PARIVAHAN: PASSENGER DEMAND TRIGGERED BUS (VAHAN) ROUTING IN INTELLIGENT PUBLIC TRANSPORT SYSTEM

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Abstract

Daily commuters using the Public Transport System (PTS) have a different experience in Comfort Perception (CP) depending on the time of day. The pick-time CP value is not good, compared to rest time. This problem raised in PTS is due to the fixed-route strategy. The issue here is addressed by implementing demand based dynamic routing approach using the SUMO tool noting service time, request allocated per vehicle, average waiting time, and average travel time over variously categorized network topology. It was observed that dynamic routing reduces the travel time of passengers from 5.3mins to under 5mins. This reduction here is achieved with a little overhead of computational time as low as 14.37ms/request. The result shows that the ratio of average waiting time to average travel time is up to 0.5 for smaller network and decreases with an increase in network size and well connected-network.

***Keywords*: Intelligent Transportation System; Demand or Request; Dynamic Routing; Scheduling; Waiting Time; Travel Time.**

1. Introduction

In the current era of modernization in transport system, large number of people residing in urban as well as rural areas are motivated to use the Public Transport System (PTS) due to increase in safety, availability and citizen friendly infrastructural development. This growth in transportation domain is also necessary in sustained economic growth of the country. Stated in [18] that a full loaded double decker bus can take off 75 cars from the road, reducing traffic congestion and hazardous gas emission in environment.

The initial setup has now reached its working capacity specially places which are densely populated and the system now fails to occupy every commuter maintaining its Comfort Perception (CP). As mentioned in [21] Comfort Perception is one of the key factors attracting passenger towards public transport specially Bus. As per Eq. (1) given in [21] CP is factor dependent on total time spend in system (In-vehicle time + waiting time) and Passenger load factor which are most important attributes for measuring Quality of services for public buses.

$$CP = 11.151 - 0.084xT - 7.630xL \qquad (1)$$

We can see from equation that Passenger Load (L) contributes more in CP than Travel Time (T). It is because of higher CP in traveling through own vehicle or private taxi people prefer using these modes of commute. With increase in private vehicle or smaller vehicles like taxis the co-related problems like traffic jams, fuel consumption and hazardous gas emission (both while driving and stopping at signals/jams) and accidents stepped-up enormously.

A huge amount research of work has been carried out in the domain of Intelligent Transport System (ITS). Many solutions were proposed and implemented to solve the issues. One of the rea-sons discussed in the paper is the Fixed route approach taken by PTS for very long time. The solution to problems raised due to fixed route is to have a dynamic routing strategy. The dynamic routing already exists in public transport system in hired taxi,

Demand Responsive Transit (DRT) or Auto-rickshaws, etc. Each solution adds an addition cost of travel to the passenger. There by increasing the travel cost/km from 5x to 10x, or even more due to small fleet size [17].
Further, there have been work on dynamic routing of vehicles for almost four decades but very little thoughts have been made to apply dynamic routing in pure public transit system in real time scenario with significant fleet size. Either the passenger demands are assumed to be known before routing begins or the fleet size and net-work size is limited, to implement dynamic routing of public buses. The paper focuses on implementing dynamic routing in public transit system having bigger fleet size of 70 with request from probable customers generated on-the-fly and route update at periodic interval, and then comparing it with existing fixed route approach used for decades simulated over same network with same generated requests.
The flow of the paper is as Section 2 discusses on Motivation & Related work carried till date in ITS, section 3 describes Architecture of the proposed system and Algorithms designed to be executed on them. Section 4 discusses on the simulation setup and its parameters. Section 5 discusses on results obtained and their comparative analysis.

2. Motivation & Related work

The need to switch from conventional transportation system to Intelligent Transportation System has touched its peak in the recent past. Ac-cording to National ITS program plan [12], 33 standard ITS user services are listed bundled into 8 groups as:

1. Travel and Transportation Management
2. Information management
3. Public Transportation Operations
4. Electronic Payment
5. Commercial Vehicle Operations
6. Emergency Management
7. Advanced Vehicle Control and Safety System
8. Maintenance and construction management

The work in this paper is focusing the Public Transportation Operations where by authors are trying to optimize the load on public transport vehicle so as to increase the CP for passenger at the same time minimizing the number of vehicles on road to optimize profit of operator and minimize hazardous gas emission to keep pollution under control.
As per 2019 article [11], in India about 30% of population are currently living in Urban areas which is estimated to rise to 45% by the year 2031. As per TOI report [19] in state of Gujarat, India, sales of Car in June-2021 [Post-COVID] has increased by 40% as compared to sales registered in June-2019 [Pre-COVID].

