Volume 6 | Co-Development Research Project

Guided Fully Automated Rapid Transportation System

Indian Institute of Technology | EcoAutoMo Pvt Ltd

Under Co-Development MoU Between

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Foundation for Innovation & Technology Transfer
at Indian Institute of Technology,
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A. Program Description

1 The Research Proposal

Co-Development of Guided Fully Automated Rapid Transportation System with AutoBots Pod taxi solution as Industry Use Case.

2 Co-Development Partners

I. Indian Institute of Technology – Delhi (Academic Institution)

II. EcoAutoMo Pvt Ltd (Industry)

3 Nature of Co-Development Effort

An MoU has been signed between Foundation for innovation and technology transfer at IITD and EcoAutoMo Pvt Ltd under an Industry-Academia collaborative development arrangement. The detailed agreement shall be affected immediately upon receipt of funds from private or public resources.

A portion of the land parcel suitable to build a test track for ~100m as a start has been allocated by the space committee at IIT Delhi.

A team of subject matter experts from different departments at IIT Delhi has been approached to participate in the effort & co-investigate. A team of senior faculty from Civil Engineering, Traffic & Transportation, Electrical Engineering, Communications, Engineering Design, and Mechanical Engineering have consented to be a part of the team effort.

3 Senior faculty from the Institute have agreed to be part of the project drawn from Electrical Engineering, Mechanical Engineering, and the Centre for Automotive Research & tribology (CART).

To enhance the quality of the research team, specialized subject experts are also expected to be drawn from other academic institutions to work on specific aspects of the program as consultants.

The scope of development works is to be split between IITD & EAM equally duly funded by private or public resources as per their respective terms and conditions concerning IP Ownerships and subsequent commercialization policies of respective organizations.

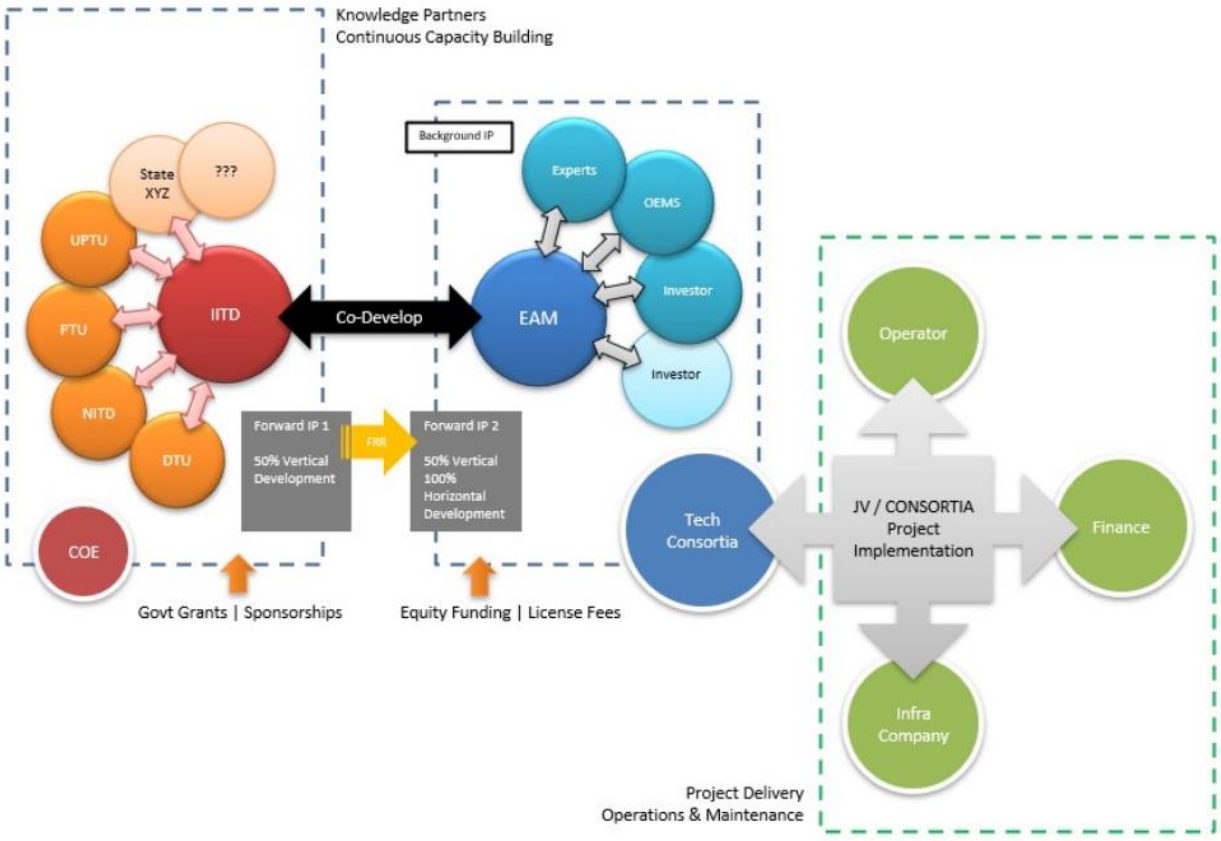


Figure 1: Stakeholder Organization Up to Commercialization

B. Summary of the Proposed Research

1 Context

Mass Public Transit Systems are yet to graduate to a level of sophistication that could be demanded of them. Off-the-shelf availability of advanced technologies makes it prudent for 'developing economies' to look into solutions that are effective, inexpensive, flexible, and easy on the taxpayers aiming to provide an indigenous ecological transport system with energy, cost & emission life-cycle efficiencies equivalent to an e-cycle for air-conditioned urban commutes.

The proposed research aims at evaluating the possibility of building urban transportation solutions that profess the above qualities.

It is well acknowledged that by the next 20 years, ~50% of the world's population will be living in urban areas. Road rights-of-way in any urban development context being a non-scalable resource by law are already consumed to capacity. Automobiles occupy ~80% of this road right-of-way, statutorily limited in width with no scope of expansion, while resulting congestion keeps increasing every day. This automobile-based congestion has already eaten up space on the limited right-of-way meant for the use of marginalized sections - pedestrians, cyclists, and rickshaws.

It is also well known that ~90% of the time people travel ‘singly’, across the world including India, using personalized modes (4W, 3W & 2-wheeler). It is futile to transport a payload of 1 person of ~80 Kg, ~90% of the time in a 4W machine ~15 times the weight of the payload with only 15% of the IC engine power reaching the tire treads for traction. The same job can be accomplished most efficiently electromechanically - using an E-Cycle at ~10% of the operational cost of a 4W.

Given the energy scenario in India and India’s dependence on foreign oil, it may be unwise to depend on fuel-based urban mobility systems for most travel requirements in urban areas.

Therefore, India needs a transportation system that is innovative and reflects the immediate needs of the country’s urban transport development imperatives, aptly encapsulating our Hon’ble Prime Minister’s call for speed & scale essentials.

2 Moving ‘masses’ in Urban Areas with PRT

There are some emerging & innovative technologies powering a class of high-speed urban mass transport products called ‘Personal Rapid Transit’. These systems profess an inexpensive transit technology that borrows the best features of the automobile (on-demand, non-stop travel, from anywhere TO anywhere), but glides above the road traffic. A fleet of small fully automated vehicles, each seating 2 / 4 / 6 people, travels on overhead guideways linking many small stations scattered throughout an urban area in a 3D network. All points in a city with such a PRT network would be close to an offline PRT station.

Operationally a PRT system would be able to move large numbers of people at the same efficiency as the e-cycle, an 80 kg payload at ~Rs 1 / km in an air-conditioned environment, compared to a minimum 1000 kg metal automobile carrying the same payload by burning fossil fuel in the IC engine, wherein only 15% of the energy reaches the tire for traction the rest getting lost in transmission and heat. Because the system is designed to reach most parts of a city (to the last walkable ~250m of actual origin or destination) using narrow elevated tracks terminating at micro-size stations, the

system would be able to move a significantly high number of commuters from their respective origin points to their destinations without the need to collect them to a single large station as accomplished in the metro system otherwise.

By being fast and convenient, and requiring a fraction of capital investment vis-a-vis current mass transit systems, PRT is our best bet for reducing traffic congestion entirely. The guides of a PRT system are so light and minimalist that they can be configured to reach almost anywhere for easy accessibility. Instead of stopping at every station as metro coaches do, riders could be taken directly to their chosen destination non-stop, cutting travel time significantly. Since the system has its dedicated guideway above the road and no conflicts within the system, there is no congestion. The PRT system is accessible to all user groups and highly eco-friendly.

The system runs on 'clean' electrical energy and has the least carbon footprint in enabling personalized mobility. Today we have the technologies waiting for an opportunity, to demonstrate this new dimension for a transport revolution. All technology components have already proven themselves, these revolutionary systems' achievement lies in exploiting & exploring alignment network logic, headway rationale, computer control, and offline station rationale.

Once demonstrated, we would have transit systems, which have the potential to

- take away entire car commuter congestion in our urban sprawls
- drastically reduce fossil fuel dependence
- release ROW space in favor of zero-carbon modes
- complete last-mile connectivity at a fraction of the cost of a metro network
- make large & distant tracts of land and housing more efficiently accessible
- make day to day cost of transport at least a third of those using automobiles.

Anupam Vibhuti, Founder EcoAutoMo Pvt Ltd has conceived and designed a transit system that can provide the aforesaid values to commuters in any city.

(Video Link: https://www.youtube.com/watch?v=OiUEIedkYmo)

3 Research Objectives

The objectives of this collaborative research effort can be split into two parts.

a. Immediate

For the immediate team research effort for 3 years, the following research objectives are proposed to be fulfilled:

- To validate the design basis for the proposed design of the new age urban 'mass' transportation system as conceived.
- To identify all technical issues involved and finalize/devise innovative solutions for difficult challenges, including traffic flow challenges.

- To build a rough prototype at 1: 1 scale, comprising of a track length of ~200 m with ~3 nos vehicle chassis mules to work in a choreographed manner, in a controlled environment. This will help validate all ergonomics and experience issues. The vehicles will be capable of moving but at controlled speeds. This will help validate all technical concerns and help learn about the engineering intricacies before attempting to build an expanded fully operational technology demonstration system at full scale.
- To build a refined prototype at 1: 1 scale, comprising a track length of ~2 km with ~10-15 fully developed e-vehicles to work in a choreographed manner, in a controlled environment and closed user group setting. This will help 3rd party validate all technical concerns. This will also help in building an OEM support ecosystem.
- To attract additional funds from both government and private sources appropriate to build and deploy the accredited technology system in limited trial public use with actual air-conditioned rides and all safety standards in place.
- To build business models, engage in market discovery towards scaling up the business and commercialization using further partnerships/funds to take this all the way to commercial readiness including business development, establishing mass production processes, vendor development, building a stable human resource base, and establishing a world-class delivery team.
- To engage with the central and state government and local authorities for respective acceptance and support.

b. Long Term

In the longer term extending upto 10 years parallel to the co-development effort, the proposed collaborative engineering effort and exercise around further work towards the full-scale realization of AutoBots as an anchor project will help fulfill the following broader objectives:

- Build a center of excellence at IITD to research guided systems and technology components and sub-components useful for commercialization.
- Build capacity amongst faculty and students at IITD as well as at affiliated centers of excellence or institutions, to serve future deployments in the country.
- Build an ecosystem around several technology adaptations or the creation of new technology systems or sub-systems required for AutoBots, leading towards several product start-ups maturing as OEM businesses for AutoBots.
- Build a state-of-the-art 'legacy' for research on 'advanced transportation technologies' in India involving vehicle and vehicle subsystems design for both passenger and goods vehicles involving alternative fuels, cell technologies, or even alternative transportation architectures.
    - On Road higher efficiency vehicles for commuters and goods transportation
        - Drone-based transportation for special services - Emergency, Fire, Medical
        - Dual-mode vehicles systems (same vehicle that runs on the road as well as dedicated guideways)
        - latest technologies around autonomous control, big data analytics, and artificial intelligence providing robust a platform for further work towards 'alternate' transport 'service' models.

- Specially designed vehicles for on-demand emergency services
    - Specially designed vehicles packet delivery logistics delivery chains for servicing the e-commerce industry.
    - Fleet aggregation and on-demand services to encourage the CASE (connected, automated, shared & electric) paradigm.

C. Background & Justification

1. Need for an Indigenous PRT System (Personal Rapid Transit)

Across many parts of the world, urban policymakers are experimenting with three broad alternative approaches toward mobility systems of the future. These are the following:

- Bus-based mass transport systems running as fixed routes, high frequency, high-capacity lines in the form of 'Bus Rapid Transit Systems' operate within the existing road right of way.
- Autonomously controlled driverless cars with vehicle-to-vehicle communication such as the 'Google driverless cars' meant to operate in mixed traffic conditions.
- Driverless pods, autonomously driven on elevated tracks/guideways along existing right of ways or special alignments in the form of 'pod cars' or 'personal rapid transit (PRT)'.

The first two alternatives necessarily depend on the existing road rights-of-way to accomplish their objectives but appear to entirely miss the point regarding the 'non-scalability' of right-of-ways and the perpetually growing number of vehicles. While the first attempts to address 'mass' transport, the second addresses 'personal' transport, with both alternatives necessarily constrained by the same ground space that they are supposed to run on.

Unfortunately, the ICE to EV paradigm further only addresses the 'energy' dimension of sustainability - completely ignoring the 'spatial' dimension of congested urban habitats. The EV policy can simply not address the absolute number of growing vehicles on our city roads.

The third alternative professes not to use rights-of-way, but to provide personalized transportation with 'high mass transportation' system capabilities. On a per 'passenger-km.' travel basis, several conventional modes popularly perceived as efficient, rate poorly in comparison to the characteristics of the 'personal rapid transit system' or 'pod cars'.

In principle, the AutoBots PRT system borrows the best commuter interface characteristics from on-demand cab services like OLA/UBER but proposes high operational capabilities, being elevated and independent of the road surface to operate on. It is also highly pervasive in comparison with the traditional 'mass' transit system, by reaching the last ~250m of a commuter's journey, highly flexible in terms of infrastructure -Station & Track relocation abilities.

