

See discussions, stats, and author profiles for this publication at: <https://www.researchgate.net/publication/283319530>

# FEASIBILITY STUDY OF PERSONAL RAPID TRANSIT SYSTEM(PRTS) IN VARANASI CITY

Technical Report · January 2014

CITATIONS

0

READS

418

3 authors:



**Jayvant Choudhary**

Indian Institute of Technology (Banaras Hindu University) Varanasi

8 PUBLICATIONS 3 CITATIONS

[SEE PROFILE](#)



**Anurag Ohri**

Indian Institute of Technology (Banaras Hindu University) Varanasi

38 PUBLICATIONS 68 CITATIONS

[SEE PROFILE](#)



**Brind Kumar**

Indian Institute of Technology (Banaras Hindu University) Varanasi

14 PUBLICATIONS 61 CITATIONS

[SEE PROFILE](#)

Some of the authors of this publication are also working on these related projects:



Generation of watershed erosion response model and interpret the soil erosion patterns of the region [View project](#)

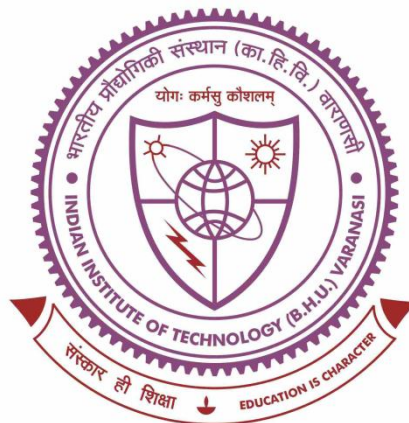


traffic noise [View project](#)

A  
**PROJECT REPORT**  
ON  
**“FEASIBILITY STUDY OF PERSONAL RAPID TRANSIT  
SYSTEM(PRTS) IN VARANASI CITY”**

Submitted in partial fulfilment of the requirements for the award of

**Master of Technology**  
In  
**Civil Engineering**  
**(TRANSPORTATION ENGINEERING)**



By  
**JAYVANT CHOUDHARY**

Roll No. – **13062013**

Under the supervision of

**Dr. ANURAG OHRI** (Assistant Professor)

**Dr. BRIND KUMAR** (Assistant Professor)

**DEPARTMENT OF CIVIL ENGINEERING**  
**INDIAN INSTITUTE OF TECHNOLOGY**  
**VARANASI-221005**

# **CERTIFICATE**

This is to certify that the project report entitled **“FEASIBILITY OF PERSONAL RAPID TRANSIT SYSTEM IN VARANASI CITY”** is being submitted by JAYVANT CHOUDHARY (Roll No: 13062013).

This Project is a record of student own work carried out by himself under my guidance and supervision in partial fulfilment of the requirements for the award of the degree of Master of Technology in Transportation Engineering of **DEPARTMENT OF CIVIL ENGINEERING, INDIAN INSTITUTE OF TECHNOLOGY, BANARAS HINDU UNIVERSITY, VARANASI-221005**

**Dr. ANURAG OHRI**

(Assistant Professor)

**Dr. BRIND KUMAR**

(Assistant Professor)

# **ACKNOWLEDGEMENT**

I sincerely acknowledge the help rendered to me by my project guide **Dr. ANURAG OHRI & Dr. BRIND KUMAR** . Without their assistance, guidance and encouragement, I would not have been able to successfully complete my 2<sup>nd</sup> Semester Project.

**JAYVANT CHOUDHARY**

**Roll No: 13062013**

## **CONTENTS**

1).Introduction to PRT	5-7
2).Advantages of PRT	8-11
3).Literature Review	12-17
4).Project case study	18
5).Data collection & analysis	19-22
6).Percentage shift & Modal split	23-24
7).PRT supply capacity	25-27
8).Financial analysis	28-31
9).Conclusion	32
10).References	33

## 1).INTRODUCTION TO PRT:- (Source: [http://en.wikipedia.org/wiki/Personal\\_rapid\\_transit](http://en.wikipedia.org/wiki/Personal_rapid_transit))

**Personal rapid transit (PRT)**, also known as podcar, is a public transport mode featuring small automated vehicles operating on a network of specially built guide ways. PRT is a type of automated guideway transit (AGT), a class of system which also include large vehicles all the way to small subway system.

PRT is designed for individual or small group, typically carrying not more than 3 to 6 passengers per vehicle. Guide ways are arranged in a network topology, with all stations located on sidings, and with frequent merge/diverge points. This allows for nonstop, point-to-point travel, bypassing all intermediate stations. The point-to-point service has been compared to a taxi.

Most mass transit systems move people in groups over scheduled routes. This has inherent inefficiencies. For passengers, time is wasted by waiting for the next arrival, indirect routes to their destination, stopping for passengers with other destinations, and often confusing or inconsistent schedules. Slowing and accelerating large weights can undermine public transport's benefit to the environment while slowing other traffic. Personal rapid transit systems attempt to eliminate these wastes by moving small groups nonstop in automated vehicles on fixed tracks. Passengers can ideally board a pod immediately upon arriving at a station, and can with a sufficiently extensive network of tracks take relatively direct routes to their destination without stops.



**Fig 1) An ULTra PRT vehicle on test track**

(Source: [http://en.wikipedia.org/wiki/Personal\\_rapid\\_transit](http://en.wikipedia.org/wiki/Personal_rapid_transit))

Perhaps most importantly, PRT systems offer many traits similar to cars. For example, they offer privacy and the ability to choose one's own schedule. PRT may in fact allow for quicker transportation than cars during rush hour, since automated vehicles avoid unnecessary slowing. A PRT system can also transport freight.

Past projects have failed because of financing, cost overruns, regulatory conflicts, political issues, misapplied technology, and flaws in design, engineering or review.

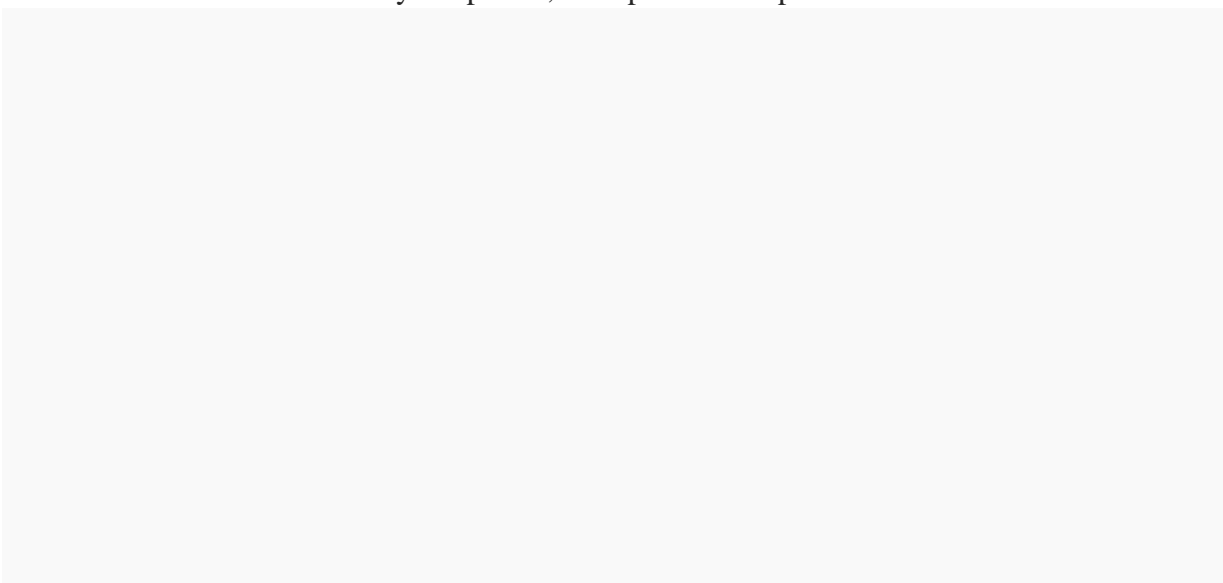


**Fig 2) Small guideway and foundation reduces right of way requirements**

(Source: [http://en.wikipedia.org/wiki/Personal\\_rapid\\_transit](http://en.wikipedia.org/wiki/Personal_rapid_transit))