P. Vansteenwegen et. al. [14] is a 2022 exhaustive survey of 150+ good papers on demand-responsive public bus systems, whereby author has divided the work done in area into 3 types: Dynamic-Online, Dynamic-Offline, and Static. Paper concludes that majority of the work done on demand-responsive transport is for passenger size less than 10 and horizon of planning is at least 1 hour.
Here we have focused on semi-flexible – as it will not be easy to replace existing system as once, many-to-many stop based approach, whereby passenger can board or alight at any designated stoppage, with fleet size of a bus (which is generally 60+).
Rios, B. et. al. [16] is another 2021 comprehensive survey on dynamic vehicle routing problem majorly of seven years from 2015 to 2021. The survey reveals that maximum work carried is on transport of good which is 40% and only 17.5% papers focus on transport of people.
Dynamic ride sharing systems was attempted in Liyanage, S. et. al. [9] where by fixed route buses strategy was replaced by dynamically rout-ed mini buses. The results conclude better occupancy, reduction in waiting and travel time, along with hazardous gas emission.
Nora N. et. al [13] and Kusuma, P. D. et. al. [8] has worked on CVRP (Capacitated Vehicle Routing Protocol) focusing on transport for goods to and from depot to customer as per dynamically raised demands. The papers concludes that there is always trade-off between numbers of customers satisfied with limited capacity and total distance travelled.
But the capacity of mini bus was only 7. This approach might not be feasible for densely populated countries like India, China, and African countries.
M. Orošnjak conducted an exhaustive literature review [10] whereby they had focused on Bus Fleet Management (BFM). Purpose of Review was to overview the existing concepts and school of thoughts about how stakeholders perceive the BFM. They explored many dimensions viz Fuel Economy, availability, operational efficiency,

pollution, etc. BFM is majorly perceived as either Routing and Scheduling problem or as maintenance and replacement strategy.
Archana et. al. [2] had done a very good work on passenger flow prediction that could help scheduler to schedule vehicles as per passenger needs.
Authors of [5] had proposed a Route Planning Maker (RPM) which has flexible user inter-face with intention to help government or transportation authority to design new routes or to update existing routes based on passenger flow.
Here data of travel is required at least 1 day before to design the routes and system cannot handle passenger who decides to travel at immediate.
On the other hand [3] stating the complexity of Dynamic Route planning introduces new challenges while judging the merit of given dynamic route. The paper proposes $O(m^3)$ to $O(m^4)$ algorithm which is acceptable only for smaller net-work and fewer number of requests.
The proposed algorithm in paper is having complexity of $O(m^2)$, where m is number of stoppages in network.
[4] had coined a new term called Deadhead Trip, which means the distance travelled by vehicle without carrying a passenger, whether it is travel from last stop to depot or depot to fuel station or even movement of vehicle during non-peak hours on scheduled route between station fully empty. The paper proposes 4 algorithms to minimize such trips and save fuel overall increasing the efficiency of vehicle and profit of the organizers.
This paper focuses on entire day request and hence handling peak and non-peak hours both.
[20] is an in-depth study of Skip stop strategy for public transport vehicle. This is with under-standing that not all stations are high demanding station and passenger are unequally distributed across the city network. The paper shows a tremendous increase in fuel efficiency and reduction in emission using the strategy.
The approach we have taken in paper is adding stops which have passenger either boarding or alighting rather than skipping, this way both peak and non-peak hour passenger flow is handled along with direction of passenger flow.
[15] discussed on emission of Green House Gases (GHG) and fuel consumption in context to load carried by the vehicle. The results in paper clearly indicates a direct relation between them.
Also, the same we have seen in Eq. (1) of comfort perception, so the algorithm implement-ed while assigning request to any vehicle consider the load on it and try to distribute it by applying criteria mentioned in section 5.
[1,6,7,22] have put their focus on solving the BFM problem by having a Dynamic Routing algorithm of public transport vehicles. The major emphasis was put on routing the vehicle as per the passenger flow request which could be taken into the system by various ways. These papers are also baseline for our result comparison and are discussed in detail in section 6.

3. Architecture and Algorithms

This section explains about the architecture of the Transport system proposed which consist of different components integrated with each other to help a traveler a comfort journey and travel from its nearest boarding point to closest station of its destination.

