Indian Institute of Technology, Bombay

ME 312: Operations Modeling and Analysis

Report On

Bus Route Optimization

Team 38

Sankalp Mistry
210020117
Dept. of Mechanical Engineering

Satyajeet Das
210100134
Dept. of Mechanical Engineering

Aniruddh Goyal
210100014
Dept. of Mechanical Engineering

Ishaan Abhyankar
21d100008
Dept. of Mechanical Engineering

***Abstract*—In this project, we addressed the challenge of optimizing bus routes to enhance passenger experience by reducing user cost, time to travel, and maintaining a reasonable bus operators cost while maximizing the demand and satisfaction of passengers in urban areas. We employed optimization algorithms and tools like GLPK and Pyomo for modeling the problem, and NetworkX for plotting and visualizing the travel grid nodes. Significantly, our approach was enriched by firsthand experiences, as we traveled these routes ourselves to deeply understand the travellers journey and the operational nuances. This practical research helped us tailor our solutions more effectively, leading to an improved bus scheduling grid network across bus stops in Mumbai and Navi Mumbai. These enhancements could potentially be extrapolated and used in other cities and areas, assuming the same conditions as those detailed in this paper. The final results indicate potential profit and provide significant improvements in efficiency of the route management and user travel satisfaction, crucial for both long distance travel and daily commutes in urban areas.**

INTRODUCTION

Urban transit systems are the lifelines of cities like Mumbai and Navi Mumbai, where a huge number of travellers depend on reliable public transport to navigate through densely populated areas. However, current infrastructure often struggle under the weight of excessive demand and high traffic congestion. Our project, motivated by the need for more efficient urban mobility, focuses on optimizing bus routing and scheduling to significantly enhance the passenger experience and operational efficiency.

Our journey began with a thorough analysis of the existing bus routes and an evaluation of passenger flows at various times of the day. We quickly realized that many routes were not just congested but also inefficiently planned, leading to longer than necessary travel times and irregular bus loads. Some buses were overcrowded, while others ran nearly empty, showing a deep imbalance in route planning and bus deployment.

Having those data with us, our aim was to provide a more responsive and efficient transit system. We thought of a network where travel times were shorter, buses were appropriately filled, balancing demand and capacity, with a vision of keeping the environmental impact minimization in mind. Achieving this meant diving deep into the details of urban transit, decoding the patterns of daily commutes, and rethinking how buses navigated through the urban maze where we implemented concept of grid nodes, further explained in the paper.

This report captures our systematic approach from the initial problem identification to its application of optimization algorithms. We didn't just tweak existing routes, we created new possible routes and compared them to existing ones.

MOTIVATION

Inefficiency in Current Routes: Observations and data analysis showed that many existing bus routes were inefficient. Buses often took longer routes than necessary, leading to excessive travel times and increased fuel consumption. This not only frustrated passengers but also increase operational costs significantly.

Passenger Discontent: Feedback from commuters indicated dissatisfaction with the current state of bus services. Issues range from overcrowded buses during peak hours to infrequent services during off-peak times. Enhancing passenger satisfaction is essential, thus making it necessary to shift towards a more passenger centric approach in route scheduling

Technological Advancement: With the rise of smart technology and data analytics presents an opportunity to improve public transit system using these tools could enable dynamic adjustments to bus routes and schedules based on real-time data, leading to a more useful and efficient system. This project was also a step towards integrating more recent technologies into everyday urban travel

OPTIMIZATION APPROACH

Our approach to optimizing the bus network focused on three critical objectives that intersect at the core of operational efficiency and passenger satisfaction. Each objective was tackled using latest modeling tools and algorithms, ensuring that our solutions were both innovative and practical.

- **Minimizing Operator Cost**: The primary goal was to reduce the costs associated with operating bus routes. This involves several strategies, including optimizing fuel consumption, delay time to reach another demanded node and improving route efficiency, this is to make sure that the buses don't try to go all over the place and cover all nodes. By using the linear programming feature of GLPK, we developed models that could suggest the most cost-effective routes based on the distance which is represented as a weight that is required for the bus to take a particular route, here a node is considered as a bus stop or any other place where travellers generally gather to get bus and routes are paths between two consecutive nodes.
- **Minimizing User Cost**: Reducing the cost to the user was not solely about lowering fares also the amount of effort a user needs to put in to travel to the nearest bus stop. This ensures that all major demanding nodes are covered by the buses, thus

enhancing the overall attractiveness of using public transportation.

