



## **Resilience of Coal Transport on the Three Rivers Waterway System**

OA4202 – Network Flows and Graphs  
Course Project (November 2011)

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**Background:**

Pittsburgh is one of the great industrial cities of the United States. \$9 billion of commerce flow through the Port of Pittsburgh annually, making it the 2<sup>nd</sup> largest inland port and 20<sup>th</sup> largest overall port in the U.S. Coal comprises 76% of the total commerce flow, making it by far the most influential commodity in that area. Coal is used to produce power to run approximately half of the country’s electrical power grid. Coal Coke is a primary resource for the production of steel. Pittsburgh currently produces 25% of steel used in the U.S. Given this information, coal can be considered a key resource and primary driver of the commerce flow along the Three Rivers.

The United States Coast Guard is responsible for the Maritime Transit System for all coastal and inland waterways. Under the Department of Homeland Security, the Coast Guard is also charged with protecting critical infrastructure and key resources from possible terrorist attacks. Specifically, through the Ports, Waterways, and Coastal Security mission, the Coast Guard must ensure the continuous flow of commerce along the Maritime Transit System. Therefore, the Coast Guard would like to assess the network that moves coal through the Port of Pittsburgh and Three Rivers and then determine how to allocate its limited number of resources. See figures 1 and 2 for an overview of the study area.



Figure 1: Inland Waterways

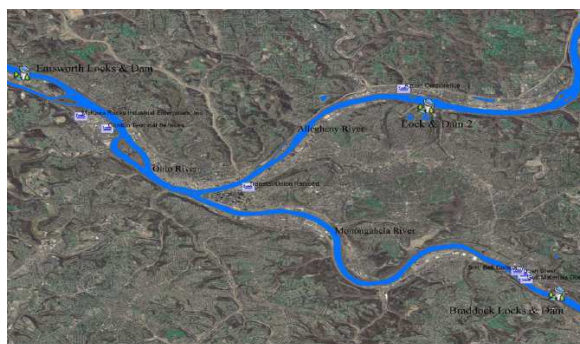


Figure 2: Three Rivers Study Area

**Building the Network**

Coal can move by three different modes of transport. To move a ton of coal one mile by **barge** would cost \$.005, by **railway** \$.05, and by **truck** \$.10. The waterways are therefore the most efficient and economical mode of transportation. Pittsburgh has infrastructure in place to move coal by all three modes of transport, however, under normal operation barges are used as the primary method of moving coal through the system. If something were to disrupt the normal flow, contingencies are in place to move coal by rail given the constraints of crane offloading capacities, and at an increased cost. To model the normal flow, we identify supply and demand locations which will be represented by nodes. We will also represent choke points and transfer locations as nodes. Arcs between these nodes will indicate that coal can move along that path. For our model we use both waterways and railways to move coal from its supply to its demand. The objective of the coal transport network problem is to minimize the overall cost given a maximized effort to disrupt. To optimize the solution to this problem, we can use a min-cost flow mixed integer linear program.

The network model we used consists of twenty-five nodes and thirty-five, two-way arcs. Overall there were two net supply nodes and three net demand nodes. Eight of the nodes are land based while the rest are river based. Of the arcs, nine are railway arcs, eight are terminal offload arcs, and eighteen are river arcs. In the GAMS model the terminal arcs are not subject to disruption. Each arc is assigned a cost and maximum capacity as seen in Figure 3.

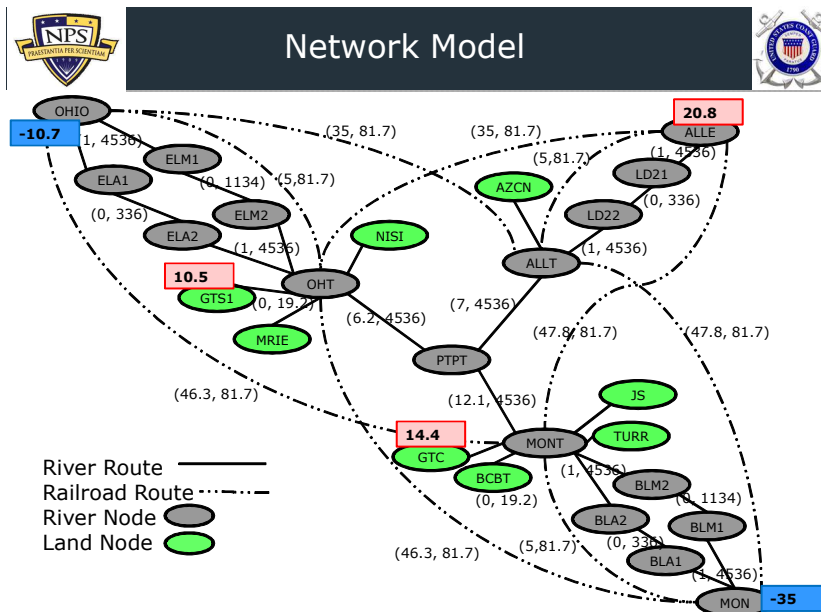


Figure 3: Network Model

Under normal operations, the coal supply flows from the Monongahela River and the Ohio River through the river arcs to the demand nodes of GTC and GTS1, respectively. The remainder of the coal supply continues along the river nodes to the net demand node, ALLE, which represents demands of terminals upriver along the Allegheny River. The base cost for normal operations is 452 units / ton-mile.

