Josh Onuska
Joe Monahan
OA4202 Networks

Problem

Backstory: Norfolk Southern Railroad Company (NS) is a rail transporter of various goods, ranging from coal and grain to raw steel and automotive parts. NS is an industry leader in the shipment of automobiles throughout North America and has a unique partnership with Ford Motor Company, for the exclusive transportation of their vehicles. Although NS ships vehicles to all of North America, we have scoped our project to focus primarily on East Coast deliveries.

The rail shipment of automobiles is big business, considering NS's 2010 earnings report that cited $650 million dollars in revenue from automotive transportation[i] and an estimated increase of 20% for 2011. For this reason, we chose to evaluate the cost effectiveness of current shipping routes and the implications of delays or disruptions.

Interdictions are a real fear for NS. In a 2010 investor relations report, NS cited risks to their transportation model as, terrorism or war, labor union strikes, and severe weather[ii]. These attacks on the network represent threats to profitability and the company's long-term success.

Problem Formulation: In our model, there are 54 nodes representing U.S. cities. Of these 54 nodes, 5 are classified as "Assembly Plant Nodes", 4 are classified as "Mixing Center Nodes", and 25 are classified as "Distribution Facility Nodes". Each assembly plant manufactures a different model of vehicle, producing a supply at those nodes. This supply is modeled as 5 distinct commodities, one for each factory, representing the different model types. Each mixing center receives an equal distribution of these commodities from the assembly plants and releases them as a separate single commodity. This new commodity now represents the vehicles as a mixed batch. The commodity then flows to distribution facilities at various locations, which all have a specific demand and capacity for mixed vehicles. The tables below reflect the nodes of the Assembly Plants and Mixing Centers.

Assembly Plants

Location	Supply	Model
Cleveland	5,000	Econoline Van
Chicago	5,000	Taurus, Explorer
Detroit	10,000	Mustang, F-150, Focus
Kansas City	5,000	F-150, Escape, Contour
Louisville	5,000	SuperDuty,Expedition,Navigator

Mixing Centers

Location	Capacity	Region
Chicago	5938	NE/NW
Louisville	3510	SE/E
Toledo	2800	NE
Kansas City	2538	NW/MW

**Assembly Plant Nodes including Supply and Model of vehicle(s) manufactured at each location. Also, Mixing Centers depicting the nodal capacity and region supported from that mixing location.

The NS rail network is an intricate web of nearly 22,000 miles of track. To simplify the problem, an abstraction of the rail system, seen below, represents paths between cities as straight lines. A single arc connects two cities and has an associated length and capacity.

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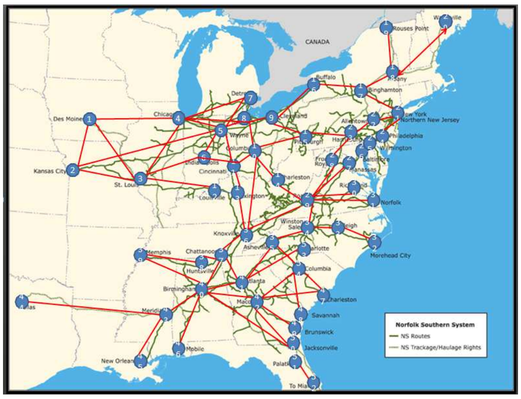
Rail Network Abstraction | GAMS Model Abstraction



