Real Time Re-routing of Public Transportation System

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***Abstract*— Nowadays, many cities are on the verge of becoming smart cities. A smart transportation system is at the heart of smart city but cities lag with an efficient transport system. The current public transport systems follows static routing based approach i.e. they have fixed routes and frequency irrespective of the demand. In this paper, we propose an innovative method to solve this problem by re-routing the bus on-the-go based on public demand. Public can interact, manipulate and have an effect on the routing of the buses. The interaction of the public demand with routing is enabled by a central server which will analyses all the demand data collected from booking application. To facilitate the on-demand nature, a dynamic routing algorithm has been proposed that prepares new route for buses in real time. This algorithm works in the cloud server and suggests new and more efficient routes based on the aggregated data collected. This is enabled by the city wide link of equi-important bus depots which serve as loci of control for routing and rerouting. After evaluating, the system shows tremendous performance gain in regions with highly skewed bus-demand. Further, we propose this model to be implemented in public transport systems as a 30 - 70 percent combination of static and dynamic routing respectively for easier adaptation by the commuters.**

***Keywords*— Dynamic Routing, On-Demand, Real time rerouting, Nodal center, Distributed processing**

I. Introduction

The world is moving towards making all the systems and processes smart, the very definition of which is something done in an efficient and optimal way. Public transportation, the nervous system of any city, is one of the most complex processes for its proper functioning. Hence, having a smart and efficient transportation system is of utmost importance for any city to function efficiently and smartly. However, as witnessed, not much attention is paid to optimize the system.

Existing System. In the current systems, routes and frequency of the buses are statically planned based on past knowledge and intuition about the demands on routes. This system is widely accepted as being the most practically efficient system. The commuters have to keep a track of bus timings and board buses accordingly. The authorities also have to run the buses only at the stipulated times. Hence, both the schedule and routes are static in nature.

Challenges. The central authority's intuition of demand, although accurate to some degree, proves to be inefficient in a lot of scenarios. One such scenario being that certain buses go empty whereas the others being heavily crowded. The demand factor is not taken into consideration in real time but the routes and frequencies are decided based on hypothetical deduction from past data of potential bus commuters. This deduction may or may not hold true. In earlier days, this system was agreed upon as the best possible system that can be used practically and achieve at least some degree of efficiency. However, with the advancements in computational power and sophistications in software technology, the existing systems can be made more efficient and smart.

Motivation. We take Mumbai, the financial capital of India's bus network as an example. There the bus network is the second most used form of public transportation system. BEST, managing body of the Mumbai's bus network introduced AC buses but because of poor demand evaluation and inefficient utilization most of the buses were either lying idle at their depots or running empty resulting in an annual loss of $12.8 million [1]. This huge loss made BEST to terminate the operation of the AC buses. Leading newspaper publications have claimed that 10 hybrid electric AC buses have been purchased which will be used for operation in the city [2]. Pune City, the Oxford of east [3] had proposed to introduce AC buses but have kept that decision on hold and instead PMPML purchased 800 regular buses [4]. Though many cities are trying to provide more comfort to their commuters and are moving towards becoming smart cities they may not succeed in doing so because most of them are just adding on resources instead of also utilizing them efficiently.

Hence, we propose a smart and intelligent transportation system in this paper, which will utilize the existing resources in an efficient manner. The system will dynamically decide the further route of a bus when it reaches one of the depots based on the current demands for different destinations from that depot. It will then notify the concerned bus driver and commuter information systems about the decision.

The rest of this paper is organized as follows. In Section II, we present the related research carried out by different people in this domain. In Section III, we explain our approach and specify the routing algorithm that we're proposing. Finally the results are demonstrated and analyzed in Section IV. The drawn conclusion and future work are presented in the last section.

II. Related work

There is an abundance of studies on the solution of route planning problem. Mandl's work [5] is considered as the benchmark in transit network route planning research and inspired many of the work that came after. There has been a limited number of research that reroutes the vehicle in real time. Most of the researchers use this concept in many different fields except urban bus transportation system.

A. Rehabilitation Bus System in Taiwan

Chi-Bin Cheng [6] uses the concept of demand analysis to provide door-to-door transportation service to the handicapped.

B. School Bus Routing Problem

Hashi [7] proposed GIS based solution for School Bus Scheduling and Routing to design a dynamic shortest and fastest route for the vehicles.

C. Comparing CPT and DRT

Kashani [8] compared two modes of transport - Conventional Public Transport (CPT) and Demand Responsive Transport (DRT) system, where both the modes were simulated separately in a grid network and compared in terms of user performance and operator cost under various demand levels. The results of their work showed that replacing CPT with DRT will improve the mobility by decreasing the perceived travel time by commuters and without any extra cost under certain circumstances.