Several states led solicitations for such 'pod car' systems for limited stretches (Delhi, Gurgaon, Thiruvananthapuram, Bangalore, Amritsar, Haridwar, Jewar Airport) have been issued and some responded to by foreign technology companies in India since 2011.

Therefore, there is a need for building an indigenous transportation system that can provide competition in the marketplace, besides promoting declared GOI goals of self-dependence, making in India as well as boosting local manufacturing.

4 2 Seat PRT system benefits vis-à-vis Automobiles

Calculations prove that a two-seat 'personal rapid transit system' powered additionally by solar panels can be more efficient, in terms of the fundamental parameters of lifecycle cost, energy, and emission, than even traveling on an e-cycle.

The two-seat 'personal rapid transit system' also promises to not only be ~15 times more efficient than a petrol-fuelled automobile in terms of energy but ~55 times more efficient in terms of cost and emit ~35 times less carbon footprint in moving one passenger one km. in the system.

Besides the system, being inherently light and thin can reach almost up to most destinations in a city, thereby completely avoiding the need for feeder trips for public transportation. This will not only create an alternative supply but relieve the already constrained right of ways of congestion caused by automobiles in favor of zero / low carbon modes.

5 2 Seat PRT systems Vis-à-vis traditional 'mass' transit systems

'Mass' transportation technologies that have historically been relied upon have been unable to assist transport system planners in finding solutions to the issues of road congestion, severe pollution, and the lack of capacity to transport huge volumes of masses.

AutoBots PRT system design basis calculations show that for the same capital expenditure in a mass transit system like a Metro, an efficient PRT system infrastructure can be installed to service 7.2 times the geographical area the metro system can service (because of stations distributed across the geographic area enabling last-mile connectivity).

Such a PRT system can service approximately 6 times the number of concluded 'passenger km' serviced by the metro system.

In addition, it can potentially do the job at 20 percent of the energy spent for doing the same work otherwise, considering energy consumed by either system on a lifecycle analysis basis, besides enabling commuters to complete their journeys in almost half the time required otherwise.

At the right price point, we could expect a major reduction in road congestion with AutoBots PRT given the virtues of last-mile reach, low-cost operations, and low total cost to the community.

6 The AutoBots Solution as a Use case

- The AutoBots solution (Video Link: https://www.youtube.com/watch?v=OiUEIedkYmo) has been conceived and designed by Anupam Vibhuti, Founder EcoAutoMo Pvt Ltd and proposes to deliver the following benefits to city dwellers, once deployed across any city:
- On-demand 24x7 service with vehicles available on demand, dispatched to the station whenever required for individualized rapid transportation, without being subject to empty running during lean demand periods.
- Service Convenience with Boarding Stations accessible within ~500m of walking and no inter-modal transfer required to complete the entire journey
- Fully automated driverless vehicles, less than ~1m wide, promising transit speeds of ~45 km/h in an air-conditioned environment vis-à-vis average journey speeds of ~10-15 km/h experienced currently.
- Configured as a network, parallel to the road system, elevated ~1m wide physical rail-based track infrastructure, 50% the width of a pedestrian pavement, supported by pillars not wider than ~0.5m, avoid consumption of the valuable road surface right-of-way.

- Offline boarding and alighting with each trip being unique and non-stop from origin to destination, at stations with a sufficient number of vehicles berthed for sudden demands.
- Fully automatic urban transit system providing rapid and personalized almost door-to-door service without any intermediate stops.
- Intelligent vehicle movement and spacing control for high throughput, equivalent to 3 lanes of car traffic on an arterial on any busy day. Maximum theoretical 'line throughput' capacity potential of ~7200 Phpdt (~ 25% that of the Metro) and a 'seat utilization capacity' of ~60% (~2X that of the Metro)
- Operationally safe journeys, with no derailment or collision possibility in a mechanically guided channeled system, and grade-separated crossings by design.
- Centralized control system for monitoring and controlling the entire fleet and routing journeys using shortest paths-to-destination algorithms.
- Light and comfortable vehicle with seating for 2 persons on each vehicle, automated smaller vehicles accelerated over relatively short distances, smaller vehicles being inherently lighter & inexpensive.
- Environmentally safe for the community, with no noise and exhaust pollution, powered by clean electrical energy, augmented with solar panels along the elevated tracks, with insignificant visual intrusion to urban scape, unlike heavy flyovers and rail systems.
- Low energy consumption by design using electrically driven vehicles with a low carbon footprint. Solar panel augmentation to the system makes its lifecycle energy & cost efficiency potentially even less than an E-cycle for moving a person in a city.
- The capital cost of deployment at ~20 Cr INR / Km of bi-directional tracks at scale, makes the system commercially viable even without government subsidies. Together with low operational cost, modular scalability, and mass production potential, with very little on-site construction time for deployments, the system can provide congestion relief to urban areas quickly.
- Studies have suggested a ~40% shift from personalized modes to similar systems being considered by the GOI in many cities. Resultant savings in fuel consumption, reduction in greenhouse gases, and dependency on fuel imports can be estimated and appreciated.
- The same infrastructure can be used for transporting goods in palletized vehicles during lean periods, especially at night.
- For smaller high-demand networks and growing cities/ suburbs, multiple lines can be installed incrementally on demand for ensuring accessibility even before a full road system becomes viable.
- AutoBots system can be built at 50% of the costs quoted by competitors to service the same demand, resulting in lower CAPEX and therefore earlier returns on investment in the infrastructure. Inter-alia the transport system can become financially and economically viable even before the urban habitation has not achieved designed saturation.

7 Approach

An MoU has been signed between Foundation for innovation and technology transfer at IITD and EcoAutoMo Pvt Ltd under an Industry-Academia collaborative development arrangement. The detailed agreement shall be effected immediately upon receipt of funds from private or public resources.

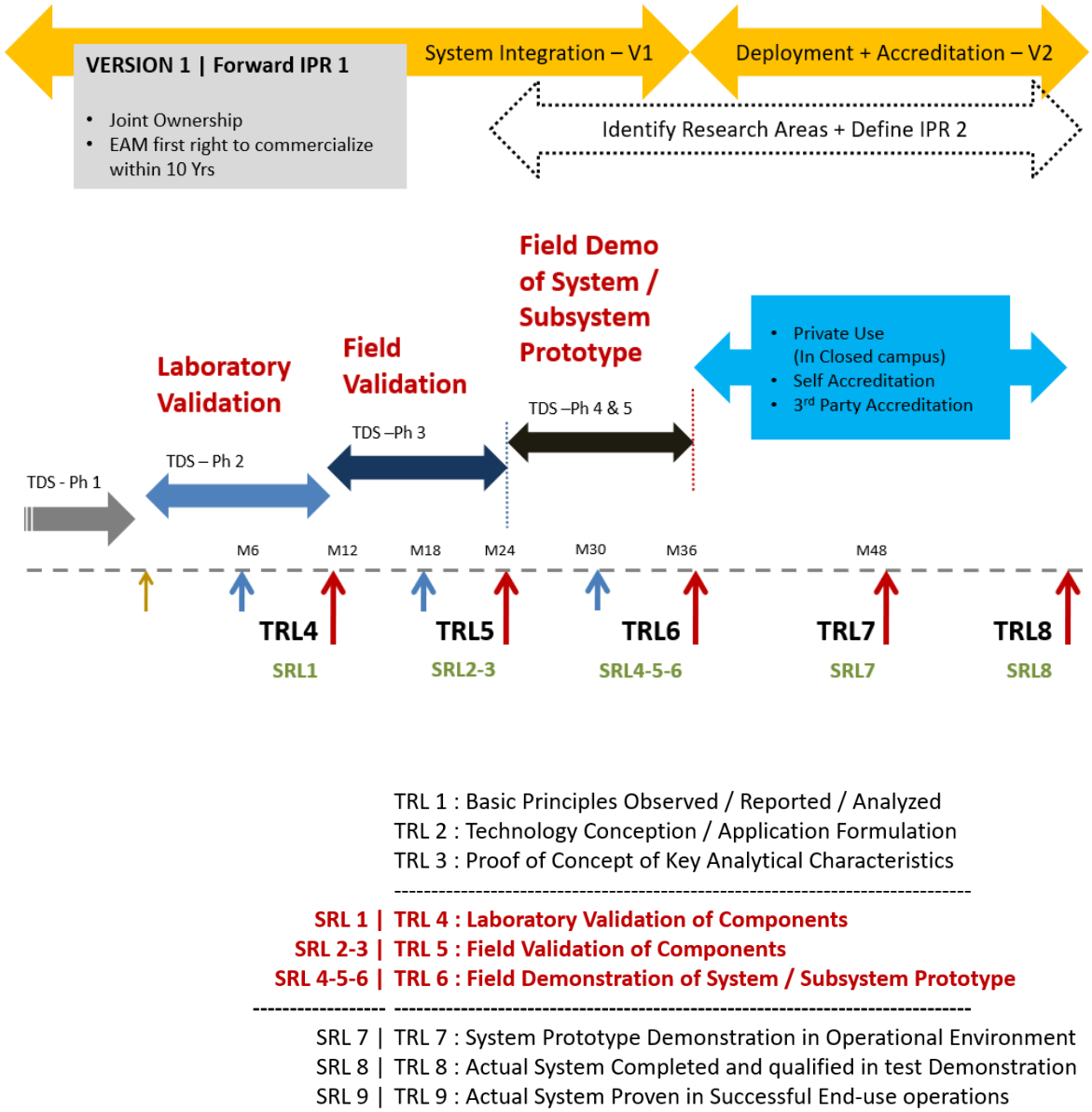


Figure 2: Co-development progression & TRL / SRL Definitions

A team of subject matter experts from different departments at IIT Delhi has been approached to participate in the effort & co-investigate. A team of senior faculty from Civil Engineering, Traffic & Transportation, Electrical Engineering, Communications, Engineering Design, and Mechanical Engineering have consented to be a part of the team effort.

Professional resources shall be involved in assisting the research team in their work.

As a first step of this proposed Co-Development Research Project, the preliminary design of the proposed AutoBots transport system, design basis calculations, and computations need to be peer-reviewed in detail by subject matter experts drawn from respective domains, encapsulated in this Techno-Commercial feasibility report.

A detailed technical review of the proposed design will be conducted, thereafter, so that the design basis is clear and accepted by the Team, and key result areas are established from the engineering and performance perspectives using virtual tools.

Several challenge areas have been identified to be collaboratively addressed across engineering disciplines by faculty with respective domain expertise, for optimal solutions.

a. Vehicle, Chassis, and Power train Design – Light weighting of chassis, Size of Motors, Tyre Vs Track material for required traction, Power pickup strategy vis-à-vis power transfer requirement, Motor power characterization and profile, Operating Voltage, and current type.

b. Switching Architecture –options between Vertical Vs Horizontal trajectory switching, Safe cross-sectional Design Vs track guidance,

c. Communication and Feedback control - Wireless communication between the central system and moving vehicles, failover layer for redundancy or bringing to a stable state, sensor location, and position feedback system.

d. Application & Traffic control System – algorithms for empty vehicle relocation to demand areas, handling Idle vehicles at platforms, handling Idle vehicles at station parking bays, platform pod choreography vis-a-vis commuter boarding rules, managing network-wide traffic flows involving temporal variations, tidal flows - city-wide, managing high demand zones & pulse demands and handling operations at high demand stations / at different station typologies.

e. Structural Design of Track & Station System – minimal sizing of tracks and pillar components as per standards, Sizing of platforms for stations, Station architecture for peak demand situations, options between track loops Vs suspension bridging while crossing carriageways.

f. Power Supply Design – Option between finger pickup on a rail bus, wireless power transfer, or onboard battery pack.

This solution architecting effort shall be followed up by detailed engineering analysis and design to build the system components ready for physical prototyping.

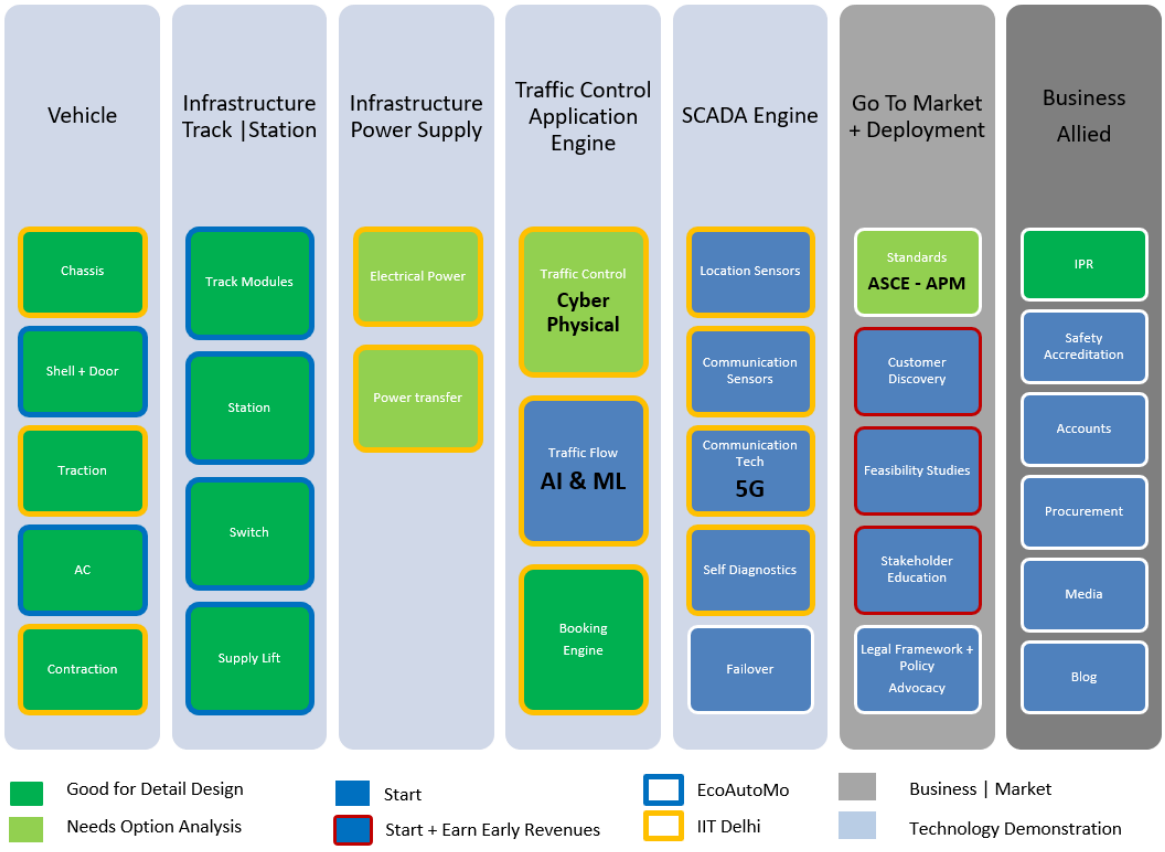


Figure 3: Task Buckets | Contributions

8 Two-Step Prototyping and Demonstration

The prototyping and demonstration system shall be done in two steps:

a. Full-Scale Prototype - Stages 1 &2

A full-scale model of the vehicle with a small station and a switch to establish ergonomics and performance at low speeds shall also be made to demonstrate the basic components of the system.

