Road Network Robustness

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Road logistics is one of the hottest problems in today's world. Many people rely on the road network to go to work, buy and deliver supplies, etc. Therefore it is reasonable to analyze the stability of our road networks. By removing roads from the road network using different strategies we test the robustness of the network. We test removal of random, high-degree and central nodes and edges. Our approach is universal for any road network, however we focus on Belgium, The Netherlands and Luxembourg road networks and compare their stability.

Introduction

A working road system is a must in today's society, since it enables us to travel, transfer goods, traverse large distances in relatively short time, go to work, etc. Road network related issues can be unpredictable and can cause many logistic problems. Therefore, it is imperative to study and constantly improve the road systems to avoid or mitigate any issues arising from sudden road failures.

We study the resilience of road networks to failures of specific roads. We analyze how a traffic jam or other similar disturbance on the road would affect the road network. In our research we focus on the road networks of the countries of Benelux (Belgium, Netherlands and Luxembourg)(1). Our goal is to compare the robustness of road networks of these three countries by simulating road failures by random as well as strategical removal of nodes and edges from the network.

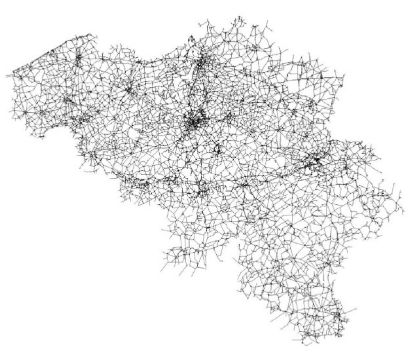

Fig. 1. Belgian road network. (2)

We also apply our algorithm for node removal to road networks of more diverse countries (USA) and compare the results.

Related work

There are many studies focused on analyzing network robustness or vulnerability. In the paper of Liu et. al. (3) nine widely used robustness measures were studied, as well as the performance of robustness measures in guiding the optimization process. Sakakibara et. al. (4) defines the robustness of the road network as avoiding isolation in a disaster. They also proposed the use of topological index to quantify the dispersion/concentration of the road network in order to assess the isolation of the districts in the city. Mishkovski et. al. (5) suggested that normalized average edge betweenness together with the relative difference, when certain number of nodes and/or edges are removed from the network, is a measure of network vulnerability called vulnerability index. They found that Watts–Strogatz model of small-world networks and biological networks (human brain networks) are the most robust networks among all networks studied in their paper. López et. al. (6) studied node vulnerability while controlling the topology of networks. Their study showed that nodes tend to become more vulnerable as the overall level of spatial autocorrelation in the network increases. In the paper of Duan el. al. (7) an approach to evaluate road network robustness based on the community structure is presented. This approach shows distinct structural diversity between communities and provide greater insight into network vulnerability under intentional attacks.

Project proposal

For this project we will be using the OpenStreetMap data for the Belgium, Netherlands and Luxembourg road networks. In a road network nodes represent junctions, while edges represent roads. Normally edges between nodes have different importance to road networks depending on time of day, distance, location, direction, etc, and this would result in multiple differently weighted networks. Therefore, due to the simplicity and the fact that kind of data is hard to get by, we will be analyzing the robustness of the networks in an unweighted network, meaning all edges and nodes are equally important. This will result in overestimating and underestimating the importance of normally low-importance and high-importance roads and junctions.

To determine the robustness we will be simulating multiple different attacks on the structure by targeting nodes, edges, and a mix of both. The attacks will consist of different approaches such as random-walks, random sampling and directed attacks. Random-walks and random sampling will simulate real-life scenarios such as traffic jams and road works, while the directed attacks will simulate targeted node and edge selection. For node and edge selection we plan to use methods such as node degree, node centrality, edge centrality and bridges. A bridge in a network is an edge whose removal causes the number of connected components of the network to increase. We will then measure the robustness of the network by computing multiple statistics, such as number of connected components, number of communities, average shortest paths, degree distribution, shortest path length distribution, etc. If the networks prove to be robust, the structure will not change or will only display a small fluctuation.

Results, contributions and preliminary work

So far, we have studied the basic network statistics of our data, such as the number of nodes, the number of edges, the average degree, the maximum degree, the number of triangles, the average triangle formed by an edge, the average local clustering coefficient, and so on. We also looked at different ways or methods of analyzing network robustness in related papers.

The results we will obtain will serve as an indicator of weak points in a road network, where we ignore the importance of a road. Therefore, this will be the analysis of the robustness of the Benelux road network. Structural robustness analysis of road networks plays a key role in cases of disasters such as earthquakes or wars. It can describe the survivability of the road network and help in emergency response.

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