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INFORMS Railway Application Section International Webinar

MANAGING ASSETS AND CAPACITY FOR SUSTAINABLE GROWTH

How Norfolk Southern Leverages Operations Research

November 19, 2020

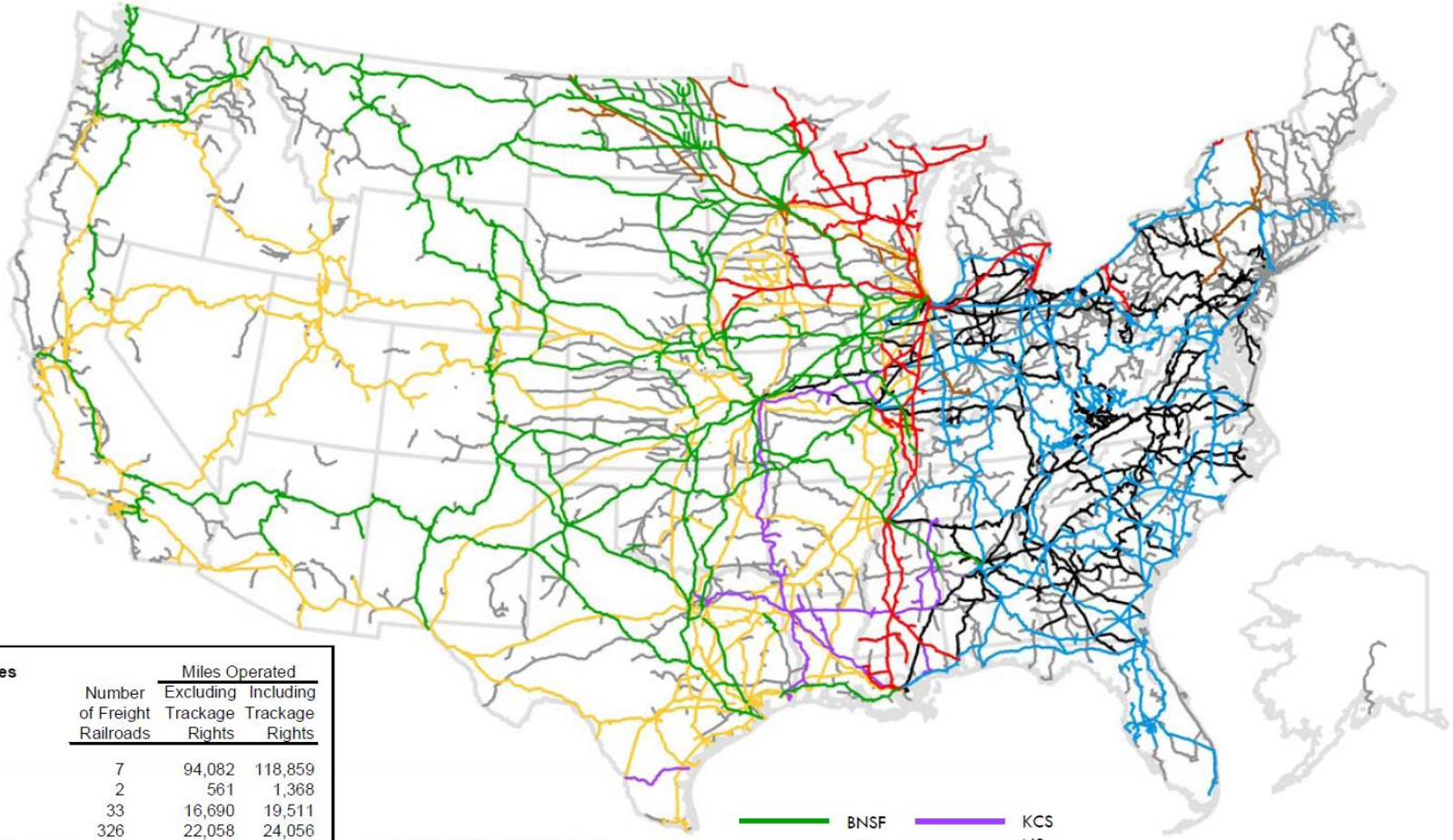
NORFOLK SOUTHERN

OUTLINE

01

US RAILROAD INDUSTRY AND NORFOLK SOUTHERN

Railroad Network of the
UNITED STATES



United States Totals	Number of Freight Railroads	Miles Operated Excluding Trackage Rights	Miles Operated Including Trackage Rights
Class I	7	94,082	118,859
Canadian*	2	561	1,368
Regional	33	16,690	19,511
Local	326	22,058	24,056
Switching & Terminal	199	6,496	6,963
Total	567	139,887	170,757

*Canadian-owned lines not affiliated with a U.S. rail subsidiary.
**Excludes 743 miles owned by Amtrak. All or some of these miles might be operated by freight railroads under trackage rights.

Map shows rail line ownership based on 2008 National Transportation Atlas Database published by the U.S. DOT's Bureau of Transportation Statistics.

CARRYING THE THINGS AMERICA DEPENDS ON

Intermodal:
12.3 million trailers and containers

Food products:
1.6 million carloads

Lumber, paper & other forest products:
1.0 million carloads

Farm products:
1.6 million carloads

Plastics, fertilizers and other chemicals:
2.2 million carloads

Sand, stone & gravel:
1.3 million carloads

Transportation equipment:
1.4 million carloads

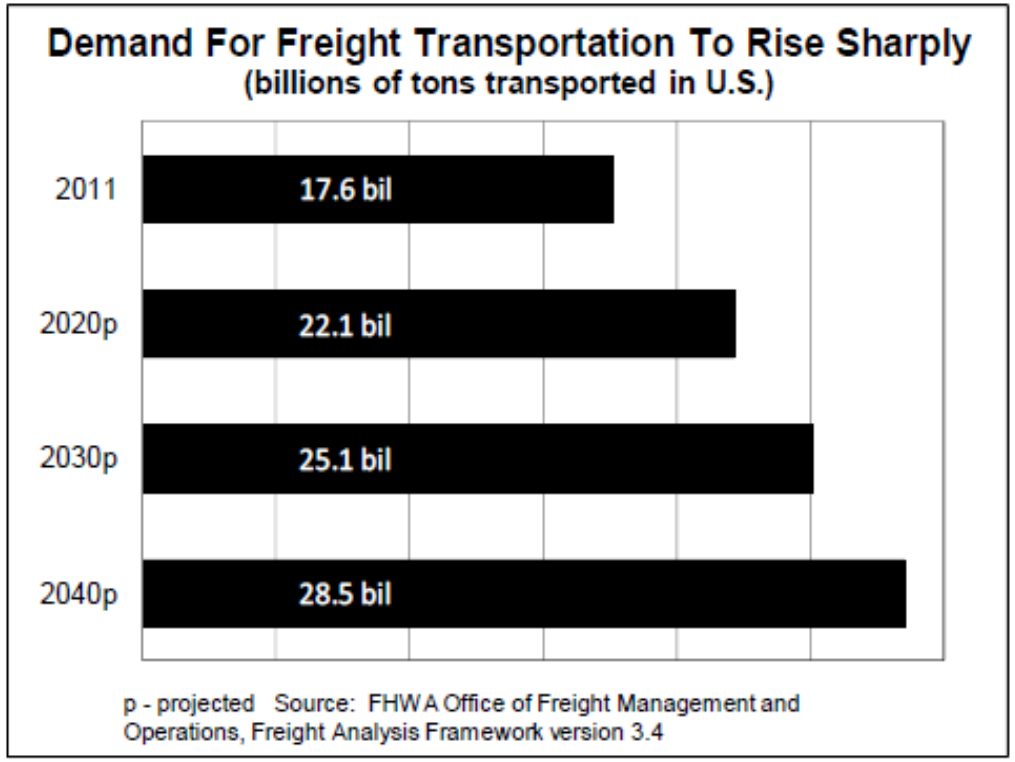
Coal:
6.3 million carloads

And much more!