The first 2 stages of the overall program shall comprise ~150 m of a track with full gauge rail spacing of 1.2 m to establish the core traction and guidance technologies. This will be combined with an offline station, parking server, and 3 vehicles to demonstrate vehicle dynamics, switching of the moving vehicle from the main track to a secondary track, and interactive movement choreography involving the 3 vehicle sets.

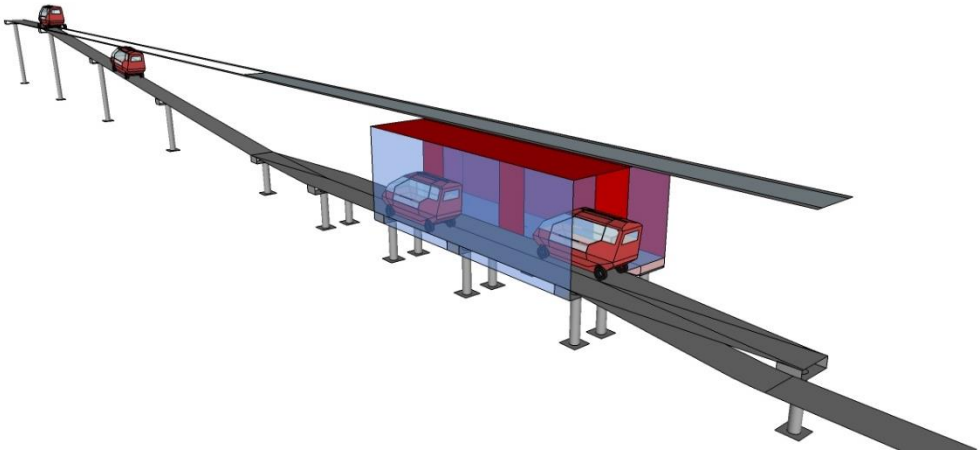


Figure 4: Single Vehicle Scale Model 1:1 system demonstrator with minimal system modules.

b. Full-Scale integration - Stages 3, 4 & 5

Build a ‘full scale’ integrated model to validate the key result areas involving all components and sub-components.

The next 3 stages shall comprise ~ 2000 m of extended tracks to establish the behaviour of the vehicles moving on different shapes of tracks. The vehicles shall themselves be designed and matured to be manufacturing-ready using best-in-class processes towards best-of-class vehicle production.

D. Co-Development Collaboration

1. Academic Institution

IIT Delhi has one the most talented resource pools amongst the faculty belonging to various engineering disciplines, with cutting-edge knowledge required for the engineering development of AutoBots. This is the primary ingredient for the successful completion of this team research effort.

Besides the human resource, the Institute has the following strengths that will be useful for this co-development research effort;

a. State of Art Labs at IITD for manufacturing scaled prototypes

b. Eco-System support and linkages with several start-ups at IITD Research Park

c. Prior entrepreneurial work and development around similar sub-components required for AutoBots are available amongst several successful companies with substantial contributions from Institute faculty members.

   1. DC Power Supply Systems
   2. Solar Priority Grid Power Supply Systems
   3. DC Motors & controllers
   4. Communication, Sensors & Feedback control systems
   5. Control System Applications

2. Industry Partner

EcoAutoMo Pvt Ltd has acquired the license to use the background IP created by Anupam Vibhuti, founder EcoAutoMo Pvt Ltd. In his capacity as well as that under Tranxit Mobility Logistics Pvt Ltd.

The background IP consists of

A. Deep dive research culminating in the following reports & papers:

   1. Design Basis & Technology System Specifications
   2. Urban Area Deployment Standards for Indian Cities
   3. Transporting Masses - Policy & Fact Disconnect - Life Cycle Analysis and Critique
   4. Application Potential of a Typical PRT system - Case Study Dwarka, New Delhi
   5. Concept of ‘Mass’ in Mass Transit System – Distortion correcting critique

B. Patents

   1. High Throughput Transportation System with seamless carriage switching between track along the vertical plane” vide Patent Application No. 202011021745 dated May 23, 2020 (Granted)
   2. Method for Trajectory shift of a vehicle unit in a transport system” vide Divisional Patent Application no.: 202112052782 dated November 17, 2021 (Granted)

3. Responsibility Matrix

	Project Tasks	**TRL4/SRL4**	**TRL5/SRL5**	**SRL6**	**SRL7**	**SRL8**
1	Vehicle					
1a	Chassis	IITD	IITD	IITD	JT	JT
1b	Shell + Door	EAM	EAM	EAM	EAM	EAM
1c	Traction	IITD	IITD	IITD	JT	JT
1d	Air Conditioning	EAM	EAM	EAM	EAM	EAM
1e	Contraction	IITD	IITD	IITD	JT	JT
1f	Drive	IITD	IITD	IITD	JT	JT
2	Physical Infrastructure					
2a	Track Modules	EAM	EAM	EAM	EAM	EAM
2b	Station	EAM	EAM	EAM	EAM	EAM
2c	Switch	EAM	EAM	EAM	EAM	EAM
2d	Supply Lift	EAM	EAM	EAM	EAM	EAM
2e	Entry-Exit Catapult	EAM	EAM	EAM	EAM	EAM
3	Power Infrastructure					
3a	Electrical Power Supply	IITD	IITD	IITD	IITD	JT
3b	Power Transfer	EAM	EAM	EAM	EAM	EAM
4	Traffic Control Application Engine					
4a	Traffic Control- Cyber-Physical	IITD	IITD	IITD	IITD	JT
4b	Traffic Flow- AI & ML	IITD	IITD	IITD	IITD	JT
4c	Booking Engine	EAM	EAM	EAM	EAM	EAM
5	SCADA Engine					
5a	Location Sensors	IITD	IITD	IITD	IITD	JT
5b	Communication Sensors	IITD	IITD	IITD	IITD	JT
5c	Communication Tech- 5G	IITD	IITD	IITD	IITD	JT
5d	Self-Diagnostics	IITD	IITD	IITD	IITD	JT
5e	Failover	IITD	IITD	IITD	IITD	JT

Table 1: Responsibility Matrix Between EcoAutoMo & IITD

In the above table,

a. IITD signifies the responsibility of Project Tasks to be led by the Indian Institute of Technology team under the Core Team Member at the Indian Institute of Technology Delhi;

b. EAM – signifies the responsibility of Project Tasks to be led by EcoAutoMo Private Limited team under the Founder at EcoAutoMo Pvt Ltd.; and

c. JT signifies the responsibility of Project Tasks to be jointly developed by IITD & EAM.

E. Status of Research & Development in the Subject

1. International status

The concept of PRT is not new but has been around since the 50s. With the advancement of computing technologies and high-speed communication systems, it is now easy to build and operate a complex system today than it was earlier. Several efforts across the world are trying to give shape to respective manifestations of the system.

Internationally there are several advanced transit systems being developed. The stage of development and systems characteristics can differ significantly – the table below is an attempt to provide a realistic indication of the stage the actively marketed systems are at.

Operational Stage				
	System	**Vendor**	**Type**	**Application(s) and Opening Date**
	Cybercab	2getthere	PRT	Masdar City, Abu Dhabi (November 2010) Floriade Exhibition, the Netherlands (April – October 2002)
	ParkShuttle	2getthere	GRT	Rivium II, the Netherlands (November 2005) Rivium I, the Netherlands (February 1999) Schiphol Airport, the Netherlands (October 1997 – May 2004)
	ULTra PRT	ULTra PRT	PRT	Heathrow Airport, United Kingdom (June 2011), Amritsar, India (planned: 2014), Bristol Test-Track, United Kingdom (2001)

	SkyCube	Vectus	PRT	Suncheon, South Korea (September 2013), Uppsala Test-Track, Sweden (2007)

Testing Stage

	System	Vendor	Type	Specifics
	LINT	Modutram	PRT	First loop test-site operational
	Microrail	Megarail Transportation Systems	PRT / Dual Mode	Prototype operational
	Skyweb Express	Taxi 2000	PRT	Prototype on short test-track

Engineering Stage

	System	Vendor	Type	Specifics
	Eco Mobility	Warsaw University of Technology	PRT	¼ scale test track available
	SwiftAPM 100	Swift Tram	PRT/ GRT	Available 2016
	Beamways	Beamways	PRT	Small-scale demo model available
	Skytran	Skytran	PRT	1:1 model available Reliance Industries has acquired a majority stake in the USA initiative.

Conceptual Stages

	System	Vendor	Type	Specifics
	Bubble Motion	BM Design	PRT	
	Cybertran	Cybertran International	PRT	
	Flyway	Swedetrack	PRT / GRT	
	ITNS	PRT International	PRT	
	Jpods	Jpods Corporation	PRT	

	Metrino (previously MIST-er)	Metrino Global Projects Ltd	PRT	1:1 model available
	Rapid Urban Flexible	RUF International	Dual-mode	
	Skycab	Skycab	PRT	
	Tri-Track	Roane Inventions	Dual-mode	
	Tubecar	Tubenet Transit	PRT	

Table 2: List of Pod Taxi Systems at different stages of readiness.

Source: http://www.advancedtransit.org

2. National Status |India

Several solicitations for autonomous 'pod car' systems (Delhi, Gurgaon, Thiruvananthapuram, Bangalore, Amritsar 2011, Haridwar 2021) led by the Indian State have been issued and some responded to by foreign technology companies in India starting in 2011.

Reliance Industries Limited has reportedly invested and acquired a majority stake in an American pod taxi technology company in February 2021.

AutoBots PRT system is a known effort towards the indigenous design and development of a transit system, belonging to the PRT / Pod Taxi transit system family.

NITI Ayog has also endorsed the AutoBots effort as a unique indigenous initiative after a presentation to a panel chaired by Dr. V K Sarwaswat. Hon'ble Member NITI Ayog in Feb 2016.

PRT / Podtaxi technology system in general has been recognized by NITI Ayog as useful for India, to be encouraged by the state for building technology demonstrations before commercial deployments as per an advisory released in Feb 2017 by NITI Ayog.

A committee was formed under the aegis of MoRTH chaired by Sh Dharam Adhikari to propose standards for the deployment of Automated Transportation systems in India. 'Automated People Movers Standards' published by the American Society of Civil Engineers has been reported[1] to have been adopted for India.

Enclosed as Annexure:

- Niti Ayog Advisory on PRT Systems – Feb 2017
- Niti Ayog Review of AutoBots System – Feb 2016

3. Novelty & Importance of Research in the context of Current

As is also evident, the best systems being deployed in the country are not able to address the issues around transport-related congestion and pollution in urban areas. Incremental improvements are being experimented with and tried under several ITS initiatives, alternative fuels, and updating of standards related to vehicles or transportation technologies.

Niti Ayog has taken the thought leadership, also to, recognize that PRT systems can be good for India from the point of capacity, energy efficiency, and suitability in the context of a deteriorating urban transportation scenario. However, in the absence of any indigenous technology system having been developed in India, only foreign technology providers are responding to Indian state-led solicitations for deployments of PRT / Pod Taxi systems in the country.

Therefore, an indigenous transportation system development effort can provide competition in the marketplace and provide an alternative to Indian cities. Thereby this effort shall also help promote declared GOI goals of self-dependence, energy security, and 'make in India' all good for the future of India as well as for sustainable urban transportation in Indian cities.

[1] https://www.livemint.com/Politics/J40xK6KI0Kf6xbJ7QY6nfO/Indias-1st-pod-taxi-on-the-way-to-follow-US-safety-norms.html

F. Target beneficiaries of the Co-development work

1. Establishment of COE at IITD for Guided Autonomous Transportation Systems

The direct beneficiary of this research effort is IIT Delhi with the establishment of a 'Centre of Excellence' for guided autonomous transportation systems, and capacity building related to human resources besides creating state-of-the-art design and testing capacity in India.

2. Customized Technology for AutoBots system

EcoAutoMo Pvt Ltd the industry partner will benefit from several key technology sub-systems developed at IIT Delhi that will be employed in the AutoBots transportation system duly integrated with complementary portions of the technology sub-systems developed at EcoAutoMo Pvt Ltd.

3. Allied Benefits

In addition, this co-development team research effort shall benefit several other groups or causes, both directly and indirectly.

- This team effort encompasses resource engagement from 6 engineering specialization verticals at IITD (Civil-Structure, Civil-Traffic & Transportation, Electrical – Power Supply, Electrical-Communication, Engineering Design & Mechanical). Therefore, the dissemination of research results in the form of publications, workshops, collaborations, and lectures in the respective verticals has the potential to impact a wider academic audience.
- This initiative and its progressions will benefit urban habitats and society as a whole with the first step in the direction towards looking for suitable mass transportation solutions for urban dwellers both in developing as well as developed countries.
- Once the full-scale system is ready, the PRT industry in India and also globally stands to gain in the process. Several PRT solicitations in India led by the State have failed to convert to actual deployments because of a lack of technology competition. Bids in the past have got reduced to a single-bidder scenario after due diligence. Out of 3 known commercially ready companies internationally (Ultra-UK, 2GetThere-Netherlands, and Vectus-Korea), only Ultra-UK has had the confidence to apply for several solicitations consistently while others have never applied confidently, presumably due to transparency issues. Many others who have applied in consortia with Indian Infrastructure companies (Skytran-USA, Mister- Poland, and Jpods, USA) are not commercially ready but at intermediate stages of technology readiness levels.
- Similar advantages would be available to all societies where transportation infrastructures are funded through public money and transparent competition between PRT proponents in the bidding processes is expected for price discovery purposes.
- Several Indian cities that have considered deploying a PRT system would eventually have a home-grown indigenous system that they can depend upon without the complications of intellectual property lock-in around imported technologies, with respective technology providers.

