Optimization of Traffic Flow in SJTU Minhang Campus

Group 11, VV214

UM-SJTU Joint Institute

Group Members:
Liu Zeyuan, 517370910029
Shi Li, 517370910032
Yuan Fangqi, 517370910206

Introduction

On national holidays, or when national examinations take place in main buildings in SJTU, continuous car flows may clog several cardinal roads of the campus. How could the congestions get eliminated? Moreover, it is also observed that some other minor roads at the same time could be passed freely all day long. Would it be possible that the imbalanced road resources could be manually redistributed more sensibly, whenever necessary? We would like to study this problem, and attempt to figure out a solution in terms of graph theory.

Previous Studies

The same problem occurred on a larger scale actually also interests the researchers. One of the ideas is to make predictions based on current situations. In the research led by Kit Yan Chan, researchers successfully apply an optimization named IPSO to the model they construct. This approach, however, is built on the basis of enough road sensors, as well as the support of computing equipment. If cost-efficiency is taken into account, this idea might not be a practical one, since congestions do not take place on campus every day.

A second approach is to employ queueing network framework during the process of the analysis. In C. Osorio and M. Bierlaire's paper, they build the traffic congestion model from a new perspective regarding "network topology", "bounded queues" and "arrival and service rates". They choose Lausanne as a prototype, and compare it with the previous models. In summary, this approach based on a fine decomposition of the phenomenon of congestion, "is of general interest for traffic control". This theoretical method would benefit the subsequent studies in terms of its effectiveness and innovation.

It is reckoned that a new method of analysis built on the basis of the referred literature should be employed to address the problem in SJTU.

Mathematical Background

Graph theory is close linked to linear algebra. To be more specific, the basic point of contact between graph theory and linear algebra is the notion of a walk. In practice, an efficient method to describe a graph is to use matrices. Usually, we could use an adjacency matrix A to represent a finite undirected graph G= (V, E), in which

$$A_G = (a_{ij})_{i,j=1}^{n} \text{ where } a_{ij} = \begin{cases} 1 & \text{if } (v_i, v_j) \in E \\ 0 & \text{if } (v_i, v_j) \notin E \end{cases}$$

In this project, however, the graph being studied could be expanded to one with directions, i.e. a_{ij} is not necessarily equal to a_{ji}. What's more, every edge also has its value of flow, so a_{ij} can be a value more than 0 or 1.

Model Construction

A complete graph of the SJTU campus is depicted in Figure 1. In this graph, every crossing is simplified as a dot, which could be treated as a vertice; the lines connecting the vertices are the roads on campus, which are edges in the graph. Colors are also added to represent different degrees of congestions. Green means the road is unblocked, while red represents a traffic jam. In order to solve the problem in general, two methods would be introduced in the subsequent parts.

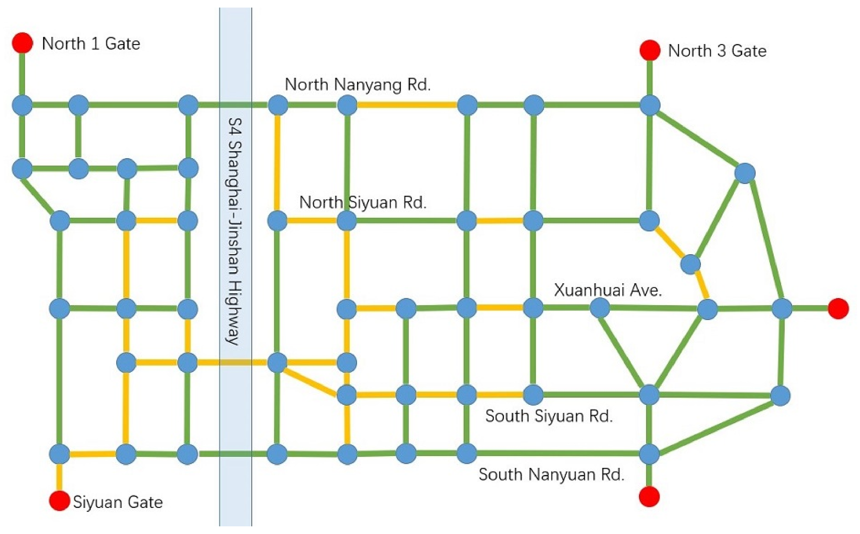

Figure 1: Congestion Simulation of the Campus

Solution I

The first solution is to change the directions of the roads from time to time. Considering the imbalanced road resources, it is a natural idea. We focus on a certain vertice in this graph. With the help of MATLAB, we successfully find a feasible algorithm concerning network flows to relieve the congestion here. The figure below depicts the result with a threshold=3.

