Planning for Demand Responsive Bus Service for Limited Area using Simulation

Sharmeela Kale and Premjeet Das Gupta

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Sharmeela Kale | School of Planning and Architecture, Bhopal
Email id: sharmilakale166@gmail.com

Premjeet Das Gupta | School of Planning and Architecture, Bhopal
Email id: premjeet@spabhopal.ac.in

Abstract: This research is aimed at evaluating the potential benefits of Demand Responsive Transport (DRT) for bus service over conventionally fixed-route bus service operated over a small area. This study is based on developing a hypothetical model for building a future scenario, resembling the working of flexible transport model by estimating total demand and assigning the estimated demand by the dynamic routing of buses to different time window setting between pickup and drop off locations by extrapolating the collected samples to total demand. The working of demand responsive transport service for feeder buses is be based on geosimulation techniques using agent-based modeling software Matsim (Multi-Agent Transport Simulation) and its extensions and visualization software is Via Simunto to generate DRT scenarios of future complex traffic flows. The efficiency of DRT services is measured through the indicators that are- Vehicle productivity (km/day), Passengers carried per bus per day (number), Average travel time duration (minutes), Average waiting time, Average in-vehicle time (minutes), Passenger usage i.e. rides per vehicle revenue hour, Operating Cost and Passenger cost. Thus this study will be analytical and generate a simulation model for transport operators to select between existing fixed-route bus services and flexible transport services for feeder buses. As a result of research, it is observed a significant reduction in passenger travel time and also reduction in operating cost of service when operated for minibuses.

Keywords: Demand Responsive Transport, Dynamic vehicle routing, flexible transport service, Public transport, Fixed route bus service, feeder bus, Simulation modelling.

1 Introduction

Rapid urbanization in India has increased the use of motorized vehicles as travel demand grows with increasing population of 4.6 times after post-independence [15], also which in turn has led to larger concentration of population in class 1 and million plus cities bringing with it the major challenges of urban transport [20]. Due to this there is increased number of registered motorized vehicles by 10.7% annually since 1950 to 2016 [20]. The growth rate of total registered vehicles during the period 2006 to 2016 were recorded by cars, jeeps & taxis and 2 wheelers 10.1% & buses was only 5.9% as per Ministry of Road Transport and Highway Annual report 2016 [20]. Increase travel demand has also caused a shift towards private vehicles from public modes, as it is observed, in number of registered motorized vehicular composition bus has reduced

from 11% to 1.1% from 1950 till 2011 [20]. This shift from public transport to private transport is due to the quality of service offered by public transport. Bus ridership in major cities like Mumbai, Delhi Chennai and Bangalore is decreasing since the past decade. Ridership of Mumbai public transport BEST is reduced from 16000 lakh passenger to 12000 lakh passenger from 2009 to 2015 as per KPMG Research analysis 2017 [17].
Based on the research conducted by KPMG share of Public Transport trips in India is only 7% whereas in Singapore is 86% and Brazil is 29% as per KPMG Research analysis 2017 [17]. Public transport also lack in required infrastructure and fleet size as Delhi has a net shortage of almost half the total number of required buses 2015 .Public transport is also facing financial crises due to which transport operators are unable to repair and maintain buses and provide the desired level of service to users which also the reason why ridership is decreasing [17].

2 Need for study:

Existing Public Bus Service provided has many problems such as fixed route which leads longer commuting time, low ridership in non-peak hours, and low frequency of buses when demand is there, congested buses during peak hours, longer waiting time, non-availability of a seat, poor customer experience and, lack of use of technology [23]. Public transport is least preferred mode of travel this is due to many reason not only service provision and quality of services, but also people's perception toward service, social status and income, safety issues, ease of travel and time saving. But in India existing public transport service are not well evolved to attract the potential costumers reducing the modal share of public transport in cities. Public transport users face longer waiting time, unpredictable travel time and problematic travel circumstances [24].

A demand of any service is based on user perception towards the service and which is always changes with time and location, how the demand is perceived will not remain same in future. Demand for public transport is also dynamic in nature and depends on user behavior and choice whether to use service or not within a specific time window at a specific location. Thus providing fixed service on static routes will not solve the problem of capturing user dynamic demand.

The shared economy in the Transport sector is a topic of discussion in recent years due to the success of emerging Uber, Ola, Lyft shared mobility providing service agencies which are the major contributor to the trend. There is a positive increasing trend towards this approach in urban areas as it has various benefits on the user side as in the case of car sharing and ride sourcing due to time-saving, convenience, monetary savings and reliability [29]. Thus using of technologies has become of prime importance for this transition towards sustainable transport in future.

Aim of the study is to assess the potential benefits of Demand Responsive Transport (DRT) under simulated conditions and explore the conditions required for its introduction.

2.1 Demand Responsive transport

DRT is advance form of public transport based on flexible routing and scheduling of vehicles between pre-know pickup and drop off locations of passengers operated as per passengers travel demand also is flexible shared transport service that brings to- gether people from the same area who are to travelling at the same time and at nearby locations [9]. Demand Responsive transport is based on some of the essential concepts of Stopping point and Flexible route and built on which there are two types of DRT which is Door to Door service and Stop based service [31], [32].

Concepts of Demand responsive service:

Stopping Points: These are the locations where user can avail DRT services which can be Endpoints of service route, Fixed Intermediate Stops at suitable locations, Pre-defined Stops not necessary fixed bus stops but can be convenient locations for passengers to board from their locality and Non Predefined Stops i.e. any location which can be preferred by user of service can be doorstep as well [32].

Route Flexibility : Semi-Fixed Routes those are fixed for specific portion that could be main roads with fixed intermediate stops and flexible along internal roads with no predefined stops or Flexible Routes where DRT service runs from an end stop point; or Virtual Flexible Routes where service runs with no fixed end or intermediate stop points and no fixed times. [32].

Technology-Based: Pre-booking and reservation systems dynamically assign passengers to vehicles and optimize the routes [31], [4].

Vehicle: Vehicle selection for DRT is of vital importance for the efficiency of offered service, various vehicles mostly cars, Buses, Mini Buses, Vans can be used [32].

Case Studies

Previous researches on DRT was focused more on the appropriate type of vehicles used for pickup and delivery and routing and scheduling of services whereas less explored issues of DRT schemes is user-friendliness [4]. The success and failure of service at macro scale are based on various factors like political influences, economic influence, socio-cultural influence and technological influence and at micro level market demand is guided by flexibility, approach to booking vehicle, operator, eligible users, geographical coverage, pricing [4], [5].

Evaluation of DRT services in Europe [21] proves that DRT is the more strategical way forward to implement in more regulated conditions without being any conflict with other public transport modes. In Europe, government has relaxed all the norms against the development of flexible shared service like route registration to promote community-based shared service.

Hong Kong, China- Public Light Bus (PBS) [7] [30] are minibus service introduced in 1969, which covers 15% of public transport trips with minibus vehicles of a capacity, not more than 16 seats. Public Light Bus provides two types of service one with green roofs (GMBs) and with a red roof (RMBs). RMBs provides non-scheduled service purely based on demand that will operate flexibly subjected to market demand and no control on routes and fare by transport authority. This service is permitted in all existing service areas except for in new town housing development in Hong Kong. They have also introduced local stopping restriction on PLBs to prevent the congestion on the curb side and at a road junction. With the policy, intervention government introduced GMBs as scheduled service as a feeder for mass transport like rail and BRTs. In the case of Hong Kong with a high capacity for Rail and Bus public transport systems where private vehicle ownership is very less there is still market to be captured for Demand Responsive Transport Service.

Study of **fixed routes and demand responsive feeder transit** [6] in Atlanta city where comparison of passengers cost and operating cost of existing feeder routes and demand responsive routes is done. It proves DRT service outperforms fixed route service and performance can be improved by adjusting routing algorithm. Demand responsive flexible routes are more cost effective and efficient as demand for service which changes widely across metropolitan area with location due to population density and specific time of day also thus comparison can be done when DRT best meet the customer demand and minimize the operating cost .