- Additional conceptions of PRT systems are possible out of the learnings from the effort. The team members can build newer versions of AutoBots or build entirely new conceptions from scratch non-conflicting with intellectual property generated from this effort.

G. Expertise with the investigating Core Team members

The proposed investigation group was selected to fulfill expertise in three broad areas as follows:

a. Subject Matter Expertise

b. Domain knowledge expertise and demonstrated research activity

c. Expertise in translating ideas into prototype reality

The resulting group for this proposed investigation spans 6 engineering specialization verticals at IITD (Electrical – Power Supply, Electrical- Communication, Engineering Design, and Mechanical, Civil- Structure, and Civil- Transportation).

What follows is a summary describing the expertise of the core team

1. Under the Indian Institute of Technology Delhi (Academic partner)

a. Through FITT at IITD

1. Prof. Brejesh Lall is a Professor in the Department of Electrical Engineering. His research interests are on topics in modulation and coding for mobile communications, and wireless communication networks. His experience with communication technologies and packet-switched systems would be useful for AutoBot's high-fidelity data communication systems.
2. Prof. Sudipto Mukherjee is Professor in the Mechanical Engineering Department. He has expertise in areas related to Mechanism, Robotics, Mechanical system Design, and Impact Biomechanics. His work is in areas of special-purpose machine design, vehicle dynamics, traction and power train systems, automation, and robotics. He has extensive experience in the design of machines and machine components besides extensive experience with materials. Their expertise shall enrich the AutoBots vehicle performance and dynamics at high speeds within the AutoBots track infrastructure.
3. Prof B. K. Panigrahi is a Professor in the Department of Electrical Engineering and also serves as the Head of CART - Centre of Automotive Engineering and Tribology He is considered the pioneer in nurturing Industry-Academia interaction in India towards R&D, Innovation, and Product Development. He is guiding this team effort and also advising the team about the optimization of the EV architecture, power train, and power transfer systems for AutoBots.

A. At NSUT

1. Prof Amit Singhal currently works at the Department of Electronics & Communication Engineering (ECE), NSUT. Amit does research in Image Processing, Molecular Communications, Next generating communication technologies, Image retrieval, Theory, and Applications of Fourier methods. Some recent publications include the modeling of COVID-19 spread, Remote Connectivity in 6G, a new measure for non-stationarity, and applications of the Fourier decomposition method in biomedical engineering.

2. Under EcoAutoMo Pvt Ltd (Industry Partner)

a. At EcoAutoMo Pvt Ltd

1. The systems group (researchers in this proposal include Anupam Vibhuti, Adarsha Kapoor & Manraj Bains, currently working in the areas of urban transportation planning, heterogeneous traffic modeling and management, network optimization techniques, artificial intelligence, machine learning, congestion mitigation, accident and safety studies and Intelligent Transportation Systems. The transportation division has expertise in survey and experimental design, data collection, quality control, and processing of micro and macro-level traffic and travel demand. The team has extensive experience working with data of varying and interacting levels of spatial and temporal resolutions (ranging from within-day, day-to-day, and long-term). Specific domain-specific expertise with this data includes model building, statistical and econometric analysis, optimization, simulation, algorithm development, and decision support applications. Their expert contributions around traffic control algorithms at a network level addressing wide area traffic flow shall enrich the traffic control application to be built especially for AutoBots - during the follow-up extended mandate of this team research effort.
2. The fabrication group (researchers in this proposal include Sanjay Arora of Competent Crimping Machinery Pvt Ltd, and Kannan Laxminarayan of Motorz Design and Manufacturing Pvt Ltd) currently heading their respective organizations will provide their respective expertise in the fabrication design and production planning of various components of the overall system. Their industry experience covers the entire mechatronics engineering focusing on the integration of mechanical, electronic, and electrical engineering systems, and also includes a combination of robotics, electronics, computer science, telecommunications, systems, control, and product engineering, which shall enrich the process of building and fabrication the entire system.

b. Through EcoAutoMo Pvt Ltd (Proposed)

1. Prof. Krishnan Balasubramanian is Professor in the Mechanical Engineering Department at IITM. His research interests include ultrasonics and acoustics, structural health monitoring micro and nano Imaging, non-destructive evaluation, materials characterization, and wave Propagation. He is involved with applications in the fields of maintenance, quality assurance, manufacturing, and design and has consulted worldwide industries seeking his expertise. His expertise shall be useful in grid extensive periodic testing and validation of structural integrity of the AutoBots track towards ensuring safe and secure transportation at all times.
2. Prof. Arul Jaychandran at IITM has expertise in advanced design methods for cold-formed steel structures, computational methods for post-buckling using the secant matrix technique, and Experimental evaluation of steel structure behavior and post-buckling behavior of thin-walled open sections. The two researchers have more than 25 years of research and professional consulting work for the industry. Their expertise shall help optimize on AutoBots modular infrastructure design, and structural analysis of all components of the infrastructure.

H. Proposed impact assessment of the initiative

1 Synergy of the R&D team at IITD

AutoBots PRT system comprises components and sub-components that demand multidisciplinary and collaborative efforts of diverse teams to be functional and efficient. Working on this team effort would engage different domain expertise and therefore serve as a motivation and trigger for further research and cross-discipline collaborations in allied areas.

The successful design and building of a fully functional AutoBots system intrinsically depend upon successful collaboration among the researchers. Seamless collaboration and marriage of the minds are crucial in both the short term and long term.

Fast-paced research would help iron out differences in the process of collaboration if any.

The work division between team resources working under FITT-IITD and those resources working under EcoAutoMo Pvt Ltd has been carefully chosen to ensure complete complementary roles.

2 New applications for social impact

AutoBots is a new way of urban transportation, potentially solving the congestion and capacity issues faced by every city today. In that sense research in this area will positively serve society as we progress toward higher technology readiness levels. Once deployed across cities, the track infrastructure can be used for carrying electrical and communication cables as well as for the movement of palletized goods, emergency services, or movement for special needs.

3 New sunrise Industry

The AutoBots mandate for Indian cities itself would boost indigenous manufacturing industries building Special Purpose Machines -Motors, Sensors, Controllers, Electrical Power Management systems, Power Inverters & Converters –AC / DC, Electronic Component manufacturers, Steel Fabrication & Manufacturing industries, and Solar Power Plants companies.

4 Furthering Frontiers in R&D

This collaborative co-development research effort would be the first step in looking at urban transportation afresh from scale, capacity, and efficiency perspectives. Besides helping give shape to the conception of AutoBots to full-scale commercial readiness levels, the effort is likely to open up allied frontiers in the personalized mass transportation space involving both hard and soft technologies.

In addition, this is likely to spawn focused efforts in many different areas of transportation the world is looking at towards solving potential future problems including the use of air-based drones, dual-mode systems, shared mules for palletized transport of goods serving the e-commerce industries, on-demand transportation for general purpose as well as for emergencies or oriented towards special needs.

5 Sustainability and growth plan of this Co-development activity

A critical output of this research is to seek patronage from government or corporate institutions towards deploying full-scale AutoBots systems at required locations.

Further grants from the government or private sector will aid in building new guided system variants other than pod taxi systems.

I. Work Plan

1 Methodology

a. Research & Design Validation

The first step towards validation of the AutoBots design as conceived will be a high-level due diligence of the system characteristics as well as a high-level due diligence of the design from an engineering feasibility point of view. Some key questions that will get addressed in this process are:

- Does the system address the issues of scalable last-mile capacious solutions for urban mass transportation?
- Does the system propose to be lifecycle energy, cost, and emission equivalent to an e-cycle for the air-conditioned urban commute?
- Does the design basis for specifications of vehicles and track flow characteristics follow from reasoned arguments?
- Is the elevated guideway track structural system capable of addressing deployability requirements from the point of view of Indian urban contexts?
- Do the vehicle components and subcomponents require new technology development or can the vehicle be built from off-the-shelf available components with required customization?
- How many components require industry displacement vis-a-vis which components can be indigenously custom manufactured?
- How does the traffic control system get architected?

b. Providing Clarity

The following issues around the new transportation system need to be concluded

- Station platform and vehicle berth sizing vis-a-vis commuter demand
- Area-wide Grid layout system architecture and system lifecycle cost vis-a-vis capacity
- Vehicle throughputs vis-a-vis speed, frequency & braking distance limits
- System level capacity, capacity multiplication
- The modularity of track component design
- Field Implementation Methodology and manufacturing processes
- Rules for operational safety
- Traction Components & Specs for vehicle chassis
- Shape & form factor for the vehicle including the general arrangement of vehicle sub-components
- Mechanical contraction system for switching from one track to another vis-a-vis switching safety
- Traffic control system algorithm - synchronous Vs asynchronous

- Location/communication Sensor on track placement frequency logic
- Traction Power using finger pickup system Vs onboard battery.
- Communication technology system/sub-system with full redundancy
- Alternative to steel for tracks, if any
- Special vehicles for special needs or vehicles for palletized goods movement

c. Detailed Design

Detail Design of full-scale model components and sub-components:

Architecting solutions from available options based upon expert due diligence and physical experimentation regarding the following issues in conjunction with a scaled operational model of the system and or specific components:

- Power pickup or transfer from Infrastructure to moving vehicles
- Data communication with complete failover safety and feedback control
- Wheel traction and power train assembly
- Track-switching electro-mechanical assembly system
- Synchronous Vs Asynchronous control for traffic flows

d. Manufacture of prototype track systems and vehicles for controlled experimentation and demonstration.

e. Data Collection

In this stage, the researchers would seek to gather data from continuing operations of choreographed movement of vehicles across different track structure formations to analyze and improve operational efficiencies and vehicle dynamics at:

- Station areas & Parking areas
- Straight track sections, curved track sections
- Switching sections

f. Build Algorithms for Data Analysis

The researchers will build algorithms to review specific data around performance-specific points of interest gathered through carefully configured test sensors, relevant to the specific engineering group related to specific components or sub-components. This will provide specific inputs for corrections required for improved performance.

g. Design Revision and improvement validations

This will involve iterative improvements around both hardware and software, based upon the continued performance data analysis till the researchers are sufficiently satisfied to progress to the full-scale development of the AutoBots system.

2 Organization of Work Elements

a. AutoBots Solution Validation

1. High-level multi-disciplinary due diligence
2. Simulation testing of broad performance and capacity claims

b. Vehicle Design Validation

1. Vehicle architecture validation
2. Components and sub-components technology option analysis
3. Vendor engagement and performance assurances
4. Identification of resource and expertise gaps
5. Engagement with external consultants if any

c. Design Development of scale model rigs and components

1. Recruitment of professional staff
2. CAD/ CAM modeling of Vehicle & Infrastructure elements
3. Identification of scale model electronic components for enabling traction and communication

d. Traffic Control System Application Development

1. Control application user Interface
2. Building traffic control algorithms
3. Simulation testing and algorithm Improvements

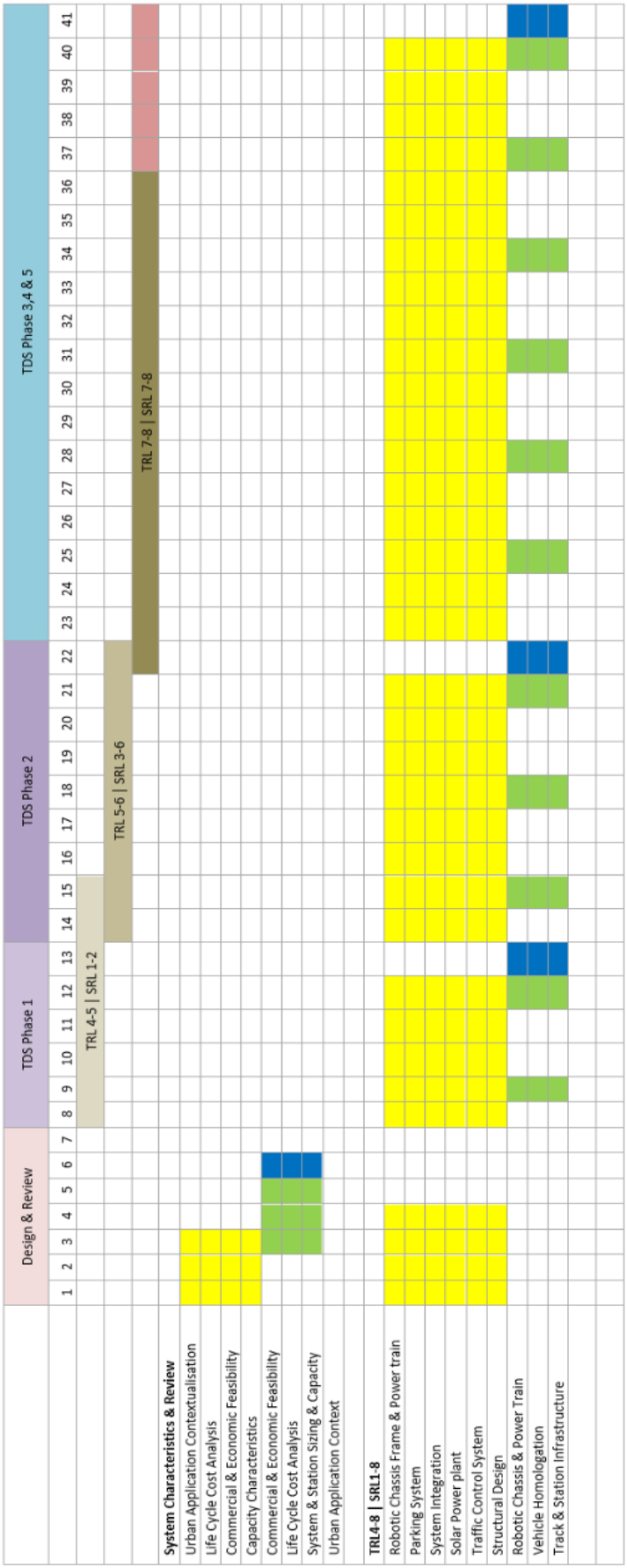
e. Communication & Feedback Integration with a traffic control application

1. Build a Scale model control system communicating with a traffic control application
2. Integration with location and feedback sensors
3. Perform test runs and data analytics – system-wide and individual rigs

f. Design improvements and documentation of results

1. Document vehicle hardware and performance specifications of components and sub-components
2. Document areas that may need further verification from the full-scale demonstration prototype performance testing and analytics.
3. Document warrants to be exercised while building the full-scale demonstration prototype.
4. Build an estimate for progressing to a full-scale demonstration system and further work toward the next stages of technology readiness levels.