Figures are 2012.

Source: Association of American Railroads (AAR)

FUTURE DEMAND FOR RAILROAD TRANSPORTATION



- The total U.S. freight shipments will rise from an estimated 17.6 billion tons in 2011 to 28.5 billion tons in 2040 — a 62 percent increase
- Railroads are cost effective, energy efficient, environmentally friendly, and safer.
- Railroads are the best way to meet this demand, but that can happen only if they have:
  - Efficient operations
  - Adequate assets and capacity, and
  - Good customer service

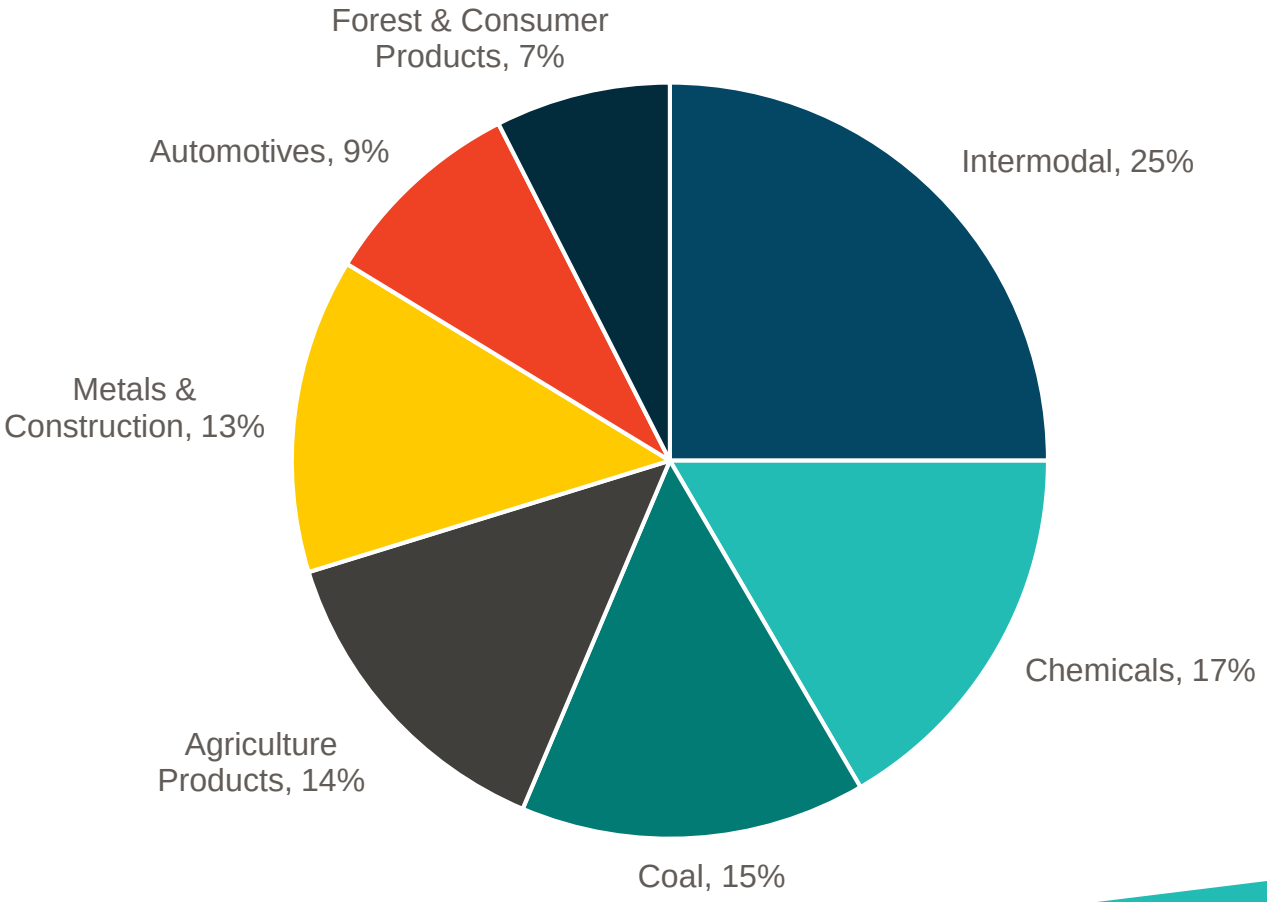
NORFOLK SOUTHERN

Number of employees	24,587
Miles of road operated	19,451
Track miles operated	35,592
Locomotives owned and leased	3,906
Freight cars owned and leased	50,553

Source: Norfolk Southern Corporation Website

2019 FINANCIAL HIGHLIGHTS

- Operating revenues
  - $11 billion
- Operating income
  - $4 billion
- Operating ratio
  - 65% (= Cost/Revenue)
- Revenue Shipments
  - 7.5 million