Survey of demand responsive transport [5] in **Great Britain states**. Since the 1970s, Demand Responsive Transport (DRT) has been promoted as a transport solution in circumstances where more traditional services are not economically viable. Mobility on demand can be designed in different ways with respect to the resolution of stops and timings, and the potential patronage. Without a commercially sustainable funding mechanism for DRT, long-term financial sustainability is always questionable.

Singapore- Study of dynamic bus routing service in Singapore where high capacity on demand mobility services efficiencies are study over conventional fixed route studies. Study focuses on dynamic routing of large capacity buses of 30 seaters to provide feeder service to mass transit in a specified highly dense travel demand area where existing fixed route 90 seater capacity buses run. In this paper [16], simulation is carried out in R language for small time interval morning peak 6:30 to 9 am is done. As a result of which various potential benefits of dynamic bus routing in terms of travel time reduction, fleet size reduction are achieved and have benefits of enhancing existing fixed routed public transport by integrating on demand mass transport mode with them [16].

Los Angeles County - A simulation study of demand responsive transit system

In this research [35] they have simulated DRT service based on two assumptions time window effect (time between calls for service and request of service) and second is zoning of a city for running service zone wise.

Simulation results of DRT were: Time-window size effect (adjusting the slag time in between call and service request)- each minute increased in the time-window size the service saves approximately 2 vehicles, 260 miles driven and 750 minutes waiting time while satisfying the same demand. Zoning policy (Zoning direction wise N, S, E and W in to 4 quadrants, clubbing of 2 zones NE,SW or SE, NW simultaneously)- centralized strategy or no zoning is able to satisfy the same demand as of zoning by employing 60 less vehicles and driving 10,000 less total miles with respect to a decentralized strategy.

Cottbus, Germany- Assessment study [2] of shared autonomous vehicles (SAV) by its introduction in market will change the existing transportation scenario. Provision of Mobility as a Service (MaaS) has potential to replace existing feeder buses or tram lines in cities with more than 2,00,000 inhabitants. This study follows a simulation based approach to introduce Mobility as a Service in Cottbus, Germany which has 1,00,000 inhabitants. Shared Autonomous vehicles are simulated using Matsim software for 21,000 trips conducted using public transport within a city for a day. Existing services include five tram line and 17 city buses with frequency of15-20 minutes each. So this existing services were replaced by feeder mini buses of 8 seater capacity on door to door and stopped based scheme bases. Walking distance to existing stops were reduced from 585 m to 270 m. it was observed that fleet utilisation was reduced from 400 in door to door scheme to 300 in stopped based scheme with same level of service provision. In case of travel time, in base case was 35 minutes which was reduced to 27 minutes using DRT services

Cases of failure of DRT in various cities as studied by Dr. Marcus Enoch in 2006 [8]

1. Dial-a-Bus- Milton, Keynes and Buckinghamshire, UK- due to hostile land use, service operated over low concentrated demand
2. Dial-a-Bus, Adelaide, SA, Australia- due to untimetabled ‘many to many’ services in the low-density area.
3. Plus Bus, Truro, Cornwall, UK- Operated over a too large area
4. Other reasons for the failure of DRT- Technical Difficulties, lack of support from the public, lack planning and market research.

Technique

An agent-based model is a model to simulate various operations simultaneously by the interaction between multi-agents with an attempt to recreate the scenario for anticipating the appearance of a complex phenomenon. Agent-based models for simulating traffic follows is proving to be most beneficial in transportation modeling. It consists of an agent i.e. individual person which is considered an object in software which has a set of attributes that gives a detailed description of the population. An agent-based model consists of i)agent (person or vehicle) dynamics, ii)transport network (nodes and links), iii)demand model, iv)route choice strategies and v) performance standards [13]. Multi-agent based modeling is one of the tools of Geosimulation that optimize the simulation with a large number of agents with their distinct specific character [2].Decision agents include Mode choice, Route choice, Location choice, Activity type choice- determining whether to go for some activity on restrict, Activity chain choice- determining of sequence to do the activity, Activity starting time choice, Activity duration choice, Group composition choice- choice of selecting group of people to do activity.

Thus concluded Demand Responsive Transport is an innovative approach over existing scheduled conventional public transport bus and taxi service with flexible demand service for customers on shared-ride mode which is cost-effective for operators and fulfills basic mobility needs of authorities. Urban Mass Responsive Transport to capture dynamic spatio-temporal demand is currently absent in urban areas and its applicability in dense urban areas is least observed. Thus testing its applicability in dense urban areas will be mostly experimenting to know whether or not this service can perform well under high demand situations. Concept of demand responsive services is adapting dynamically to demand by routing and scheduling of fleet vehicles and operating without any fixed routes or timetables. Also such kind of services are successful when implementing in a specific part of the city rather than for an entire city [9].

Study Area

Case study area selected is Pune city being least contributor to public transport usage among similar cities like Mumbai, Chennai, Bangalore and Ahmedabad [23] [34] [36]. Metro service is under implementation process in Pune city, so area for study purpose is one of the catchments of Metro Station area in Pune City. As per City Development

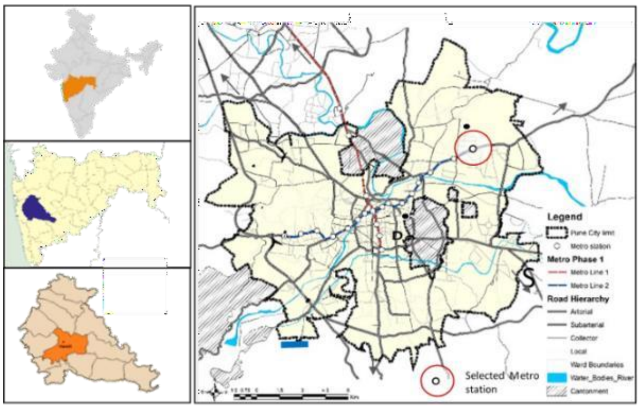

Fig. 1. Case study area

Plan [26] of Pune, analyzing the growth of city it is evident that urban sprawl is significantly in the eastern, southern and south-western directions beyond the administrative boundaries. So chosen metro station for research is last station of corridor 2 which is Ramwadi, as demand for feeder service is highest at end station of mass transit.

Delineation. - Study is based of conceptual model of building future scenario. Developing a model for providing Demand responsive transport for future feeder demand. For this purpose area delineation is based on catchment area of Metro station where there is possibility of providing such DRT services considering trunk line, road widths, activity areas, neighboring landuse and distance from Metro station.

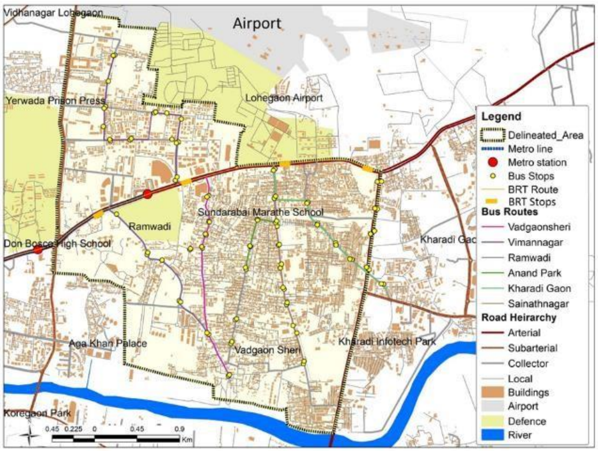

Fig. 2. Delineated area with existing bus routes

Study area population is 107556 persons over an area 9.13 Sq.km with density within area ranging from 35 to 350 persons/ha [25]. Study area is served by total of 15 routes for five destinations or end locations within study area i.e. 15% of total 371 routes in Pune city [27]. Study area has 15 bus routes that serves to 6 destinations i.e. Vadgaonsheri, Vimannagar, Kharadi Gaon, Anand Park, Ramwadi, Sainathnagar, within study area and these bus routes are overlapping with one another as each destination is served by more than 1 route so only 6 routes are visible in the map (Fig. 2.). For example, Vadgaonsheri area is served by 3 routes i.e. via Ramavadi, via Shubham society and via Anand Park. Buses routes connects study area with three major destination Pune Station, Ma Na Pa and Swargate within the Pune city.