3 Proposed schedule of Activities & Milestones



J. Outcomes

1 Outcomes and Outputs of the co-development

As a specific outcome, the proposed team exercise and analytics around the scale model will result in the following

- Academic Proof of concept: Prove that commuting masses can indeed be transported with high throughput, with an equivalent energy efficiency of an e-cycle in an air-conditioned environment in urban areas at average speeds over 40 km/hr without the need for feeder systems.
- Team Creation: Establish a team of experts and resource personnel capable of building a full-scale technology demonstration of AutoBots PRT.
- Establishment of technical specification for further work in building a full-scale demonstration system: Derive intricate and tactical knowledge of technology limits and constraints to be employed while attempting the full-scale technology demonstration.
- Building specific proposals for further funding: A realistic estimate of funds required to ensure the continued success of this initiative shall be established and shall be sought from government or corporate institutions.

As a co-lateral output, at a broader level, the proposed multidisciplinary team exercise working on AutoBots as an 'anchor' project, shall help in building a complete eco-system under a COE framework, researching into 'advanced guided transportation technologies' at IITD, that will be useful for the country.

At the moment no institute in India is attempting or doing anything of the scale being proposed. Several universities of international repute are working towards transportation solutions and there is substantial focus and interest in researching and building new technologies for transportation. Student and faculty groups at MIT, WARR, and DELFT have built prototypes of high-speed tube transportation technologies. Several others are actively engaged in enhancing E-V system technologies looking for enhanced ranges for batteries or light-weighting vehicles using composites. Similarly, Cardiff, Leeds, Harvard, MIT, etc have done substantial research in application-based technologies addressing challenges around urban / inter-urban transportation services.

2 Plan of action for Utilization of Research Outcome

a. Apply for Funding for further work on AutoBots

With sufficient insight and engineering confidence gained through this team research effort, the team shall attempt to gather funds for the full-scale deployable system of AutoBots.

b. Apply for Funding towards the strengthening of 'Advanced Guided Automated Transportation System Research Center' at IITDelhi

The team is currently composed of researchers across different departments, and at different stages in their careers. As a research base encompassing different disciplines, the outcomes, and the capacity to be built shall be open to researchers at IIT Delhi, the use of its resources will be a preferred research choice for faculty and researchers in IIT Delhi looking at research within the

transportation domain. This initiative is expected to grow and is likely to attract the larger automotive industry community to look at advanced solutions for the future.

c. Build a Full-Scale commercialize system for AutoBots based on specific learnings from the research and development effort

The parameters of the indoor and outdoor test demonstration system developed shall be tested under control conditions to establish the final specifications of the system to be implemented. This shall happen as per the Summary of Phases as outlined herein.

3 Scope of Phases 1 & 2

The indoor demonstration facility would be built on full scale to include ~120 m straight guideway (including safety margins) with a secondary guideway of approximately 60 m. (excluding safety margins) The guideway will be built with a full gauge rail spacing of 1.2 meters. The port and starboard tracks will have independent position sensing and inverter drives. The guideway will be split into multiple blocks to allow for block-to-block handoff. The vehicle will consist of 2 full-scale robotic chassis assemblies, with contraction axles. Although this vehicle will be a 'sled' with no shell, the size of the vehicle and power train assemblies will be the same as those planned for a 2-passenger vehicle.

Maximum travel stroke will be approximately 45-90 meters for different speeds, including travel into the inclined section.

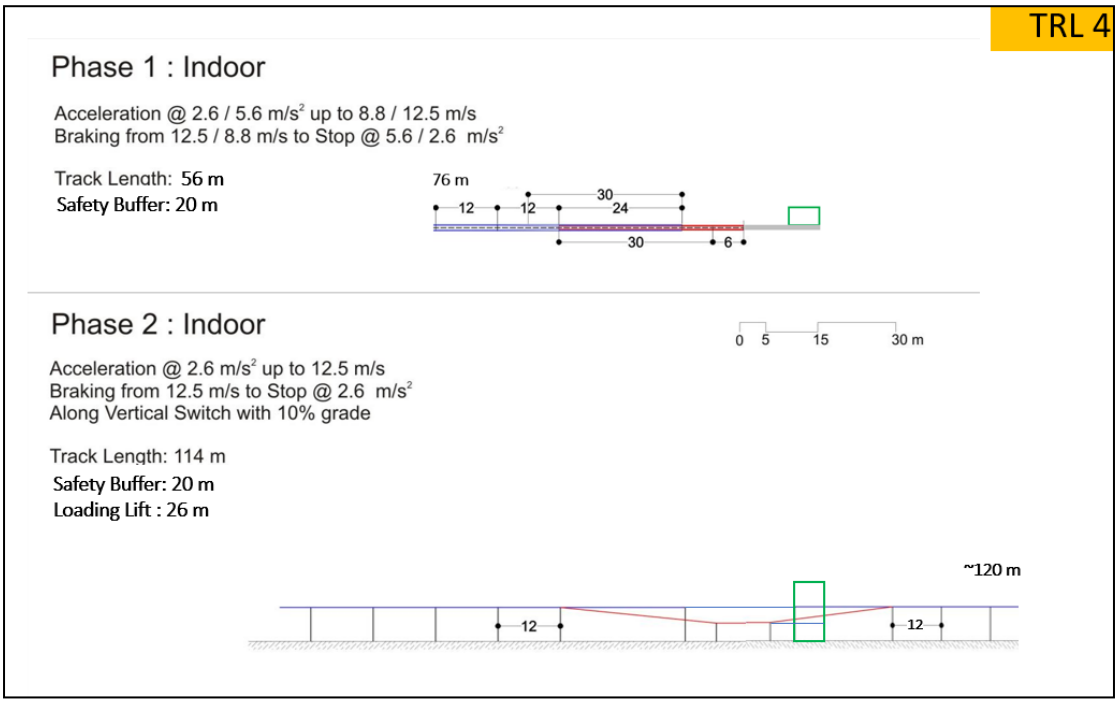


Figure 5 Phase 1 & 2 Demonstration

a. Phase 1: 30 m test track and sled-type vehicle chassis | Duration: 3 months

During phase 1 the Members will deliver a full-scale test track ~75 m in length that will allow vehicles to be accelerated at 2.6 m/s2 or 8.8 m/s2 to achieve 8.8 m/s (32 Kmph) or 12.5 m/s (45

Kmph) and then braked to a stop. The track will be designed so that in later phases it can be extended to allow speeds of 12.5 m/s (45 Kmph). The control system developed for this first section of the track will be extendable to control a complete test loop with switches and multiple vehicles. Other work to be performed during this phase includes the design of the full test loop and planning for future phases.

Deliverables:

1. ~75 m test track and 1 sled-type vehicle chassis
2. A 2-passenger complete chassis prototype as conceived with robotized axle contraction, and braking as intended to be manufactured.
3. A complete set of drawings and cost estimates for construction of the Phase 2 portion of the test track and preliminary drawings for the complete test loop, including switches and banked turns.
4. Sizing & product identification for the track sensors, inverters, and other power electronic components.
5. Design and development of a control system, including position sensing, for the complete loop with estimates of time and cost to complete software development required for Phase 2.
6. A detailed report of Phase 1 activities.

b. Phase 2: ~120 m Test Track with Vertical switch @ 10 % grade & Design of 10m turns | Duration: 3 months

Phase 2 integrates all guideway subsystems and manufacturing methods, allows the identification of problem areas, verifies vehicle dynamics, and provides information for estimating vehicle dynamics at 12.5 m/s. The vehicle will be tested at speeds up to 12.5 m/s (45 Kmph) and with acceleration and braking at rates up to at least 5.6 m/s2. 2 vehicle sleds shall be tested for the right of way and running performance at the switches. The testing will focus on verifying that the system operates as expected, analysis of ride quality, and identifying any unanticipated problems.

Deliverables:

1. A ~120 m test track with a vertical switch with an additional sled-type vehicle already built for indoor test track
2. An operational Vertical switch
3. Detailed design for a 10m, 20m, and 30m turns and Horizontal width
4. Detailed design of vehicle shell and interiors including HVAC & infotainment devices.
5. Documents describing any variation from the Phase 1 design.
6. A detailed report of Phase 2 activities including test results.
7. Analysis of reliability and safety issues.
8. Demonstration of operation of vehicle and control system.

4 Outdoor Scope - Phases 3, 4 & 5

This extended development plan is proposed to focus on constructing a full test loop. The test loop will be designed to verify the performance of the integrated propulsion and suspension systems and vehicle design and to allow extended testing to verify the availability, reliability, maintainability, and

safety of all subsystems including the traffic & power control system at the stations, and the track segments.

The test loop includes a 500 m loop section for testing at speeds up to 45 Km/hr consisting of turns with 10 m, 20 m, and 30 m meter radii to demonstrate maneuverability, a 300-meter radius vertical turn, and a 10% grade to demonstrate hill/station climbing ability, a 60-meter super elevated turn to demonstrate banking, 2 offline stations with 2 vertical switches to allow vehicle passing and station ingress-egress and several horizontal switches for direction change. The control system will be able to handle multiple vehicles starting, stopping, and switching with short headway and will have the capability to be upgraded as system complexity increases. 3 units of 2 passenger seat vehicles, will be constructed to demonstrate the versatility for a variety of capacities.

c. Phase 3: Construct 264-meter test track with 10 m turn | Duration: 3 months

During Phase 3, a 10 m horizontal turn will be added to the 114 m straight section with an additional 10 m before the curved section and 24 m along the straight section segment (cumulative straight section to reach 12.5 m/s) with a cumulative total track length of 264 m, a 2 passenger vehicle will be fabricated as per final specifications and manufacturing intent with all its subsystems as conceived, detailed construction plans for phase 4 of the test loop will be finalized and final planning for completion of the loop, (switches and high-speed turns) will take place. Horizontal station topographies shall be designed for Phase 4.

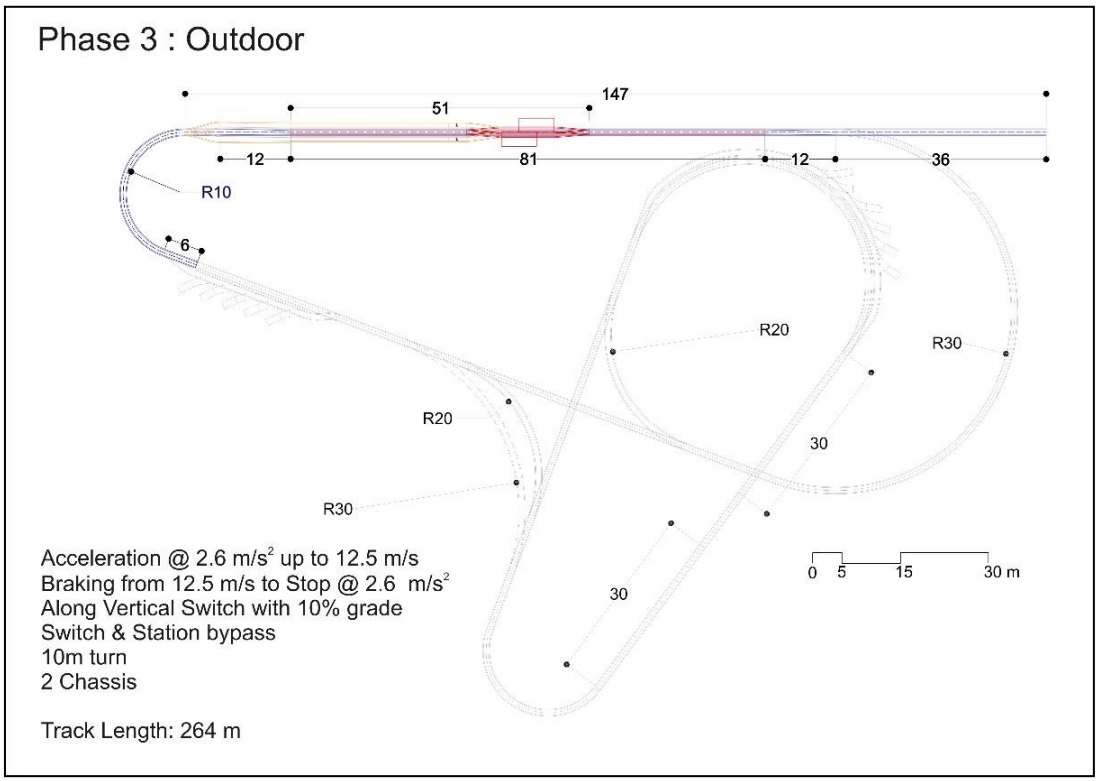


Figure 6: Phase 3 Demonstration

Deliverables:

1. An extension of the Phase 2 test track that includes a 10m extended turn of cumulative length of ~150 m

2. A 2-passenger complete vehicle prototype as conceived for marketing purposes with robotized axle contraction, braking, and a demonstrable vehicle shell as intended to be manufactured.
3. Complete documentation for constructing the Phase 4 extension and preliminary plans for the Phase 5 extension.
4. Demonstration operation of the 2-passenger vehicle and 10-meter turn.
5. A detailed report of Phase 3 activities including test results.

d. Phase 4: Construct 472 m test track for 12.5 m/s vehicle operation & saw tooth station Operation | Duration: 9 months: 18 months from Month 0.