Using the GAMS model to determine and disrupt the most critical single arc caused the cost to more than double to 1026. The most critical single arc is the connection between Point Pitt (PTPT) and the Allegheny Transfer node (ALLT). This disruption caused the coal supply to ALLE to utilize railroad arcs to meet demand as seen in Figure 4. The second most critical single node is the Monongahela River Transfer (MONT) to PTPT. This caused the supply from the MON destined for the ALLE to move by rail while the Ohio coal transport was unaffected. The cost of the second most critical arc is 1022. These are the only two critical arcs given a single disruption.

Given two simultaneous disruptions the cost was still 1026 due to the redundancy of the railroad structure in the study area. The cost remained the same when using the second pair of arc disruptions. Given three simultaneous disruptions the enemy is capable of shutting off flow through the Braddock Lock and Dam system, BLM1 and BLA1. This causes longer railway routes of larger coal tonnage

increasing cost to 1934. A second set of three arc attacks focused disrupting flow of coal from the MON to the ALLE. The demand was still met at a cost of 1263.

Only four simultaneous arc attacks were able to stop demands from being met. Since the model penalizes unmet demand, the cost becomes a staggering 25,838. Four attacks completely isolate the upper Allegheny River from the coal supplies as seen in Figure 5. If we defend those four arcs, the next four-arc attack only cost 2337 and changes the attack focus to the Monongahela River.

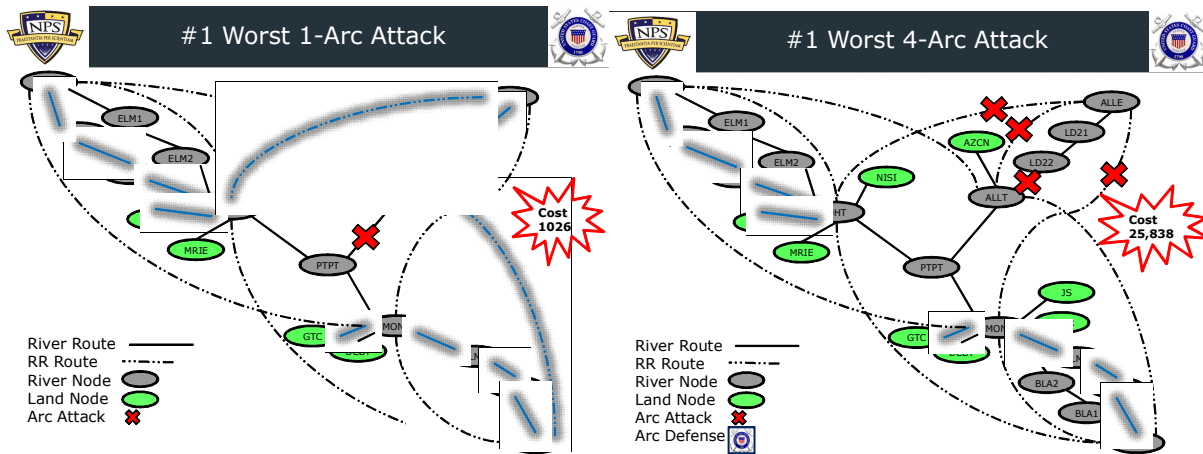


FIGURE 4: Worst 1-arc attack

Figure 5: Worst 4-arc attack

**Summary and Conclusions**

In summary, to make our model run, yet best reflect realistic flows, we had to make some assumptions. If these assumptions prove to be incorrect, then the solution may vary from the one we present. We assume the flow in and out of the study area as a net flow supply or demand. A more realistic approach could involve modeling each river as a multi-commodity to more closely track the total flow, not the net flow. We used a timeline of one week for our model. We assume an attack on any one arc in our network would cause a minimum of a seven day disruption. Modeling this problem in the context of a month or year would introduce diversity in the length of time an arc would be removed from the system depending on the infrastructure and method of attack. For example a lock and dam would take longer to repair than a bridge. The cost ratio of barge compared to rail was 1:2.5. The exact ratio is not known and would vary from location to location, however all data reviewed indicates that the cost of rail is higher than the cost of barge.

The most notable results from our study show that one attack at a critical location along the waterway could double the cost of flow. Four simultaneous attacks would increase the cost of the system 50 times that of normal operations, creating a significant economic impact. The Coast Guard could prevent a major economic impact to the system by protecting the four most critical arcs. Further study for this project would entail validating the assumptions, analyzing multiple time frames, and then broadening the scope to enlarge the flow network.