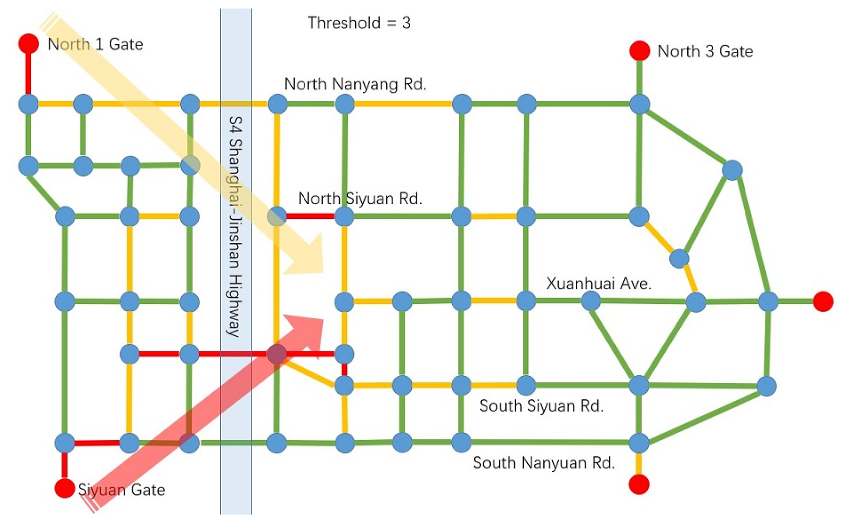

Figure 2: Result when Threshold=3

We also conceive a table to demonstrate the degree of optimization with various values of thresholds. The larger it is, the more optimization would be carried out throughout the campus. About the details of the algorithm, please refer to **https://github.com/shili2017/VV214-Project** if you are interested.

THRESHOLD	Congested Roads	Very Congested Roads	One-way Roads Needed
Unoptimized	25	13	0
1	30	8	11
2	32	7	10
2.5	31	8	8
3	32	8	6
4	31	9	5
8	28	10	4
10	27	12	2

Table 1: Results with Different Thresholds

We further extract some other parts of the graph to verify this solution. Every Sunday afternoon, the traffic flow exceeds its maximum since a huge number of students return to school. Through field surveys for the roads around Dormitory East 22, we get the following traffic diagram.In the figure, we represent each two-way lane by a two-way arrow, and add two numbers representing the actual and maximum traffic flow of each road. The green/orange arrow means the flow rate of the road is in an acceptable range. However, if the arrow is marked as red, we need to take some measures to prevent roads from being too congested.

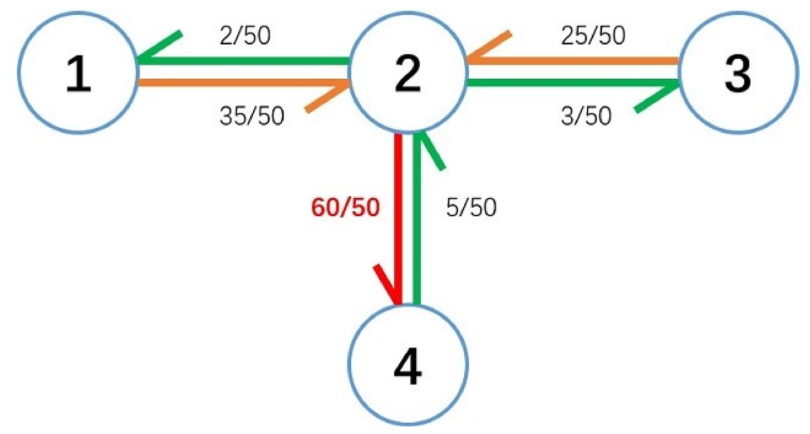

Figure 3: Traffic Diagram around Dormitory East 22

The method of using a one-way street is an effective one to solve this problem. The road between Crossroad 2 and 4 could form a one-way street, through which the actual flow rate can be divided by 2. Each road having a flow of 30, this is within the safe range. Meanwhile, for the flow of 5 moving from Crossroad 4 to 2, they need to choose another way, for example, going from 4 to 3 to 2 or 4 to 1 to 2. The improved traffic diagram is shown the Figure 4.