III. Proposed method

A. System Overview

In the bus transportation network of any city, the bus stops are namely of 3 types - bus depots, bus junctions and intermediate stops between any two depots or junctions. Initially, major bus depots and junctions of the city are to be identified. These major depots and junctions are referred to as nodal centers in the rest of this paper. The identification of these nodal centers will be carried out by analyzing past traffic data and population density data of the city.

After efficient analysis and identification of the nodal centers, the system can be deployed in the city. For the purpose of deployment, a network of distributed servers is formed. Each nodal center has a server of its own as shown in the diagram below, referred to as nodal center server (NCS) in the rest of this paper.

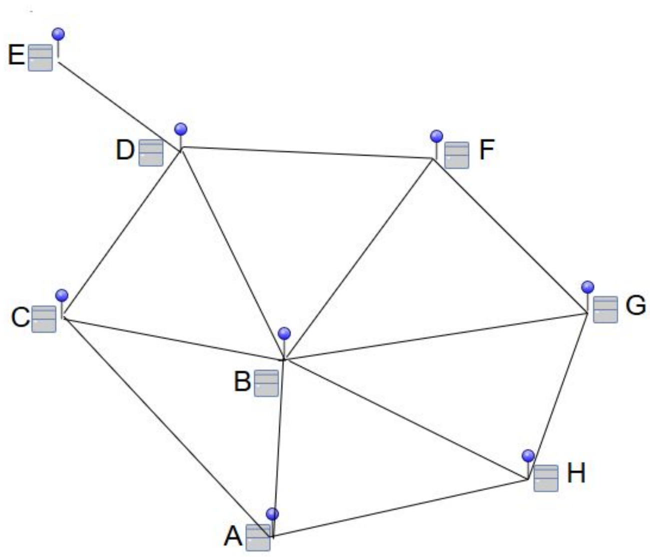


Fig. 1 Example of distribution of nodal centers within a city

Such a system is setup to facilitate distributed processing. Each NCS can take its decisions by using a different customization of the algorithm considering the nature of that nodal center. Each NCS has the responsibility of the routing decisions of that nodal center only. The NCSs of different nodal centers can communicate and collaborate for the purpose of functioning synchronously and efficiently.

Another benefit of such a system is that it avoids a central point of failure in case a server goes out of service. By using distributed system, only the nodal center whose NCS is out of service will be affected instead of the whole system.

The operational flow of the system after identifying the major nodal centers would be as follows.

- Commuters book the tickets via a mobile application on their phone.
- The request for the destination on a particular route is sent to the central management web server (CMWS).
- The CMWS will further send the demand to all the concerned NCSs.
- Whenever a bus reaches a nodal center, the nodal center server will take a decision on where to route the bus based on the demands it has at that particular instant of time.
- The decision is notified to the bus driver, commuter information systems and all other concerned stakeholders.

The below diagram depicts the entire operational architecture of the system.