Source: 2019 Norfolk Southern Corporation Annual Report

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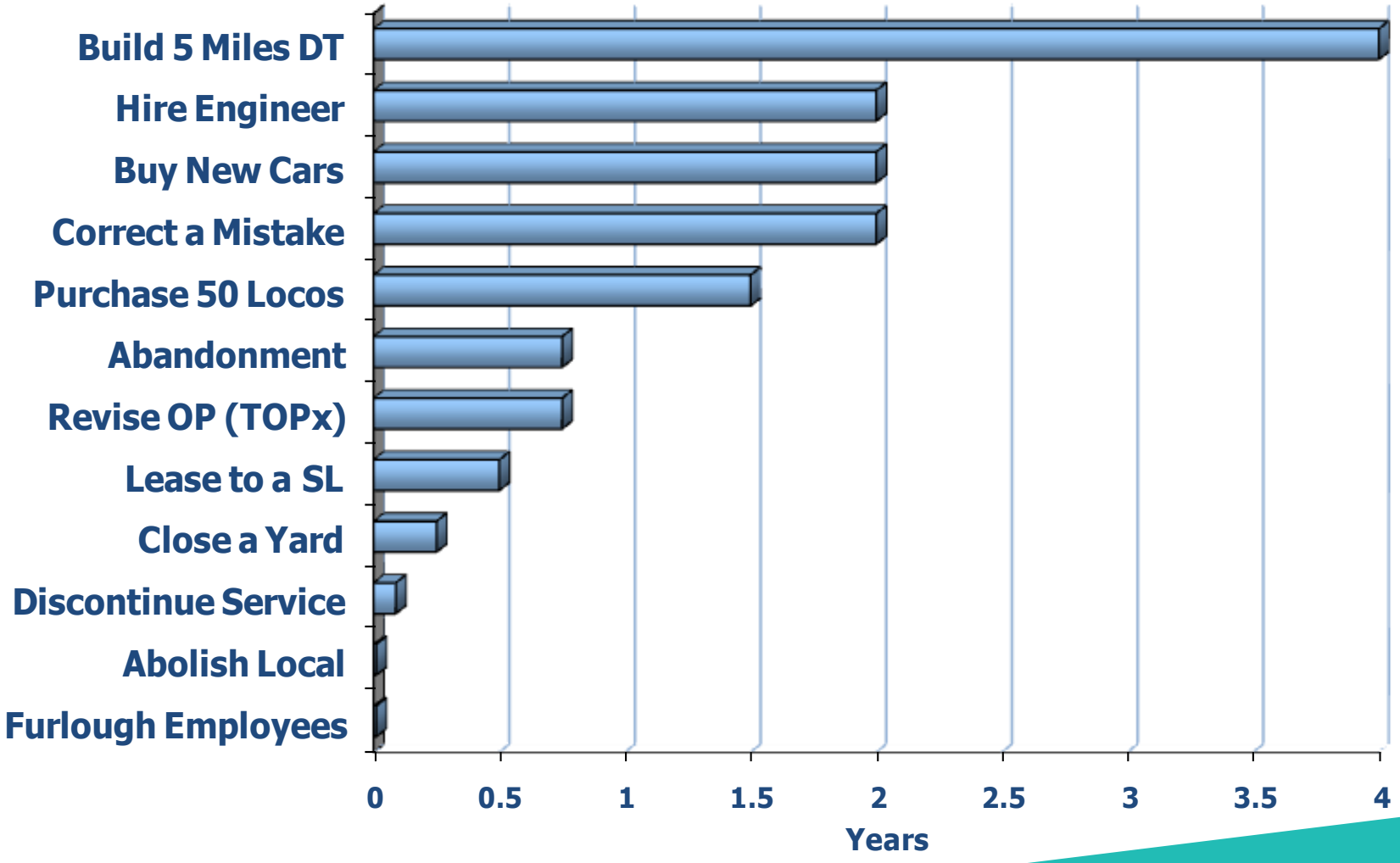
OR TOOL SUITE AT NORFOLK SOUTHERN

PLANNING LEAD TIME

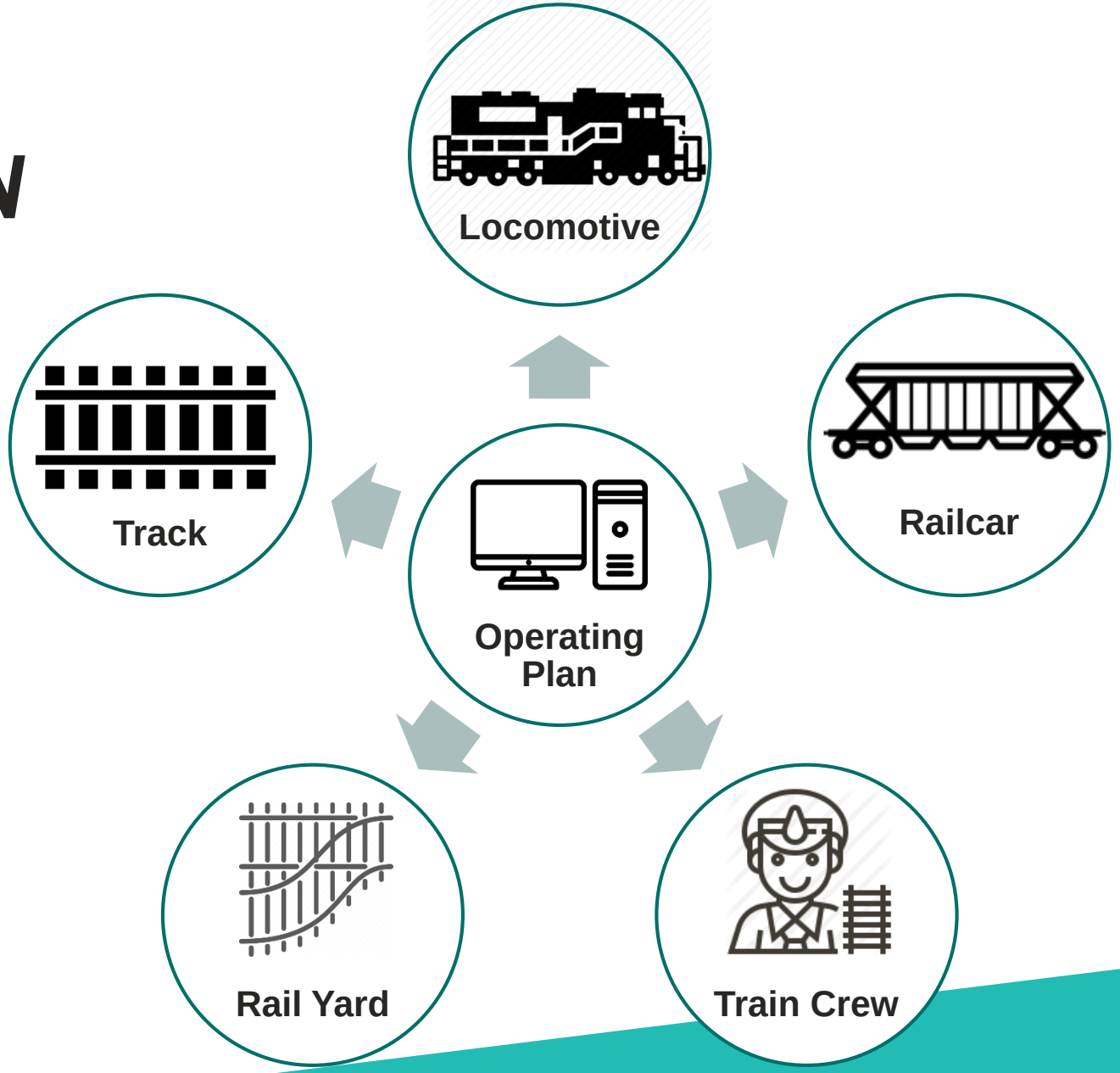


THE CHALLENGES

- Optimize assets and capacity based on expected, rather than historic demand
- Better manage extensive capital requirements
- Reduce lead times needed to acquire assets and capacity
- Have the right assets and capacity in the right place at the right time to meet the expected demand

OR TOOL SUITE AT NORFOLK SOUTHERN

- Develop operating plan
- Manage assets and capacity
- 14 OR models covered in this presentation



03

DEVELOPING OPERATING PLAN

FROM TRAFFIC TO OPERATING PLAN

Traffic Dataset

- Historical shipment records
- New business opportunities
- Future shipment forecast