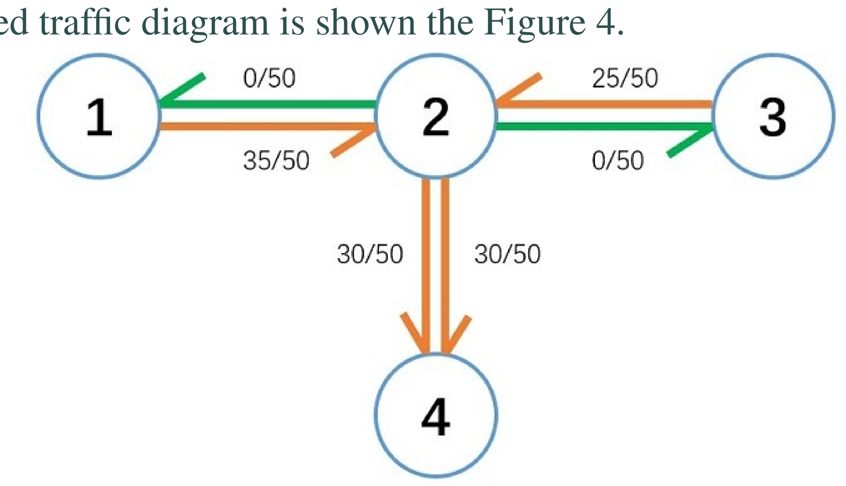

Figure 4: Improved Traffic Diagram by Using One-way Street

Solution II

A second solution is more realistic, in which shuttle buses are to be employed. While a one-way street is always used when the actual traffic flow is a little larger than the maximum traffic flow, using shuttle buses can deal with the situation of poor traffic environment. For instance, when there is a worldwide test held in Shanghai Jiao Tong University, a large number of contestants will enter our campus, which makes the road even more congested. An actual traffic diagram taken when there is a test day is shown in Figure 6.

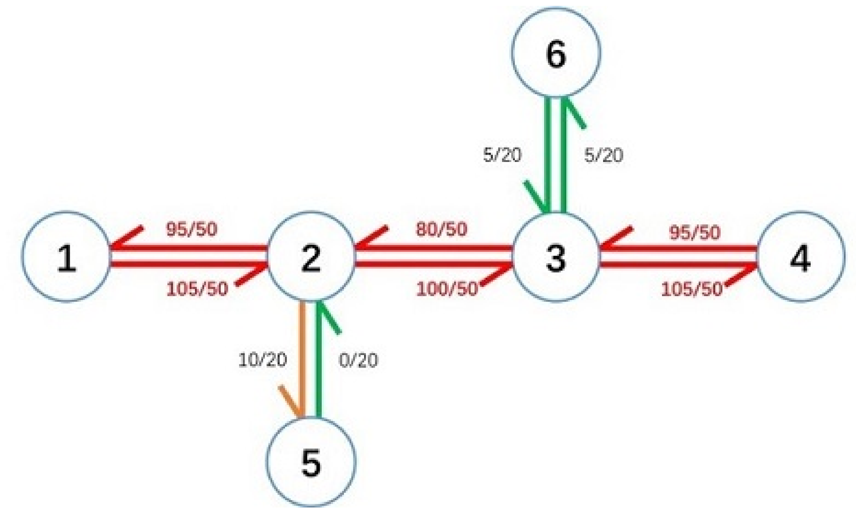

Figure 5: Actual Traffic Flow on a Test Day

In this situation, it is no longer decent to arrange one-way streets, since there are large traffic flows in both directions of the road. Using shuttle buses could be a good idea, going from Crossroad 1 to Crossroad 4 and back from 4 to 1. Since a bus can accommodate nearly 50 people but add to traffic flow only about 1.5 units, it will relieve traffic pressure largely and effectively. Figure 6 shows the improved traffic diagram after only adding 4 shuttle buses.