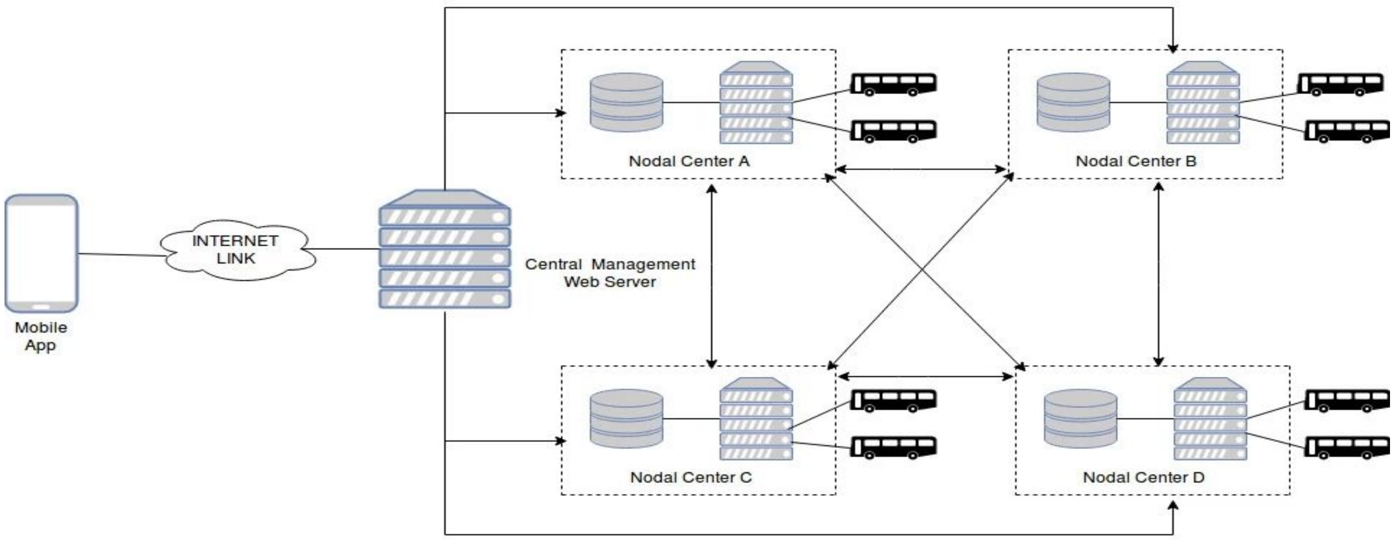


Fig. 2 Proposed architecture of the system

B. Mathematical Model

For the purpose of devising the algorithm, we will be considering the following factors -

- D_s - It is the number of commuters waiting at a nodal center to reach a particular destination. There will be a different D_s for different destinations.
- D_b - It is the number of commuters which are already travelling in a bus and intend to go to some further destination after reaching the nearest nodal center. There will be different D_b for different buses running on road.
- t_w - It is the mean waiting time of all the commuters waiting at a nodal center to board a bus for a particular destination. There will be different t_w for different destinations from a particular nodal center.

$$t_w = (t_{w1} + t_{w2} + ... + t_{wN}) \ / \ N \tag{1}$$

where,

t_{w1} , t_{w2} are the waiting times of individual commuters for a particular destination.

N is the number of commuters for that particular destination.

$$\therefore \ t_w = (\sum_{i=1}^{N} t_{wi}) / N \tag{2}$$

We model the problem of dynamic routing as a decision optimization problem at the NCSs. The NCS at any given nodal center has to make a decision about where to route any incoming bus. If more than one bus arrive simultaneously at the nodal center, then the nodal center has to decide the most optimal further routes of all of them by considering all of them and their commuters distributions. For keeping a track of the buses arriving in near future, we propose to have a threshold time interval, T_{int}, within which all the arriving buses will be considered simultaneous. This will ensure that the routes are designed by keeping a near future scenario in mind.

To take the decision about the further routes for the simultaneous buses, we require an objective metric to compare all the possible routes for each bus. Thereby, we define a metric, referred to as score(S), which assigns a numeric value to any possible route for each bus. The score signifies the incentive or value added by routing that bus to that route.

The score calculation process determines the way the buses are routed and utilized. For calculating the score, we need to consider the above explained 3 factors D_b, D_s and t_w. We can further reduce them to two logical factors for any bus that arrives the nodal center. These are the factors in which we have to trade off in order to arrive at a decision.

- Displacement factor - This factor is given by D_b. For any bus arriving at the nodal center, D_b for any route signifies the number of persons that would be needed to be displaced if that route is not taken. The concern is to minimize displacement as much as possible. Hence, D_b for a route will be a positive incentive in routing that bus to that route.

- Commuter waiting factor - This factor is given by D_s and t_w combined. At the nodal center, these two values combined signify the net commuter waiting for a particular route. There could be one commuter waiting since a long time or many commuters waiting since comparatively shorter time.

Based on the above two factors, we arrive at the following equation to calculate score of routing a bus to a particular destination or route.

$$S = \alpha . D_b + \beta . t_w . D_s$$

In the above score value calculation equation, there is an effect of both the logical factors, i.e. displacement factor and commuter waiting factor, so that there is a balanced trade off between the two. Apart from D_b, D_s and t_w, the equation introduces two new coefficients, α and β, which can be explained as follows -

- Comfort coefficient (α) - It signifies the weightage that is given to the number of commuters for a particular route already travelling in the incoming bus. Its value should be set such that the displacement and discomfort are minimized. Ideally, $\alpha \geq 1$

- Time coefficient (β) - It signifies the weightage given to the number of waiting commuters and their waiting time. Its value should also be set so that the perceived waiting time is reduced. We are taking the waiting time t_w in minutes, the value of β is taken in order to normalize the entire part and have proper trade off. Ideally, $\beta \leq 1$

These coefficients have the potential to alter the entire routing and should be predefined by the implementing authority.