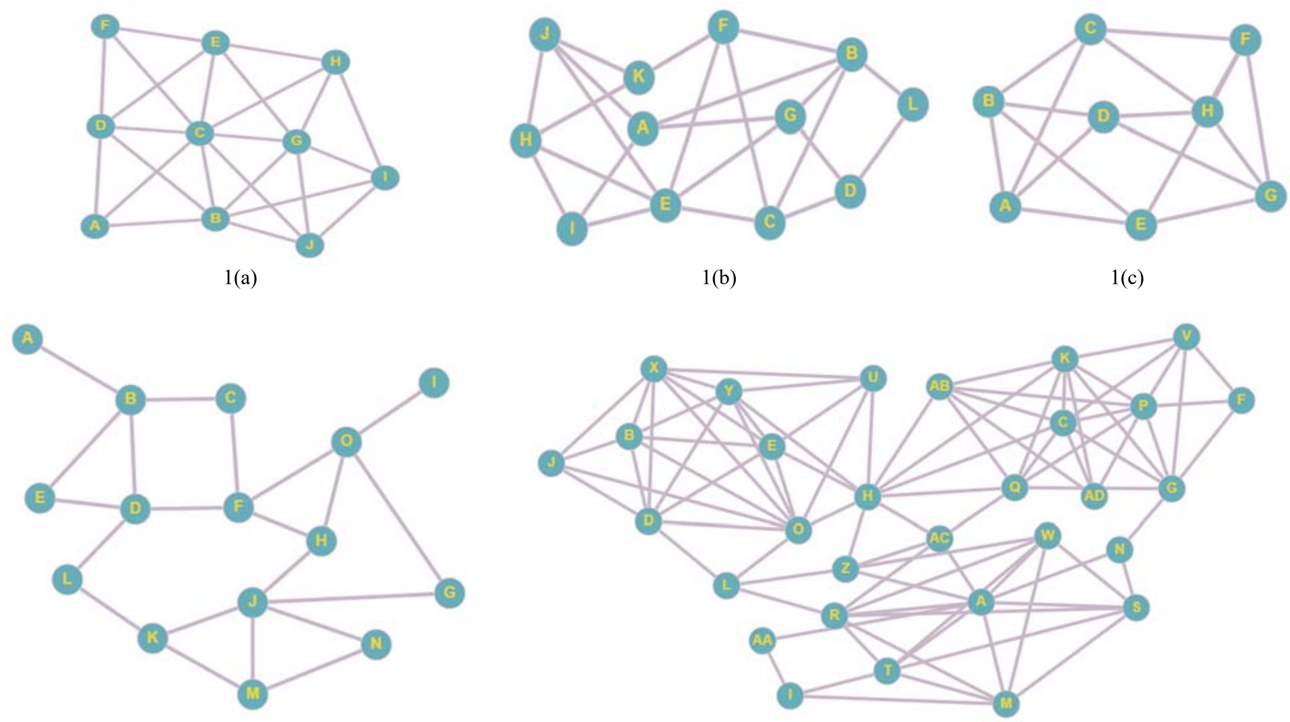
3.1. *System Components*

The system consists of below elaborated major components: -

- Network Design: The design of city network can be modelled as a Graph G (N, E) were
  - N: be number of nodes in graph representing bus stops
  - E: be number of edges in the graph representing connecting roads.
  - d_i: Degree of node i in city network.
  - D: Total degree of graph equal to $\Sigma_i d_i$

The characteristics of the network are mentioned below:

1. The network in Figure:1a is a network with at least 1 node which is connected to almost all nodes (i.e., degree close to N −1) in the net-work and E for the city network is at least 2x of total number of nodes in the network.
2. The network in Figure:1b is the network with minimum 2x number of edges to number of nodes but no node having degree greater than ½ of total number of nodes.
3. The network in Figure:1c is the network which is k-regular (i.e., graph which have all vertices of degree k)
4. The network in Figure:1d is a Mandl network with 15 nodes and 20 edges. The Mandl's Swiss network is considered in many of the research focuses on public transport network.
5. The network in Figure:1e is the network which is a mumford0. This network is with 30 nodes and 90 edges.



1(a) 1(b) 1(c)

1(d) 1(e)

Figure 1: Different Tested Networks for Algorithm

- User Demands/Requests: Let U = {u_1, u_2, …, u_n} be the set of users using the ITS and makes a request to generate a ticket to travel denoted as T = {T_1, T_2, …, T_n} from PTS. A request made by user u_i is modelled as a quadruple $\{T_i, L_i^S, L_i^D, PTS_{id}\}$ where $L^S{}_i$ and $L^D{}_i$ be defined as the source and destination location for any ith ticket having timestamp denoted by T_i at which the ticket is generated, and PTS_{id} denotes the public vehicle registered with ID of the PTS. In the system $|L^S{}_i, L^D{}_i|$ denotes the total number of generated demands using DUAROUTER Algorithm implemented in module of RandomTrip generator in SUMO tool over a period of time (a day), and $|PTS_{id}|$ denotes the count of PTS that are servicing all the request.
- Public Transit Vehicle (PTV): The Public transit vehicle identified by PTV_{id} is the vehicle which finally fulfils the request/demand of the commuter. The algorithm of route selection discussed later, makes and attempt to assigns a PTV to every request Ui entering into the system. All the request which algorithm fails to assign a PTV contributes to the request dropping probability Pb and is a crucial parameter for deciding best Route selection Algorithm.
- Ticket Issuing Counter (TIC): Ticket issuing counter (TIC) is the device which takes up the request/demand from the user, forward it to the server for Route Selection and PTV allocation Eq. (2) to the request. The route selection and PTV allocation server than returns PTV_{id} for the request to the TIC and TIC will issue ticket which contains the following attributes

$$TKT_{U_i}^{PTSV_{id}} = \sigma(L_i^S, L_i^D, PTSV_{id}, T_i, B_T, A_T) \qquad (2)$$