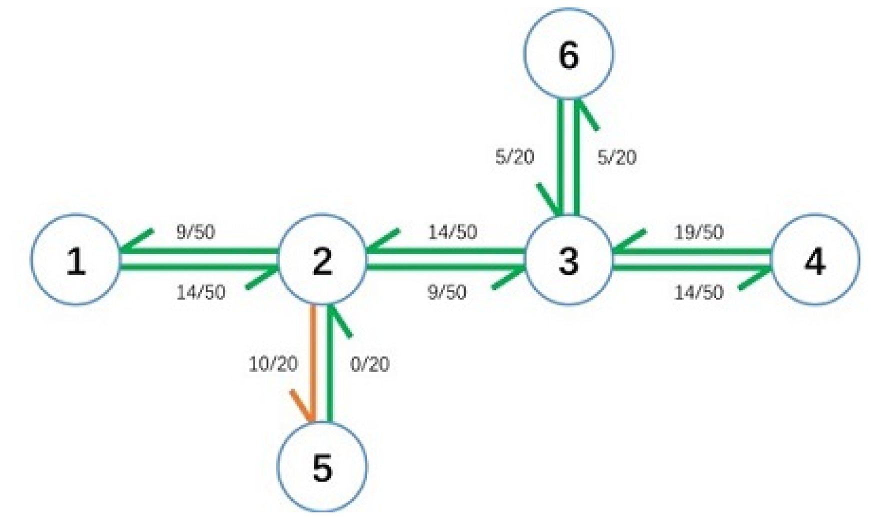

Figure 6: Improved Traffic Diagram after Adding 4 Shuttle Buses

Finally, we re-apply this method to the first graph simulating the campus, depicted in the figure below. Compared with Figure 2, it could be observed that more lanes turn green with the help of shuttle buses, proving it has a better effect.

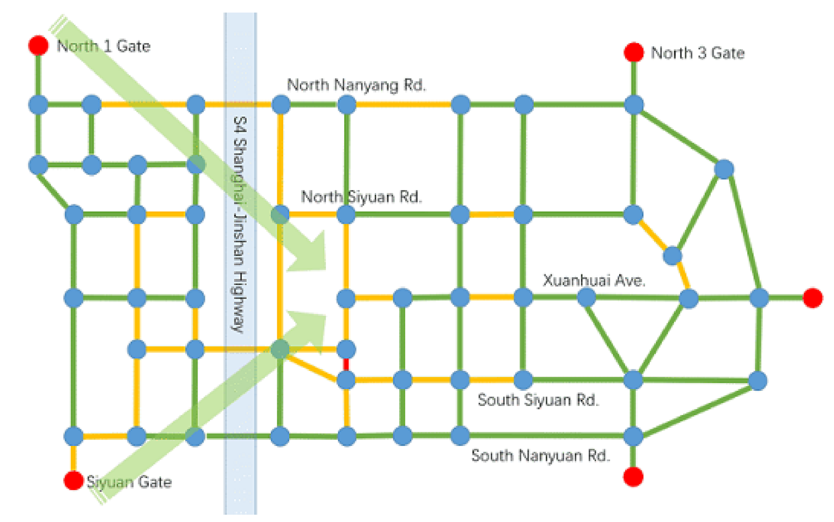

Figure 7: Improved Result after Adding Shuttle Buses

Forthcoming Research

In this simplified model, efforts have been made to deal with the potential congestions, with two solutions worked out. Cosnsideering the feasibility and efficency, both methods are decent, with the second one seeming more effective. If there are further researches, a model with more complex conditions and a larger size should be taken into account for study, so that the results obtained in this project could be utilized again, with more possible solutions being raised.

References

[1] Kit Yan Chan; Tharam S. Dillon and Elizabeth Chang. "an intelligent particle swarm optimization for short-term traffic flow forecasting using on-road sensor systems". *IEEE Transactions on Industrial Electronics*, Issue10, Volume 60, 2013.

[2] C. Osorio and M. Bierlaire. "a surrogate model for traffic optimization of congested networks: an analytic queueing network approach.". *Ecole Polytechnique Federale de Lausanne*, 2009.

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