C. Routing Algorithm

For the purpose of optimizing the route selection decision, we prepare a matrix for the scores of all the simultaneous buses at any instant of time known as score matrix. It contains the scores for all possible selection of routes along with the permutations of those routes in the available simultaneous buses. Hence, at any instant when decision is to be made, a score matrix of all available simultaneous buses vs all possible routes or destinations is prepared. For ex. , if there are two simultaneous buses, B_1 and B_2 currently available and three possible routes, R_1 , R_2 and R_3 score matrix will be prepared as -

Bus / Route	B_1	B_2
R_1	S_{11}	S_{12}
R_2	S_{21}	S_{22}
R_3	S_{31}	S_{32}

Based on the above matrix, the following algorithm is applied for decision.

Algorithm 1: Routing Algorithm

1. Fetch the values of D_b , D_s and t_w from the database.

2. Fetch the predefined values of α and β from the database.

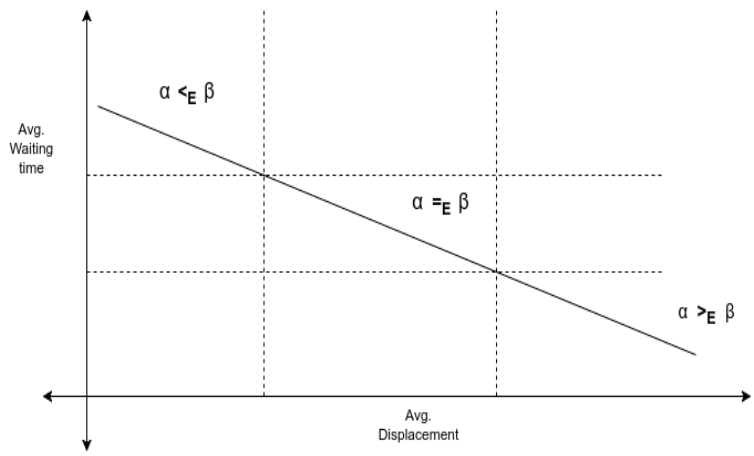
3. Calculate scores matrix for all the simultaneously available buses and possible routes at the given nodal center based on the following equation.

$$\alpha.D_b + \beta.t_w.D_s$$

4. Apply backtracking, branch and bound or dynamic programming to select the routes and permutation of buses for those routes which maximizes the sum of scores of the selected arrangement.

IV. Experiments and results

A number of simulations on buses and passenger data were performed using the above equation. We simulated the system over different set of values of α and β. By studying the variations of average waiting time and average commuter displacement over different simulations, we discovered the following kind of overall relation or trend.



where,

$\alpha >_E \beta$ signifies α has more effect than β on the score. This implies the ratio α / β is high.

$\alpha <_E \beta$ signifies α has less effect than β on the score. This implies the ratio α / β is low.

$\alpha =_E \beta$ signifies α and β have equal effect on the score. This implies the ratio α / β is moderate or balanced.

Based on our simulations, we discovered that for system to function in a balanced manner where both average waiting time and average commuter displacement are in medium range, the values of α should lie within the range

$$1 \leq \alpha \leq 1.5$$

whereas β should lie within the range,

$$0.01 \leq \beta \leq 0.02$$

The higher the value of α, the more is the focus on the comfort of the commuters within the bus. The higher the value of β, the better is the service provided for people waiting at the nodal centers.

Based on the results of simulations, we could also categorize the nodal centers into two types - major nodal centers and minor nodal centers. Major nodal centers can be considered as articulation points or cut-vertices in a graph. While the others being minor nodal centers. We discovered that, for minor nodal centers, the value of α should be on the higher range whereas for the major nodal centers, the value of β should be higher. Hence, as per our results, the value of α and β should be set differently for different nodal centers based on the nature of demands at that center.

For the transportation system to perform effectively and efficiently, a proper balance between the values of α and β is crucial. This values can be tuned overtime for optimal efficiency.

V. Conclusion and future work

In this paper, we tried to solve the problem of transportation system by introducing real time rerouting of buses based on the demand of commuters waiting at a particular nodal center along with considering the demand of commuter within the bus.

We found out that this real time rerouting is lot more efficient than default static routing. It not only gives the commuters an on-demand feel but also helps in utilizing resources efficiently and reducing the congestion on road thereby reducing the traffic. Further, we propose this model to be implemented in public transport systems as a 30 - 70 percent combination of static and dynamic routing respectively for easier adaptation by the commuters.

Although there are a few factors in our system that need to be considered while developing this solution. The first one is the traffic and second is the fact that buses might not return back to the original stop from where they begin. This would lead to mismanagement of time during initial hours. These factors are required to be taken care of while implementing such a system.

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