Decision Models Final Project

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Istanbul Metropolitan Municipality Final Report

Smarty Variables:

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1. Introduction

Istanbul is the largest city in Turkey, with 13.5 million people, and spans across two continents: Europe to the west and Asia to the east. The city continues to grow, mostly due to immigrants, but the population growth has led to problems such as increased traffic and aging infrastructure, both of which affect the efficiency of the city's current fire stations. In addition to the dense population, Istanbul is filled with cultural heritage, with castles and monuments from hundreds of years ago. Thus, well-organized fire stations are not only necessary to protect the people, but also the culture of the city.

The Istanbul Metropolitan Municipality (IMM) wants to find the optimal locations for new fire stations that can reach fire incidents within 5 minutes. The purpose of this project is to present and solve a simplified version of the real life problem faced by the IMM.

2. Problem Overview

The Istanbul Metropolitan Municipality (IMM) needs to know where to build additional fire stations in Istanbul, Turkey in order to maximize coverage of its districts. A district is considered covered if it can be reached by a fire station within 5 minutes. Istanbul is organized into 790 districts, and a district is considered covered if the district can be reached by the fire station within five minutes. The fire stations come in four sizes: A, B, C, and D. The A and B type stations have more capacity (more fire trucks) than the C and D type stations. Finally, the report assigns weights to certain districts depending on whether or not there are cultural heritage sites in the district, the heavier the weight, the more "important" the district is.

These network style problems are common in cities, especially densely populated ones, that need to optimize their emergency service systems. The problem here can be solved with three different methods: set covering, maximal coverage and center-type.

Method 1: Set covering model
Using this method, the objective function was to minimize the cost of building fire stations such that every single node is covered by a fire station that is at most 5 minutes travel time away. This can also be interpreted as minimizing the number of fire stations to be built.

Method 2: Maximal covering model
Using this method, the objective function is to maximize the number of nodes covered by a fire station that is at most 5 minutes travel time away, given a fixed budget for building fire stations.

Method 3: Center-type model
Using this method, the objective function is to minimize the maximum system-wide distance (or response time in this case) given a fixed budget.

The original researchers used the set covering and maximal covering models because the center-type model could leave certain districts with unusually long response times. For our project, we have decided to use the maximal coverage model in order to answer the question: at which nodes do we build fire stations such that we maximize the number of nodes covered by fire services, subject to the budget constraints?

3. Methodology
For our project, we have decided to use the maximal coverage model in order to answer the question: at which nodes (districts) do we build fire stations such that we maximize the number of nodes covered by fire services, subject to the budget constraints?

In order to answer the question, we start by drawing the network of districts in Istanbul.

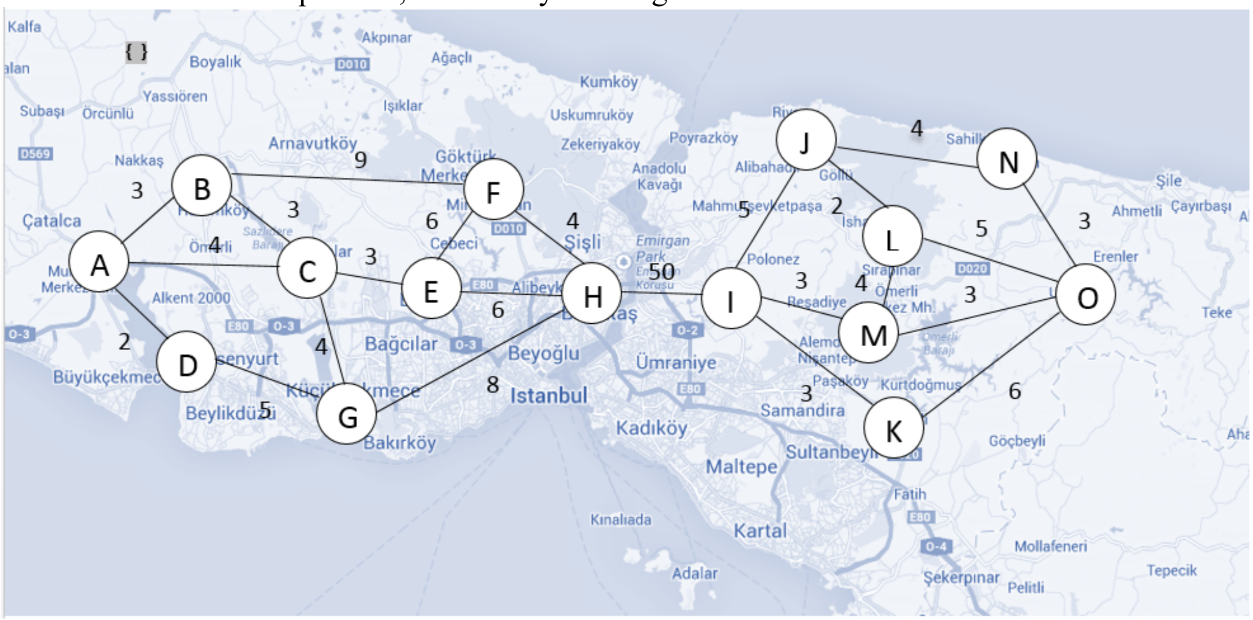

Figure 1: The nodes represent the districts in which a fire station can be build and the edges represent the time it takes to travel between the nodes.

Next, we set our decision variables. The first decision variable takes into account if a fire station should be built in each district, represented by nodes A to O. The second decision variable determines if the district is covered by a fire station (the first decision variable). Districts will only be covered if a fire station is within 10 minutes travel time.