Blocking Plan

- Block: a group of railcars going from one yard to the next yard
- Block O/D is different from individual shipment O/D

Train Schedule

- Train route, arrival and departure time at each stop
- Each train carries one or more blocks
- Pickup and setoff of blocks along train route

Terminal Clock

- Train inbound and outbound activities in a rail yard over 24 hours
- Railcar connection from inbound to outbound trains (dwell time)

Network Simulation

- Simulation of new operating plan using traffic dataset
- Volume reports and statistics for block, train, crew, terminal, and line density

* An operating plan development may involve partial or complete process, depending on scope and timeline

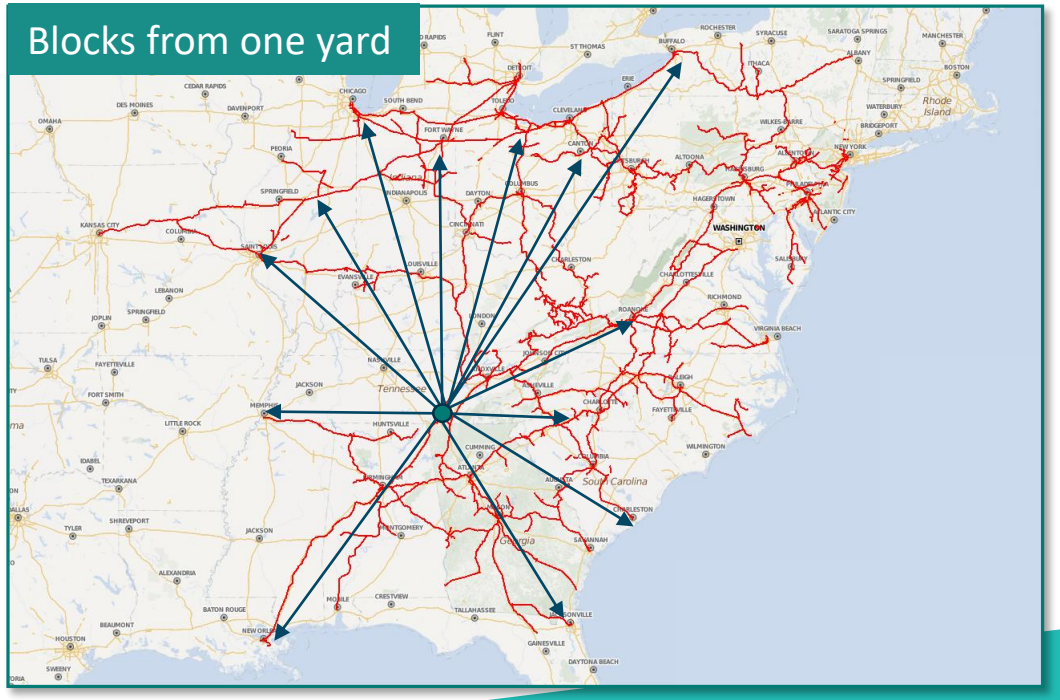
DEVELOPING BLOCKING PLAN

*Optimal Blocking Model (OBM)**

- Generate an Optimal Blocking Plan
  - Based on forecast or historical traffic
  - Identify block O-D pairs, block routes, and block volume

- *OBM* Model Objectives
  - Minimize car miles traveled
  - Minimize handling or classification

- Primary Uses of *OBM*
  - Zero-based plan, e.g., network redesign
  - Plan adjustments due to traffic shift
  - Continuous improvement
  - Sensitivity analysis, e.g., blocking capacity
  - Network optimization, e.g., yard rationalization



** Partner with Innovative Scheduling, now Optym*

DESIGNING TRAIN SERVICE

Scheduled Train Service

- Manifest train for carload traffic, operating on a weekly, repeatable schedule
- Mixed freight and multiple car types
  - General merchandise such as paper, lumber, plastics, fertilizers, metals, …
  - Automotive or finished vehicles
  - Intermodal flatcars, contains and trailers

Unscheduled Train Service

- Unit Train, also known as Bulk Train, for bulk commodity, operating on demand
- Single commodity and car type
  - Coal
  - Grain
  - Crude oil
  - …

DESIGNING SCHEDULED TRAIN SERVICE

Optimal Train Model (OTM)

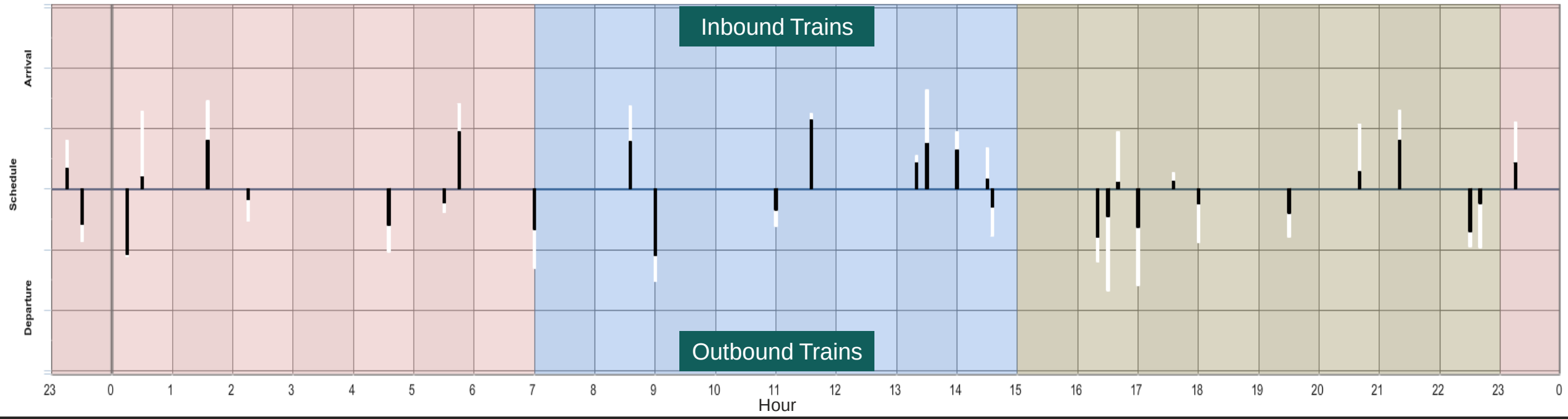
- Generate Optimal Train Schedule
  - Based on a blocking plan
  - Determine train route, frequency, day-of-week operation, and detailed schedule (or timetable)
  - Determine block-to-train assignments, block pickup and set off
- *OTM* Model Objectives
  - Minimize train/crew starts
  - Minimize car days
- *OTM* Algorithms
  - MIP model and heuristics
- Primary Uses of *OTM*
  - Zero-based plan, e.g., network redesign
  - Incremental train plan changes
  - Continuous improvement

DESIGNING UNSCHEDULED TRAIN SERVICE

Unit Train Generator (UTG)

- Design Unit Train Service
  - Provide essential service for bulk commodity customers
  - Using historical or future traffic forecast
- *UTG* Algorithms:
  - Utilize statistical analysis to identify patterns in unit train service
- Generate Complete Unit Train Service Plan
  - Train symbol
  - Train route
  - Train schedule
  - Train frequency
  - Train size