- **Maximizing Demand Satisfaction**: Maximizing demand satisfaction ensures that the bus services and travels though those areas which are often crowded and filled with travellers waiting for busses. This objective was addressed by creating a model that predicts passenger flow at different times and locations, thereby allowing for the allocation of bus resources where they are needed most. By using NetworkX, we visualized and simulated various scenarios to see how changes in the network would affect overall demand satisfaction.

  All approaches mentioned above are mathematically represented below for better understanding

Idea behind the problem

In big cities like Mumbai, Bangalore, Delhi, there are places which are the hotspots for working people. These working hubs are daily crowded and many people go to and from this place via various modes of transport. Buses and trains are the two major public transports used. Taking example of Navi Mumbai in our case, Airoli is known to be the corporate hub of outer Mumbai where people go for work form all over Navi Mumbai, Thane, and Mumbai. Getting inspired to help these people have a comfortable and convenient travel, we decide to implement to a bus route for a bus service to cater maximum number of people in these areas. People in these areas travel from various locations of the city to a common destination (the hub) and get down over there. This happens mostly in the morning and these people again get back to their towns in the evening so the flow is reverse in this case.
Cityflo is one of the famous bus services in Mumbai which travels through the peak rush areas at peak hours to cater the public and make maximum profit. Though these bus services are not very wide spread and they travel through cities, for eg. from Navi Mumbai to Mumbai and Thane.
We inspire from this demand and existence of such a service, to plan a bus service and find an optimal route catering the working public of Navi Mumbai for a smooth and convenient travel from their nearest bus stops to their final working hubs.

Objectives

Main Objective:

To find the most optimal route for the provided grid of bus stops and their demands which is based on maximizing customer demand and travel satisfaction as well as minimizing the cost of operation.

Secondary Objectives:

After getting the most optimal route for single bus travel, we try to increase the coverage throughout the grid and run multiple buses and correspondingly find the best routes for each one of them.

Mathematical Formulation

In this section we highlight our mathematical equations that we optimize and the corresponding constraints. We make sure that these equations are linear and can be solved by the linear programming methods such as the inverse simplex method or the primal-dual interior point method. The basis of these equations are few research papers and basic understanding of vehicle dynamics and different mathematical variables. Now we begin with the first iteration with the base case and move forward by complicating the equations one by one and increasing the number of constraints based on the newly added variables. We begin with naming the variables to be used,

Nomenclature

Symbol	Description
I	Set containing all the bus nodes
i, j	Denotes node number i, j
D_i	Demand at node i
s_i	Binary variable (decision variable)
c_{ij}	Operating cost of bus travelling from node i to j
x_{ij}	Binary variable (decision variable)
k	Number of buses
p_{ij}	Cost for the user to travel from node i to j
s	Start node
e	End node

The above defined variables are used in the objective function and constraints that we make ahead. They are used in all the three iterations with some variations in their names in the further iterations.

Decision Variables:

The decision variables in all our iterations are x_{ij} and s_i.
x_{ij}: Binary constraint, value is 1 if a bus passes through node i to node j else it is 0. This binary constraint will help us find the routes in our grid of widespread nodes. Continuity of these positive edges needs to be checked for a particular bus.
s_i: Binary constraint, value is 1 if a bus passes through node i, else it is 0. The 1 values of all these s_i's are used to connect the routes on the map.

ITERATION 1

This is the case where we run a single bus through the entire grid of bus stops starting from node 1 and ending on the final destination of the passengers which is node 25. The objective function for the same is a basic one shown below

Objective function:

$$maximize: \quad \sum_i D_i s_i - \sum_i \sum_j c_{ij} x_{ij} \tag{1}$$

Objective function terms:

- The first term of our objective function captures the demand at the bus stops. Here the multiplication of D_i with s_i makes sure that if a node is passed, then the demand at that node is satisfied which makes the value of our decision variable 1
- The second term of our objective function captures the operational cost of our bus service. Travelling cost is defined as the fuel consumed by the bus as well as other logistics cost. It will make sure that the bus doesn't travel all the stops in a go

Meaning of our objective function:

- The objective function tries covering the maximum demand nodes so that it can maximize its potential profit. Also, the operational cost will make sure the cost of travelling doesn't exceed the marginal profit increase of capturing a few more people from few more bus stops

Constraints

- Node Constraint:

$$s_i = \sum_{j \in I} x_{ij} \quad \forall i \in I \tag{2}$$

Those constraint above is named as node constraint because it decides the value of our decision variable s_i based on the summation of values of path leaving the node i. It also makes sure that a bus cannot pass the same node again and again. This prevent the cycling effect that created an infinite loop