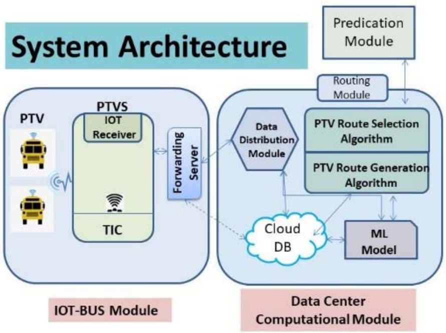
like $L^S{}_i$ and $L^D{}_i$ are the source and destination location, $PTVS_{id}$ is the Public Transit Vehicle Stoppage id, T_i is the Time when the request is 0made to the system, are mentioned in Ticket will be used to compute various other parameters like Estimated Travel Time (T_T) and Estimated Waiting Time (W_T), these parameters are used to limit the travel time and waiting time so as to maintain the Comfort Perception and also avoid route divergent issue that might arise due to the dynamic nature of system.

- Route Selection/Prediction: The proposed here are PTS route generation/ prediction algorithm. Route decision algorithm proposed in [1] denoted as $R = \{R_i^{curr}, t_i^0, F_i, \eta_i, Q_i, R_i^{prev}, \delta\}$ where R_i^{prev} and R_i^{curr} denotes the previous and reaching stop of public transport vehicle PTV_i which can take request represented by (L_i^S, L_i^D) raised at time T_i. Here t_i^0 denotes the initial start time of the PTS from designated stop, F_i denotes the fuel indicator to service the request, η_i denotes the emission indicator of the vehicle, Q_i denotes the passenger capacity, T_i^{prev} denotes the previous requests stored a historical transaction, and δ denotes the percentage of dropped requests on a given route R.

- The Fetch_Route procedure is called for fetching the possible PTV's which can fulfil the request and if no such vehicle is found Check_Route procedure tries to find all possible routes R_i's is on which the request can be forwarded by making change in routes currently PTV's are following. With all possible PTV Update_Path procedure for updating R and adding request into it.
- PTS Stops: Public Transport Stop (PTS) is defined all possible locations from where a passenger can board or alight making a travel ticket request. This PTS can be represented by a 6 attributed tuple as $\{A_i^T, D_i^T, C_i, S_i, MAX_T, \tau(R)\}$ where A_i^T and D_i^T represents the estimated arrival and estimated departure of PTV_i at PTS_T, C_i denotes cost of route currently followed by PTV_i and it cannot exceed MAX_T and τ(R) is the total response time taken by PTS for computing route information and assigning the best possible PTV for every request raised. The information about route request generated from PTS can be given to Machine Learning module which can be utilized for analysis and future predictions.

3.2. *Architecture of PIBS-IPTS*

PIBS-IPTS is a 4-module architecture defined in Figure 2. The modules are described below:



- IoT-Bus Module: The IoT-Bus module is the IoT setup on set of 'n' Public Transit Vehicles PTV (PTV_1, PTV_2, PTV_3, ..., PTV_n) running in the network for carrying passenger from their requested location L^S_i to its destined location L^D_i, at 'm' distinct Public Transit Vehicle Stations PTVS ($PTVS_1$, $PTVS_2$, …, $PTVS_m$) having atmost 'p' Ticket Issuing Counters TIC (TIC^k_1, TIC^k_2, ..., TIC^k_p) at $PTVS_k$. All these requests (T_i) are forwarded to Server, where server module is executed and a bus is assigned to fulfil the request.
- Computational Module: The Computational module receives the messages generated at PTS_j by 2 IoT modules, working in coherence with each other as described above. The server module consists of majorly 3 algorithms: Route selection, Route generation, and Prediction. These algorithms are explained in detail below:

  Route Selection Algorithm: This paper proposes the Route Selection Algorithm-1 which is one of the major components of the architecture.

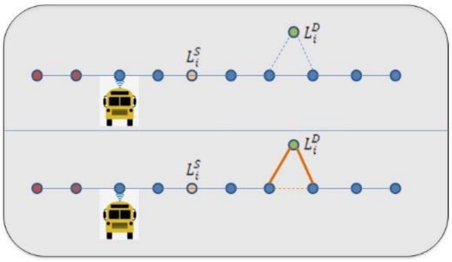
  Every request T_i received by server is first processed by Route Selection Algorithm. The algorithm searches in its current PTV_Route table, this table contains information of all the PTVs running in the system and route currently followed by them. The algorithm finds all possible PTVs which can fulfil the request i.e., passenger can take to proceed for its journey. While making this attempt to search PTV(s) one of the 2 cases can happen with regards to fulfilment of the request.