The objective of Phase 4 is to extend the ~150 m track to ~500 m, construct additional 2 passenger vehicles and test the vehicle at speeds up to 12.5 m/s (45 Kmph). It will also include the construction of additional switches and testing the switch under operating conditions. Horizontal station topographies for wide curves shall be designed for Phase 5.

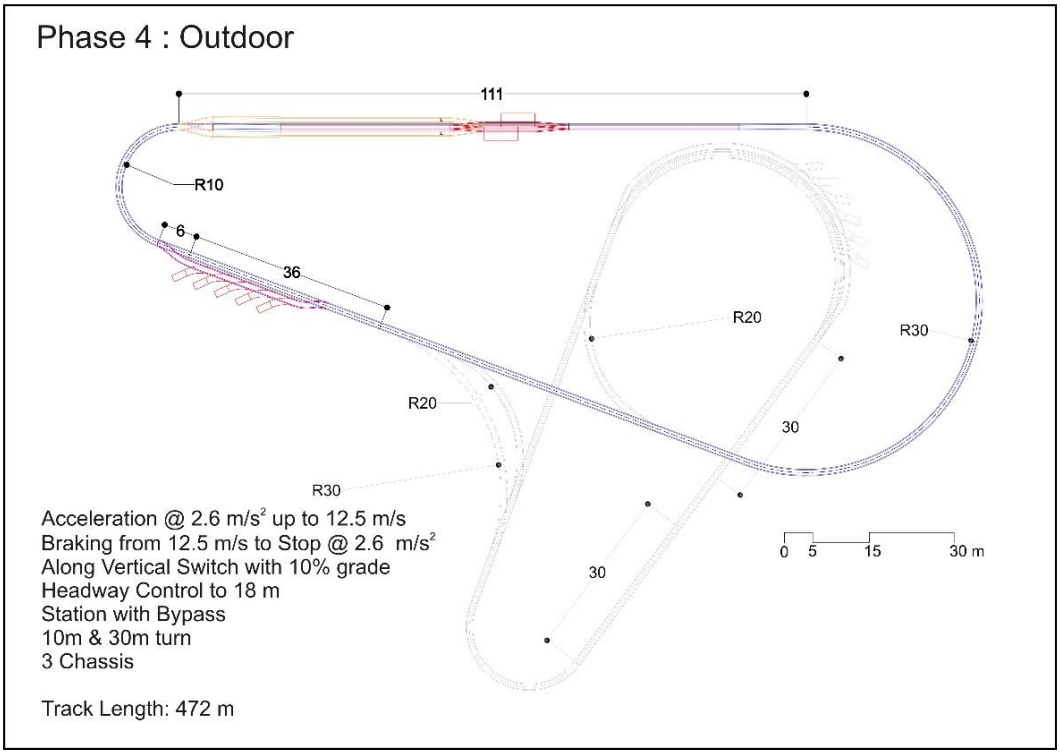


Figure 7 Phase 4 Demonstration

Deliverables:

1. A test track of ~500 m is suitable for testing vehicles at speeds of 12.5 m/s.
2. A switch suitable for switching vehicles offline and which will allow non-switching vehicles to operate at speeds up to 12.5 m/s.
3. Design an intersection configuration for crossings.
4. 3 service-ready full-size vehicles capable of carrying 2 seated passengers with robotized axle contraction, braking, and a demonstrable vehicle shell as intended to be manufactured.
5. Demonstration of vehicle operating at 12.5 m/s and negotiating all switches and conditions.
6. A report documenting the activities of Phase 4.

e. Phase 5: Complete ~1000 m full test loop and extensive testing | Duration: 12 months

The objective of Phase 5 is to complete the construction of a test loop of approximately 1000 m that includes all aspects of a guideway needed for an urban installation. This includes 10, 20, and 30-meter radius horizontal turns, an intersection configuration for crossings, and vertical switches with station bypass that will allow vehicles to pass each other without colliding. Endurance testing will be done to identify possible failure modes.

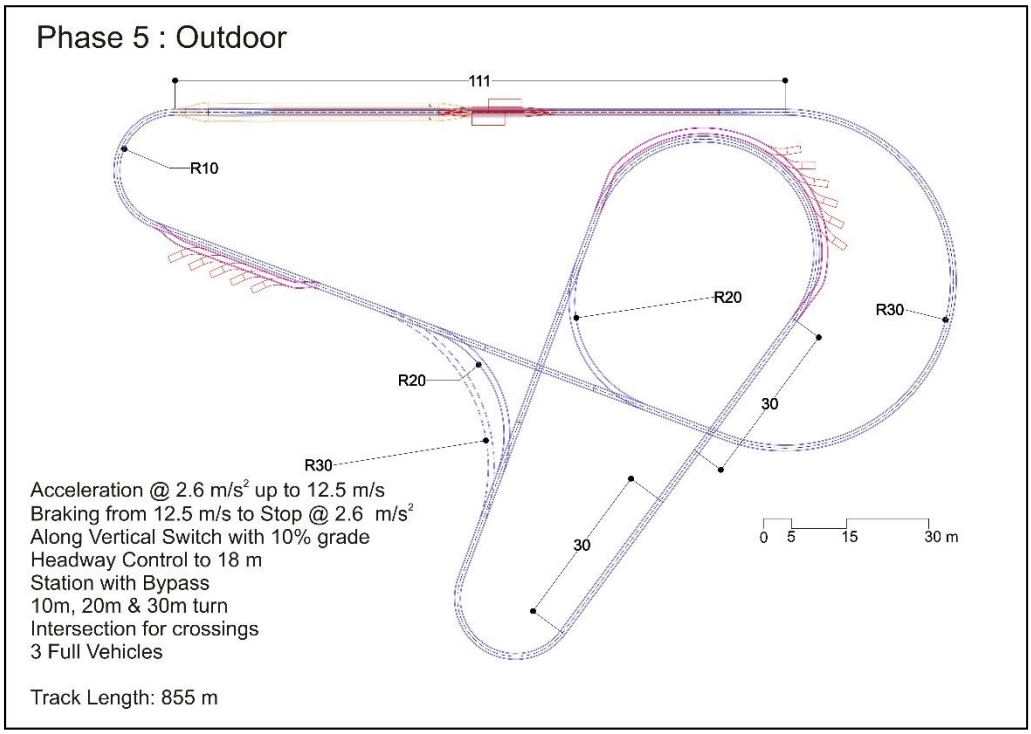


Figure 8 Phase 5 Demonstration

Deliverables:

1. A complete test loop capable of testing vehicles at speeds up to 12.5 m/s and including all major guideway components required for an urban installation.
2. Demonstration of operation of 3 multiple vehicles over an extended period
3. A detailed report of Phase 5 activities including test results.

5 Limited Public Use Trials

Extend or refresh the demonstration system to a 2-3 Km usable loop in a non-public (campus) context and use it with 10 vehicles demonstrating the Final System Technology.

6 Documentation

Documentation of Final System Technology Specifications: Results of Phase 1 to Phase 5 of the Test Pilot shall be used to establish the final specifications for implementing a full-scale commercial application for any solicitor at any specified location.

K. Requirement of Funds

1 Salaries

	Phase 1 & 2 | ~100 m System	Track Length m		70		180	
	18 months duration			**Ph 1**		**Ph 2**	**Ph1 + Ph2**
			Months	**6**		**12**	
1	**Human Resource -Technical**	Nos	MM Rate	**66300000**		**132600000**	**198900000**
1.1	Lead Aggregator	1	500000	3000000	1	6000000	
1.2	Project Manager	7	300000	12600000	7	25200000	
1.3	Standards & Safety Consultant	1	500000	3000000	1	6000000	
1.4	Mule System Integrator - Consultant	2	500000	6000000	2	12000000	
1.5	Mule System Integrator - Assistant	2	150000	1800000	2	3600000	
1.6	Electrical Control Design - Application	5	250000	7500000	5	15000000	
1.7	Electrical Control Design - Assistant	5	200000	6000000	5	12000000	
1.8	Mechanical Design - Consultant	6	200000	7200000	6	14400000	
1.9	Mechanical Design - Assistant	4	150000	3600000	4	7200000	
1.10	Steel Structure Design - Consultant	1	200000	1200000	1	2400000	
1.11	Control System Software Architect	1	450000	2700000	1	5400000	
1.12	Control System Software Developer	3	150000	2700000	3	5400000	
1.13	Control System Software Tester	3	150000	2700000	3	5400000	
1.14	Control System Software QA/QC	3	150000	2700000	3	5400000	
1.15	Solid works / CAD Operator	4	150000	3600000	4	7200000	
2	**Administration, Travel & Network**	Nos	MM Rate	**8100000**		**16200000**	**24300000**
2.1	Visualiser & Communication	2	100000	1200000	2	2400000	
2.2	Sourcing Manager	2	200000	2400000	2	4800000	
2.3	Admin & General	2	150000	1800000	2	3600000	
2.4	Accounts	2	75000	900000	2	1800000	
2.5	Assembly	4	75000	1800000	4	3600000	
3	**Office Overheads**	Nos	MM Rate	**7200000**		**14400000**	**21600000**
3.1	Office Consumables	1	200000	1200000	1	2400000	
3.2	Travel & Business @ 500000 / Month X 2	2	500000	6000000	2	12000000	
	Sub Total	61		**74,400,000**		**148,800,000**	**223200000**
	Miscellaneous @ 20%			14,880,000		29,760,000	**44640000**
	Total of all Items			**89,280,000**		**178,560,000**	**267840000**
	Attrition & Change Management @ 30%			26,784,000		53,568,000	**80352000**
	Total of Human Resources			**116,064,000**		**232,128,000**	**348192000**
						348,192,000	**348192000**

2 Material

	Phase 1 & 2 | ~100 m System	Track Length m		70		180	
	18 months duration			**Ph 1**		**Ph 2**	**Ph1 + Ph2**
	3 Vehicle Units | Station Block | Ticket Kiosk			**6 Months**		**12 Months**	
Sl No	**Item**	**Qty**	**Rate**	**1**		**2**	
1	**Mule Chassis Mechanicals**			**11340000**		**10560000**	**21900000**
1.1	Aluminium/Composites Chassis & Roll Cage, Suspension, Compression Gas Spring	3	1500000	4500000	4	6000000	
1.2	Contraction Device	6	500000	3000000	4	2000000	
1.3	Actuator Guides	6	200000	1200000	4	800000	
1.4	Switch Guides	6	200000	1200000	4	800000	
1.5	Wheels Rims, Guide Wheels, Brakes	12	120000	1440000	8	960000	
2	**PowerTrain 3.5KW each**			**2400000**		**1600000**	**4000000**
2.1	One-sided Mount Hub Motors with Integrated controller 48V DC, nominal 100Nm and 3KW, peak 140Nm and 4KW, max 700 rpm, advanced FOC control, CAN communication, 4Q operation, IP67	12	200000	2400000	8	1600000	
3	**Vehicle & Shell**			**8860000**		**6110000**	**14970000**
3.1	Motor with 4Q Drive for Doors	12	200000	2400000	4	800000	
3.2	Vehicle ECU with CAN bus	4	700000	2800000	3	2100000	
3.3	RFID Reader	12	10000	120000	4	40000	
3.4	Emergency Recovery Device AC to 48V DC	6	150000	900000	3	450000	
3.5	Powerline Ethernet Adaptor	12	20000	240000	6	120000	
3.6	NiFePO4 / NiCAD Battery On Board	6	150000	900000	4	600000	
3.7	Air Conditioner	3	500000	1500000	4	2000000	
3.8	Vehicle Shell Fabrication	3	1500000	4500000	2	3000000	
4	**Tracks Components**			**3188000**		**5326000**	**8514000**
4.1	RFID / Transponders	60	2000	120000		240000	
4.2	Power Pickup Rail	70	5400	378000		756000	
4.3	Powerline Ethernet Adaptor	12	20000	240000		480000	
4.4	Power Pickup Rail	70	35000	2450000	110	3850000	
5	**Track & Station Block**			**15200000**		**7410000**	**22610000**
5.1	Track & Column	70	60000	4200000	110	6600000	
5.2	Station Block	1	5000000	5000000			
5.3	Station AC + Air Curtain		75000		2	150000	
5.4	Air Curtains		15000		4	60000	
5.5	Booking Kiosk		600000		1	600000	

5.6	Catapault System- 16KW Alternator, 16 KW Motor, Supercapacitor 48V 166F, Control Unit	2	1200000	2400000			
5.7	Lift Structure & Mechanism	2	1800000	3600000			
6	**Communication & Control Room**			**4160000**		**4390000**	**8550000**
6.1	Industrial PC	3	250000	750000			
6.2	Track Sensors	35	10000	350000	55	550000	
6.3	Controllers	3	200000	600000		600000	
6.4	Road Side Units	4	240000	960000	8	1920000	
6.5	On Board Units	6	150000	900000	4	600000	
6.6	Radar	3	120000	360000	6	720000	
6.7	Smart Display TV	2	120000	240000			
7	**Power Supply**			**660000**		**440000**	**1100000**
7.1	AC -DC Power Supply	3	100000	300000	2	200000	
7.2	Online UPS 5KVA	3	120000	360000	2	240000	
7.3	Generator Standby	2	750000	1500000			
7.4	Grid Connected Solar Power + Storage 5 KW		500000		2	1000000	
8	**Workshop Office**			**3680000**		**800000**	**4480000**
8.1	Structure with Lighting and Electricals	60	20000	1200000			
8.2	Tables & Chairs	20	12000	240000			
8.3	Storage Racks Industrial	20	2000	40000			
8.4	Office Equipment- PC, Printers, Large Format 3-D printer	10	100000	1000000	4	400000	
8.5	Software Licences- Ansys, Solidworks	6	200000	1200000	2	400000	
8.6	Air Conditioner	4	75000	300000			
	Sub Total			**49488000**		**36636000**	**86124000**
	Miscellaneous Items @ 20%			9,897,600		7,327,200	**17224800**
	Total of all Items			**59,385,600**		**43,963,200**	**103348800**
	Experimental Redundancy @ 30%			17,815,680		13,188,960	**31004640**
	Total of Hardware Material			**77,201,280**		**57,152,160**	**134353440**
						134,353,440	**134353440**

3 Summary Investment Schedule

a. TDS Stage 1 & 2 | SRL 0 - 1 | TRL 4 - 5

Based upon formal quotes received from the Industry, Academic / Research participants the total investment towards Stage 1&2 of TDS is approximately INR 48 Cr (6 M USD), subject to statutory applicable taxes.