Then, we retrieve our data. We calculate the shortest path from each node to all the other nodes (210 total calculations). For instance, the shortest path from node A to node B is 3, and the shortest path from node A to node E is 7. Calculating the shortest path between two nodes can be done using a simple network optimization model in which we minimize the time it takes to travel between two nodes. However because the shortest paths are used as data in our model and there are 210 shortest paths to calculate, we just computed them by hand. We keep only the shortest paths that are less than or equal to 10 minutes, all others are replaced with 0. We then indicate determine the active shortest paths f by multiplying the first decision variable (build or don’t build) by the shortest path.

Next, our objective function is to maximize the number of covered nodes. Since our objective is to maximize number of nodes covered, Solver will first try to put a “1”. However, if there is no active shortest path for Node i, Solver will be forced to put a “0”, indicating that the node is not covered.
Our objective function is subject to certain constraints. The decision variable corresponding to the decision variable of whether or not the district is covered must be less than or equal to the

sum of active shortest paths coming out of it. The last constraint is the budget constraint of $2,000,000, and because one fire station costs $1,000,000, the number of fire stations built must be equal to 2.

Finally, our model is simplified given the assumptions we put in place. First, we limit the number of possible locations to 15 instead of the original 790 districts across Istanbul. We needed a reasonable number of districts so that the model would make meaningful decisions, but because also have to calculate all the shortest paths between all the nodes as data (discussed in the next paragraph), too many nodes would give Excel Solver too much data to handle. Second, we assume that there is only one type of fire station, instead of four, with uniform capacity, that way each fire station has a supply of 1 fire truck. Third, we assume that each node in our model is equally important for requiring fire services, as opposed to assigning weights to each district based on importance, because our goal is to maximize the number of nodes. Fourth, we consider a district to be covered by a fire station if the district can be reached by a fire station within 10 minutes. Lastly, we assume the cost of a fire station to be $1,000,000 (the costs of fire stations were included in the paper) and the budget to be $2,000,000. Thus, the maximum number of fire stations that can be built is 2, which is appropriate for our small network size.

4. Mathematical Model

Data:
Tij=Time from node i to j
Costi=Fixed cost for building one fire station

Decision Variables:
Let Xibe the decision variable whether or not to build a fire station at Nodei
Let Yibe the indicator variable whether or not Nodeiis covered by Xi

Intermediate Variables:
Aij=If Arc from node i to jis in use
SPij=Shortest Path from node i to j=AijTij

Objective Function:
Maximize i=AOYi

Constraints:
Xi,Yi,Aijare binary
Xi,Yi0
i=AOXi=Fire Station BudgetCosti
SPij10
all j flowing out of iSPij+all j flowing into iSPij(all j flowing out of iSPij+all j flowing into iSPij)10
Yiall j flowing out of iSPij+all j flowing into iSPij
[NET FLOW CONSTRAINTS]

5. Analysis

6. Appendix

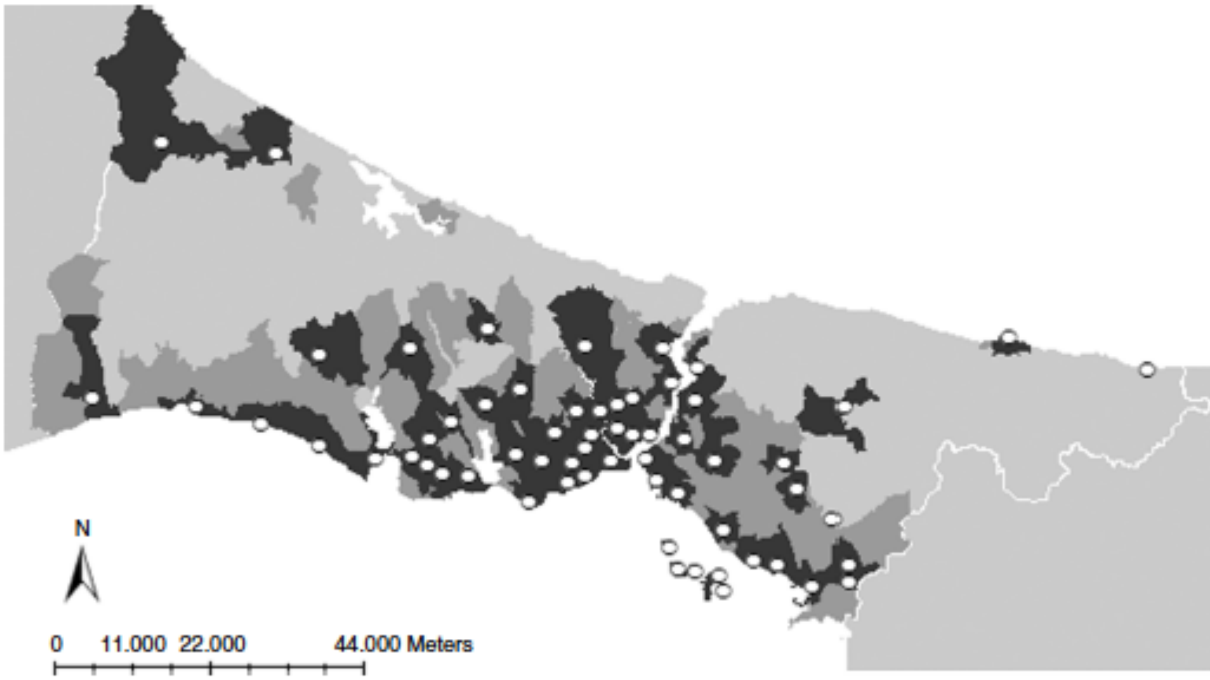

Figure 1: Map of Istanbul’s Current Fire Stations