TERMINAL CLOCK

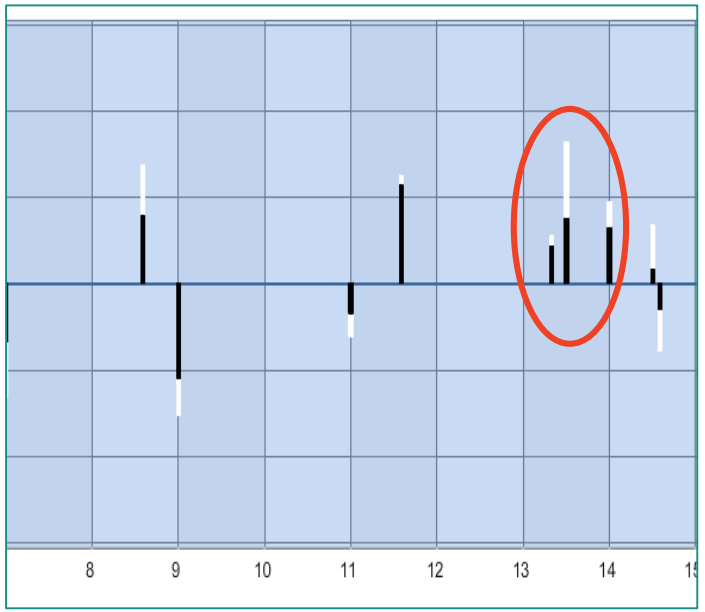


OPTIMIZING TERMINAL CLOCK

Terminal Clock Optimizer (TCO)

- Terminal Congestion
  - A car spends about 2/3 of its time dwelling at terminals.
  - Bunching of arriving/inbound trains or departing/outbound trains
  - Causing resource contention, capacity shortage, and train delay
- Business Goals
  - Increase car velocity, a key element of PSR (Precision Scheduled Railroading)
  - Reduce terminal congestion
- *TCO* Model Objectives
  - Reduce car dwell time at terminal to improve car velocity
  - Balance train arrivals and departures to reduce terminal congestion
- *TCO* Algorithms
  - Optimize train arrivals and departures to reduce car dwell time and balance terminal clock
  - Subject to yard capacity constraints

Terminal Clock
(1st Shift 7 AM – 3 PM)



OPERATING PLAN DEVELOPER (OPD)

A network simulator of “virtual railroad”

- Simulate entire railroad operations and quantify potential impact of any operating plan changes prior to implementation

Network planning and service design tool

- Transitioning to PSR (Precision Scheduled railroading)
- Yard rationalization
- Continuous improvement

NORFOLK SOUTHERN

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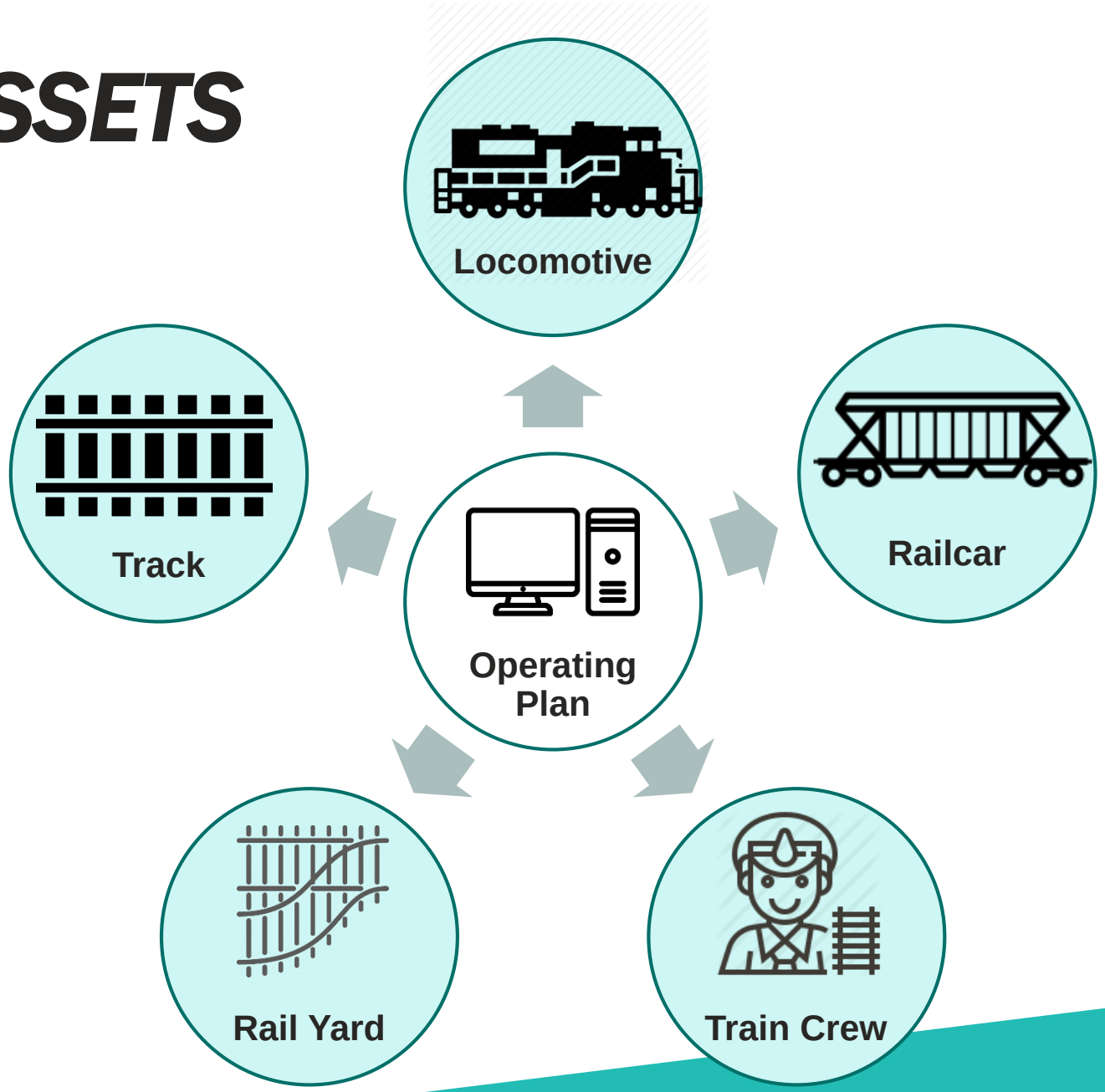
MANAGING ASSETS AND CAPACITY

MAJOR ASSETS



MANAGING LOCOMOTIVES

Locomotive Fleet Planning

- Locomotives are expensive yet critical equipment for transporting shipments
- Take a long lead time to acquire
- Lack of locomotives will cause train delay and hinder future growth
- Determine the right locomotive fleet size is important for railroad operations