Material & Prototype Costs are Estimates.

	Phase 1 & 2 | ~100 m System	70	180
	18 months duration	**Ph 1**	**Ph 2**
	3 Vehicle Units | Station Block | Ticket Kiosk	**6 Months**	**12 Months**
Sl No	Item	1	2
1	Mule Chassis Mechanicals	113	106
2	Power Train 3.5KW each	24	16
3	Vehicle & Shell	89	61
4	Tracks Components	32	53
5	Track & Station Block	152	74
6	Communication & Control Room	42	44
7	Power Supply	7	4
8	Workshop Office	37	8
	Hardware Material	495	366
	Miscellaneous Items @ 20%	99	73
	Total of all Items	594	440
	Experimental Redundancy @ 30%	178	132
	Total of Hardware Material	772	572
			1344
1	Human Resource -Technical	663	1326
2	Marketing & Administration	81	162
3	Office Overheads, Travel & Network	72	144
	Sub Total	744	1488
	Miscellaneous @ 20%	149	298
	Total of all Items	893	1786
	Attrition & Change Management @ 30%	268	536
	Total of Human Resources	1161	2321
			3482
	Stage 1 & 2 Total		4825

b. TDS Stage 3, 4 & 5 | SRL 1 - 8 | TRL 5 - 8

As per information available in the public domain, the ULTRA system was brought to TRL 7 Stage of readiness, using Government of UK grants. A total of 30 M Pounds was invested by ATS Ltd, the promoting company, up to 2005 to build and test the prototype at the test track at the University of Cardiff, UK.

In 2005, British Airports Authority awarded the contract to ATS Ltd to deliver a part of the larger people-mover system to be built around Heathrow Airport as a part of a competition to build an eco-friendly people-mover for the future.

A sum of 7.5 M Pounds was further invested by BAA in the company to help deliver a portion of the larger system connecting terminal T5 and the adjacent parking lot.

We have targeted to reach TRL7 by investing a total of INR 100 Cr (~15M USD / ~ 10 M Pounds) which is approximately a third of the investment put in by ATS Ltd.

- equivalent effort of human resources @30% cost
- off the shelf hardware components

Hence it is estimated that a further sum of INR 70 Cr (~9 M USD) would need to be invested during TDS Stage 3, 4 & 5 (TRL 5 - 8 | SRL 1-8).

- OEM Supply Chain and Relationship Building
- Advocacy and Mindshare Building
- Marketing & Business Development
- Media & Press
- Patents & Documentation
- Testing & 3rd party Safety Accreditation

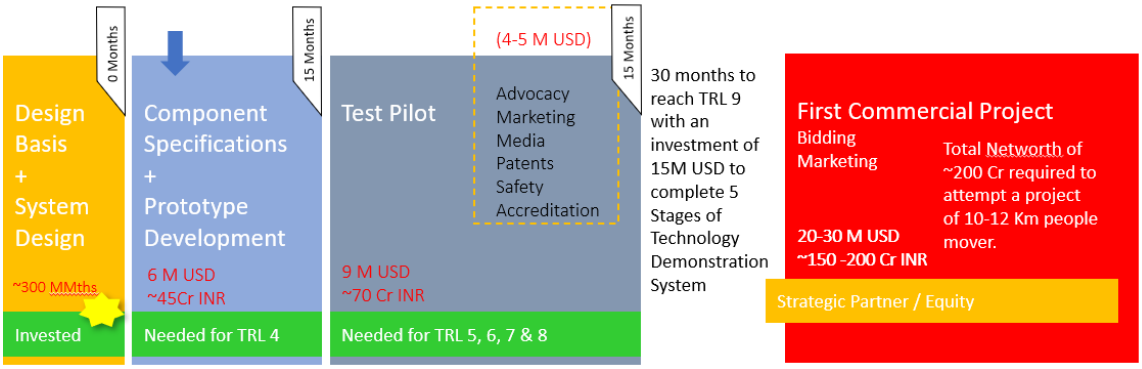


Figure 9: Investment Schedule TRL 4-8 & SRL 1-8

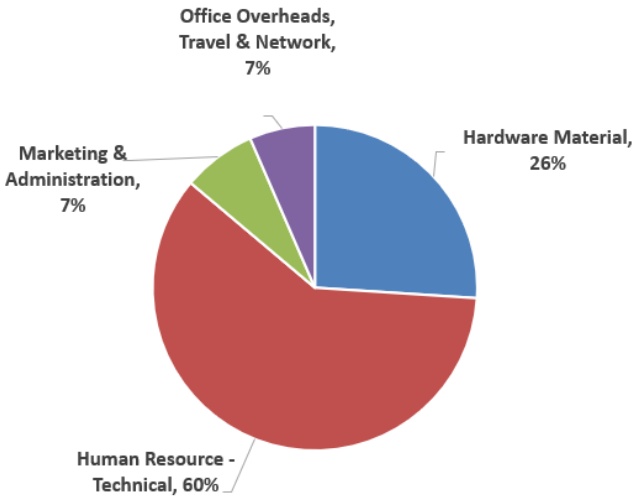


Figure 10: Investment Areas

L. Annexures

Annexure 1: MoU between FITT-IITD & EcoAutoMo Pvt Ltd

Memorandum of Understanding for Research & Development Cooperation between
Foundation for Innovation and Technology Transfer (FITT)- industry interface unit of Indian Institute of Technology Delhi – (hereinafter referred to as FITT which term includes its successors and assigns)
And
EcoAutoMo Pvt Ltd (hereinafter referred to as EAM which term includes its successors and assigns).

(Individually each party is referred as "Party" and collectively as "Parties" in rest of MoU)

Whereas EAM has proposed an arrangement for a novel public transport system called AutoBots, based on electrically powered vehicles running on a network of elevated tracks in a fully autonomous mode, comprising of most sub-systems of electric vehicle technologies

Whereas preliminary work, as detailed later, in developing the arrangement, concept and analyzing its feasibility has been acquired as license by EAM for exclusive use in India as Background IP.

Whereas EAM has approached IITD through the team mentioned below, for engineering development of the concept and to provide technical knowledge and support for realizing it

Whereas FITT- Industry interface unit of IIT Delhi - is an education and research institute engaged in research in many areas.

Whereas FITT, through, its faculty namely, Professors Brejesh Lall, S Mukherjee and B K Panigrahi, wishes to engage in the development of the stated concept and similar guided autonomous system variants, providing the technical basis needed culminating as Joint Foreground IP/s.

Whereas FITT nominates Prof Brejesh Lall as the MOU in charge and the key person responsible for all activities stated under this MOU.

Now this MOU witnesses the terms and conditions for cooperation between the Parties, for working towards setting up a mechanism for joint work on Autobots, including possibly setting up of a Centre of Excellence for Autonomous Mobility Technologies. This MOU should enable joint activities between the parties (not limited to) for developing prototypes, a working transport system and subsequent commercialization of AutoBots and/or similar guided autonomous system variants collectively referred to as system variants.

AIM OF THE PARTNERSHIP:

i. To leverage IIT strength in areas of electric power technology, 5G communication technology, mechanical design and development, design for vehicle safety, control systems design towards development of the

system variants.

ii. To engineer concept specific components and technologies from base up to meet relevant performance and safety standards.

iii. To optimize the system to provide efficient transportation solutions for the urban scenario in India.

iv. To jointly/individually approach Funding Agencies for supporting this initiative through funding research, development and testing (on top of the existing IP) of different modules of this technology, and for beta testing of the technology.

v. To create an extended ecosystem for research and development in urban transportation, by connecting with other institutions/organizations of repute and engaging in joint activities

vi. To develop national capacity for the promotion of electric mobility, by involving and training allied industry and academia in other parts of the country including faculty and students, through this collaboration and support of appropriate government department/private industry.

vii. To support commercializing the technology on the basis of realistic timeframes to be agreed upon mutually when funds are available.

viii. To work towards encouraging other organizations / institutes towards building capacities in furthering expertise in this area in the country.

ROLES & RESPONSIBILITIES:

Role of EAM

1. Manufacture / integrate the system variants covering laboratory prototype development, field validation and field demonstration stages.
2. Engage with IITD designated faculty for progressive advancement of technology components for subsequent use in the system during and after the joint development period.
3. Vendor development
4. Commercialize System / Technology
5. Installation, maintenance
6. To jointly work with FITT/IITD in arranging funds for activities mentioned in this MOU.

Role of FITT/IITD

1. Technology detailing and prototype development.
2. Evolve new technologies and / or optimization upgrades

3. To jointly work with EAM in arranging funds for activities mentioned in this MOU.
4. Endeavor to build a testbed for the class of mobility specified in the MOU
5. Run Affiliation programme for capacity building.

FUNDS USAGE

This is a Co-Development Agreement between EAM and IITD. It is agreed that Funds coming into FITT shall be administered as per IITD rules. Funds coming into EAM shall be the responsibility of EAM.

DELIVERABLES & TIMELINES

A key tangible outcome of this MOU is the development of a fully built functional system and complete track after test and validation as a live product for hands-on education and learning as functional test beds on the IITD campus (or at a partner site). The timeline shall depend on the availability of resources. But is targeted that the estimated Total Time for reaching TRL 8 would be 24 months from the date of full availability of funds for the development programme. The programme shall start only when a minimum initial corpus of 10 Cr is available through the funding sought by IIT Delhi and funds raised by EAM.

COMMERCIALISATION

1. EAM shall have the first right to refuse the use of any such patents thus generated from joint ongoing research or IPR developed further.
2. All IP can be commercialized by IITD in any industry not similar to or in competition with EAM's primary business area of elevated autonomous mobility electric vehicles
3. Components developed jointly by IITD and EAM (whose IP is owned jointly), shall be available to either party on payment of fees to the other party on mutually agreed terms and may be made available to a third party through licensing, if agreed mutually
4. Components developed by IITD whose IP is owned solely by IITD, may be made available to EAM on non-exclusive basis on mutually agreed terms.
5. IPR not utilized / deemed fit by EAM for system variants can be commercialized for any other industry not in competition with EAM primary business .
6. EAM shall be responsible for the commercialization of the system variants. They shall hold this right for an initial period of 10 years from the date of conclusion of the development project.

TERMINATION OF MoU

1. Rights over backgroung IPR for system variants shall remain exclusively with EAM and its relationships with any other entity shall be unaffected.
2. All rights over any forward IPR created through this MoU, further work on the same and commercialization rights of the same shall vest with both parties

equally upon termination.

3. Rights over existing IPR at IITD shall remain exclusively with IITD and its relationships with any other entity shall be unaffected.

PUBLICITY

The Parties agree that neither will use the name or trademarks of the other Party or its employees in any advertisement, press release or publicity with reference to this MoU or any product or service resulting from this Agreement / Projects, without prior written approval of the other Party.

Executed on 2nd day of August 2019 This MoU is signed and witnessed as follows:

Name: ~~Col~~ Naveen Gopal
Designation: Chief Operating Officer
Authorized person representing FOUNDATION FOR INNOVATION AND TECHNOLOGY TRANSFER,
Indian Institute of Technology, Delhi Hauzkhas, New Delhi

Name:
Designation: Founder & President
Authorized person representing M/s EcoAutoMo Pvt Ltd (EAM)

Witness 1:	Witness 2:	Witness 3:
Name: Brij. Brijesh Lall	Name: Prof. B.K. Panigrahi	Name: Mrs. Neelam Dube
Address: Bharti School IIT Delhi	Address: Electrical Engg. IIT Delhi	Address: Director Ecoautomo Pvt. Ltd. D 113, East of Kailash New Delhi

4

Annexure 2: Co-Development Agreement

To be formalised based upon Funding commitments from Private or Government.

Annexure 3: Core Team

a. List of Investigators from Academia - FITT-IITD

Investigator	Name	Designation	Signature
Principal	Prof Brejesh Lall		
Co-Principal	Prof BK Panigrahi		
Co-Principal	Prof Sudipto Mukherjee		

Prof. Brejesh Lall

- Former Head, Bharti School of Telecommunication Technology Management
- Department of Electrical Engineering, Indian Institute of Technology Delhi

He completed PhD in 1997 from IIT Delhi in the area of Multirate Signal Processing. He joined Hughes Software Systems in September 1997 and worked there for nearly 8 years in the Signal Processing group. He worked on Source Coding and PHY layer solutions for many communication technologies such as terrestrial wireless, GEO and LEO Satellite communication systems, Satellite broadband and others.

He returned to his alma mater and joined IIT Delhi as a faculty member in 2005. Since July 2005 He has been in the Electrical Engineering Department and has contributed to research & teaching in the general area of Signal Processing. He has graduated 13 PhD students during that period, further 6 have submitted their synopsis. Besides, them 29 research scholars are pursuing PhD under his supervision. He has completed numerous sponsored projects and consultancies and is working on several others. The total number is close to 47 and the total budget outlay in excess of Rs. 70 crores.

The areas in which he has been publishing and doing sponsored research are centered on signal processing. The areas include, object representation, tracking and classification, odometry, depth map generation, representation and rendering. He is also exploring vector sensor based underwater acoustic communications, and performance issues in molecular communications.

He is the former head of Bharti School of Telcom Technology and Management, and the co-ordinator of two centers of excellence, viz. Airtel IIT Delhi Centre of Excellence in Telecommunications and Ericsson IIT Delhi 5G Center of Excellence. He is also the incharge of an IoT laboratory that He set up in collaboration with Samsung. Besides this, he is the NCC co-ordinator of IIT Delhi.