3 Methodology

The need for the study requires a wide variety of population samples to analyses and capture the spatio-temporal travel demand of the study area.

Using Yamane [14] sample size calculating formula as in equation below, Yamane formula is a simplified version to determine sample size for large population size to determine the sample size that will reflect a similar proportion of interests among datasets. The sample size is been estimated at 95% confidence level

$$n = \frac{N}{1 + N(e)^2}$$

Where n is the sample size, N is the population size, and e is the level of precision i.e 5%. So 400 samples of data were collected.

Sampling approach was systematic cluster sampling to pick up a sample of 10 people each from 40 different clusters formed based on distance factor summing up to a sample of 400 people. Each cluster formed is a small-scale representation of the total population which is mutually exclusive and collectively exhaustive. The survey questionnaire included detailed travel dairy of passenger's trips with respect to departure and arrival timings and location and the second part encompasses stated preference survey for different mode users to estimate willingness to shift to demand responsive bus service in future.

3.1 Future scenarios for research

This research is based on travel mode which is not present at today's time, so to evaluate the performance of such service it is mandatory to estimate the demand that will be attracted by DRT service or the potential users of new feeder service based on various conditions.
So two scenarios are generated based on probable demand for DRT:
1. Future demand for DRT will be same as Fixed route public bus service
2. Future demand for DRT is based on passengers willingness to shift from other modes (two wheeler, auto, taxi) to DRT.

A Conceptual model to develop for future scenario challenges
This study is based on future travel behavior of mode which is not available at present so it requires to set up some assumptions to understand what will be the best suited DRT situation for the selected case study area, for the same, there are various major challenges in the process which are-

1. The assumption of the appropriate fleet size is on the trial and error method.
2. Estimating future demand for existing fixed route service and future demand for feeder trips.

3.2 Simulation modelling

Agent-based model simulates the simultaneous operations and interaction of multi-agents to recreate the scenario and predict the appearance of complex traffic flows.

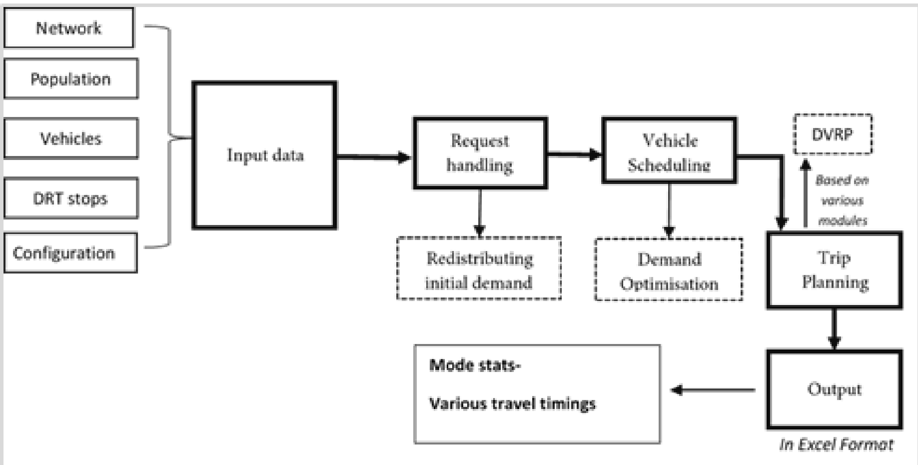

Fig. 3. Simulation process

It is capable of simulating private cars, two-wheeler traffic, and public transport traffic with a large level of detailing and it also simulates pedestrians and cyclists traffic. Agent based modeling can be done for a limited time window in most of the cases is full one day and we can track any single agent in simulation. Agents involved in the simulation are each passenger with the planned trip and DRT vehicles [19], [28].

Matsim is available in a jar file that works on java platform and to carry out simulations in Matsim there is a need to have an understanding of programming languages like java, python and various file formats in the computer [19]. To carry out simulations input data needs to be in XML file format which includes network file, populations or plans file, vehicle file, DRT stops file and configuration file, all these files need to be saved in .xml file format to use them in simulation. Java codes were operated on Eclipse, which is an integrated development environment or workspace for computer programming used widely as this is open source software [1], [12], [28], [29].

Input File format

All the files used for running the simulations are listed below.

1. Network file: Network file includes all the nodes of the intersection, links that connect the nodes, width of the road, speed on-road and one way and two-way details with UTM coordinates to make the network that resembles the real network on the ground.
2. Population file: Population or plans file is the estimated travel demand, i.e. the list of agents and their day plans or travel inventory of each individual passenger. Agent plans are different when they travel on a fixed route and different when they travel by flexible route. When they travel by fixed-route then details of which link they will be traveling needs to be given and when they travel by flexible route only details of start and end location need to be given.
3. Vehicles file: Vehicular plans are mentioned with the number of DRT vehicles, the capacity of vehicle and location of start and point.
4. DRT stops file: DRT stops file comprises of locations of DRT stops for boarding and alighting of passengers into and from DRT vehicles given in UTM coordinates.
5. Configuration file: Configuration file is a most important file which runs the simulation and states all the conditions such as minimum waiting time of passenger, vehicle stopping time, type of scheme to be used, late arrival window of passengers, required statistical results. [1], [28], [29].

Definitions

To understand the scenario generations of two scenarios as stated before in chapter 3.1 and results obtained from simulations we need to understand the various terminologies used in analysis further which is as follows:

1. **Time Window setting:** Time window setting is conditions of different timings that have been assumed and assigned to agents in simulations to enhance the accuracy of results obtain, to make simulations more realistic in nature.

i) Vehicle stopping time window: It is the maximum time for which vehicle will stop at DRT stop when requested by the passenger or else there will be no stopping of the vehicle at all the stops.

ii) Passenger Waiting time window: Passenger waiting time or passenger pickup time is the time for which passengers will have to wait for vehicle or time for which passenger is more likely to wait for vehicle and is assumed based on existing average waiting time.

iii) Late arrival window: Late arrival window is passenger not arriving on time at DRT stop it is introduced to capture the probable human behaviour of traveling.

2. Rejection Rate: It is the percent of trips or demand requests not served by DRT service in simulations. But in real world scenario it will be ride requests not served on time or rides which will have more waiting time than expected due to abnormality in handling requests in software caused because of multiple requests occurring at same time or vehicle is taking too long to reach DRT stop due to many reasons like congestion, late arrival of passengers etc.

3. Ride request: This are number of requests made by passenger to book a DRT ride through IT application, phone call or through message.

3.3 DRT stop location based on road width

The proposed DRT type for the study area is stop based service as minibuses cannot access remote locations. New DRT stops (Fig. 4.) are located such that all the areas are

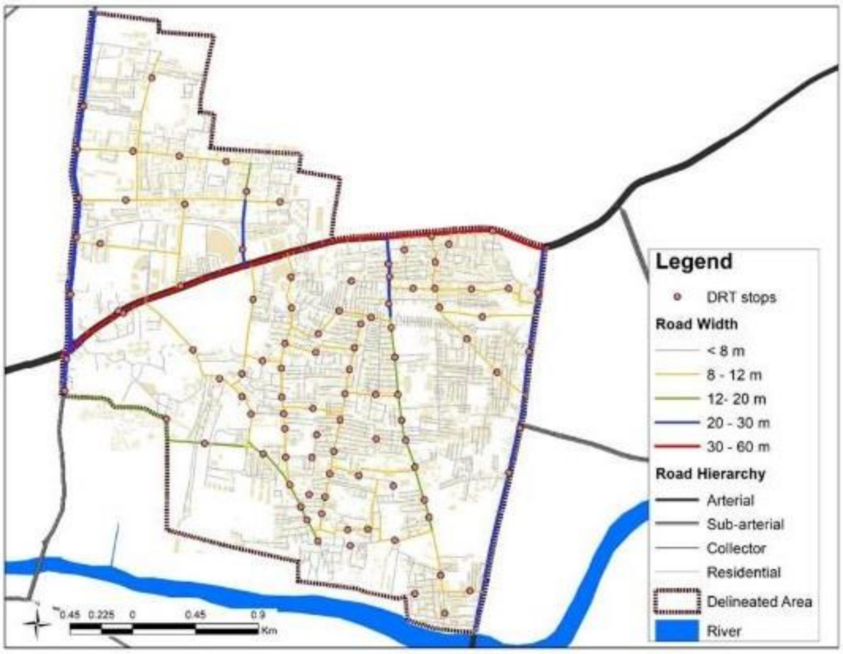

Fig. 4. New DRT stop locations

accessible within 300m of walking distance or less than 7 mins walking time which is an existing average walking time for public transport users. DRT stops are located based on existing public transport demand as well such that stopping points are more in existing high demand areas by identifying high-frequency bus routes and daily ridership generated from the area. Considering the widths of roads it has been proposed that DRT stops for the minibuses are located on roads having a minimum width of 8 m or more.