  Case-I: PTV(s) found in PTV_Route table: While searching route(s) to fulfil request T_i algorithm may return a set of routes PTV(s) and this set is given to Bus_selection algorithm to find optimum vehicle PTV_i opt as per Eq. (3) for T_i

$$PTV_{opt}^{i} = Bus\_Selection(PTVs, \pi, \max_{\tau}) \qquad (3)$$

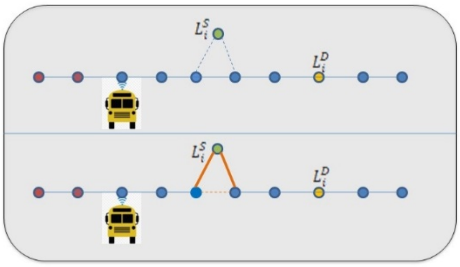
  Here π is the cost function. The cost function comprises of the different attributes like Load Carried by all eligible PTVs (LC^{PTVk}), Fuel Level of all eligible PTVs ($Fuel^{PTVk}$), Estimated Load when the PTV arrives at PTSVid from where the request is generated $Esti^{PTVk}_{LC}$, Estimated Travel time for the request U_i for each possible PTVs $Esti^{PTVk}_{TT}$

Case-II No Route found in PTV_Route table: If no direct route is available in the Route Table, then Algorithm calls Update_Path function. The duty of this function is to find that either of the 3 options: if only source L_i^S or only destination L_i^D or both source and destination of the request is not available in the Route Table. These steps depend on the Route Fetch failure and are as below:



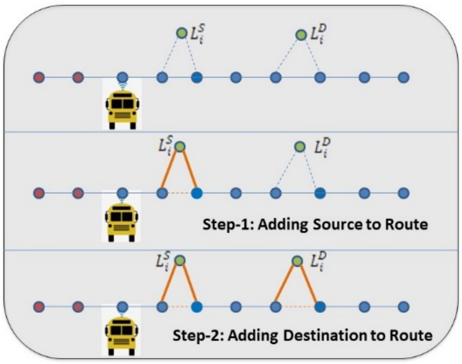
e Update – Destn

(a) If Source of request L_i^S exist in at least 1 route of PTV_Route_Table but Destination L_i^D is not available then the method Re_Update_Route is called. This method analyses all the routes which can be updated as shown in figure to satisfy the request. Figure 3a indicate the scenario where the source of any request is available in at-least one route on which any PTV is moving. This route is updated in a way that Destination of that request could be added to route. As it can be seen in the figure while updating the route Algorithm takes into consideration the threshold (MAXτ) set for any route. The route length and total travel time should not exceed the threshold value. That will also limit the total travel time of all passengers and maintaining the comfort perception (CP) of the overall system. This threshold also solves the issue of route divergent which can also lead for a PTV to get into an infinite travel due to dynamic nature of the system.



Update- Source

(b) If Destination of request L_i^D exist in at least 1 route of PTV_Route_Table but Source L_i^S is not available then the method Re_Update_Route is called. This method analyses all the possible routes which can be updated as shown in figure to accommodate this request. Figure 3b indicates the scenario where the source of any request could be added to route(s) to satisfy the request. While updating route(s) of any (PTV) the algorithm maintains the threshold limit of travel by any PTV, that directly limit the in-vehicle time of all the commuters. Also, the algorithm check that destination already existing in route is also not crossed by the PTV. Else that can make vehicle move away from the route destination, increasing the undesirable travel time.



ce – Destination

(c) If neither Source L_i^S nor Destination L_i^D exist in any route of PTV_Route_Table then the method Re_Update_Route is called. This method analyses all the routes which can be update as shown in figure to accommodate this request. Figure 3c demonstrates a situation where neither source nor destination exist in any route. This is the most critical case to handle. The algorithm first tries to add Source into all possible PTV's route assuming that Destination exists in them. After adding source, it calls the method of adding destination for that request.

The set of PTV s are then given to Bus_Selection Algorithm. The responsibility of Bus_Selection Algorithm is to find best vehicle and send it in response to PTVS from where the request(s) is/are generated, also it makes entry into its own table about request and its various attributes tuple (TS_i, $L^S{}_i$, $L^D{}_i$, PTV_{id}, MAX_τ, $MAX\_TT^{Esti}{}_i$, $MAX\_WT^{Esti}{}_i$) where these records will be used in future request allotment.

4. Simulation setup

Demand based Route Decision Prediction Algorithm was implemented and executed with numbers of request as mentioned in Table 1 over 5 different city networks with different characteristics as shown in Fig. (1) which are described in Section 4.1. The result in the Fig. (4) and Fig. (5) are observed.

Sr. No.	1	2	3	4	5
# of request	1000	2000	3000	5000	10000

Table-1: No of requests/demand

The algorithm is executed with different selection criteria of the possible PTV which can be allotted to the request. One thing to be noted here is in Fig. (4) that Network-1 [NW-1] represented in Fig. (1a) has least dropping of request which less than 100 per 10000 requests [almost negligible], but we cannot consider this network for further discussion. As nodes of network are highly connected and such network of road in real world is not possible to have as it will not be feasible to develop such infrastructure and such high junction connectivity.
Below are the 6 different criteria for PTV selection satisfying the request.