However, the theory remains active. For example, from 2002–2005, the EDICT project, sponsored by the European Union, conducted a study on the feasibility of PRT in four European cities. The study involved 12 research organizations, and concluded that PRT

- would provide future cities "a highly accessible, user-responsive, environmentally friendly transport system which offers a sustainable and economic solution."
- could "cover its operating costs, and provide a return which could pay for most, if not all, of its capital costs."
- would provide "a level of service which is superior to that available from conventional public transport"
- would be "well received by the public, both public transport and car users."



### **Comparison of Personal Rapid Transit with existing transport systems**

(Source: [http://en.wikipedia.org/wiki/Personal\\_rapid\\_transit](http://en.wikipedia.org/wiki/Personal_rapid_transit))

Similar to automobiles	<ul style="list-style-type: none"><li>• Vehicles are small—typically two to six passengers</li><li>• Vehicles are individually hired, like taxis, and shared only with the passengers of one's choosing</li><li>• Vehicles travel along a network of guideways, much like a network of streets. Travel is point-to-point, with no intermediate stops or transfers</li><li>• Potential for on-demand, around-the-clock availability</li><li>• Stops are designed to be off the main guideway, allowing through traffic to bypass stations unimpeded</li></ul>
Similar to trams, buses, and monorails	<ul style="list-style-type: none"><li>• A public amenity (although not necessarily publicly owned), shared by multiple users</li><li>• Reduced local pollution (electric powered)</li><li>• Passengers embark and disembark at discrete stations, analogous to bus stops or taxi stands</li></ul>
Similar to automated people movers	<ul style="list-style-type: none"><li>• Fully automated, including vehicle control, routing, and collection of fares</li><li>• Usually off-grade—typically elevated—reducing land usage and congestion</li></ul>
Distinct features	<ul style="list-style-type: none"><li>• Vehicle movements may be coordinated, unlike the autonomous human control of automobiles and bikes</li><li>• Small vehicle size allows infrastructure to be smaller than other transit modes</li><li>• Automated vehicles can travel close together. Possibilities include dynamically combined "trains" of vehicles, separated by a few inches, to reduce drag and increase speed, energy efficiency and passenger density</li></ul>



## **2). ADVANTAGES OF PRT**

(Source: Ultra Fairwood Green Transport. (2009) “DPR of PRT Amritsar Project”)

### **2.1) AVAILABLE ON DEMAND**

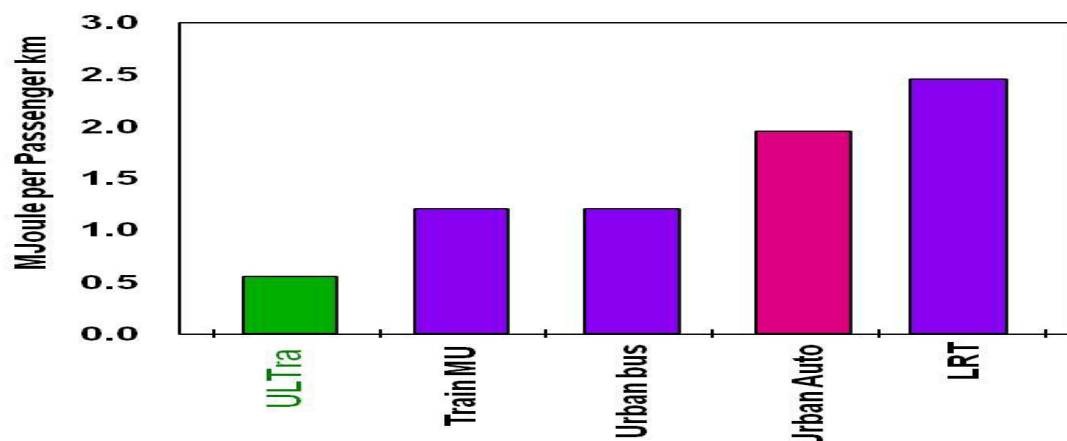
PRT is an automatically controlled personal taxi system of four-seat vehicles that run on their segregated guideway network. Transport is available on demand at any of a series of stations distributed around the city like cabs. The empty vehicle management system ensures that a vehicle is nearly always available at cab-rank as required. Simulations of many applications have shown that almost all passengers would obtain immediate service from a waiting vehicle, even at peak periods.

### **2.2) NON STOP**

All stations are off-line, so there is no need for vehicles to stop in their journey. As a result, although maximum speeds only need to be 40 km/hr in most applications, trip times are still reduced by a factor of between two and three compared to cars or buses in a typical city centre, or to light rail.

### **2.3) ENVIRONMENTALLY SUSTAINABLE**

Because the ULTra vehicle is electrically powered, there is zero emission in the city, but, in any case, overall emissions are significantly reduced. The average system energy usage is 0.55 MJ per passenger km. This can be compared with figures between 1.2 and 2.4 MJ per passenger km shown for conventional forms of transport. The typical benefit compared with cars is over 70%. Importantly, in peak periods when cars (and buses) are restricted by congestion this benefit rises to nearly 90%. This energy saving translates directly into reduced carbon dioxide emissions.



**Fig 3) ENERGY CONSUMPTION VS MODE OF TRAVEL**

( Source: DPR of PRT Amritsar )

## 2.4) LOW COST

The structural cost of elevated guideway construction is lower than that of an equivalent footbridge. This is because the system loadings at around 2000N/m<sup>2</sup> are less than the pedestrian crush loads required for footway design, i.e. 5000N/m<sup>2</sup>. This also means that the system can be run into buildings designed to existing floor loading codes with no structural change. Complete system cost also includes other infrastructure such as stations, together with vehicles, control systems and support, such as ticketing and closed-circuit television (CCTV). These costs vary considerably with details of the application but typical costs for a complete system, i.e. infrastructure, control system and vehicles, projected in a variety of applications are around £5M per kilometer of guideway. Applications studies show that these costs are around one third of the cost of a light rail system doing a similar task.

Mode	Capital Cost/Mile (\$M)		
	Low	Average	High
Observed Construction Costs			
Heavy Rail	\$110	\$175- \$250	\$2,000*
Light Rail	\$25	\$50-\$70	\$195
APM – Urban	\$30	\$100-\$120	\$145
APM – Airport	\$50	\$100-\$150	\$237
BRT Busway	\$7	\$14-\$25	\$50
BRT Tunnel	\$150	\$200 - \$250	\$300
Theoretical Engineering Cost Estimates			
PRT One Way	\$15	\$20-\$35	\$50
PRT Two Way	\$25	\$30- \$50	\$75

Notes: \* Includes tunnel construction

Sources: Kerr 2005, TCRP R90, GAO 2000, Vendor estimates & case studies

## 2.5) SAFE AND SECURE

PRT also offers significant benefits in personal security. All trips are undertaken only with companions chosen by the passenger. As noted above, during peak periods 90% of trips are available immediately on demand. Off peak, this figure rises to 100%, since vehicles can be assured to be available at all stations. Thus, the risks associated with waiting for public transport are almost eliminated. Further, all stations will be under continuous coverage by CCTV, with direct links to the controller available from all vehicles and from all stations via help buttons. In addition, in-vehicle CCTV is an option where required.