4 Data Analysis

As per the primary survey conducted to collect information of travel dairy inventory of study area it is observed, public transport users from study area is only 12.67% as per modal split of motorized trips and trip rate is 1.3, therefore total 8858 passengers from study area travel daily by public transport service and 64 large capacity 45 seater bus is utilized for public transport service of study area. Existing total number of bus trips per day is 964 in the study area which constitutes to be 6% of total bus trips of the city.

Analyzing the temporal demand (Fig. 5.) for public transport based on collected samples and extrapolating it to total demand using programing tools on the eclipse in java code, it is observed that peak demand requests per hour during the morning is between 8:30 to 10:30 and in the evening is between 18:00 to 20:00. At this time demand for DRT is highest which is 2600 requests per hour in the morning and 2400 requests per hour in the evening

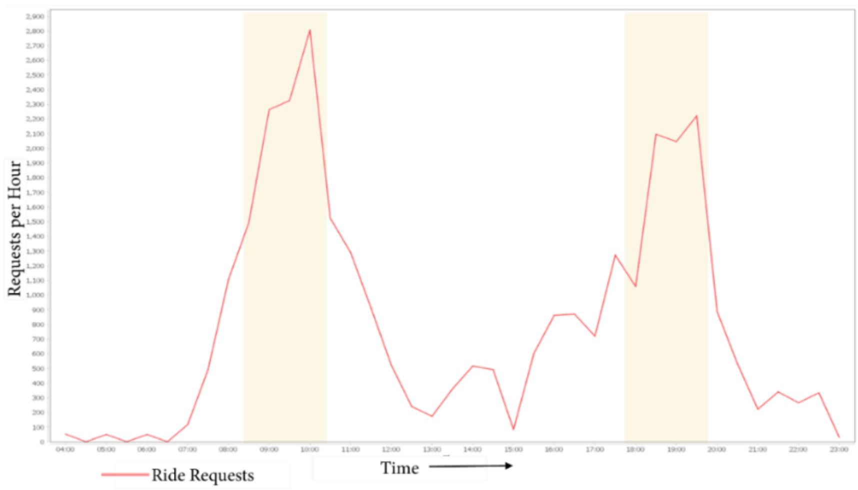

Fig. 5. DRT ride request per hour for temporal travel demand with the morning and evening peak demand for DRT highlighted in graph

4.1 Scenario 1: Demand for Demand responsive feeder service is the same as the existing demand for Public Transport

Various assumptions are made within Scenario 1 and again six different situations in the form of options are generated based on permutations and combinations of indicators with certain changes within each sub scenario to optimize the results of the scenario and measure the efficiency of DRT under simulated conditions. Scenario 1 is based on the following assumptions.

Indicators for generating different situation:

1. Fleet size- 60, 65, 70, 72, 75 and 76
2. Vehicle capacity- 16 seater
3. Demand – Existing demand of PT 8,858 persons and 11,515 trip
4. Time Window setting–
   i) Passenger waiting time– 5 min, 8 min and 10min
   ii) Vehicle stopping time– 30 sec, 45 sec and 60 sec

Scenario generation is based on assumptions of different fleet size of DRT vehicles, fleet size number was derived from trial an error method. The scenario is simulated with the different fleet sizes to fulfil the same demand and results obtained are average pickup time of passenger, rejection rate in simulation and travel demand fulfilled by simulation with each different fleet size.

Table No. 1: Scenario 1 based on assumptions of parameters

	Base case	Option 1	Option 2	Option 3	Option 4	Option 5	Option 6
Target Demand	8858	8858	8858	8858	8858	8858	8858
Demand fulfilled	11515	11170	11170	11285	11285	11400	11400
Fleet size utilization	64	60	65	70	72	75	76
Vehicle capacity	45	16	16	16	16	16	16
Rejection rate	-	3%	3%	2%	2%	1%	1%

Time Window Setting

Time window setting in simulation is used for simulating data with real-life scenarios by considering passenger waiting time restriction i.e. maximum time passenger is willing to wait for bus service and stopping time of vehicle on DRT stops to serve maximum demand by DRT.

Determining Stopping time for DRT vehicle at stopping points

To determine optimized stopping time for vehicle 18 simulations were run with 30 sec, 45 sec and 60 sec stopping time.

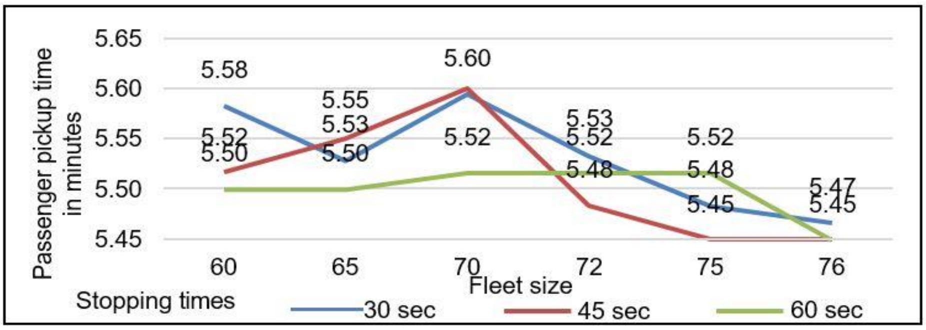

Fig. 7. DRT stopping time and rejection rate for scenarios

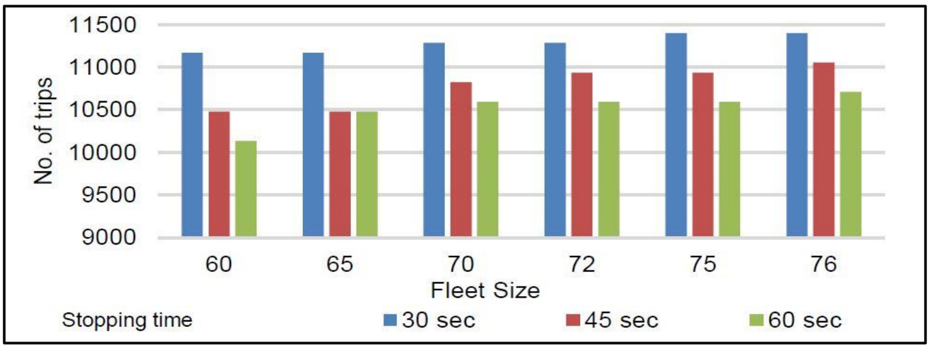

Fig. 8. Demand served by changing DRT vehicle Stopping Times - 30 sec, 45 sec and 60 sec

To determine stopping time window for DRT vehicles simulations were run for six options each with three different stopping time-30 sec, 45 sec and 60 sec. The efficiency of demand served by DRT increases by decreasing the stopping time of DRT vehicles at stopping points. It is evident from the simulation results in Fig. 6, 7 and 8, with increasing stopping time restriction window of passengers, rejection rate also increases, so the most desirable stopping time for vehicle obtained is 30sec with maximum travel demand fulfilled up to 99%. With every 30 sec decrease in stopping time of vehicles, there are an additional 760 trips demand served.