Realtime Locomotive Shop Routing

- Locomotives are due for scheduled inspection and maintenance at a fixed interval under Federal Railway Administration (FRA) regulations
- The real-time optimization model routes FRA-due locomotives to the right shops at the right time to reduce locomotive downtime and improve locomotive utilization

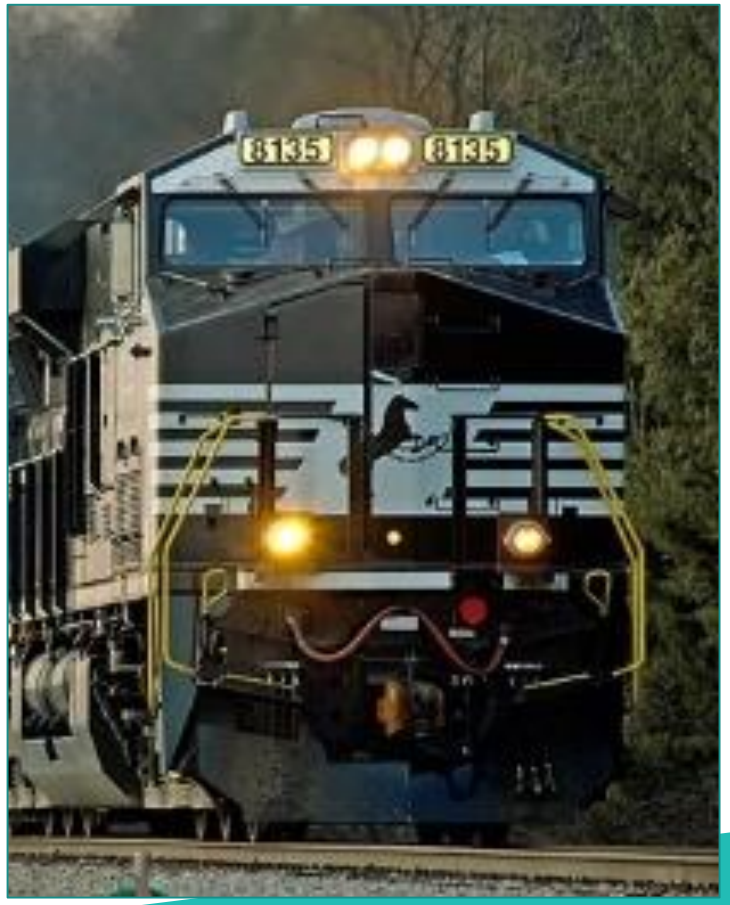
LOCOMOTIVE FLEET PLANNING

Locomotive Assignment and Routing System (LARS)

- Determine locomotive fleet size to meet current and forecasted demand for train service including:
  - Scheduled trains
  - Unscheduled unit or bulk trains

- Locomotive planning is a complex process and subject to many operational constraints and business rules, e.g.,
  - Train priority: intermodal, manifest and unit train
  - Special equipment: cab signal, Locomotive Speed Limiter (LSL)
  - Allowable power swap locations
  - Consist busting not preferred
  - Locomotive repositions: in-tow or light engine moves

- *LARS* Algorithms*
  - Approximation Dynamic Programming (ADP)
  - Combining optimization and simulation

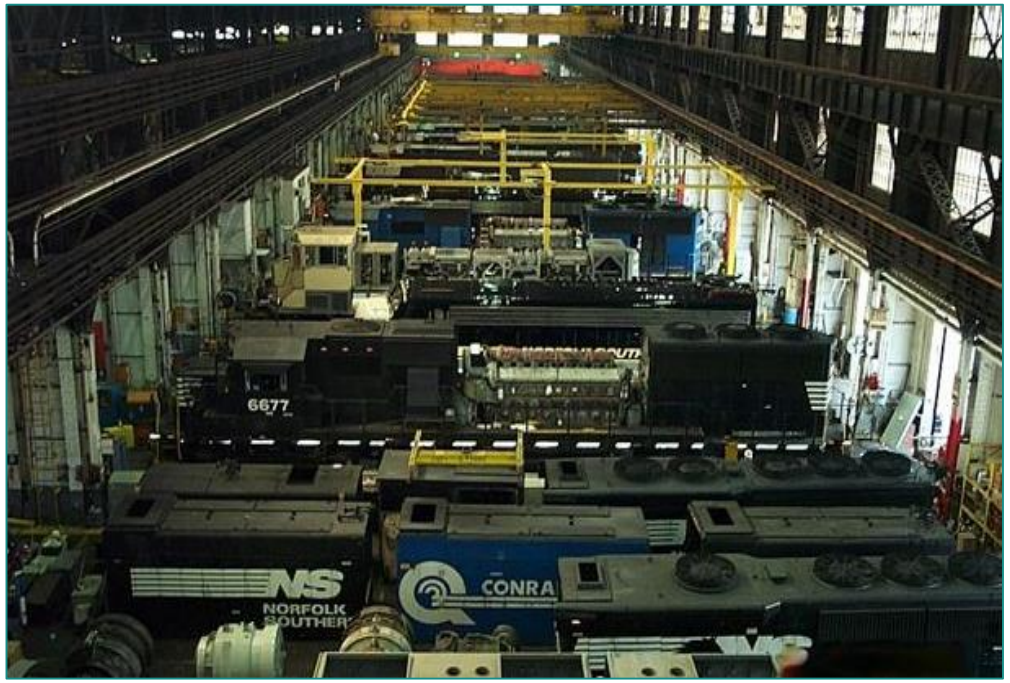


** Partner with Princeton University. Winner of the Best Paper Award, Society for Transportation Science and Logistics, INFORMS, 2015*

REALTIME LOCOMOTIVE SHOP ROUTING

LARS Shop Routing Optimization System

- Determine Optimal Routes for FRA-due Locomotives
  - Minimize locomotive down time
  - Maximize on-time arrivals and shop compliance
- Model Constraints
  - Home shop preferred to alternative shops
  - Shop capacity considered to reduce congestion
- Business Benefits
  - Improved home shop compliance
  - Improved on-time arrival at shop
- Model Extension
  - Optimal shop routing for unscheduled locomotive repairs is under development



MANAGING RAILCARS

Railcar Fleet Planning

- Railcars are expensive to own and maintain and take a long lead time to acquire
- NS railcar fleet is composed of 50+ car types with each satisfying specific demand
- It's imperative to determine the right fleet sizes to minimize costs yet be prepared for future growth

Realtime Empty Car Distribution

- After a railcar is unloaded and becomes empty, where should the car go next?
- The model finds the next load by matching car supply with customer demand
- The model optimizes and automates the empty car distribution to improve car utilization and better serve customers

RAILCAR FLEET PLANNING

Strategic Fleet Planning Model (SFPM)

- Determine optimal car acquisition strategies to maximize long-term profits over the entire fleet (50+ car types):
  - How much revenue/profit will not be earned if do nothing?
  - Is it better to lease cars or buy cars now?
  - When to purchase and how many to purchase?