1. Criteria-1 [A1]: In typical scenario for any Public Transport System the vehicle runs on a circular route. Assuming 1, 2, 3, ..., etc are stoppages generally, the routes are like 1-2-3-4-3-2-1 i.e., the vehicle takes exactly the same path but in reverse while returning to the route source. But in this approach, we executed the PTV to have a different return route keeping the route source and destination intact. For ex-ample, 1-2-3-4-5-6-1.
2. Criteria-2 [A2]: The second PTV selection criteria is probabilistic. Here all the possible PTVs are scanned one after another and with 90% probability selection is done for any PTV. This approach was with intention to have some sort of distribution of request so as to minimize load on any route and maximize the usage of PTV.
3. Criteria-3 [A3]: The PTV selection Algorithm-3 is on criteria of least loaded PTV from all possible PTV that could satisfy the request.
4. Criteria-4 [A4]: This approach was with intention to have maximum passenger on fewer number of routes; hence selection was done based on most loaded PTV.
5. Criteria-5 [A5]: In this selection algorithm it was probabilistic selection of PTV from least loaded to most loaded possible PTVs.
6. Criteria-6 [A6]: In this selection algorithm, an attempt was made to minimize response time per request so that the total time taken in Ticket issuing by TIC is optimized and the PTV could be intimated about route updation well in time.

Results of the above simulation runs are discussed in next section.

5. Results and comparison

The solution proposed here majorly focuses on balancing the passenger load throughout the system increasing the Comfort Perception (CP) for the passenger. The system tries to identify the best possible route to which the passenger request could be assigned in a manner that the average passenger load of all the vehicle is balanced with minimal variance of passenger load and then as-signing a vehicle to follow the route. For the same the passenger is assigned to route not directly to vehicle.
The algorithm was executed in SUMO tool and results obtained are shown in Figure 4 and 5. Detailed discussion is here for each result.
The Figure 4 shows the number of requests dropped Vs number of total request generated in system in different network under different algorithm simulation environment.
Fig. 4a represents approach A1. This approach supports the dynamic nature of algorithm reducing the number of request drop. In this approach it was observed that the dropping probability was around 25% for network 1b and 1d, around 20% for Network 1e which is Mumford0 network. For network 1c the value is between 10% to 15%.
Results of A2 obtained has the number of requests dropped are almost same as selection algorithm-1, which is in actual quite high. Hence not considered for further discussion.
From Fig. 4b it was observed that in criteria A3 the request drop was reduced by 3% to 6% as compared to PTV selection criteria A1 & A2.
By executing criteria A4, the service provider can satisfy maximum customers by running more PTV on high demanding routes and fewer PTV on less demanding routes. This will minimize the overall working cost of the system. Fig. 4c shows request dropping probability for this Algorithm was in difference of ±1% in comparison to all above selection criteria.
Criteria A5 was with intention to have the distribution of passenger across the PTV which is selected with some probability from least loaded to most loaded. Better dropping probability was achieved but with a trade-off increase in response time. Fig. 4d shows the number of dropped request while the response time which increased by 2 to 10 ms/request on an average, is shown in Table 2a.
Criteria A6 was implemented to minimize the response time that could be observed in Table 2a. The average response time is reduced in range of 3 to 8 ms/request as compared to all algorithm, but at the same time the

average waiting time and average travel time are towards the higher end, this is because the vehicle selection is done at random.

For algorithm-6 at one end we have least response time but on the other end we have highest waiting time and travel time. Overall increasing the total time of passenger in system. This will direct effect on comfort perception of passenger and the overall comfort level of passenger decrease. The more the passenger interact with system the lesser is the comfort perception.

In the Figure 5 Route-# indicates that # number of routes are active in the system, i.e., # number of vehicles are running in system to fulfil the passenger request.

1. The pattern for request drops with respect to number of requests made to the system remains same across all the algorithms executed on networks with different characteristics. This concludes that we can put focus on blocking probability observed in different network.
2. Here we can observe that blocking probability is very high (~25%) for sparsely connected network like NW-2 and NW-4, while it is very low (<1%) for highly connected network like NW-1. But practically having such highly connected network is not possible for any city network.
3. NW-4 (MandL Network) and NW-5 (Mum-ford) which are standard networks used by many researchers to simulate the real city scenario are having high (i.e., 15% to 25%) blocking probability for all algorithms. So, efforts were put to reduce the request dropping probability for these networks.

Most important parameters for any transportation system viz Average Response Time, Average Waiting Time, and Average Travel Time are tabulated in 2.