## **2.6) INCREASE USE OF PUBLIC TRANSPORT**

With PRT it is possible to provide real-time passenger information to the commuters inside pod, at pod stops and at PRT terminals. The information displayed informs the passengers about the details of the next arriving pod, route no, destination expected time of arrival/departure, which brings a level comfort. This increases the confidence of public to reach their destination on-time and contributes towards reducing congestion on roads. Hence PRT will contribute for shifting people from using private vehicles to public transport.

## **2.7) LESS CONSTRUCTION AND NEGATIVE ENVIRONMENT IMPACTS**

The PRT project does not include any major construction work, widening of roads or other activities which contribute towards negative environmental impacts such as air pollution, water pollution, noise pollution, community severance and impacts on vegetation / land degradation by the implementation of proposed PRT project.

## **2.8) GREATER CONSUMER SATISFACTION**

Commuter satisfaction indicates the degree to which transportation consumers are accommodated by PRT service offerings. Customer satisfaction is often measured by using surveys, questionnaires, or focus group interviews. Indirect measures related to satisfaction can be observed including the amount of travel in various modes, mode options, and the quality of service as well as the number of complaints and/or compliments.

## **2.9) REDUCTION IN TRAFFIC CONGESTION**

Traffic congestion is a serious problem in all urban areas. The problem is growing faster in developing countries where urbanization and the use of motorized vehicles are increasing rapidly. Congestion causes delays and uncertainty, wastes fuel, results in greater air pollution, and produces a larger number of crashes. PRT can help to mitigate congestion by helping people plan travel better, by suggesting alternate routes, elevated network and keeping travelers well informed. Reduction in traffic congestion enhances mobility and reduces per capita fuel consumption.

## **2.10) SOCIAL IMPACTS:**

PRT basically focuses on enhancing pedestrianization. It can increase overall productivity by reducing total transportation cost including costs to consumers, businesses and governments of for vehicles, parking and roads. Pedestrianization can be a catalyst for more development patterns that provide economies of agglomeration, which can reduce the costs of providing public services and increase productivity due to improved accessibility and network effects. Although these productivity benefits are difficult to quantify, they can be large: just a few percentage increase in property values, a few percentage reduction in automobile and parking costs or few percentage increase in business productivity in a community can total hundreds of millions of rupees. Walking, as we know, has numerous social and health benefits. Vehicle

free street would encourage people not only to walk but also enjoy the experience. Besides, walking having obvious health benefits, it also encourages increased social interaction and hence cultural benefits as well.



**Fig 4) A congested street before PRT**



**Fig 5) Same street after PRT**

(Source: Ultra Fairwood Green Transport. (2009) “DPR of PRT Amritsar Project”)

### **3). LITERATURE REVIEW** (Source: “Viability of PRT in New Jersey”)

Personal Rapid Transit is advance mode of transportation has a history of development that goes over 40 years. It has been studied by governments, universities and research organizations, and transportation agencies around the world.

Literature summaries and the history of PRT have been widely documented by several authors. A recent review of the PRT publications carried by Dr. Wayne Cottrell of the University of Utah’s Department of Civil and Environmental Engineering found that “about two hundred PRT writings have been published since 1964” (Cottrell 2005). These documents provide context for various development programs and historical reference for current development activities.

This section summarizes the history of PRT development with details regarding development programs, recent application studies, which serves as a report on PRT interest around the world and “lessons learned” from history.

#### **3.1)Early History of PRT**

An historical review of PRT development prepared by J. Edward Anderson in 1998 credits the oldest work on PRT to Donn Fichter who started developing concepts in 1953 that resulted in a 1964 publication entitled, “Individualized Automated Transit and the City” (Anderson 1998).

##### **3.1.1) Aerospace Research Program**

A major PRT research study was carried by the Aerospace Corporation between 1968 and 1976. The Aerospace Corporation is a non profit corporation created by the United States Air Force to enhance missile system development. In 1968, the firm decided to use aerospace technology to solve urban problems and concluded that high-capacity PRT would have this potential.

The program included detailed analysis of the requirements for a PRT system and a trade off analysis of components. They developed a prototype system that included a narrow, U-shaped guideway and a vehicle suspended above the guideway propelled by on-board linear electric motors. The system employed electromagnetic switching in the guideway. The Aerospace Corporation also develop computer simulations to calculate the feasibility of operating large PRT networks with thousands of vehicles. The study findings were documented in the book Fundamentals of Personal Rapid Transit published in 1978 (Irving 1978).

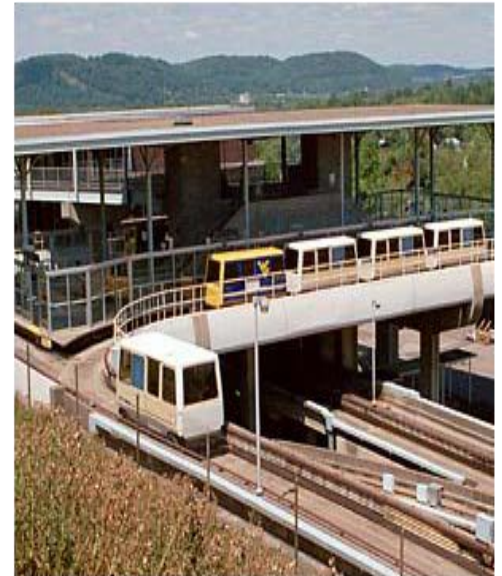
##### **3.1.2) Morgantown Group Rapid Transit** (Source: “Viability of PRT in New Jersey”)

In the late 1960’s, the University of West Virginia in Morgantown became interested in PRT systems through the efforts of Professor Sammy Elias, the then Head of the Industrial Engineering Department. The University was land-constrained and distributed among three different campuses in a city with very congested streets. A PRT system was identified as the best method to move students between campuses and the staRRcar system was selected for implementation under an UMTA funded comparative study.



According to researchers, at the time the Morgantown system was being designed, the scheduled opening date was a main concern. Cost-effective construction was not a principal objective. Further, none of the firms that were working on the project had ever worked with PRT before and they had limited time to fully enquire about the technology. The focus on completing the system by a certain date affect the development and forced design compromises. For example, the system uses large heavy vehicles which necessitated the use of larger guideways and stations. As a result, cost of construction was four times the initial estimations (Anderson 1998, Raney and Young 2004).

The Morgantown system began limited operation in 1972 and was expanded to its present capacity in 1975. The system is a fully automated, on-demand, off-line station transit system as shown in Figure 7. The Morgantown system has been in continuous operation since 1972. The system includes 8.7 lane miles of guideway and a fleet of more than 70 operating vehicles. The system accommodate two million passengers per year and since 1972, more than 63 million passengers have used the system. At peak travel times, the system can serve 30,000 passengers per day (Raney and Young 2004). Although it is normally referred to as a PRT system, it is technically a Group Rapid Transit (GRT) because it uses vehicles that could transport up to 21 passengers.