- Continuity Constraint:

$$\sum_{i \in I} x_{ij} = \sum_{j \in I} x_{ji} \quad \forall j \in I \setminus \{S, e\} \tag{3}$$

The constraint above makes sure that all the buses entering a particular node j, leaves that node. This is applied to all the bus nodes in I except for s and e which are the start and end nodes

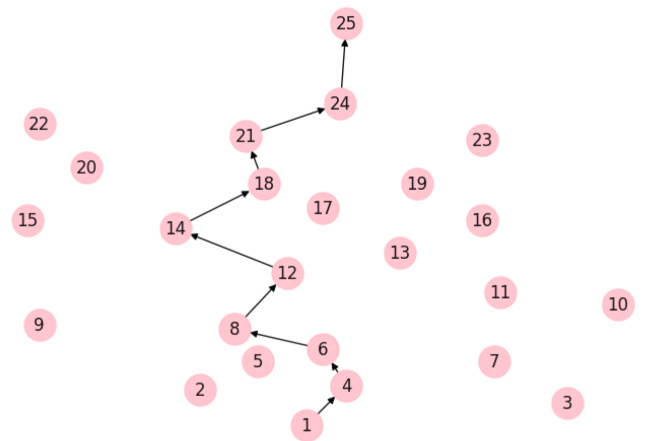

Fig. 1. Bus route obtained for a single bus traversing through the grid

- Start and end constraint:

$$\sum x_{sj} = 1 \quad \sum x_{je} = 1 \quad \sum x_{js} = 0 \quad \sum x_{ej} = 0 \tag{4}$$

This constraint makes sure that no route enter the start node while making sure that one route starts from it. Similarly, it also makes sure that no route originates from the end node while making sure that all the routes end at this node only

Given information

- Total number of bus stops = 25
- Start node = 1
- End node = 25

Results

As shown in figure 1, we can see that we find a path starting from 1 and ending on 25. This route covers the bus stops numbered 4, 6, 8, 12, 14, 18, 21, and 24. The reason behind such a route can be due to the high demands at these nodes or lower cost of travelling cost through these routes. We can further analyse the optimal behaviour of these routes by changing the values of demands at particular nodes and testing whether the route is bent towards the more demand node or not which is tested ahead in the report.

Solver results:

Value of the objective function = 7554.75
This value signifies the potential profit the bus service

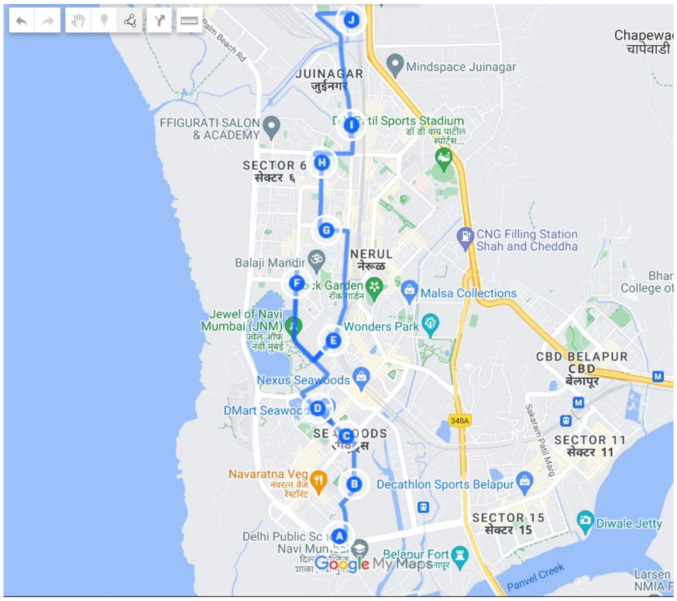

Fig. 2. Optimal route plotted on Google maps. City shown is Navi Mumbai

could make if travelled along the route shown in the figure 1. We can change the starting node of the bus to any of the nodes and the solver will give us the most optimal route catering the maximum demand while minimizing the travel cost

Figure 2 shows the route plotted on actual maps with bus stops highlighted. A bus service is recommended to use this route to maximize their potential profits and can run multiple buses on this route to cater maximum number people there.

Iteration 2:

In this iteration, we increase the number of buses and allow them to have two different routes.

