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New York City Subway Interdiction

EXECUTIVE SUMMARY

Background

When it comes to the number of operating stations, the New York City (NYC) subway network is the largest rapid transit system in the world. In 2012, the NYC subway system averaged 5.4 million rides per day Monday thru Friday, 3.2 million rides per day on Saturday and 2.5 million rides on Sunday.[1] The number of rides given per day coupled with the number of operating stations, makes the NYC subway network a powerful tool for anyone looking to blend into the surrounding population and make a quick exit. Additionally, consisting of 468 operating stations, 209 miles of track and 34 subway lines, the NYC subway network provides a near perfect network graph from which to devise and apply a minimum cost flow network and interdiction.

Problem

It has been less than 24 hours since several art pieces; valuing in the millions of dollars, were stolen from the New York Metropolitan Museum. Fortunately, the New York Police Department (NYPD) was able to confirm a positive identification on one of the perpetrators from a video surveillance camera located across the street from the museum. With further police work, the NYPD knows the perpetrator frequently travels the NYC subway system and was recently seen near Times Square, which gives him 4 possible subway stations to enter. Furthermore, the NYPD knows that the perpetrator has possible ally's working with him and if he reaches the South Ferry, the 168th station or one of the two airports (LaGuardia or JFK) he will be able to disappear out of the reaches of the NYPD.

Assumptions

- Perpetrator is restricted to Subway; therefore, once the perpetrator enters the system via one of the four optional starting nodes, he's going to remain in the system until he either reaches one of the five possible exit stations or he's caught via our interdiction strategy.
- Once the perpetrator enters the subway system he's only concerned with minimizing the number of stops he encounters while transiting from the start to end node. Therefore, the time and distance it takes to travel between each transfer stations is irrelevant in this model.
- Starting Nodes:
  - Times Square, 42nd St.
  - 34th St.
  - Grand Central
  - 47th – 50th St., Rockefeller Center
- Escape Nodes:
  - South Ferry
  - Sutphin Blvd, Archer
  - Jackson Heights, Roosevelt Ave
  - Howard Beach, JFK Airport
  - 168th St.

[1] *Subway and Bus Ridership Statistics 2012*. New York Metropolitan Transportation Authority. April 2, 2013. http://mta.info/nyct/facts/ridership/index.htm

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Scope

The geographic confines of the model lies entirely within the structure of the NYC subway system; the model is an effort to track and eventually interdict the perpetrator's movements throughout the subway system as he attempts to reach one of the five possible escape nodes. The first step in creating the network is to determine which of the available 468 operating systems to utilize. Once the determination is made as to which nodes to use, the arcs will simply be the subway lines that directly connect each station to their respective neighboring stations. As previously stated in the assumptions, because the perpetrator is restricted to the subway, the perpetrator exiting the subway at a station and departing the system is of no concern. Therefore, only transfer stations are nodes, i.e. nodes where the perpetrator is able to enter a station on one train and exit the station on another train in an attempt to reach an end nodes and evade interdiction.

The length of each edge is the number of subway stations encountered in between transfer stations, and the statistic that the perpetrator will be looking to minimize. Additionally, the perpetrator will enter the subway system near Times Square, meaning he will enter at one of the four Starting Nodes and will attempt to reach one of the five Escape Nodes to evade capture. With the above fact in mind, a system within the NYC subway structure consisting of 42 nodes and 158 edges can be sufficiently creating and demonstrate the utilization and interdiction of a min-cost flow.

The actual interdiction strategy consists of the NYPD essentially eliminating an arc by holding the train at the transfer station until everyone on that train has been identified. Additionally, because each train pulls into a station at a unique platform, by interdicting one arc, not all arcs entering that respective node are cut off.

Analysis / Results

Running the problem through multiple scenarios, we found that the path the perpetrator took drastically changed depending on the number of interdictions we implemented. His first path, with no interdictions, had him starting at Grand Central and led him to LaGuardia Airport with a total of four stops. With two interdictions, the perpetrator still escaped to LaGuardia, but had him utilizing a different starting node and encountering five stops. From there, we progressively increased the number on interdictions by a factor of one to see how the number of interdictions influenced the perpetrator's path. After effectively cutting off LaGuardia Airport, the perpetrator started going to the next closest escape node which was the South Ferry, where he continued to escape on the third, fourth and fifth interdictions with a longest path of 11 stops. Interdictions six and seven resulted in the perpetrator proceeding to the 168th St. station, where he escaped via the George Washington Bridge. The eighth and ninth interdictions forced the perpetrator to travel all the way across the city to JFK airport, for a total of 22 and 27 stops respectively. It was not until we had a total of ten interdictions that we were able to stop the

perpetrator from escaping.

In analyzing the results, we not only found our interdictions to be effective at eventually stopping him, but we also found them, and his response paths, to make sense via manual confirmation of the subway map. With that, we decided to change our program so that we were not able to interdict arcs that went directly into exit nodes. In doing so, we found that it only took one more interdiction to stop the perpetrator, despite a completely different set of arcs being utilized; where the new interdicted arcs were blocking his routes near the start of the program vice the exit nodes.

Finally, additional modifications that could be implemented for further follow-on analysis are:

- Time layering the actual subway schedule to his escape route and giving the perpetrator a drop dead time to ensure escape.
- Minimizing transfer stations instead of subway stations.
- Adding probabilities of capture on each arc based on the number of rides given per day.

Figure 1: NYC Subway System Map
Green Nodes: Starting Nodes
Blue Nodes: Ending Nodes

- **No Interdictions:** Grand Central to LaGuardia Airport
- **Minimum Interdictions to ensure capture:**
  - Ten Interdictions
- Arcs interdicted differ as the number of interdictions increase.