Algorithm	Average Response Time				
	NW-1	NW-2	NW-3	NW-4	NW-5
A1	8.22	18.92	11.70	17.40	335.63
A2	11.98	23.26	12.89	22.12	244.92
A3	14.37	20.78	11.73	18.77	231.07
A4	11.86	20.78	9.86	20.25	229.50
A5	11.86	23.15	12.61	20.44	230.37
A6	10.85	20.26	10.95	17.43	244.98

(a) Average Response Time

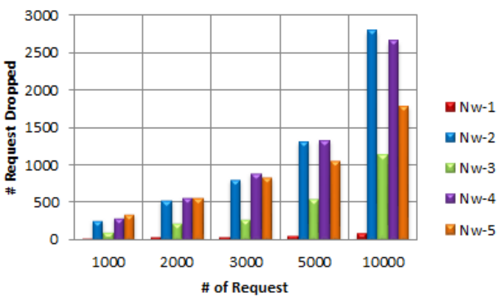
Algorithm	Average Waiting Time				
	NW-1	NW-2	NW-3	NW-4	NW-5
A1	5.23	4.11	4.30	5.05	7.06
A2	5.61	4.31	4.38	5.03	6.59
A3	4.78	3.91	4.04	4.90	6.00
A4	6.70	3.91	4.35	5.16	8.84
A5	6.06	4.16	4.24	5.13	7.13
A6	5.59	4.25	4.27	5.15	7.16

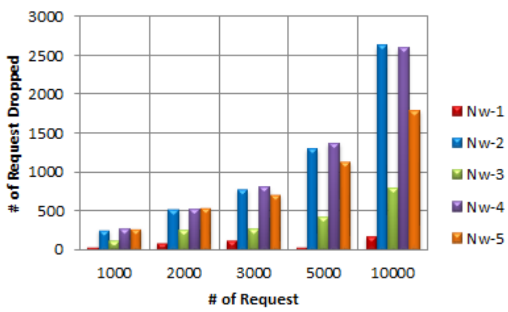
(b) Average Waiting Time

Algorithm	Average Travel Time				
	NW-1	NW-2	NW-3	NW-4	NW-5
A1	4.75	3.77	4.07	4.85	8.64
A2	5.25	3.74	4.07	4.88	7.97
A3	4.42	3.53	3.79	4.71	7.39
A4	6.22	3.53	4.27	4.89	9.96
A5	5.57	3.84	3.93	4.83	8.58
A6	5.44	3.93	4.11	4.93	8.61

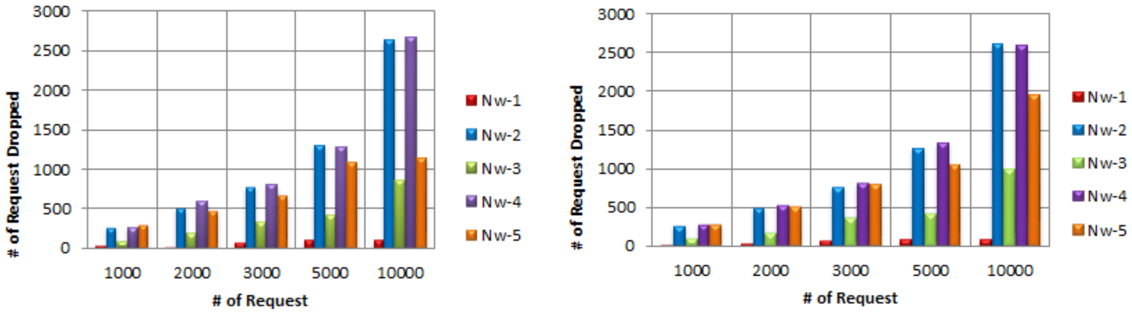
(c) Average Travel Time

Table 2: Various tables of observable parameters



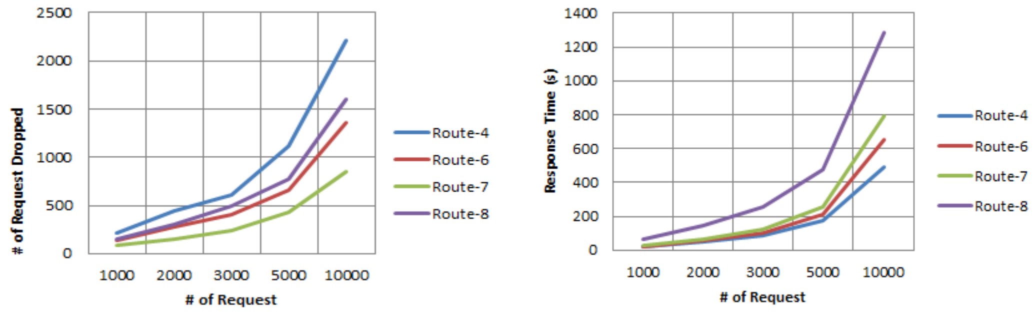


(a) Dynamic Routing – First available selection (b) Dynamic Routing - Least Loaded PTV Selection