Determining Passenger waiting time restriction

To determine optimized passenger waiting time restrictions or maximum passenger pickup time for bus 18 simulations were carried out with 5 minutes, 8 minutes and 10 minutes waiting time restriction.

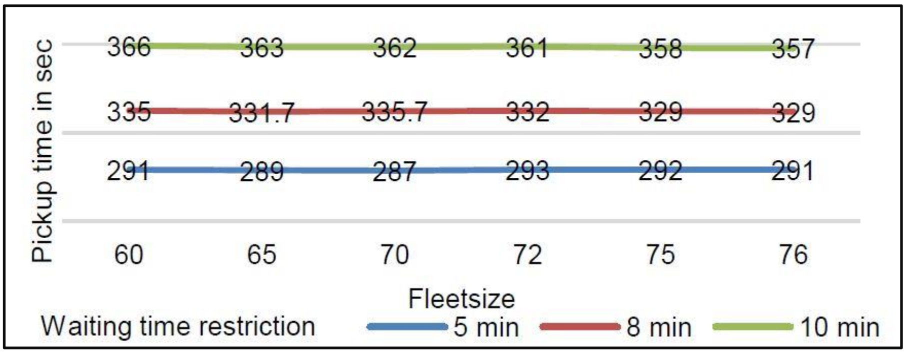

Fig. 9. Average pickup times obtained from waiting time restriction of 5 min, 8 min and 10 min

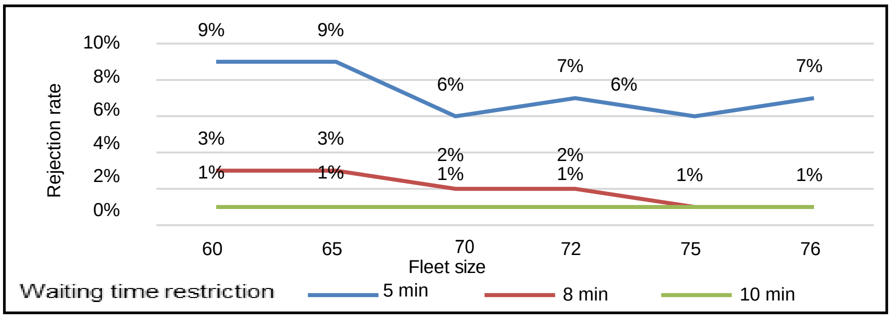

Fig. 10. Passenger waiting time restriction and Rejection rate for Scenario 1

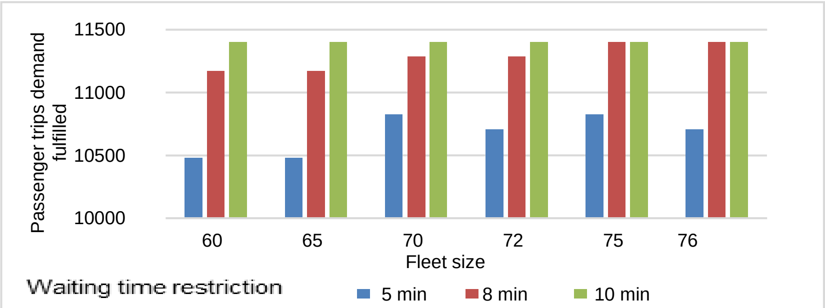

Fig. 11. Demand served by changing waiting time restrictions- 5min, 8min and 10min

To determine waiting time window for passengers simulations are run under six settings each with three different passengers waiting time restriction window of 5min, 8min, 10min. The waiting time window is selected based on existing waiting time for the bus which is 5 min to 15 min with average waiting time of 11min. So the selected range is such that the maximum time people are willing to wait for the bus is below the existing average waiting time window of 11min. Based on the results of the simulation, time window for passenger waiting time selected is 8 min as it has the least trip rejection rate and its average waiting time for the passenger is 5.5 min, which is close to the existing minimum waiting time for the bus in peak hour. Also, smaller pickup time creates difficulty in handling the ride requests and trip planning, as studied from case failure of DRT [9]. Also it is observed with an additional 1 min of waiting time restriction from 5 minutes to 8 minutes there is an additional 210 trips demand served and which remains a constant 8 minutes to 10 minutes.

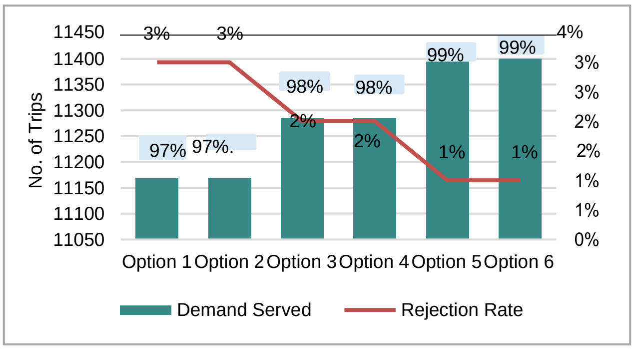

Fig. 12. Demand Served by DRT under simulated conditions

Selected time window settings for stop based DRT service are stopping time of DRT vehicle of 30 seconds and passenger waiting time restriction of 8 minutes. Six Simulation were carried out with 6 different fleet sizes, with 30 seconds vehicle stopping time window and 8 min passenger waiting time window. Travel demand served by DRT vehicles shows demand served increases with number of vehicles used and is high for 75 vehicle- Option 5. Rejection rate decreases with number of vehicle used and is lowest for in case of Option 5 and 6 which is 1%. So from the above analysis quality of service provided remains same after fleet size of 75 mini buses.

Passenger - Efficiency Indicators

Passenger side efficiency indicators are measured by various travel timings of passenger while using public transport to travel like average walking time, average waiting time, average in vehicle time and total travel time also average distance travelled per person. Following table shows the values of existing base case and six scenarios generated using simulation for efficiency indicator.

Table No. 2: Passenger Efficiency Indicators

	Base case	Option 1	Option 2	Option 3	Option 4	Option 5	Option 6
Fleet size	64	60	65	70	72	75	76
1.Average Walking time (mm:ss)	7:00	4:52	4:29	4:29	4.30	4:12	4:25
2. Average waiting time (mm:ss)	11:0	5:35	5:31	5:35	5:32	5:29	5:29
3. Average distance travel/person/day (km)	3.1	2.09	2.09	2.089	2.089	2.093	2.115
4. In-vehicle time (mm:ss)	7:00	6:47	6:53	6:51	6:55	7:00	7:02
5. Total Journey time (mm:ss)	25:0	17:14	16:53	16:55	19:39	16:41	16:56

Travel times

Passenger waiting time*:* In the existing base case average waiting time of passengers for travelling in public transport is 11 minutes and which ranges from 5 minutes in peak hour to 15 minutes in the non-peak hour. Waiting time for public transport buses also shows spatio-temporal change throughout the area as per the frequency of bus trips in the area. The frequency of bus trips in Vadgaonsheri and Kharadi gaothan area is high

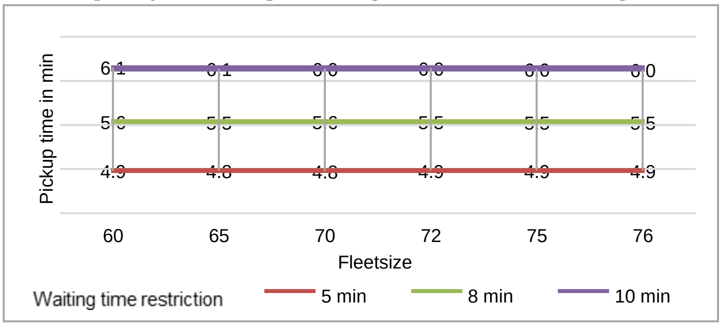

Fig. 13. Average waiting times obtained from a pickup time window of 5 min, 8 min and 10 min

as compared to the rest of the area. After simulating 6 different fleet sizes with different time window settings results obtained show average waiting time can be reduced to approximately 5 min 30 sec by allowing passenger pickup time restriction to 8 min.