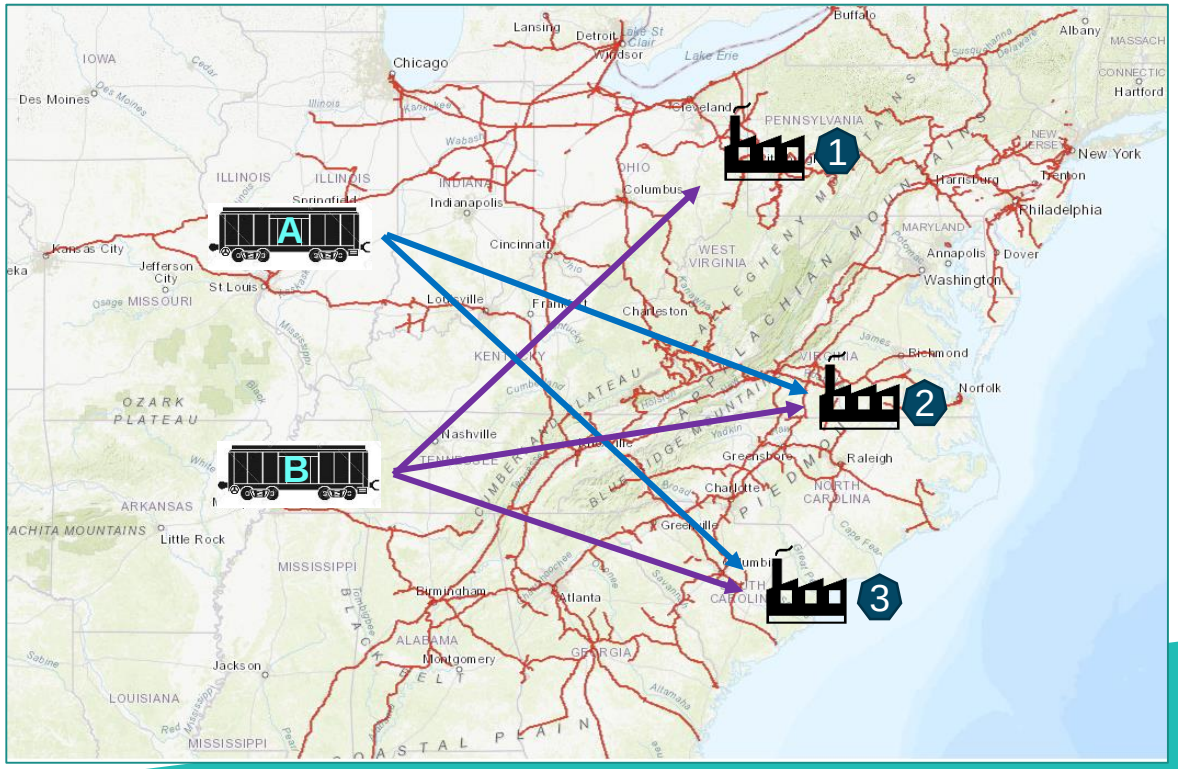
- Key components of *SFPM*
  - Monte-Carlo simulation model to analyze fleet outlook over a multi-year horizon and quantify revenue/profit at risk associated with car shortage

  - Optimization model (IP) generates a multi-year schedule of purchases, leases, repairs, and modifications to maximize profit, given budget constraints

REALTIME EMPTY RAILCAR DISTRIBUTION

Real-time Optimization Engine in TEAMS (Thoroughbred Equipment and Asset Management System)

- Business Goals
  - Maximize equipment utilization, minimize costs, and provide best customer service
- Model Objectives
  - Minimize railcar travel time and distance
  - Reward on-time arrivals
  - Provide right equipment
- Model Constraints
  - Potentially limited supply
  - Equipment preference
  - Operating plan for railcar routing
- Algorithms
  - Modeled as a Transportation Problem
  - IP formulation solved using CPLEX



MANAGING TRAIN & ENGINE (T&E) CREWS

Crew Capacity Planning

- Right-size regular crew pools and extra boards to meet current and future train demand
- Evaluate the impact of changes in traffic volume, train plan, rest rules, crew mark-off, and government regulations

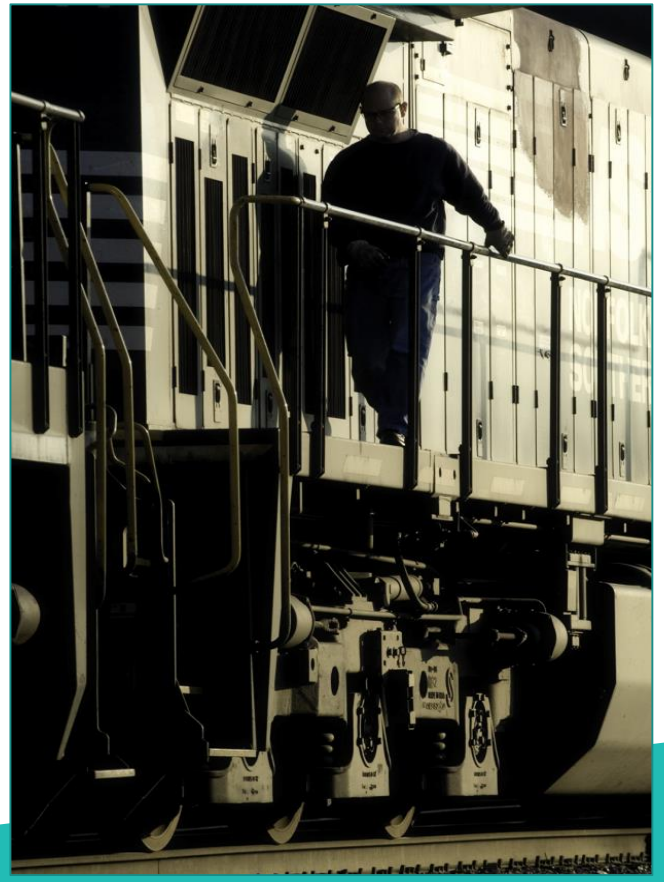
Realtime Crew Optimization

- Crew dispatching involves crew-to-train assignment and crew reposition to balance crew flow (i.e., deadhead) or prevent crew detention
- The model optimizes crew assignment and reposition to improve crew utilization and reduce total crew cost in deadhead, detention, taxi, and lodging

