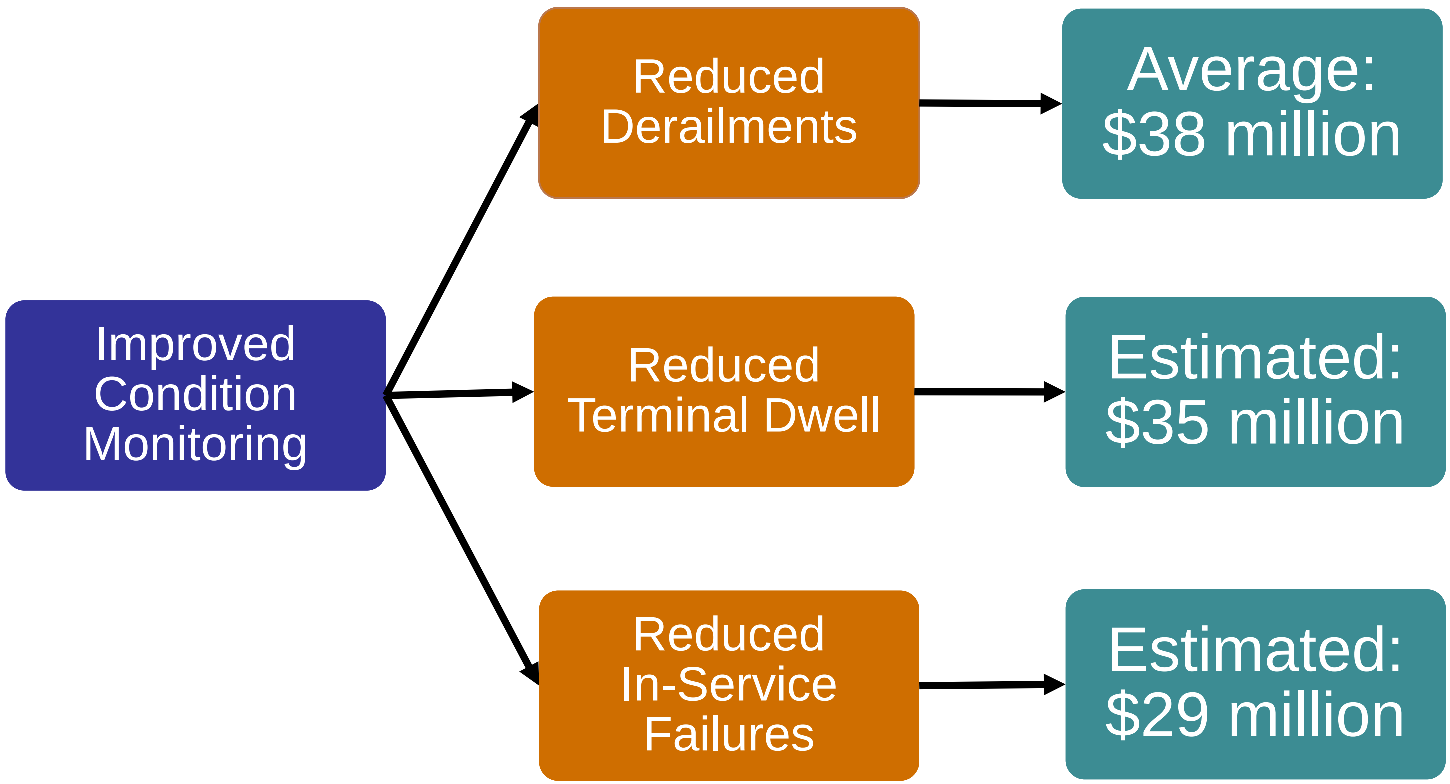
Summary of Variability Analysis

- Train delay variability increases with both ISF length and traffic volume
- Variability is much more evident on single-track routes
- Mechanical ISFs affect variability on double-track routes, but only at very high traffic volumes
- Increased variability results in a higher probability that trains will experience longer delays, resulting in indirect waste in the form of increased time buffers
- Although costs are more difficult to quantify, variability negatively impacts the level of service that railroads can offer customers

Future Mainline Efficiency Research

- Develop a metric to determine the effectiveness with which critical railcar components can be monitored:
  - A function of ACMT accuracy and the statistical probabilities for equipment-caused ISF
  - Requires extensive data collection and analysis
  - Can be used to determine the proportion of ISF costs that could be recovered using ACMT
- Quantification of train delay costs associated with major derailments
  - Performing RTC simulations for 24-48 hour ISFs is not practical
  - Empirical analysis using historical derailment data may be the best approach

Summary



Total Potential Savings of over $100 million per year

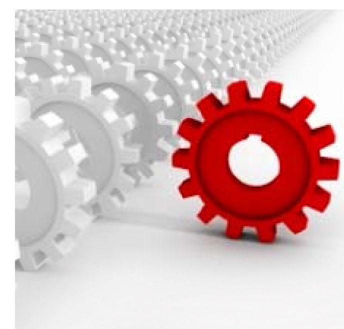
Slide 47

ILLINOIS - RAILROAD ENGINEERING

Additional Future Research

- Include estimates of environmental clean-up and litigation costs due to equipment-caused derailments
- Develop a methodology for determining what proportion of equipment-caused derailments and ISFs can be prevented using ACMT
- Apply six sigma and statistical process control (SPC) methods to improve maintenance efficiency and reduce operational variability

http://wayzata.com/2010/06/30/train-derails-in-wayzata/



Acknowledgements

- Bill GeMeiner, Gary Haddock, and Steve Beckwith, Union Pacific Railway
- Tom Guins, TTCI
- Hayden Newell and Nate Stoehr, Norfolk Southern Corp.
- Don Lauro, CSX
- Darrel Iler, CN
- Jeremiah Dirnberger, Alumni, Univ. of IL at Urbana-Champaign
- Chaz Gross and Mark Dingler, Univ. of IL at Urbana-Champaign
- CN Graduate Research Fellowship in Railroad Engineering

Questions / Comments?