In the next case average waiting time can be reduced to 4 minutes approximately by allowing passenger pickup window restriction to 10 minutes and reduced to 6 minutes approximately by allowing passenger pickup time window to 5 minutes.

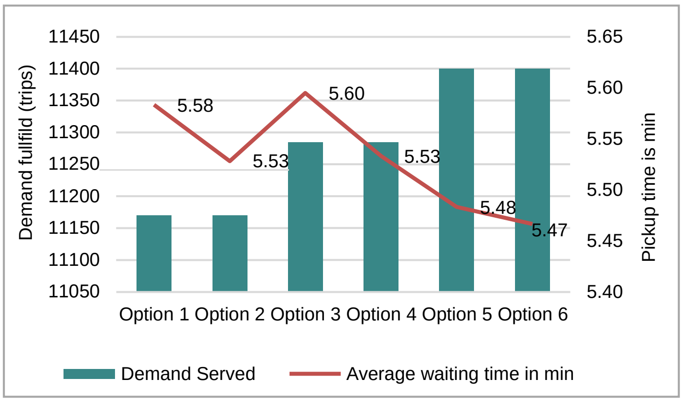

Fig. 14. Average waiting for demand served by DRT

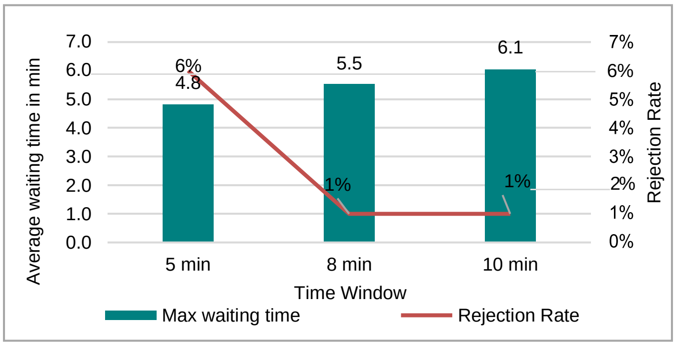

Fig. 15. Average waiting times for different waiting time windows- Fleet size 75

Results

Time savings: Average waiting time for bus reduces by 0.5 times of existing waiting time. Average Walking time to bus stop reduces by 0.43 times of existing walking time. Average In-vehicle time remains almost the same. Average total travel time reduces by 0.32 times and average per passenger distance travelled reduces by 0.35 times of existing average distance travelled.

Operators- Efficiency Indicators

Operator's efficiency indicators include Demand served efficiently by DRT service, rejection rate of service, fleet utilization, total distance travelled, operating cost, average distance driven. Following table shows the operator efficiency indicator values for base case and six scenarios based on assumption for DRT case.

Table No. 3: Operators Efficiency Indicators

	Base case	Option 1	Option 2	Option 3	Option 4	Option 5	Option 6
Target Demand (persons)	8858	8858	8858	8858	8858	8858	8858
Demand fulfilled (trips)	11515	11170	11170	11285	11285	11400	11400
Demand fulfilled %	100%	97%	97%	98%	98%	99%	99%
1. Fleet size utilization	64	60	65	70	72	75	76
2. Vehicle capacity	45	16	16	16	16	16	16
3. Total distance Travelled	3987	8893	8693	8719	8798	8904	8648
4. Operating cost Rs	3,38,895	2,06,318	2,01,678	2,02,281	2,04,114	2,06,573	2,00,634
5. Average Driven Distance km	228	118	99	99	97	94	91
6. Rejection rate	0%	3%	3%	2%	2%	1%	1%

Operating cost for minibus reduces to 0.35 times operating cost of existing 45 seater buses as mini buses consume less fuel compared to large capacity buses which, fuel consumption of 45 seater buses is almost 3.25 times more than 16 seater mini buses. Existing PMPML buses has operating cost of 85 Rs per km Operating cost of minibus considered is 1.45 Rs per seat per km as per WRI bus aggregator viability study [33].

Table No. 4: Vehicular km per day by changing waiting time restriction

Waiting time restrictions sec	**Distance driven in Km**					
	Option 1	Option 2	Option 3	Option 4	Option 5	Option 6
5 min	7873	7921	7915	7947	8057	8055
8 min	8893	8693	8719	8798	8705	8648
10 min	9485	9430	9401	9421	9541	9399

With every increasing minute waiting time restriction from 5 minutes to 10 minutes distance travelled increases by 300 km per day. Thus lower waiting time reduces distance travelled.

Vehicle occupancy

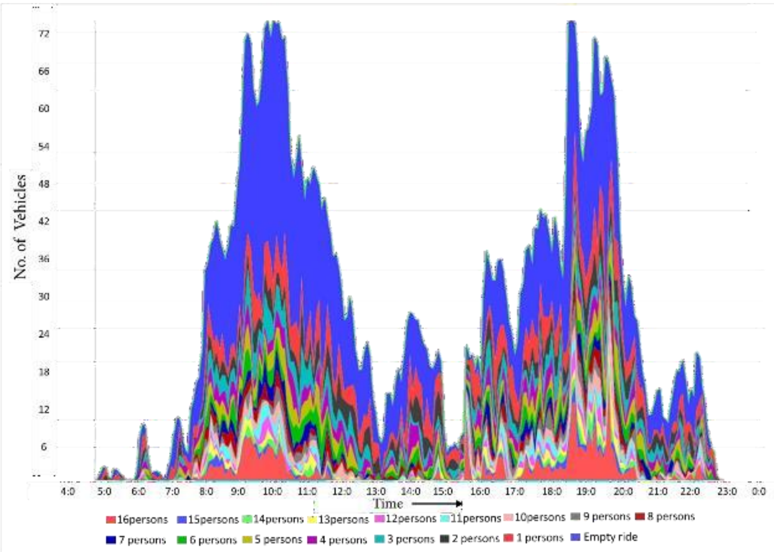

Fig. 16. Vehicle occupancy ratio for scenario 5 with fleet size 75

Vehicle occupancy at each time interval of 75 vehicles is plotted. In peak hours 9:00 to 10:00 in the morning and 6:30 to 7:30 in the evening, there is 100% utilization of vehicles and occupancy for 11% fleet size is 100% that is 16 persons. These results obtained from simulation can be used to identify the actual number of vehicles required at any point of time instead of departing all fleet vehicles in the field, the rest of the vehicles can put to other use. Also, similar occupancy data for each individual bus at each point of time is a data gap in the base case so comparison for the same is not done.

4.2 Scenario 2: Demand for DRT based on passenger's willingness to shift from other modes (Public Transport, Two Wheeler, Auto, Taxi) to DRT.

Stated Preference Options for DRT

To estimate probability of persons willingness to use DRT service if provided in future, stated preference survey was done for persons with existing mode as four wheeler, two wheeler, auto rickshaw, cab and public transport for set of 6 options where they were asked a choice whether they will use DRT or their existing mode under certain conditions of waiting time, walking time, travel time and travel cost.

Total of 400 samples were collected from individual households and each individual answered a set of 6 options in Yes or No to shift to DRT, so in total 2400 datasets were available to estimate the probability of shifting to new mode. As per the primary survey out of total samples 100 car users, 168 two wheeler users, 50 bus users and 62 auto, cab users and were survey. State preference questionnaire to conduct survey for future DRT users is mentioned in the Table no. 5 and 6.