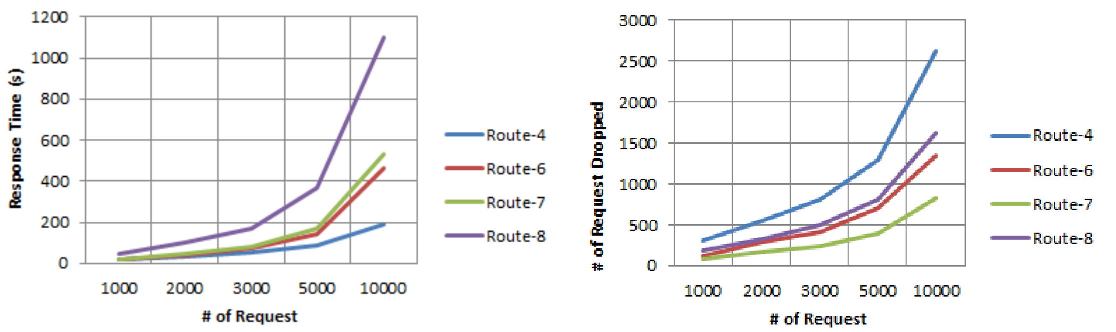


(c) Dynamic Routing - Most Loaded PTV Selection (d) Dynamic Routing – Probabilistic PTV Selection from least loaded to most loaded

Figure 4: Request Generated Vs Request Dropped



(a) Dynamic Routing - Varying Initial Routes (b) Varying Initial Routes – Response Time



(c) Dynamic Routing - Varying Multiple Initial Routes (d) Varying Multiple Initial Multiple Routes - Response Time

Fig 5: MandL Network with Different Number of Routes

But interesting point to observe is Algorithm A4 (selection of PTV with highest loaded) is having lowest response time in comparison to other algorithm for majority of the networks. This signifies that highly filled vehicle has respectively faster chance of finding an PTV for any request. On the other hand, for algorithm A4 the Average Travel Time and Average Waiting Time are highest.

It could be observed that algorithm A3 (selection of PTV with least load) is preferable with respect to Average Waiting Time and Average Travel Time. As with lesser passenger on board the PTV will take less time for pickup and drop due to limited number of stoppages in the route.

In [1] algorithm was designed and executed only on one network, here the algorithm has executed on 5 networks with different characteristics. Of which NW-1d and NW-1e are standard networks used by many researchers for simulation run of real city networks.
The average response time in [1] the request dropping probability was 3.5% for 1000 request and here our algorithm had 2% for 1000 request. But as the number of requests is increased the dropping probability becomes same for both algorithm on same network.

In [6] authors have considered a very small network of 8 nodes whereas here we have considered multiple networks with various nodes (up to 30).
The average response time taken by algorithm shown in [6] is 1.22 seconds. But algorithm shown here for an 8-node network NW-1 takes maximum 14.37ms for algorithm A3 and minimum 8.22ms for algorithm A1.
In [7] the minimum travel time for Scenario one where fleet size is 24 is 5.3 minutes for 3693 requests. Whereas in our scenario for 10000 request the average travel time for Network NW-4 with 17 nodes is ~5 minutes considering average speed of PTS is 30kmph.
Since there is no previous work done in implementing dynamic routing for public transit system on Mandl and Mumford network, simulation runs were done for comparison with dynamic routing. Table-3 shows the comparative results for the percentage of passenger not getting direct bus for their travel destination. As per the results we can clearly say that in comparison to static routing 25% more passengers gets direct bus to their destination.

Routing	%age passengers with no direct route		
	A1	A2	A3
Dynamic	17.26	15.57	7.53
Static	21.2	20.6	11.38

Table 3: %age of Passengers with no direct route in MandL Network with 6 buses in system

Routing	Buses					
	B1	B2	B3	B4	B5	B6
Dynamic	48	65	30	29	27	11
Static	44	86	19	30	24	7

Table 4: Highest number of passengers boarded in bus in MandL Network with 6 buses in system at any instance

Now looking at Table-4 we can compute the standard deviation of peak load carried by any vehicle when total of 210 passenger request are satisfied in the system when algorithm A3 is used for selecting PTV for servicing any request. We can observe that standard deviation for dynamic routing is 17.17 and for static routing is 25.53. This is due to dynamic nature of system and load balancing strategy taken by algorithm.
If we consider the peak load in each case, which is 0.3 in case of dynamic algorithm and 0.41 in case of static routing and compute Comfort Perception (CP) we will get CP value to be 8 for dynamic routing and 7.24 for static routing. It proves dynamic routing to be better with a greater number of passengers having direct route to destination and higher comfort perception.

6. Conclusion and future work

The request drop indicates that the system was not able to identify a direct route between the asked Source and Destination. The same is also possible in fixed routing strategy, where a passenger does get a direct bus to the destination it wants to travel. In future, efforts could be made to reduce this even further. Dynamic Routing for vehicles in Public Transport System have started gaining interest of research community. This has become a key point of focus in Intelligent Transport System. Even though there is a drop-ping probability, still the system is able to serve 88% of the request with a little overhead of up to 14.37ms of computational time. As future work implementing a network design algorithm and integrating it with the dynamic routing algorithm to have best initial routes so that there is no drop-ping of request can be done.

Conflict of Interest

The authors have no conflicts of interest to declare.

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