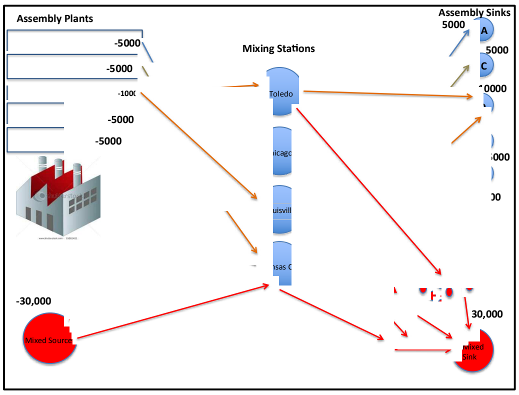


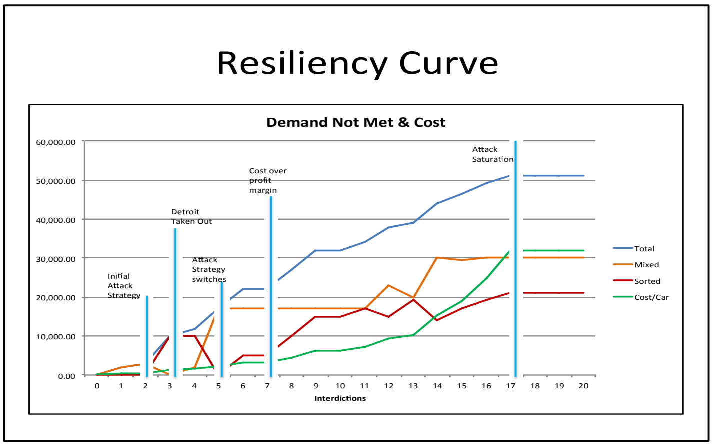
**Figure1: Abstract depiction of the Norfolk Southern Company rail network overlaid on a map of the US.
**Figure2: Abstract depiction of the model implemented in GAMS. Supply, demand, and node/arc relationships represented.

This problem was modeled as a multi-commodity flow (see GAMS model abstraction above) in order to handle the various vehicle models and subsequent mixture of vehicles being transported. In total, the assembly plants supply 30,000 sorted vehicles of 5 different types and each distribution facility demands a certain quantity of these vehicles after they have been appropriately mixed. The primary goal of the network is to satisfy this demand by supplying the requisite amount of vehicles to distribution facilities at the lowest cost.

Results

The initial results of the model yield an average cost of $212 to ship a vehicle from plant to distribution facility with all vehicle demand satisfied. However, as the number of interdictions increase, the cost to transport vehicles quickly rises. After one attack on the network the average cost per vehicle is $386 and DNM rises to 2,000 vehicles. With 5 attacks on the network, the average cost per vehicle jumps to $2,303 and DNM rises to 17,000 vehicles. At this point, most of Ford's profit margin is consumed. When 17 interdictions are added to the model, the average cost per vehicle reaches a maximum of $31,873 and DNM rises to the point where no vehicles are delivered to distribution centers.

The resiliency of the network is depicted in the chart below where DNM and Cost are plotted against interdictions.



** Resiliency Curve: Demand Not Met (DNM) and Cost are graphed vs. Interdictions. The chart illustrates that cost and Demand Not Met rise as the number of interdictions increase.

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Explanation

The model seeks the shortest path of delivery and returns the route along with any Demand Not Met. As interdictions are introduced to the model, arcs between nodes are considered impassable. Initially with just one or two interdictions the best placement of attacks (from the attacker's perspective) occurs at the terminal edges of the network where there are isolated distribution facilities resulting in the most loss of demand per attack. The first attack prevents vehicles from going to Meridian, and New Orleans; major southern distribution facilities, whereas the second attack cuts off Miami. With three attacks, the strategy switches to attacking Detroit, our largest producer of vehicles, and prevents 10,000 sorted vehicles from reaching mixing centers. As we continue to add interdictions, the model combines the strategies of cutting off the isolated distribution centers and isolating assembly plants until interdiction saturation occurs at 17 attacks. At this point no further demand can be denied with additional attacks.

Due to the hub and spoke design of our network it is interesting to find that rail miles actually decrease as interdictions increase. The reason for this is two-fold. First, as interdictions increase DNM increases and less vehicles are delivered resulting in fewer rail miles. Additionally, those that are delivered are more likely to be closer to the mixing centers, resulting in a reduced average shipping distance per vehicle.

We also discovered that DNM is a driving force for cost increases associated with interdictions. Our network is very susceptible to unsatisfied demand in the event of an interdiction. As the resiliency curve shows, the cost of delivery quickly increases after just a few interdictions. This cost increase is mostly attributed to the penalty factor we implemented that accounts for DNM as a cost associated with loss in profit due to lost sales. Supply issues can significantly impact a company's market share.

Open-Ended Analysis: As a part of our open-ended analysis, we allowed the model to choose to bypass a mixing center and reroute all supply through only three mixing centers. To our surprise the best path bypassed the Chicago, IL mixing center, routing all vehicles into Louisville, Toledo, and Kansas City. Eliminating one of the four mixing centers resulted in an increase in profitability, with an estimated weekly savings of $195,375!

Limiting Assumptions: More detailed information would certainly be helpful. Despite our best efforts, NS Executives for Automotive Transportation were unable to divulge actual data concerning Ford's contract and shipment numbers. Most of our supply and demand data was derived from open source sales numbers. While we feel we are definitely in the ballpark, actual data would make things more realistic and interesting.

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[i] 2010 Norfolk Southern Investor Relations Report