Table No. 5: Stated preference survey options for car users

If Car user						
Option	1	2	3	4	5	6
Waiting time	2 min	5 min	8 min	5 min	5 min	2 min
Walking time	8 min	12 min	12 min	3 min	8 min	12 min
Travel time	1.25 times	1 times	1 times	1.25 times	1 times	1.25 times
Travel Cost	0.5 times	0.5 times	1 times	0.5 times	1.5 times	1 times
Choice						

Choice= 1- Existing Mode; 2- DRT

Table No. 6: Stated preference survey options for other users

2 wheeler, IPT, PT						
Option	1	2	3	4	5	6
Waiting time	5 min	8 min	5 min	2 min	5 min	2 min
Walking time	3 min	12 min	12 min	8 min	8 min	12 min
Travel time	1 times	0.5 times	1 times	1 times	0.5 times	1.5 times
Travel Cost	1.25 times	1 times	1.25 times	1 times	1.5 times	1.5 times
Choice						

Choice= 1- Existing Mode; 2- DRT

Willingness to shift to DRT

The conditional probability (Pr) measures the chances of occurring an event such that person will be choosing DRT mode over its existing mode. So the choices asked in stated preference survey whether to use existing mode or DRT is dependent variable which is dependent on four independent variable as in stated preference survey i.e. walking time, waiting time, travel cost and travel time. To measure the dependency of variables, logistic regression was necessary and since the variable of choice was dichotomous in nature Binary logistic regression was performed to analyses willingness to shift to DRT. Model development was based on two choices to select among DRT or existing mode, so binary logit model is used which is of the following form.

Pr (DRT/ EM) = Probability of shifting to DRT conditioned on existing mode (EM)

$$\Pr(DRT/EM) = [e^{VDRT}]/[e^{VDRT} + e^{VEM}]$$

Where,

VDRT = Deterministic component of utility of DRT,

VEM = Deterministic component of utility of Existing Mode

$V_{Car} = 0.617 - 0.007\, Tw - 0.020\, Ti + 0.0001\, Tt - 0.085\, Tc$

$V_{2w} = 0.841 - 0.108\, Tw - 0.126\, Ti + 0.029\, Tt - 0.05\, Tc$

$V_{Bus} = 1.082 - 0.004\, Tw - 0.011\, Ti – 0.002\, Tt – 0.158\, Tc$

$V_{Auto+Cab} = 3.19 - 0.305\, Tw - 0.215\, Ti - 0.033\, Tt - 0.020\, Tc$

Where,
Tw = Waiting time; Ti = Walking time; Tt = Travel time; Tc = Travel cost

Table No. 7: Goodness of fit test results

Hosmer and Lemeshow Test			
	χ2	*df*	*p*
Car	2.562	8	.959
2 wheeler	5.604	8	.691
Bus	6.428	8	.599
Auto and cab	14.393	8	.072

As per the results, to evaluate goodness to fit of logistic model dataset against the actual outcomes suggests that, in above table *p*- value for all four modes as for Hosmer and Lemeshow Test is > 0.05 which states the model is good fit.

Table No. 8: Results for willingness to shift to DRT

	Option 1	Option 2	Option 3	Option 4	Option 5	Option 6	Existing
Car	47%	44%	30%	49%	22%	32%	51%
2wheeler	51%	17%	31%	47%	30%	38%	75%
Bus	63%	48%	60%	49%	37%	36%	48%
Auto and cab	58%	5%	12%	36%	19%	11%	25%

As per primary survey analysis trips outside study area which has more than 3km travel distance are 74% of the total motorized trips, out of them 40% of passengers are willing to use mass transit such as Metro or BRT in future. And people's willingness to shift to DRT based on this estimated population is calculated using binary logistic regression.

So demand estimation in second scenario is based on willingness to shift is calculated as the results of state preference survey in table 21 the highest maximum number of people willing to shit to DRT to travel to mass transit (metro rail, BRTs) from every other mode under six option is 48% of Car users, 51% of two wheeler users, 63% of public transport users, 58% of auto-rickshaw and cab users which is total demand of 11444 persons and 14876 trips.

Passenger - Efficiency Indicators

In second scenario demand is based on number of existing car, two wheeler, public transport and IPT users willing to shift to DRT, where existing waiting and walking time for private vehicle users is zero, so average waiting and walking time for only IPT

(Auto and Cab) and public transport users is considered in this scenario i.e. average 7 minutes walking time and average 7:30 minutes waiting.

Table No. 9: Passenger efficiency indicators for 2nd scenario

	Base case	Option 1	Option 2	Option 3	Option 4	Option 5	Option 6
Fleet size	-	75	80	85	90	95	96
1. Avg. Walking time (mm:ss)	7	3:52	3:29	3:29	3.30	3:12	3:25
2. Avg. waiting time (mm:ss)	7:30	5:12	5:11	5:11	5:13	5:08	5:08

Average waiting time for various passenger pickup time

Average waiting time for different pickup time window is least in case of 5 minute window which is approximately 4.4 minutes for all fleet sizes and in maximum for 11 minute waiting window which is approximately 5.6 minutes for all fleet sizes. Similar approach to select time window setting as explained in Scenario 1 is adopted, such that waiting time window is less than the average waiting time for existing mode which in this case is also 8 min.

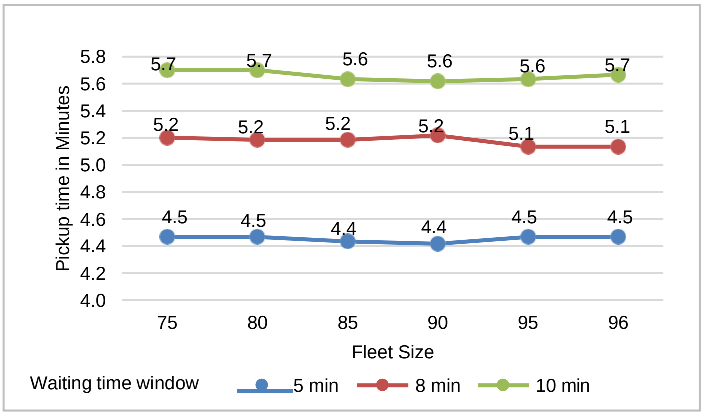

Fig. 17. Average pickup time window for waiting time window restriction for Scenario 2

As in existing case average waiting time in auto is 4.5 min and public transport is 11min. It is observed with each 1 min increase in waiting time restriction from 5 min to 8 min there are additional 264 trips demand served and which remains constant after 8min. Average pickup time obtained after simulation is 5.2 min.

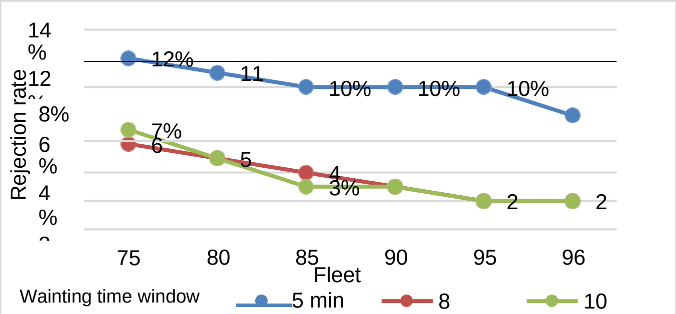

Fig. 18. Average waiting time window and rejection rates for Scenario 2

In this case, the scenario rejection rate for 8 min window and 10 min window is almost the same and the number of trips served increases from 5 min window to 8 min window. The existing waiting time window is 7.30 min, it was necessary to select a close time window so that not pickup time for passengers should not increase that will create inconvenience, so 8 min window is adopted to fulfil the travel demand.

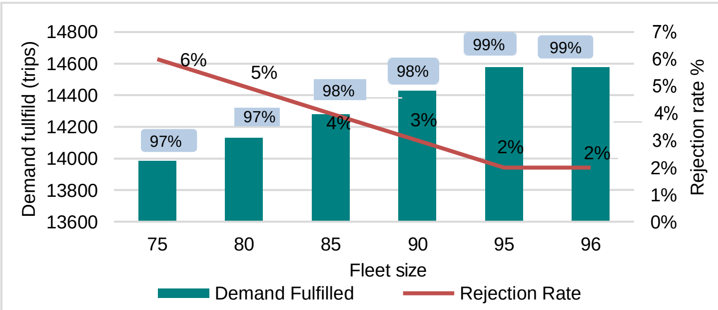

Fig. 19. Demand served by DRT in scenario 2

Results obtained by simulating travel demand of 11444 persons, with different fleet size of bus 75, 80, 85, 90, 95 and 96 it is observed there is reduction in waiting time and walking time for IPT and public transport users but for private vehicle users there will be increase in travel time by DRT bus service.