Objective function:

$$maximize: \sum_k \left[\sum_i D_i s_i^k - \sum_{i,j} c_{ij} x_{ij}^k - \sum_{i,j} p_{ij} s_i^k \right] \tag{5}$$

Objective function terms:

- We can see that the first two terms are almost the same with an added summation for all the k buses. So basically we are now maximizing the demand catered by all the buses and minimizing the travel cost of all the buses
- The third term in this modified objective function is for user access cost. This cost is defined as the cost a user at a non traversed node needs to bear to travel to the nearest node and catch the bus. This cost makes sure that if we are missing any node with higher demands then our objective function value decreases and we try to account for that too.

Meaning of our objective function:

- The modified objective function makes sure that we also account for the user satisfaction cost and not only look at the revenue by customers and cost of the buses. This is our first step looking at the customer satisfaction aspect of bus route optimization problem.

Constraints:

- Node Constraint:

$$S_i^k = \sum_{j \in I} x_{ij}^k \quad \forall i \in I \ \forall k \tag{6}$$

- Continuity Constraint:

$$\sum_{i \in I} x_{ij}^k = \sum_{j \in I} x_{ji}^k \quad \forall j \in I \setminus \{S, e\} \ \forall k \tag{7}$$

- Start and End constraints:

$$\sum x_{sj}^k = 1 \ \sum x_{js}^k = 0 \ \sum x_{ej}^k = 0 \ \sum x_{je}^k = k \tag{8}$$

- All the constraints are almost the same, they are just modified for the k number of buses. The last end constraint is modified for k number of uses ending at a particular selected end node, which is our final destination

Given information:

- Number of buses (k) = 2
- Start node for first bus = 2
- Start node for second bus = 3
- End node for all the buses = 25
- Total number of bus stops = 25

Results:

The case for two buses running across the grids from two different start points is not very different from the previous case. We can see from the figure 3 that the buses follow two different routes to reach the same final destination 25.

Route for bus 1: 2-5-6-8-12-14-15-20-21-22-25

Route for bus 2: 3-7-10-11-13-16-17-19-23-24-25

These optimal routes are obtained by choosing 2 and 3 as the starting points. These starting point can manually by changes to some other node value to get the optimal route in that case

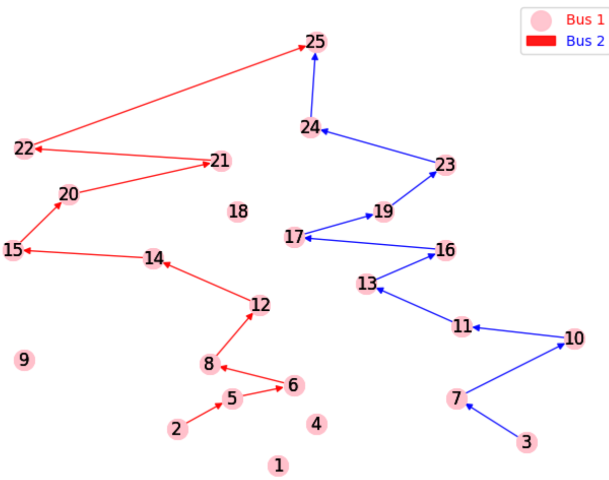

Fig. 3. 2 buses travelling through the grid

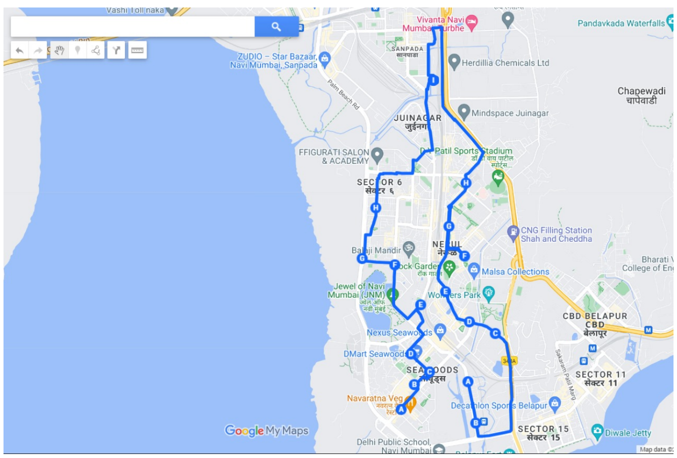

Fig. 4. Optimal route for 2 buses plotted on Google Maps

Solver results:

Value of the objective function = 9413.2 This value signifies the potential profit for running 2 buses along the grid shown. Figure 3 shows this route as plotted using NetworkX. From figure 4, we can see the actual routes plotted on Google maps. These are the two optimal routes along which the bus service can run their buses.

ITERATION 3

This iteration involves running 3 buses through the same grid and finding the most optimal routes for them under similar constraints. The objective function remains the same as before just that the number of buses is increased to three.