**Fig 7) Morgantown off line station**

(Source: “Viability of PRT in New Jersey”)

Since the 1970’s, PRT development has continued with varying levels of support and interest. Between the 1970’s and 2000, the major efforts to develop or PRT or related technologies were the UMTA AGRT program and the Raytheon/RTA program.

### **3.1.3) UMTA AGRT program**

The objective of the AGRT program was to develop larger vehicles that needed less frequent headways than PRT systems and therefore less advanced technology sub-systems. As a result of the AGRT program, several automated large-vehicle transit systems were planned and implemented in the 1980's.

### **3.1.4) Chicago RTA/Raytheon Program**

The most important PRT program undertaken since the 1970's in the United States started in the mid 1990's, when the Chicago Regional Transportation Authority (RTA) program to develop PRT technology in partnership with the Raytheon Corporation Phase one of the program began in 1990 with the funding of two different evaluation studies of competing PRT technologies. The Taxi 2000 design was the one of the technology component of the Stone and Webster proposal.



**Fig 8) Raytheon PRT Test Track**

(Source: "Viability of PRT in New Jersey")

The studies were completed in 1992 and resulted in the selection of the Taxi 2000 design as the preferred alternative in 1993.

In June 1993, as part of phase two of the program, the RTA choose the Raytheon Corporation to join in a public/private partnership for the development of a PRT system. Under terms of the agreement, the RTA and Raytheon jointly funded a \$40M technology development program. In return, Raytheon was given the rights to the technology and provided the RTA with a 1.3 percent commission on future sales. A three-year program was structured to complete the Taxi 2000 system design, engineer various system components, develop a prototype test track, and conduct system testing.

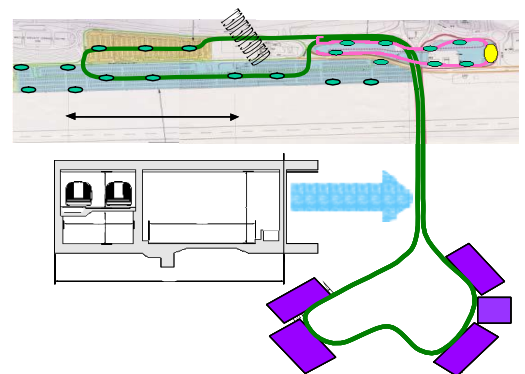
The program resulted in the construction of 2,200 foot test track in , Massachusetts with three vehicles and one off-line station as shown in Figure 8. The test track was successfully demonstrated off-line station manoeuvres, 2.5 second headway operations and network management of vehicles (Anderson 2005).

### **3.2) RECENT DEVELOPMENTS**

Since 2000, there continues to be considerable development and interest in PRT around the world. In this section we discuss about two state of art PRT system that is Heathrow airport and PRT Amritsar.

#### **3.2.1) HEATHROW AIRPORT**

In October 2005, the British Airport Authority (BAA) and Automated Transport Systems (ATS) announced an agreement to acquire a pilot implementation of the ULTra PRT system for Heathrow Airport. The agreement between BAA and ATS also include an investment of approximately \$13 million in ATS in return for 25 percent of the firm's equity. The agreement calls for ATS to complete the development of the ULTra system with investment funds distributed upon meeting various developmental milestones.



**Fig 9) Heathrow airport track**

(Source: "Viability of PRT in New Jersey")

The initial Heathrow application was designed to link remote parking lots with the Central Terminal Area using the ULTra system operating through a small access tunnel. The design called for 4.7 miles of guideway, 78 vehicles and 27 stations serving multiple parking stops and Terminals 1, 2 and 3 as shown in Figure 9. The Ultra system is constructed to replace shuttle buses serving 8,000 passengers per day. It is anticipated that the PRT system will save an approximate 8.4 minutes per trip. Recent developments call for the pilot system to now support the new Terminal 5. Plans call for the pilot to be complete in 2008.



### **3.2.2).PRT AMRITSAR :-** (Source: Ultra Fairwood Green Transport. (2009) “DPR of PRT Amritsar Project”)

The project will be on a BOT basis with a service life of 35 years. The project is known as the Personal Rapid Transit (PRT) public transport system. This utilise the use of highly intelligent computer controlled driverless, battery operated 4-6 seat vehicles running on an elevated guide way. The initial phase of the project will encompass PRT System from railway station & Bus stand to Golden Temple with 3.30 Kms with 7 stations and the subsequent phase build-up will spread over the rest of Amritsar. The PRT system will be integrated with existing and proposed public transport systems in the city (Bus, train) and compiled all such systems so as to enhance total transport connectivity within the designated area. PRT will provide the last mile connectivity.

**3.2.2.1) TECHNICAL DETAILS:-**The project consists a guide-way that will cover few important portion of Amritsar .In order to provide the “last mile connectivity” to visitors. There will be 7 stations along the route.

**3.2.2.2) STATIONS:** All stations will be elevated as per site requirements and off-line and have state-of-art ticketing systems, access control and security systems. Ticketing systems would be user friendly linking manual to digital systems. Stations will have individual back-up power.

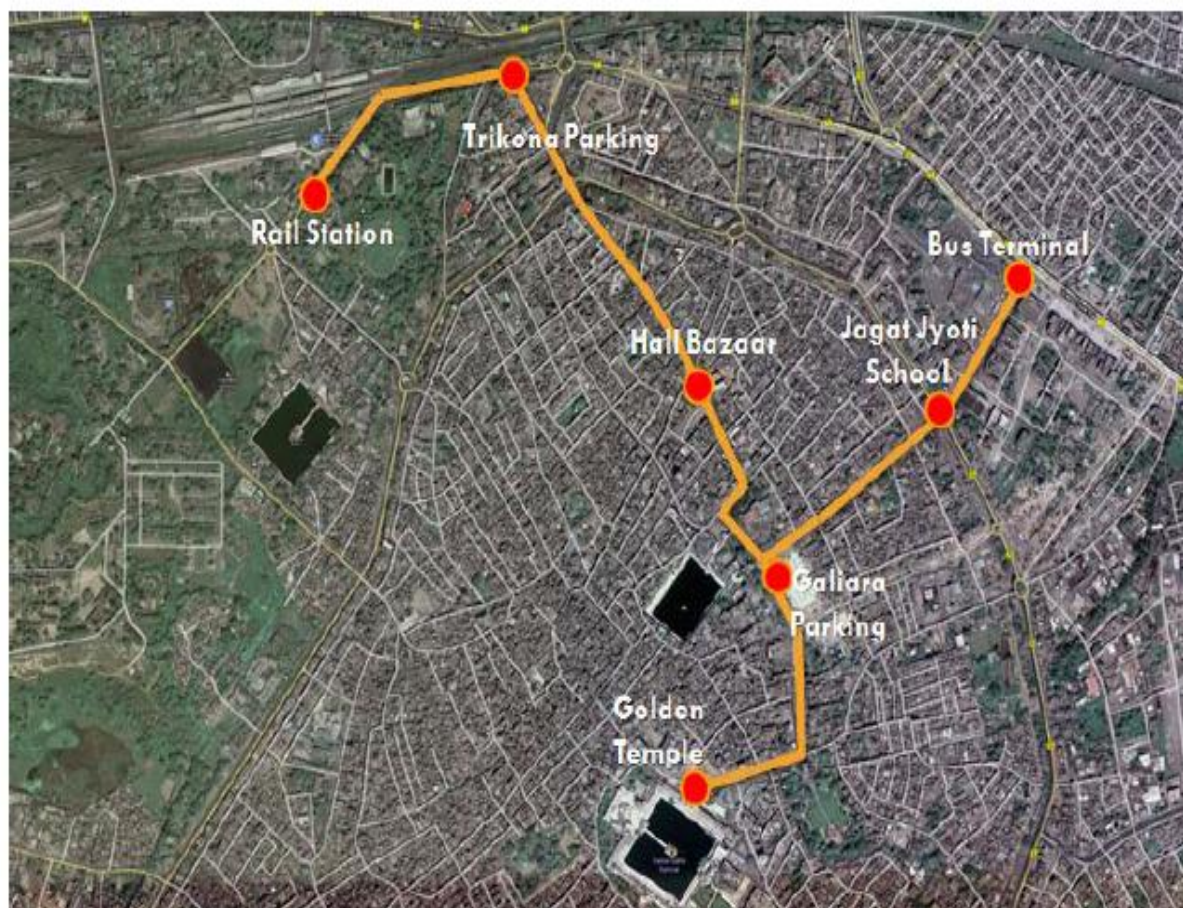
**3.2.2.3) GUIDEWAY:** The guide way will be positioned above grade as per site requirement.