To simulate demand of 14879 passengers 6 cases generation with fleet size from 75 to 96 were done. Fleet size of 95 is ideal to implement in this case as it has least rejection rate & average pickup waiting time.

Table No. 10: Average travel time and travel cost for existing and DRT mode

	Car	2 Wheeler	Bus	Auto & cab	DRT
Average time min	14.58	12.37	25.05	18.45	17.12
Average cost Rs	16.466	7.893	6.876	34.54	10.368

Results:

Travel time and Travel cost: Existing average travel time and travel cost to reach metro station using modes such as a car, two-wheeler, public transport, auto, cab, and DRT bus service are mentioned in the table no. 12. It is observed, DRT will be beneficial in reducing travel times for exiting public transport and IPT users by 0.32 times to 0.07 times of existing travel time whereas, of car and two-wheeler users travel time will increase slightly by 0.17 times to 0.41 times of existing travel time. So to fulfil future feeder demand of mass transport systems 95 fleet vehicles of 16 seater buses will be required. And since it is the hypothetical scenario so existing bus fleet usage, distance travelled and investment cost is unknown so there is no scope for evaluating operator side efficiency indicators, but none the less the operating cost of mini bus as explained in scenario 1 will always be less than 45 seater capacity buses.

4.3 Conclusions

As per the results obtained from Scenario 1 and 2 by using DRT of 16 seater capacity mini buses as feeder to metro will be efficient in reducing travel time and increase convenience. Existing average waiting time of 11 min for bus service will be reduced to 5:30 min. Existing average walking time to bus stop is 8 min with new stopping points of DRT accessible within 300m walking distance time is reduced to 4:12 min. Providing DRT within small area increases the efficiency of shared service by making it feasible to operate for transport authority. Within peak hour 9:00 to 10:00 and 18:30 to 19:30 DRT has 100% vehicle utilisation and 5 hrs in day there is more than 50% vehicle utilisation.

In non-peak hour when vehicle utilisation is low DRT vehicles can be used for intra area trips for work- IT industries, recreation- Shopping Mall, education- Private coaching classes. With increasing 1 min of passenger waiting time restriction there is additional 210 trips served and decreasing stopping time of vehicle by 30 sec increases additional 710 trips served per day.

Dynamic Pricing

Existing static price of public transport will not be financially viable for DRT. So, principle of dynamic pricing needs to be followed, where price changes with respect to demand and supply. Price for DRT will be maximum during peak hours when demand for DRT is high and minimum during non-peak hour when it is easy to get DRT when demand is low.

Table No. 11: Earnings from existing and DRT service

	Base Case (Fixed route bus service)	DRT Option 5 in Scenario 1
Total passenger travel time hrs	9297	6352
Earnings from passenger in Rs	2,16,998	2,10,148
Operating Cost	3,38,895	2,06,573
Benefit cost ratio	0.64	1.23

In existing scenario of public transport bus service, earnings from bus service is lower than the spending's on operation of bus service, thus transport authorities procures huge losses that is why it is not possible for them to provide quality service. Also after introduction of DRT, it is not possible to achieve profit with the same public transport pricing.

Fig. 20. Dynamic pricing for DRT bus service

Moreover people are willing to spend more when they are assured to get convenient and comfortable service. So the dynamic pricing of DRT bus service is derived, considering the temporal demand variation of ride requested per hour throughout day as depicted in Fig. 5. Therefore, proposed dynamic pricing for DRT is estimated such as the price will be highest in morning and evening peak hours i.e. 1.5 times of exiting price during peak hours, 4 hours per day and price will be 1.38 times of exiting price during 2 hours followed and preceded by peak hours i.e. 8 hours per day and will be same during rest of the time during low demand in non-peak hour.

Change in Mode of Travel

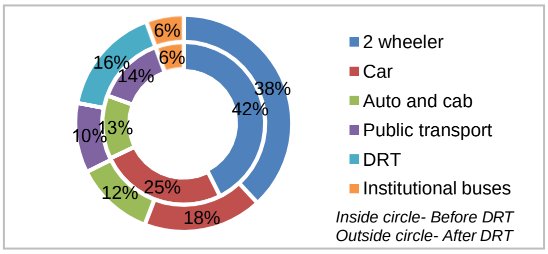

Fig. 21. Modal shift after introduction of DRT services in Scenario 2

After introduction of DRT bus services as a feeder there will be shift of passenger's mode of travel from existing fixed route public bus users, private vehicle users, auto rickshaw and cab users to DRT service. Change in mode has calculated based on the people's willingness to shift to DRT from existing mode as per the results of state preference survey conducted to estimate the probability of people willing to shift from each individual mode in Table. N. 12. Modal share of public transport usage will increase from 12.67% to 26% and private vehicle usage will reduce for two wheeler and car users by 4% and 7%.

Table No. 12: Change in mode of travel

	Before DRT		After DRT	
Mode	%	Persons	Persons	%
2 wheeler	42.6	29782	26640	38.1
Car	25.3	17687	12398	17.7
Auto and cab	13.83	8858	8228	11.8
Public transport	12.67	9669	7284	10.4
DRT	0	0	11444	16.4
Institutional buses	5.6	3915	3915	5.6

Table No. 13: Reduction in private vehicle usage

Shift to DRT	
Existing private vehicle users	47469
Private vehicle users reduced after DRT	8431
Reduction %	18%

After introduction of DRT there will be 18% reduction in private personalised vehicle usage which will improve road congestion situation urban area. Out of total reduce private vehicles users 60% are car users and 40 % are two wheeler users.

5 Recommendation

Demand responsive bus services have the potential to shift users from single occupancy vehicles to mass transit and help alleviate urban road congestion. Demand responsive services will be successful when operated over a small delineated area rather than of the whole city, as unshared ride distance increases beyond 4 km travel distance, so if the unshared ride distance increase for the large capacity vehicle it will not be financially beneficial for transport authority to operate such services. In this study, travel demand is estimated only for the passengers traveling outside the study area by mass transit like metro rail which will be coming in 2 to 3 years or existing BRTs or passengers using existing fixed route public bus service, due to which the ride requests are maximum in morning and evening peak hours, so total fleet size of DRT vehicles is underutilized in non-peak hours during this time intra area travel trips need to be targeted which are generated due to presence of IT industrial area and educational institutions which have flexible timings.

In case of Scenario 1 where demand for DRT is the same as that of existing public transport demand, option 5 with fleet size 75 and in Scenario 2 where demand for DRT is based on people willing to shift to DRT from existing mode, option 5 with fleet size 95 vehicles is the ideal situation for implementation of such project. Average waiting time for existing fixed route bus reduces by 0.5 times when operated as demand responsive bus service. Average walking time to bus stop reduces by 0.43 times of existing walking time. Average In-vehicle time remains almost the same. Average total travel time reduces by 0.32 times and average per passenger distance travelled reduces by 0.35 times of existing average distance travelled.

To make DRT service financially viable concept of dynamic pricing needs to be followed or else project will not be successful which will increase the cost of public transport by 1.5 times of existing cost in peak hrs., and will be same in non-peak hrs., or else increasing the cost by 0.3 times throughout the day will balance the cost. There is a potential of value addition to existing fixed route public bus service if integrated with the mass on demand ride sharing service or DRT feeder service as per the results obtained from research.

This research may help is giving insights of working of dynamic routing of bus and mass ridesharing service but this research can be further continued to achieve more realistic results.

5.1 Way forward in research

Concept of minimum occupancy of vehicle is missing in research addition of which will give better results for operator's efficiency indicators.

Further research can be taken to make demand responsive service more realistic on ground for implementation by including –

- Changing the composition and combination of DRT stop locations,
- Combination of varied capacity bus service,
- Adjusting zoning effect with decentralisation and centralisation and
- More importantly working with realistic spatio-temporal data on daily basis.
- And identifying minimum allowable time between pre booking and scheduling of ride for trip planning can only be done post implementation.

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