MANAGING ASSETS AND CAPACITY FOR SUSTAINABLE GROWTH

How Norfolk Southern Leverages Operations Research

November 19, 2020
OUTLINE

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US RAILROAD INDUSTRY AND NORFOLK SOUTHERN
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

- **Sand, stone & gravel:**
  - 1.3 million carloads

- **Plastics, fertilizers and other chemicals:**
  - 2.2 million carloads

- **Transportation equipment:**
  - 1.4 million carloads

- **Coal:**
  - 6.3 million carloads

**And much more!**

Source: Association of American Railroads (AAR)

Figures are 2012.
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
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<table>
<thead>
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<tbody>
<tr>
<td>Number of employees</td>
<td>24,587</td>
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<tr>
<td>Miles of road operated</td>
<td>19,451</td>
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<tr>
<td>Track miles operated</td>
<td>35,592</td>
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<tr>
<td>Locomotives owned and leased</td>
<td>3,906</td>
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<tr>
<td>Freight cars owned and leased</td>
<td>50,553</td>
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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
OR TOOL SUITE AT NORFOLK SOUTHERN
PLANNING LEAD TIME

- Build 5 Miles DT
- Hire Engineer
- Buy New Cars
- Correct a Mistake
- Purchase 50 Locos
- Abandonment
- Revise OP (TOPx)
- Lease to a SL
- Close a Yard
- Discontinue Service
- Abolish Local
- Furlough Employees

Years
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
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
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
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
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
MANAGING ASSETS AND CAPACITY
MAJOR ASSETS

- Locomotive
- Railcar
- Operating Plan
- Track
- Rail Yard
- Train Crew
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
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

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

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<tr>
<th>Operations Planning</th>
<th>Asset &amp; Capacity Planning</th>
<th>Realtime System</th>
<th>Network</th>
<th>Yard</th>
<th>Line of Road</th>
<th>Crew</th>
<th>Locomotive</th>
<th>Railcar</th>
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<td>Network Optimization</td>
<td>Terminal Clock Optimization</td>
<td>In Production</td>
<td>Key Functions Deployed</td>
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<td>Locomotive Shop Routing</td>
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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 at clark.cheng@nscorp.com