**3.2.2.4) VEHICLE:** The vehicle has a net weight of 850 kgs and a max. loaded weight of around 1300 kgs. The vehicle will run on synthetic 13 inch tubeless tyres. The guidance and control system will be a combination of laser and wireless connectivity. The vehicles driverless and the motive power is taken from on-board batteries. The vehicles always have sufficient residual battery power so to ensure that pods never stop between stations. An extremely intelligent computer system controls the management of the entire system and ensures continuous optimal system operation and safety.

**3.2.2.5) INDIGENOUS MANUFACTURE:** There will be a phased indigenous manufacturing program for the vehicles. This will ensure continuity of sales and service at optimal levels of cost and functionality.

### **3.2.2.6) SYSTEM CAPACITY**

The pods are designed to carry upto a maximum limit of 6 passengers. System flexibility exists for providing changes in the routing quickly and with minimal disruption to public life. Increased capacity will be continuously incorporated by optimizing routes and service levels.



**Fig 10) Proposed PRT track for Amritsar**

Source: Ultra Fairwood Green Transport. (2009)  
“DPR of PRT Amritsar Project”

## **4). PROJECT CASE STUDY**

In the recent years tourism has grown in India from local economic activity to a major global industry giving employment to a large number of people at various levels. Varanasi is one of the districts of India with a great potential for tourism. Varanasi is home to the holiest shrines of Hindus including the Kashi Vishwanath Temple. Thus Varanasi is rich in historical, religious, and heritage sites. Even though there is great potential for tourism in Varanasi, the city lacks planning for tourism and supporting infrastructure. Core area becomes chaotic during festivals and religious events as number of pilgrims visit the respective temples especially Kashi Vishwanath. Measures taken by local authorities like vehicle restricted zone etc. will help to address some of the congestion problem- but it is not sufficient.

Basic objective of this Varanasi PRT proposal is to provide a sustainable transport infrastructure solution by integrating PRT System from railway station & BHU with Godowlia. Significantly reduce congestion, especially in bottlenecks during peak hours. So PRT would greatly help Varanasi to become a truly modern, integrated, 21st Century Heritage city.

The project assumes even greater importance considering that rate of increase of registered vehicles is 5% in Varanasi. The PRT, which is proposed as an elevated transport system will go a long way in helping to reduce the congestion on the roads in a sustained way.

### **4.1).THE PROJECT CONCEPT**

The project will be on a BOT basis with a specified concession agreement to operate for 30 years. The project is known as the Personal Rapid Transit (PRT) public transport system. This envisages the use of highly intelligent computer controlled driverless, battery operated 4-6 seat vehicles running on an elevated guide way. The initial phase of the project will encompass PRT System connecting railway station & BHU to Godowlia with 8.0 Kms with 9 stations. The stations suggested are

1. Varanasi junction railway Station
2. Kashi vidyapeeth
3. Shastri nagar
4. Sigra
5. Rathyatra square
6. Godowlia square
7. Bhelupura
8. Durgakund
9. BHU

The fare structure is proposed to be at par with existing Transport system per passenger KM fare structures will make travel by PRT very affordable for the public. The PRT network is eco-friendly and carbon positive. It is envisaged that the PRT system will remove a considerable number of motorized vehicles from Varanasi roads thereby helping to reduce congestion on the roads.

## **5). DATA COLLECTION & ANALYSIS**

The main two data need to be collected are travel demand assessment and modal shift. These data provides the total numbers of persons travel on the proposed route and number of personal willing to shift to PRT for a standard fare. The data should be collected for the peak hours to judge the per supply capacity of PRT. For travel demand assessment vehicular and pedestrian count are conducted and number of persons travelling on the proposed route are calculated. Vehicular and pedestrian counts are done by elevated observations.

Household, socio economic and trip information has been collected from the road side interviews and the similar information has been collected from the workplace interviews in the establishment survey. Willingness to shift (WTS) and willingness to pay (WTP) surveys have been conducted during both roadside interviews and workplace interviews. These surveys are user opinion surveys where the users are first informed about Personal rapid System, its utilities and benefits. Then the users are asked if they will be willing to shift to PRT if it is introduces in their area. If the answer is yes then we suggest them the standard fare to PRT and again note their response

The areas where surveys are conducted are

- 1) Varanasi junction railway station
- 2) Rathyatra square
- 3) Lanka

The information collected in response sheet during surveys from each individuals are

- Age
- Sex
- Income
- Occupation
- Travel mode
- Origin of journey
- Destination
- Journey distance
- Time accumulated in journey
- Cost invested in present mode
- Willingness to shift at standard fare in form of Y/N



fig 11) **RATH YATRA SQUARE**

The base year trips per day have been taken as number of persons travelling over the proposed route each day. The number of base trips for each mode is taken as product of number of vehicle of particular mode and its average occupancy. Average occupancy is calculated by considering a given number of vehicle in each mode. It is required to calculate average occupancy because there is variation in number of occupants from vehicle to vehicle. Of course for pedestrian the average occupancy is taken as 1.0 only

<b>Trip mode</b>	<b>No of vehicles/pedestrian at peak hour</b>	<b>Average occupancy</b>	<b>Base year trips per peak hour</b>	<b>Base year trip per day</b>
<b>Two wheeler</b>	3168	1.3	4,119	43,358
<b>Cycle rickshaw</b>	612	1.75	1,071	11,274
<b>Auto rickshaw</b>	1704	4.4	7,497	78,916
<b>Car</b>	996	2.8	2,789	29,358
<b>Bicycle</b>	1218	1.1	1,218	14,106
<b>Pedestrians</b>	498	1.0	498	5,242
<b>Total</b>			<b>17,314</b>	<b>1,82,254</b>

4

### **WILLINGNESS TO PAY/WILLINGNESS TO SHIFT**

During the Survey, the interviewees were given a general idea of the PRT and asked whether they would like to adopt such a mode that would be elevated in nature, and hence give them a relief from the congestion they face everyday, has advantages such as comfort, safety, reliability, nominal waiting time, public yet personal in nature and quick, without any intermediate stops. People were assured that system would be for the common man, and the cost of travel would be between that of a bus and an auto. People were asked how much they would pay for the same journey by PRT, rather than their usual modal availability. The survey attracted different queries from the people, along with enthusiastic inputs regarding the expectations from a new system that had the potential to address the mobility issues in Varanasi. In the Varanasi project, questions pertaining to the Willingness to Shift and Willingness to Pay Surveys were integrated with Socio-economic Survey.