CREW CAPACITY PLANNING

Planning Tool to Simulate Crew Operations and Optimize Crew Capacity

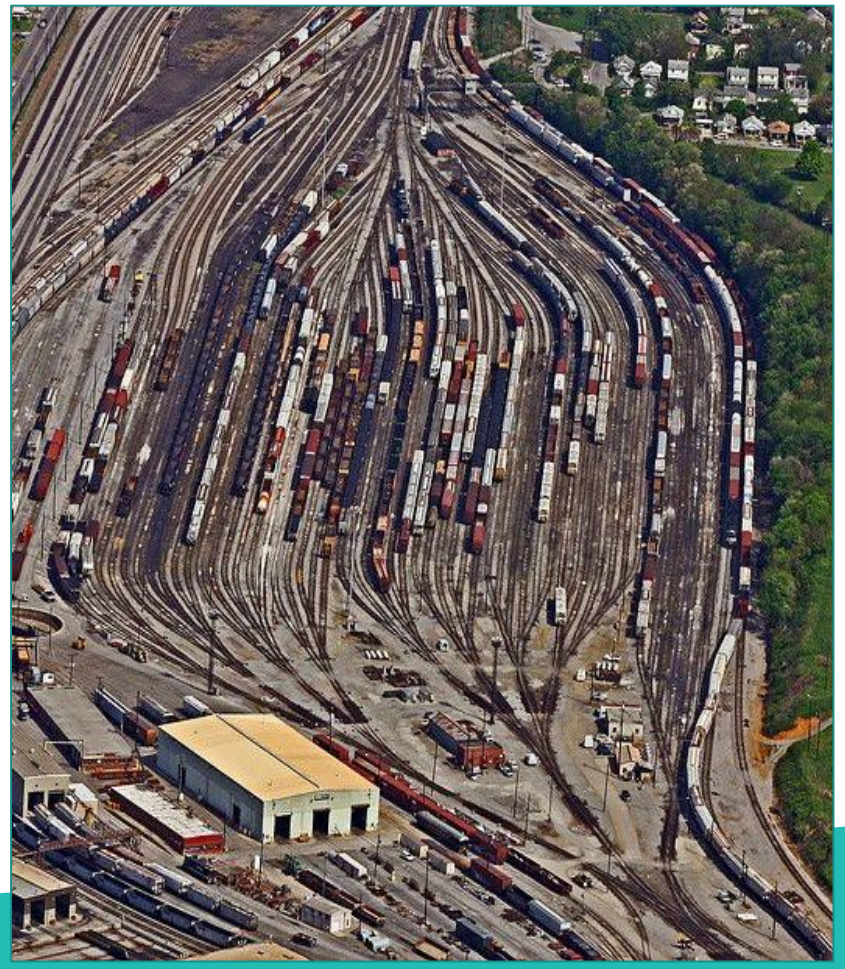
- Business Goals
  - Right size regular crew pools and extra boards to meet current or future traffic demands
- Model Objectives
  - Minimize crew costs and train delays
- Model Constraints
  - Federal regulations, e.g., hours of service
  - Crew operating rules, e.g., max on-duty time
  - Crew rest rules, e.g., minimum rest time at home and away
  - Train schedule and crew profile
- Algorithms and Outputs
  - Combining crew simulation and optimization models
  - Optimal size of each regular pool and extra boards



RAILROAD YARD CAPACITY PLANNING

Capacity Planning Tool for Marshalling Yards

- Business Goals
  - Understand yard capacity in order to develop robust operating plan
  - Evaluate the impact of changes in train plan, yard infrastructure, resource level, and operating policy
- Model Objectives
  - Determine yard capacity
  - Optimize the allocation of yard resources
- Algorithms
  - Models are developed based on key capacity drivers in the yard such as yard infrastructure, resources, and operating plan
  - Models are modularized so they are adaptable and scalable for various yard types



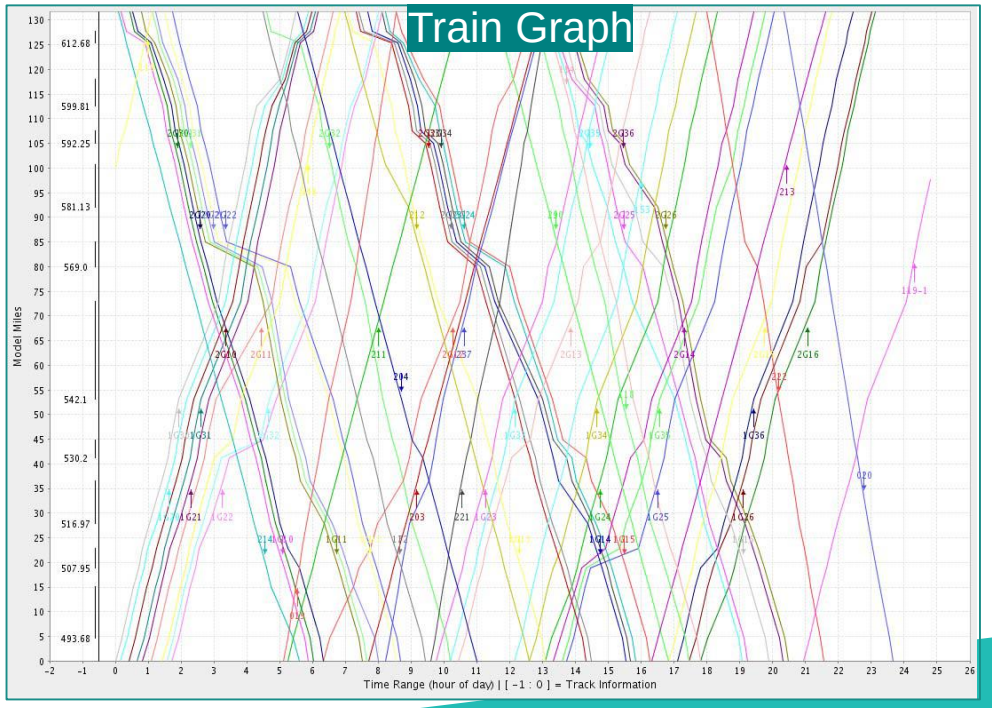
LINE CAPACITY PLANNING

LineMAX: A Planning Tool to Determine Line Capacity and Utilization

- Business Goals
  - Determine practical capacity of major line segments and identify potential bottlenecks in the network

- Key Features and Parameters in *LineMAX*
  - Track authority: centralized traffic control (CTC), automated block signaling (ABS), and dark territory
  - Track type: Single and double track
  - Siding: length, # of sidings, distance in between
  - Topography: grade and curvature
  - Operation: train speed, headway separation

- *LineMAX* Algorithms and Outputs
  - An integer programming (IP) model for meet-pass planning
  - Add model trains to fill available slots
  - Determine line capacity as the max number of trains operating on a line segment



05

SUMMARY

Operations Research (OR) Tool Suite for Operations Planning and Asset & Capacity Management at Norfolk Southern

	Network	Yard	Line of Road	Crew	Locomotive	Railcar
Operations Planning	Network Simulator Optimal Blocking Model Optimal Train Model Unit/Bulk Train Generator	Terminal Clock Optimization		Crew Simulator		
Asset & Capacity Planning	Network Optimization	Yard Capacity Planning	Line Capacity Model	Crew Capacity Planning	Locomotive Fleet Sizing	Railcar Fleet Planning
Realtime System				Crew Balancing	Locomotive Shop Routing	Railcar Distribution

In Production · Key Functions Deployed · Under Development

CLOSING REMARKS

Success Factors

- Work closely with business partners so optimization is not a black box
- Align the modeling effort with company's strategic plan and business needs
- Delivery an OR model as a robust software solution, so it is always available and working properly

Future Trends

- Realtime optimization systems to improve productivity and efficiency
- Automation of decision making and digital transformation
- Prescriptive analytics: combining optimization with prediction for maximum benefits

THANK YOU

For questions or comments,
please contact Dr. Clark Cheng
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