Given information:

- Number of buses (k) = 3
- Start node for first bus = 3

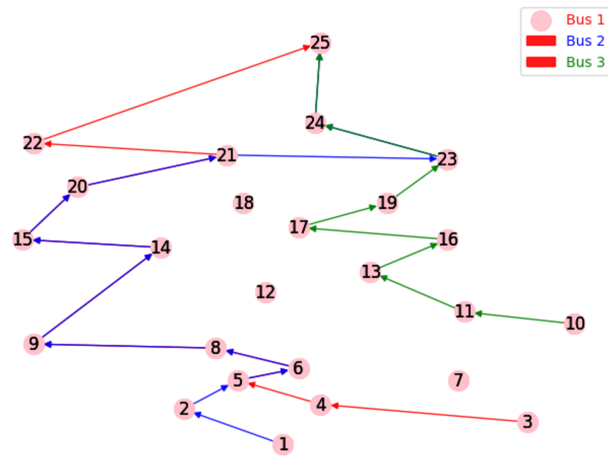

Fig. 5. 3 buses travelling through the grid

- Start node for second bus = 1
- Start node for third bus = 10
- End node for all buses = 25
- Number of bus stops = 25

Modified variable names:

Modified Variable	Description
s_i^k	Binary node variable for kth bus
x_{ij}^k	Binary edge variable for kth bus

All other variables remain the same. We can say that these unchanged variables are the characteristics of the grid and do not change with the number of new buses or routes being introduced

Results:

From figure 5 we can see that three routes are made from three different starting points on our grid. We can change the starting points manually to get the best possible combination of routes with multiple buses
Route for bus 1: 3-4-5-6-8-9-14-15-20-21-22-25
Route for bus 2: 1-2-5-6-8-9-14-15-20-21-23-24-25
Route for bus 3: 10-11-13-16-17-19-23-24-25
These are the optimal routes obtained using the given nodes defined above as the starting nodes

Solver Results:

Value of objective function = 2562.3
This value shows the potential profit the bus agency can make if made to travel through these set of nodes.
Figure 6 shows the optimal routes plotted on Google maps which are to be followed for most area coverage by the buses and minimum cost by achieving maximum customer satisfaction.

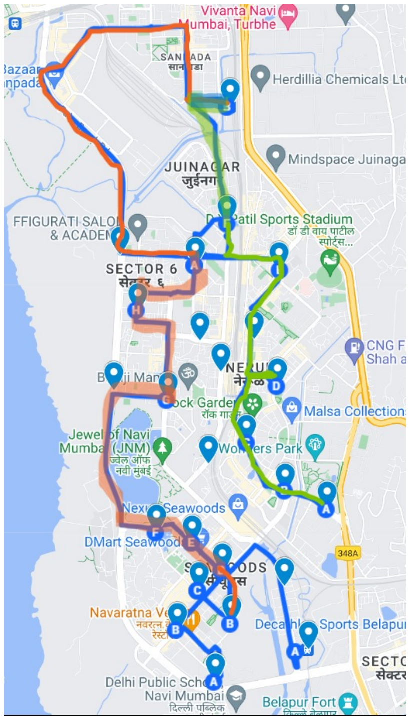

Fig. 6. Optimal routes for 3 buses plotted using Google Maps

User access cost - could be better!

The third term in our objective function is related to customer satisfaction. This term was originally different from what it is shown right now. We made the most efficient and optimal term to account for the nearest user access cost. But there were some issues we encountered when finding the optimal solution using glpk solver.
Our current term accounts for the cost of all the nearest edges for a particular traversed node and adds it to the cost of our term. But this leads to addition of traversed edge as well and non traversed edge. Also, when we move to the next traversed node, that is when the value of i increments, we get another iteration of non-traversed and traversed node pair which might be common to the previous one. Also, it causes double counting instead of nearest bus stop cost counting. As we can see in figure 7, the 17th node is close to both 18 and 12, for our given sub optimal term used, it double counts the cost for both, the 12 and 18th node, and adds to the user access cost which is not optimal. Hence we thought of a new term which could account for both the problems simultaneously.

$$cf * \sum_{i}(1 - s_i)min(l_{ij}/s_j) \ \forall j \in I \tag{9}$$

This term above is the perfect term to account for the user access cost. Let us break it down step by step. cf is the cost factor we multiply to the equation to normalize it