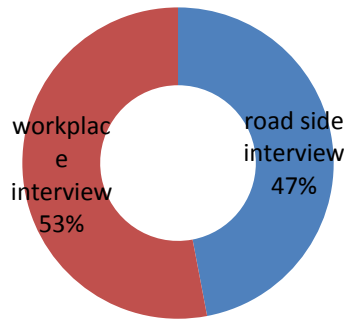
The information collected in response sheet during surveys from each individuals are

- Age
- Sex
- Income
- Occupation
- Travel mode
- Origin of journey
- Destination
- Journey distance
- Time accumulated in journey
- Cost invested in present mode
- Willingness to shift at standard fare in form of Y/N

## SALIENT FEATURES OF SURVEY

**4**

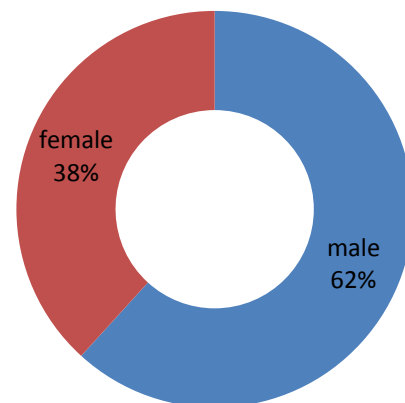
sample collection as per  
mode of survey



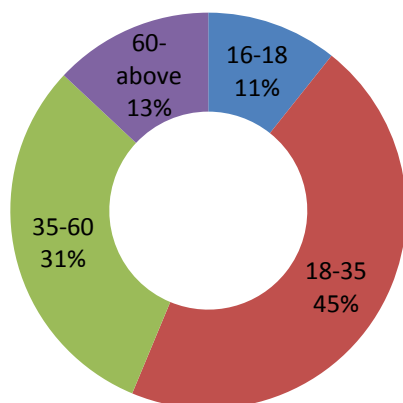
Trip mode	Road side interview	Work place interview
Two wheeler	12	45
Cycle rickshaw	18	17
Auto rickshaw	38	21
Car	08	14
Cycle	15	11
Walk	11	07
<b>total</b>	<b>102</b>	<b>115</b>

<b>Male</b>	134
<b>female</b>	83

**gender composition**

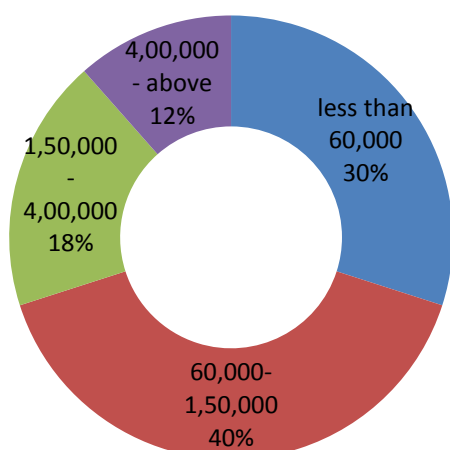


### age distribution



Age	No of samples
16-18	23
18-35	98
35-60	66
60-above	28

### Income group(per annum)



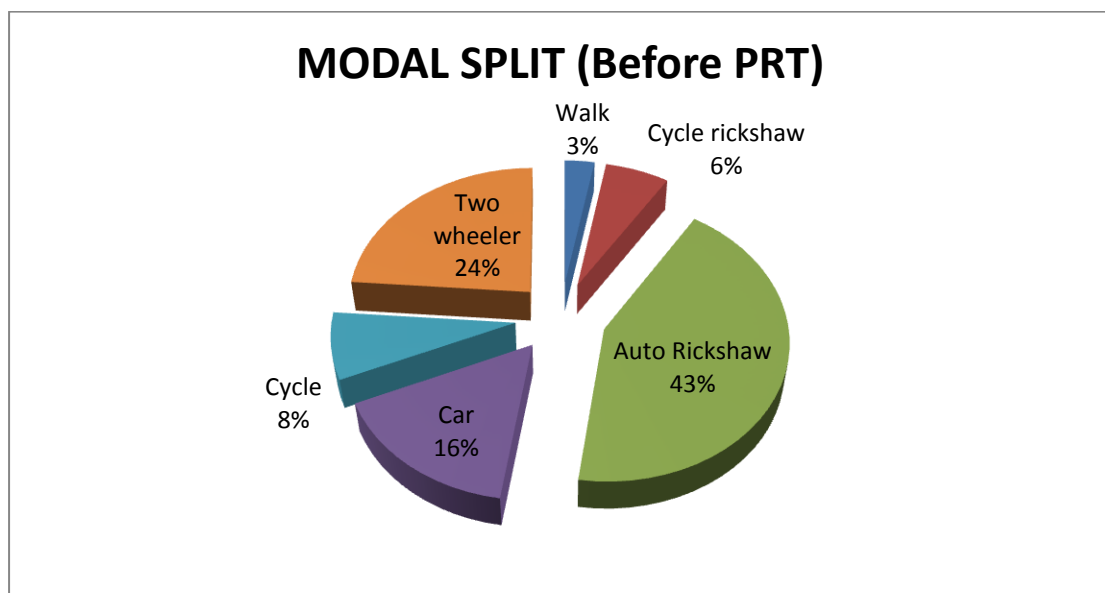
Income group (per annum)	Sample
Less than 60,000	65
60,000-1,50,000	87
1,50,000-4,00,000	40
4,00,000-above	25

## **PERCENTAGE SHIFT TO PRT:-**

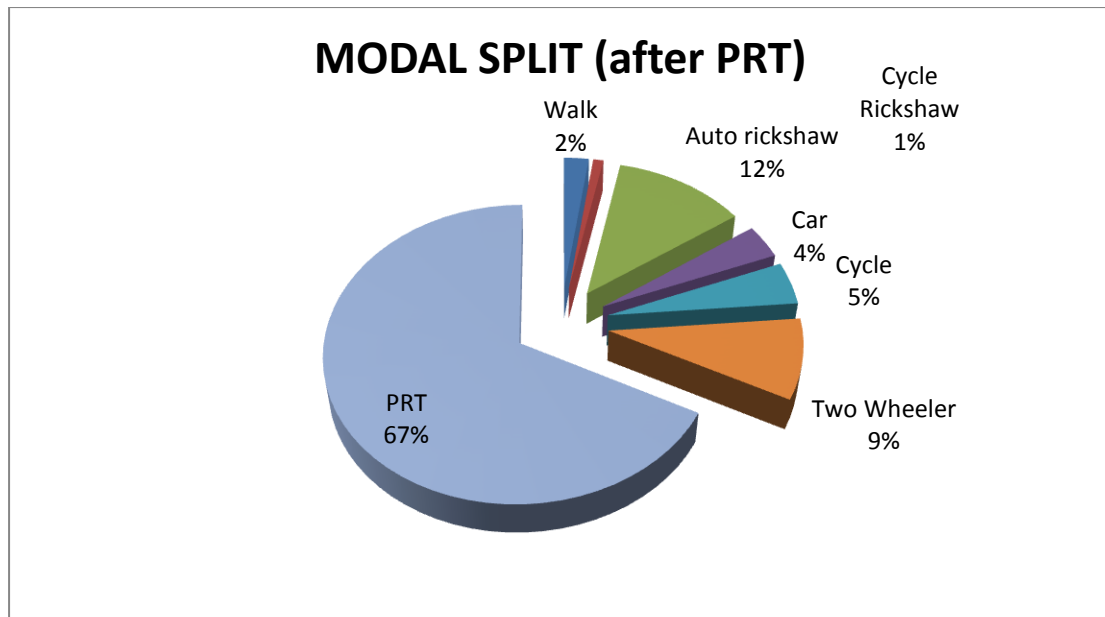
Mode type	Percentage shift	Base year trip per peak hour	Travel demand for PRT at peak hour
Two wheeler	63	4,119	2,595
Cycle rickshaw	85	1,071	910
Auto rickshaw	72	7,497	5,398
Car	77	2,789	2,148
Bicycle	40	1,340	536
Pedestrian	21	498	105
Total		17,314	11,692