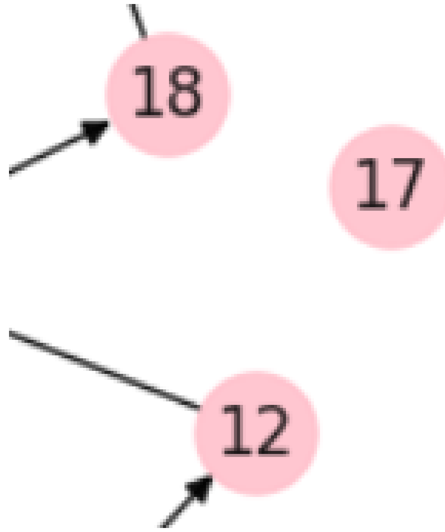

Fig. 7. Common edge connection for 17th node

to other cost levels which is based on various user factors and the number of people wanting to travel to the nearest stop for a bus ride. The term $(1-s_i)$ makes sure that we are looking at only the non traversed node ($s_i = 0$). Then the next multiplied term is used for finding the minimum distance of this node i to some node j. the $/s_j$ term makes sure that this minimum is found only for the traversed nodes ($s_j = 1$). This cumulatively accounts for the best possible nearest user access cost at all the nodes.
Another point we made sure is that not all the nodes are connected to each other, for eg the left extreme nodes have no connection to the right extreme nodes and hence when we calculate the user access cost, we only see the stops adjacent to traversed route and not all the permutation of nodes. This makes sense in real world too because an employee would not travel far away from its home bus stop just to catch bus, rather they would prefer some other route convenient to them. Hence we came up with finding multiple optimum routes and so that we can over maximum demand in an area which again leads to a better customer satisfaction technique due to availability of bus at different locations on the map
Problem: The issue with this term is that it made our equation **non-linear** and our solver was unable to solve it. More complex and better solvers can be used to get better results.

Constants and Values

There are various constants we used as well as made while modeling our objective function and they are described in this section.

- D_i: Constant that denotes the demand at a fixed bus stop (node). This demand has units of rupees and is found using information about number of daily customers at that bus stop and the price that they have to pay for trip from that bus stop to the final destination (node 25). The demand is found based on experience and also visiting few places in real life and talking to the bus conductors of various buses. After getting the average number of people getting in the us at a particular bus stop, we multiply it with the average ticket cost which we got inspired by the NMMT buses and adjusted our prices accordingly. Same prices cannot be used because a government service would offer lower prices as compared to a private one

- c_{ij}: Constant that denotes the cost of bus operating between node i to j. This cost is in the units of rupees. The factors considered in finding this value are distance between the nodes (calculated using google maps), speed and mileage of the bus, logistics charge and fuel cost. We used average values of these variables found using NMMT bus travel experience and data. This cost is completely based on the bus models and features and has no relation with the demand at the nodes. Various other geographical, environmental and government factors might affect them but we chose to ignore that
- p_{ij}: Constant that denotes the cost for user to travel from node i to j. This cost is in units of rupees and similar to the bus operating cost. In fact it is a scaled version of this variable with a few modifications made by averaging our based on distance. This variable is used to find the user access cost.

Assumptions

Few major assumptions are highlighted below,

- We assume that all the passengers get down at the same final stop (node 25) which is the corporate hub of Navi Mumbai. This assumption is based on the idea behind the problem that major crowd of this bus service is the employees going to work there
- We use average values of constants to make our problems easier to solve
- The value of our objective function is potential profit the bus service can earn by running buses on these routes.
- We haven't accounted for bus capacity which may lead to changes in the objective function value
- We assume that the demand at a node is not dynamic and calculate the best route
- We ignore the traffic and weather conditions which might affect certain turns/bus stops.

Node Number	Bus Stop
1	Nerul Sector 46 & 48
2	Sector 47 Petrol Pump
3	Seawoods Link Cabin
4	Shivdan Society
5	Nerul Sector 42
6	Nakhava Chowk
7	Marvel Society Nerul Sector 50
8	Kendriya Vihar Sector 38
9	T S Chanakya
10	Air India Colony
11	Sterling College / Centurion Mall
12	Nerul Gymkhana
13	Nerul Police Thane
14	Onkar Society
15	Nerul Sports Club
16	Meenatai Thackeray Hospital
17	Nerul (W)
18	Nerul Village
19	Nerul Sector 11 15
20	Kukshet Gaon (M.S.E.B)
21	Sarsole Koliwada
22	Barbeque Nation
23	S.I.E.S. College
24	Chincholi Talav
25	Juinagar
26	Airoli

TABLE I
NODE NUMBER AND BUS STOPS

Modifications for testing purpose

We modify our single bus route case (Iteration 1) over here to see whether our model tries to change its if initial condition is changed
Initially the demand at node 17 (D_{17}) = 262. For this particular demand setup, the route is as shown in the optimal case of iteration 1. Now if we change the demand at this node to some different value, let us analyze that,
New demand at node 17 (D_{17}) = 1500
We can see that the route is bent towards capturing demand of node 17. This happened due to increase in the potential profit by covering this demand over the extra operational cost by the bus and hence it takes a detour/changes its route to the modified one as shown in figure 8.
This result shows that the solver works fine in its optimization task and even manually we would prefer changing the route to the newer one to maximize our chances at profit.

Testing our model

Now we try to test our model's optimal solution to real life bus route cases. The real life bus cases are planned on experience of travelling in Navi Mumbai for all these years. These routes are decided by the **Navi Mumbai Municipal Transport (NMMT)** bus corporation. We

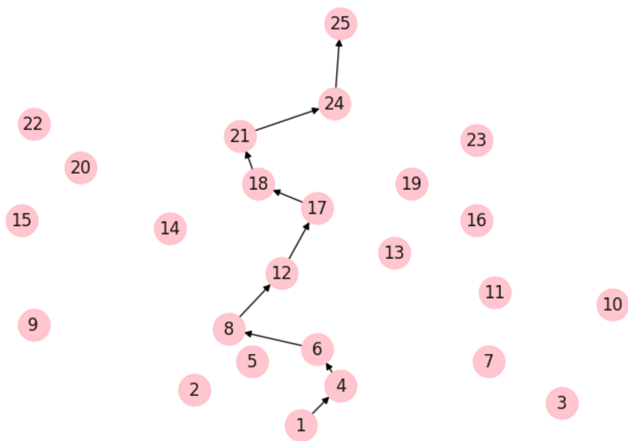

Fig. 8. After modifying the demand at node 17

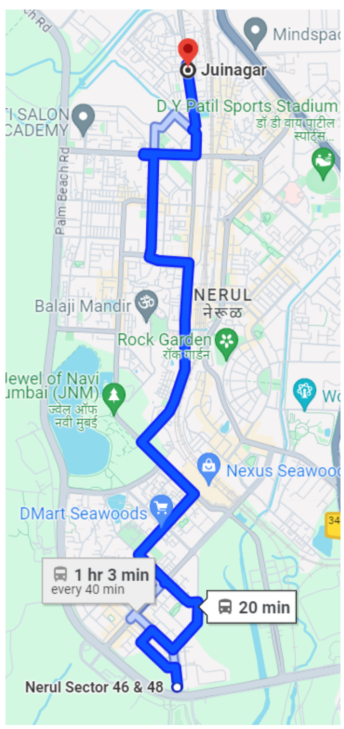

Fig. 9. Bus route of 502 LTD

searched for bus routes between these bus stops and found few bus routes running between them. Below is the bus route of bus number **502 LTD** run by NMMT and between Juinagar bus station and Nerul 46 & 48 Sector.

Figure 9 shows the bus route of 502 LTD bus. After comparing it with our optimal route for single bus, we can see that the route almost matches to the one we found with a very few changes.
The reason behind the difference in the routes might be due to congestion at specific places due to which the

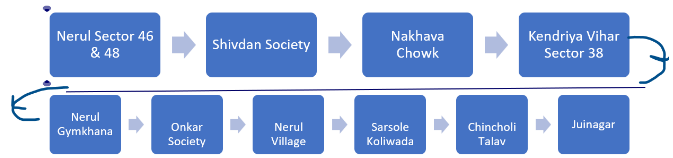

Fig. 10. Optimal route with real bus stop names. These set of bus stops can be traversed to get the most out of the town in terms of customer demand and travel efficiency

government bus prefers other routes as compared to the optimal one that we found. Also, they might not be aware such a route/turn connecting specific nodes exist and we can pitch it to them so that they can implement and try them out