## **6). MODAL SPLIT:-**

According to the calculated shift from each of the existing modes, there will be a change in the modal split of Intra Varanasi Trips when PRT is introduced. There will be reduction in trips of each of the existing modes. The existing modal split and the new expected modal split of Intra Varanasi trips has been shown below in Figure







**Figure 13 : Modal Split Before and After PRT in Varanasi**

After the introduction of PRT in Varanasi, the most significant reduction of 31% and 15% is expected in Auto rickshaw trips and Two wheeler trips respectively. The reduction in personal modes of transport will reduce the carbon emissions and the congestion on roads. The reduction in congestion on roads will help the cycle rickshaw pullers in reducing their time taken to complete one trips and they can increase the frequency of their trips.

## **7). PRT SUPPLY CAPACITY:-**

The base year travel demand is 1,23,074 trips/day. The PRT supply capacity has been considered to serve the peak hour demand. The peak hour demand has been taken to be 9.5% of the total traffic, equivalent to the peak hour demand on PRT of 11,692 trips per hour.

The PRT operational characteristics have been taken according to ULTra PRT pod car system. The dwell time for PRT has been assumed as 30 seconds. PRT can operate with minimum time headway of 3 seconds. The average time headway on which the proposed PRT system would run in peak hour is 3.6 seconds. The average occupancy of PRT has been assumed as 4 expecting that ride sharing will occur during the peak hour. An off-peak occupancy rate of 3 has been assumed, yielding an average occupancy rate of 3.3 ( $4.0 \times 30\% + 3 \times 70\%$ )

The operational characteristics taken as follows

- |                               |                                |
|-------------------------------|--------------------------------|
| 1) Distance headway (Average) | = 30 meters                    |
| 2) Speed of PRT (Average)     | = 30 kmph                      |
| 3) Average occupancy          | = 3.3 per pod                  |
| 4) Average trip length        | = 3.3 km (from primary survey) |
| 5) Route length               | = 8 km                         |

The operational characteristics, the number of pod cars required to serve the peak hour demand have been calculated.

$$\begin{aligned}\text{Time headway} &= \text{distance headway} \div \text{speed} \\ &= 30 \div 8.33 \\ &= 3.6 \text{ sec}\end{aligned}$$

$$\begin{aligned}\text{Time taken to complete 1 trip} &= \text{avg trip length} \div \text{speed} \\ &= 3.3 \div 30 \\ &= 6.6 \text{ min /trip}\end{aligned}$$

Consider dwell time of 30 sec

$$\text{Time taken to complete 1 trip} = 6.6 + 0.5 = 7.1 \text{ min/trip}$$

$$\text{Number Of Trips Made by each Pod in 1 Hour} = 60 \div 7.1 = 8.45 \text{ pod trips/hour}$$

$$\begin{aligned}\text{Number Of Pods in 1 Km Length at Any Instance} &= 1000 \div \text{Headway} \\ &= 1000 \div 30\end{aligned}$$

$$= 33.33 \text{ pods/km}$$

$$\text{Number Of Pods In 1 Km Length For Bi-directional Track} = 33.33 \times 2$$

$$= 66.66 \text{ pods/km}$$

$$\text{Number Of Pods in the Entire Network Length} = \text{No. Of Pods in 1km Track} \times \text{Route Length}$$

$$= 66.66 \times 8$$

$$= 533 \text{ PODS}$$

534 Pods is the maximum number of pods that the network can handle at the given speed & headway excluding the pods docked at stations.

$$\text{Number Of Trips Made By All Pods in the Entire Network} =$$

$$= (\text{No. Of Trips Made By each Pod}) \times (\text{No. Of Pods})$$

$$= 8.45 \times 533$$

$$= 4507 \text{ pod trips/hour}$$

$$\text{Maximum Number Of Passengers Trips Possible in the Entire Network} =$$

$$= (\text{Total Pod Trips}) \times (\text{Avg. Occupancy})$$

$$= 4507 \times 3.3$$

$$= 14,873 \text{ Passenger trips/hour}$$

Considering 20 % Reduction for Empty Runs in the System

$$\text{System Capacity} = 14,873 - (0.2 \times 14,873)$$

$$= 11,899 \text{ Passenger Trips/hour}$$

$$\text{Passenger – Km Covered in 1 Hour} = \text{System Capacity} \times \text{Average Trip Length}$$

$$= 11,899 \times 3.3$$

$$= 39,265 \text{ Passenger-km per hour}$$

The system capacity of the PRT system in Varanasi has been calculated to be 11,899 passenger trips per hour. The peak hour demand is 11,692 passenger trips per hour which is less than the system capacity. Hence, the system will be capable of handling the expected peak hour demand on the network. The difference between system capacity and peak hour demand is very little. This would not be the case during the rest of the day including the off-

peak hours as the travel demand would not be same throughout the day. The number of Pod Cars required to achieve this system capacity is 533 Pod Cars excluding the pods docked at the stations.

## 8). FINANCIAL ANALYSIS:-

Detailed financial analysis has been carried out to calculate Net Present Value (NPV) and Internal Rate of Return (IRR) of the project. IRR value of 17% is obtained after performing detailed calculations of the project. A project is generally considered worth investing if the IRR value of the project is greater than 16%. Various factors have been considered for carrying out the financial analysis. These factors have been classified into five categories listed below in the Table

FACTORS		VALUE
TIME	Concession period	30 yrs
	Construction period	2 yrs
OPERATIONAL	Headway	30 m
	Speed	30 kmph
	Average occupancy	3.3
	Average trip length	3.3 km
	Route length	8 km
DEMAND	Base year trip per day	1,82,253
	% shift to PRT at minimum fare	67.53
	Desired fare per km	Rs 4
	Estimated demand (trips/day)	1,23,074
	Ridership growth rate	5%
	% increase in fare every 3 years	20%

COSTS	Capital cost per km(in crores)	44.48
	Operational and maintenance cost	
	A) Man power cost (crore/yr)	12.89
	B)Electricity cost	4.4 crore/year
	c)AMC & Royalty	5% of fare
FINANCE	Interest rate	10%
	Loan Repayment Period	15 yr
	Tax holiday	100% for 5 year
	Tax exemption	30% for 5 year
	Tax rate	35%
	Depreciation rate(pods)	20%
	Depreciation rate(civil structure)	5%
	Discount rate	10%
	CRF for given rate and loan replacement period	0.13147

These factors have been used for preparing the Cash Flow Statement of the project. The total revenue has been taken as the total of Fare Revenue, Advertisement Revenue and Commercial Rent revenue. The total operation and maintenance cost has been taken as the sum of Manpower Cost, Electricity Cost & AMC & Royalty Cost. The Net Operating Income

has been taken as the difference of total revenue and total cost. The interest paid and depreciation has been subtracted from the net operating income to achieve Profit Before Taxes (PBT). Taxes have been calculated as 35% of PBT and subtracted from PBT to get Profit After Taxes (PAT). The CFAT have been discounted to their Present Value considering the Discount rate as 10%.