Future of this Problem

This bus routing project opens up several exciting areas for further development and refinement. As urban areas continue to grow and technology grows, the methods we employ to enhance public transportation systems must evolve accordingly. Below, we explore potential future improvements that could significantly impact the effectiveness of bus routing strategies
Including Real-Time Data in Objective Function: Currently, our objective function models static scenarios based on historical data, but urban transit dynamics are continuously changing, influenced by countless real-time events. By incorporating real-time data into the objective function such as the number of passengers boarding and alighting at each stop—we can change our approach into a much more dynamic model. This enhancement will allow us to adjust routes and schedules instantly in response to actual passenger flows
Dynamic Bus Routing: The future of urban mobility lies in its ability to change and consider new options. Introducing a machine learning model to interpret real-time data can revolutionize how bus routes are planned. Such a model would adjust routes dynamically based on immediate inputs like user satisfaction, bus occupancy, and live traffic conditions. For instance, if a particular route is experiencing unexpected delays or higher demand, the system could reroute buses in real time to alleviate congestion and balance load. This approach not only improves passenger experience but also enhances operational efficiency
Random Starting Nodes: In our current model, starting nodes for routes are predetermined, which might not always align with optimal service delivery as city dynamics shift throughout the day. Allowing the model to choose starting nodes based on certain parameters—like peak traffic areas, event schedules, or even weather

conditions—could lead to more efficient routing solutions. This flexibility would help in better addressing the sporadic surges in demand typical of urban centers, ensuring that service availability directly aligns with commuter needs

Sustainability: An essential aspect of future development is sustainability. This includes deciding the number of buses active on a particular route and selecting the type of buses used—whether electric, hybrid, or conventional fuel-based. Optimizing these choices can significantly reduce the carbon footprint of public transit. Furthermore, by carefully analyzing the expected passenger loads and trip frequencies, transit authorities can optimize bus deployment, ensuring that every route is economically and environmentally justified.

Conclusions

The project was an overall great learning experience. We tried to solve a real-life problem up to some extent. The problem still has many things that can be solved even more extensively. Taking into account the time variance and other variables like passenger interest and competitor bus companies can make it even more interesting and tough to solve!

Acknowledgement

We owe a huge thank to everyone who supported us through this project. Special thanks to **Prof Narayan Rangaraj**, for invaluable guidance and wisdom and also grateful to our **TA, Amritaansh Nair** for his constant support and insightful feedback.

Github Repository of Code and Data

GitHub Repository

References

[1] "Route Optimization of Urban Public Transportation."
[2] "Flexible Bus Route Optimization Scheduling Model."
[3] "Bus Route Planning in Urban Grid Commuter Networks."
[4] "Zone-based Public Transport Route Optimisation in an Urban Network."
[5] "Campus Shuttle Bus Route Optimization Using Machine Learning Predictive Analysis."
[6] "GLPK (GNU Linear Programming Kit) Documentation."
[7] "Pyomo – Optimization Modeling in Python," Springer, 2nd ed.
[8] "NetworkX Documentation."
[9] "Advanced Public Transportation Systems: The State of the Art Update 2006," U.S. Department of Transportation.
[10] "Machine Learning for Dynamic Route Optimization in Public Transit Systems," Journal of Artificial Intelligence Research.
[11] "Real-time Traffic Management Models for Public Transportation," Transportation Research Part C: Emerging Technologies.
[12] "Sustainability in Public Transportation: Environmental Assessment of Different Vehicle Technologies," Environmental Science & Technology.
[13] "Linear Programming: Foundations and Extensions," International Series in Operations Research & Management Science.
[14] "Dynamic Programming and Optimal Control," Athena Scientific.

Contributions

Sankalp Mistry

Started off with reading a few research papers and Cityflo blogs. Got inspiration from them and designed a problem statement as stated in the section 'Idea behind the problem'. Made mathematical terms and finally designed the objective function along with the constraints for our model. Got the idea of 'user access cost' from the research paper and implemented it using the terms mentioned in the paper above. Handled the pyomo modeling and solving using the glpk solver. Used NetworkX to plot the grid and routes through them. Devised the optimal non-linear user access cost term but couldn't find any solvers to move forward with. Played along with the model to test it for different conditions. Handled the idea behind the problem, mathematical formulation, all iterations, assumptions, and other modifications part of the report.

Satyajeet Das

Started the journey by reading multiple research papers and testing out an initial model such that the bus travels to maximum demand nodes using Pulp, Brought the concept of grids to represent a map and did some initial visualization using NetworkX, Finally contributed to the abstract, introduction, motivation, optimization approach and future of this problem sections in the report

Aniruddh Goyal

Read many research papers along with listed down key constant variables like fuel consumption, bus mileage etc, Brainstormed different ideas related to user satisfaction terms in objective function. Helped Ishaan in finding the demand value at multiple nodes and contributed in report

Ishaan Abhyankar

Finding the demand values at each node by travelling and talking to the bus conductors. Plotted the optimal route given by the software using Google Maps. Found the NMMT bus that travels on similar lines. Helped in the initial mathematical formulation.