The detailed Cash Flow Statement has been prepared and shown in the The NPV and IRR of the project have been calculated from the cash flow statement. The NPV of the project is **INR 551.40 Crores** and the IRR is **17%**.

**8.1) CAPITAL COST:-** one time setup cost for plant or a project. Generally this amount is acquired through from the market in the form of loan for certain repayment period and interest rate.

- Loan acquired for this project is of **Rs 355.84 crores** @ interest rate of **10%** and for repayment period of **15 years**
- For given data Capital Recovery Factor (CRF) comes out to be **0.13147**
- This CRF has to multiplied with principle to get installment for each year
- In this case installment comes out to be **Rs.46.78 crores** per year

**8.2). OPERATION AND MANAGEMENT COST:-**

- Manpower cost should be increase by **1%** every year, by considering inflation
- Electricity cost should be increase **5%** every year.
- AMC & royalty should be taken as **5%** of Fare

**8.3). OPERATING INCOME:-**

Fare revenue should be calculated by taking product of trips around the year with basic fare.

- ridership growth rate should be taken in account, here ridership growth rate is **5%** per year
- Fare should also be increase **20%** after every **3 years**
- Ads revenues & commercial revenue should be increase in a same way as fare.

**8.4). NET OPERATING INCOME :-** It is taken as

$$\text{NOI} = \text{TOTAL REVENUE} - \text{TOTAL O \& M COST}$$

**8.5). DEPRECIATION :-** It is taken as **5%** for civil structure & **20%** for pods

**8.6). PROFIT BEFORE TAX (PBT):-** it is measure of firm's profit that exclude depreciation, Taxes & interest paid.

$$\text{PBT} = \text{NOI} - \text{DEPRECIATION} - \text{INTEREST PAID}$$

**8.7).TAXES:-** taxes should be calculated on PBT

Here **100% tax** exemption is provided for first **5 years**, and then **30%** exemption is provided for next **5 years**.

**8.8). NET PROFIT AFTER TAX:-** it is taken as profit of firm after inclusion of tax.

$$\text{PAT} = \text{PBT} - \text{TAX}$$

**8.9). CASH FLOW AFTER TAX (CFAT):-** it is taken as

$$\text{CFAT} = \text{PAT} - \text{DEPRECIATION} - \text{TAX ON INTEREST PAID}$$

**8.10). INTERNAL RATE OF RETURN (IRR) :-** is the interest rate at which the net present value of all the cash flows (both positive and negative) from a project or investment equal zero.

- Internal rate of interest is used to evaluate the attractiveness of a project or investment. If the IRR of a new project exceeds a company's required rate of return, that project is desirable.
- If IRR falls below the required rate of return, the project should be rejected.
- A project is a good investment proposition if its IRR is greater than the rate of return that could be earned by alternative investment

The formula for *IRR* is:

$$0 = P_0 + P_1/(1+\text{IRR}) + P_2/(1+\text{IRR})^2 + P_3/(1+\text{IRR})^3 + \dots + P_n/(1+\text{IRR})^n$$

where  $P_0, P_1, \dots, P_n$  equals the cash flows in periods 1, 2,  $\dots$  n, respectively; and IRR equals the project's internal rate of return.

The IRR of this project comes out to be 17% which justifies this project

**8.11). NET PRESENT VALUE:-**

In finance the net present value (NPV) or net present worth (NPW) of a time series of cash flows, both incoming and outgoing, is defined as the sum of the present values (PVs) of the individual cash flows of the same entity.

$$\text{NPV} = R_1/(1+i)^1 + R_2/(1+i)^2 + R_3/(1+i)^3 + \dots$$

*i* is the target rate of return or discount rate per period;

$R_1$  is the net cash inflow during the first period;

$R_2$  is the net cash inflow during the second period;

$R_3$  is the net cash inflow during the third period, and so on ...

The discount rate is a number used to convert the values of the expected future cash flows into their present values. Accept the project only if its NPV is positive or zero. Reject the project having negative NPV. While comparing two or more exclusive projects having positive NPVs, accept the one with highest NPV



## **9).CONCLUSION:-**

The promise of PRT has been in the public discussion for over 40 years. It has not reached maturation for a variety of reasons but remains an enduring idea that offers the unique and rare combination of potentially improving the quantity and quality of transit service while reducing costs, congestion, and environmental impact. This opportunity is available through the innovative application of advanced yet commercially available technology in a new form designed for public transportation. the PRT project in Varanasi if properly implemented, can provide a fast, systematic, efficient, intelligent, safe and economical transport mode to Varanasi. It can be used as a part of a tourism industry if used in a intelligent manner. As a public transport it seems to be a financially beneficial option as we saw in financial analysis. It seem to handle peak traffic flow efficiently as well as gives a good rate of return of 17%. Hence it could be employed as a future mode of transport for Varanasi

## **10).REFERENCES:-**

1. Jain Udit, Sarkar P.K, Vibhuti Anupam,(2013), “ BENCHMARKING OF PERSONAL RAPID TRANSIT SYSTEM (DYNAMIC MODEL)”, *TRB 2014 Annual Meeting*
2. Carnegie, Jon A. ,Voorhees, Alan.M, (2007),“ Viability of Personal Rapid Transit In New Jersey”, *The State University of New Jersey*
3. Gilbert Richard and Anthony Perl. (2006). "Grid-connected vehicles as the core of future land-based transport systems". *Energy Policy* 35 (5): 3053–3060.
4. Tebay Andy. (2013). “PRT System to Open for Suncheon Bay Garden Expo”. <http://kojects.com/2013/02/13/prt-system-to-open-in-april-for-suncheon-bay-garden-expomore-1411>.
5. Ultra Global. (2013). “Heathrow announces plans for an additional Personal Rapid Transit (PRT) system”. <http://www.ultraglobalprt.com/heathrow-announces-plans-additional-personal-rapid-transit-prt-system-heathrow>.
6. Ultra Global. (2013). “World’s first and largest urban PRT system announced”. <http://www.ultraglobalprt.com/worlds-largest-urban-prt-system-announced>.
7. Anderson J. Edward. (2009). "An Intelligent Transportation Network System: Rationale, Attributes, Status, Economics, Benefits, and Courses of Study for Engineers and Planners”. *PRT International, LLC*
8. European Commission. (2009). “Moving ahead with PRT”. [http://ec.europa.eu/research/environment/newsanddoc/article\\_2650\\_en.htm](http://ec.europa.eu/research/environment/newsanddoc/article_2650_en.htm).
9. European Commission. (2004) “Fifth Framework Programme Key Action - City of Tomorrow and Cultural Heritage”. *EDICT Final Report*.
10. Vibhuti Anupam. (2009). “Personal Rapid Transit: A Suitable Mass Transit Alternative for India”. *Institute of Urban Transport*
11. Ultra Fairwood Green Transport. (2009) “DPR of PRT Amritsar Project”. *Detailed Project Report*.
12. Sukanya Sumi. (2010). “Gurgaon eyes elevated pods” *The Times of India, New Delhi*.
13. Paul G.S. (2011). “Rapid transit system to be a reality soon”. Amritsar tribune Newspaper.
14. Project report of “Jawaharlal Nehru National Urban Renewal Mission (JNNURM)” *Varanasi*
15. [http://en.wikipedia.org/wiki/Personal\\_rapid\\_transit](http://en.wikipedia.org/wiki/Personal_rapid_transit)