He has mentored 5 startups, in the areas of Virtualization, Geo-fencing, UAV based solutions and recommendation and data mining. He actively participate in building and deploying technology. He have also served as expert in numerous government and private agencies in aspects related to signal processing.

Education

- PhD, Digital Signal Processing (1999, Indian Institute of Technology, Delhi)
- Ph.D. Thesis, Some Studies on Characterization and modeling of Stochastic Processes in the Multiscale Framework This work involved proposing a new model for representing stochastic

- processes (both one-dimensional and two dimensional) in the multiscale framework. The information at any scale was represented as function of information at the previous scale and innovations not present in the previous scale. A model for generating information of a finer scale version given a coarser scale version was proposed. Also proposed was a new characterization for wide sense cyclostationary processes.
- ME, Electronics and Communication (1991 –1992, Delhi College of Engineering, DU Delhi)
- BE, Electronics and Communication (1987 –1991, Delhi College of Engineering, DU Delhi)

Technical Experience

- Parametric Video Compression
- Information Theory applications to Biometrics
- Multirate Statistical Signal Processing, with application to Images.
- Adaptive Signal Processing, including application to echo canceller.
- Speech Coding, including G.729 and G.723.1
- Image Coding, including H.261 and H.263
- Physical layer processing, including channel coding, control code and interface with host processor and also with IF for satellite based wireless communication systems
- Physical layer processing, including channel coding, hopping, power measurement, control
- code and interface with host processor and also with IF for terrestrial wireless communication systems (GSM/GPRS/EDGE)
- Modems for telephone lines and wireless (terrestrial and satellite) channels (for 2G and 4G applications)
- Multiple access techniques, TDM in FDMA and MC-CDMA

Projects executed in the industry

- Physical layer processing for GSM/GPRS/EDGE based system: Managing a team of 25 engineers, working on development of platform and physical layer functionality for a low-cost GSM/GPRS/EDGE based communication system. The work includes understanding requirements, system architecture definition, S/W-H/W partitioning, S/W architecture. Besides this my responsibility includes, planning, monitoring the ensuring quality process for activities to ensure testing of H/W, development and integration of physical layer functionality and development of test tools. Managing a team of 4 engineers working on feature enhancements in the physical layer functionality for GSM/GPRS/EDGE based communication system. The work includes, understanding requirement, functional specification, design, implementation on Lucent 16410 and Lucent 1620 DSPs and integration. Feature enhancement work includes, measurement related enhancements, hopping related enhancement, channel coding related enhancements and certain proprietary functionalities. Implementation in Fixed point 'C' of the channel coding functionality and the GMSK modem. Besides, project management and people management responsibilities, my role includes providing technical guidance

- Channel coding and embedded enhancements to support new vocoders in a moving satellite based mobile communication system: This project involved implementation for new channel coding support and also the corresponding updations in the diversity and DTX support. The work involved implementing a feature to dynamically download code while processing for another call is in progress. Also design and implementation for diversity support for a dual-slot call was implemented. Loopback functionality was added to the system, design and implementation for that support was done. All these applications were for a mobile communication system over a moving satellite. In this project I was the technical manager of an 8-member team
- Modem for an MC-CDMA based 4th Generation Wireless Mobile Communication System: This project involved simulating the MC-CDMA modulator, including the frequency spreading (using IIFT as the implementation technique), scrambling, multiplexing and modulation. It also involved implementation of MC-CDMA demodulator, including descrambling, estimation, despreading and decision on TMS320C62x processor. Tools for board control and FPGA initialization were also implemented. This project was part of solution for an MC-CDMA base 4th Generation Wireless Mobile Communication System. In this project I was the technical manager of a 3-member team.
- Modem implementation and statistics and data generation tools for packet data application over a fixed satellite: This project involved implementation of pi/4 QPSK modulator on TMS320C6x processor for fixed satellite mobile communication data application. MATLAB simulations for the modulator and de-modulator were generated to verify the performance. For the same system tools for generating statistic and data generation were implemented on TMS320C6x processor. In this project I was the technical lead for a 2-3-member team.
- Echo-Canceller implementation and testing against G.165 / G.168: This project involved implementation of a 16 msec tail length echo canceller in TMS320C54x using the TI reference code. This code was tested against the ITU-T Standards G.165 / G.168. I worked on this project independently Channel coding for wireless / satellite communication system.
- G.729 code in TMS320C54x: This project involved implementing G.729 and testing it for it exactness against the ITUT reference code. I was the technical lead for a 3-4-member team.
- H.263 implementation: This project involved implementation of H.263 in ‘C’. I was the mentor of a 4-member team. This effort was part of the OASIS.
- Speech coding, tone processing and echo cancellation application for fixed satellite based communication system for voice and data solution for enterprise applications: This project involved integrating assembly code (TMS320C54x) for G.729, DTMF, echo canceller and interfacing with a host processor. The source coded data is sent to the host processor, which sends this data over a satellite channel. I was part of a two-member team.
- Channel Coding and Modem for moving satellite based mobile communication system: This project involved working on channel coding for a mobile communication system. I worked on interleaving, puncturing, code for driving ASICs and on GSMK and QPSK modulation. I worked on TMS320C5x and TMS320C3x processors. I worked as a part of a 34-member team

Projects Completed at IIT Delhi

S.No.	Project	Sponsoring Agency	Sanctioned Amount (Rs)	Duration
1	Modernization of Spuermankets Using Rfid Technology	Industrial Research & Development, IIT Delhi.	74500.00	2008-2009

2	Development of Mobile Video Full Duplexing Decoder & Renderer System	M/s Bharti Airtel	2515000.00	2011-2013
3	Characterization of Ocean Noise using Multiscale Modeling Techniques	Naval Research Board, Ministry of Defence	2860000.00	2008-2013
4	Development of Video Compression Scheme Based on Parametric Coding	S T Microelectronics Pvt. Ltd.	1980000.00	2008-2012
5	Sampling and compression for multiview 3-D displays	Department of Science & Technology (DST)	3543289.00	2010-2014
6	Managing Intangible Cultural Assets through On ltological Interlinking	Department of Science & Technology (DST)	3800000.00	2010-2014
7	Development of Robust Document Image Understanding System for Documents in Indian Scripts (OCR) Phase II	Department of Electronics &Information Technology	118622500.00	2010-2014
8	Development of Algorithm for Detection of Spatio temporal Discontinuity Werrors in Video	Interra Systems	1562500.00	2011-2013
9	AICET Social Media Analyser	M/s Bharti Airtel	3751000.00	2013-2014
10	Compressive Sampling for Imaging Application	Akshi Technologies	836000.00	2013-2016
11	National Programme on Perception Engineering	Ministry of Communications & Information Technology	26082000.00	2014-2018

Ongoing Projects at IIT Delhi

S.No	Project	Sponsoring Agency	Sanctioned Amount (Rs)	Duration
1	Video Conference and Collaboration (VCC) stack innovation support	Enhanced Communications Tech Pvt. Ltd. India	450000.00	06-05-2020 to 05-11-2020
2	Advice Consultancy for Punjab Sindh Bank	Punjab & Sind Bank, India	600000.00	01-03-2020 to 31-05-2020
3	Cisco Sponsored Research in 5G Wireless & Networking (to be funded from the unspent of RP02564 & RP02750)	CISCO, Sez Unit India	2082271.00	20-02-2019 to 31-0302021
4	Artificial intelligence based mobile app for identification and advisory of maize diseases and insect pests.	ICMR India	4258100.00	01-01-2019 to 31-12-2021

5	Validation and Fine Tuning of the Computer Aided Diagnosis of Pulmonary Tuberculosis Model for the Indian Subcontinent	CRDF Global United States	737270.40	01-11-2018 to 13-10-2020
6	Building end-to-end 5G Test Bed	Ministry of Communications & Information Technology India	290105000.00	01-04-2018 to 31-03-2021
7	Phenomics of Moisture Deficit Stress Tolerance and Nitrogen Use Efficiency in Rice and Wheat – Phase - II	Indian Council of Agriculture Research India	6599242.00	01-01-2017 to 30-06-2020

Publication

1. “Measure for degree of time variance and measure for the degree of non-stationarity: application to discrete LPTV systems” AK Dutta, SD Joshi, B Lall Signal Processing 183, 107995, 2021
2. “A Novel Method for CNN Training Using Existing Color Datasets for Classifying HandPostures in Bayer Images” M Chandra, B Lall SN Computer Science 2 (2), 1-10, 2021
3. “An Ontology Representation Language for Multimedia Event Applications” N Pahal, B Lall, S Chaudhury Journal of Web Engineering, 217–252-217–252, 2021
4. “ADAADepth: Adapting Data Augmentation and Attention for Self-Supervised MonocularDepth Estimation” V Kaushik, K Jindgar, B Lall arXiv preprint arXiv:2103.0085, 2021
5. “Pedestrian behaviour analytics on dashcam videos in chaotic environments” P Mukherjee, B Lall IEEE Sensors Journal, 2021 “One Shot Audio to Animated Video Generation”N Kumar, S Goel, A Narang, B Lall, M Hasan, P Agarwal, D Sarkar arXiv preprint arXiv:2102.09737, 2021
6. “Temporal Causal Modelling on Large Volume Enterprise Data” R Mohan, S Chaudhury, B Lall IEEE Transactions on Big Data, 2021 “Statistical Modeling and Performance Analysis of Cooperative Communication in Frequency-Selective Underwater Acoustic Channel Using Vector Sensor” M Rawat, B Lall, S Srirangarajan IEEE Sensors Journal 21 (6), 7367-7379, 2021
7. “Automatic Quantification of Plant Disease from Field Image Data Using Deep Learning” Kanish Garg, Swati Bhugra, Brejesh Lall Proceedings of the IEEE/CVF Winter Conference on Applications of Computer Vision, 2021
8. “Multi-Modal Adaptive Normalization for Audio to Video Generation” N Kumar, S Goel, A Narang, B Lall arXiv preprint arXiv:2012.07304, 2020 “Few Shot Adaptive Normalization Driven Multi-Speaker Speech Synthesis” N Kumar, S Goel, A Narang, B Lall arXiv preprint arXiv:2012.07252, 2020 “Methods and systems for providing multivariate time series clustering for customer segmentation” J Wilson, P Kapadia, V Vasudevan, S Chaudhury, B Lall US Patent 10,853,828, 2020
9. “Deep LF-Net: Semantic Lung Segmentation from Indian Chest Radiographs Including Severely Unhealthy Images” A Singh, B Lall, BK Panigrahi, A Agrawal, A Agrawal, DJ Christopher, arXiv preprint arXiv:2011.09695, 2020
10. “Deep Learning for Automated Screening of Tuberculosis from Indian Chest X-rays: Analysis and Update” A Singh, B Lall, BK Panigrahi, A Agrawal, A Agrawal, B Thangakunam, arXiv preprint arXiv:2011.09778, 2020

11. Paradigm Shift in Public Warning Systems: A Two-tier Approach towards Broadcasting P Gandotra, V Bhatia, B Lall 2020 IEEE REGION 10 CONFERENCE (TENCON), 309-313, 2020
12. 18. “Assessment of Impact of Beamwidth of Directional Antennas on Successful Transmissions mmWave Adhoc 5G Networks” G Shukla, MT Beg, B Lall IETE Journal of Research, 1-8, 2020
13. “Multi-modal sensor fusion using symmetric skip-autoencoder via an Adversarial Regulariser” S Bhagat, SD Joshi, B Lall, S Gupta IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing, 2020
14. “Semantics Preserving Hierarchy based Retrieval of Indian heritage monuments” R Gupta, P Mukherjee, B Lall, V Gupta Proceedings of the 2nd Workshop on Structuring and Understanding 2020
15. “6G for Bridging the Digital Divide: Wireless Connectivity to Remote Areas” A Chaoub, M Giordani, B Lall, V Bhatia, A Kliks, L Mendes, K Rabie, arXiv preprint arXiv:2009.04175, 2020
16. “Modeling and prediction of COVID-19 pandemic using Gaussian mixture model” A Singhal, P Singh, B Lall, SD Joshi Chaos, Solitons & Fractals 138, 110023, 2020
17. ‘Conditional Random Field based salient proposal set generation and its application in content aware seam carving” P Mukherjee, B Lall Signal Processing: Image Communication 87, 115890, 2020
18. “PerceptionGAN: Real-world Image Construction from Provided Text through Perceptual Understanding” K Garg, AK Singh, D Herremans, B Lall Joint 9th International Conference on Informatics, Electronics & Vision, 2020
19. “A Data-Driven Framework For Deploying Sensors In Environment Sensing Application” A Grover, B Lall IEEE Transactions on Industrial Informatics, 2020
20. “Improved Polynomial Neural Networks with Normalised Activations” M Goyal, R Goyal, B Lall 2020 International Joint Conference on Neural Networks (IJCNN), 1-8, 2020
21. “Angle of Arrival Distribution in an Underwater Acoustic Communication Channel With Incoherent Scattering” M Rawat, B Lall, S Srirangarajan IEEE Access 8, 133204-133211, 2020
22. “Method and apparatus for converting content using cloud” S Malaviya, B Lall, S Chaudhury, A Gupta US Patent 10,681,122, 2020 “Evolving Air Pollution Monitoring Systems for Green 5G: From Cloud to Edge” Pimmy Gandotra, Brejesh Lall 2020 8th International Conference on Reliability, Infocom Technologies and Optimization (Trends and Future Directions) (ICRITO, 2020
23. “Deep feature fusion for self-supervised monocular depth prediction” V Kaushik, B Lall arXiv preprint arXiv:2005.07922, 2020
24. “Image fusion using symmetric skip autoencoder via an Adversarial Regulariser” S Bhagat, SD Joshi, B Lall arXiv preprint arXiv:2005.00447, 2020
25. “A 6G white paper on connectivity for remote areas” H Saarnisaari, S Dixit, MS Alouini, A Chaoub, M Giordani, A Kliks, arrive preprint arXiv:2004.14699, 2020
26. “A novel method for removing baseline drifts in multivariate chemical sensor” A Grover, B Lall IEEE Transactions on Instrumentation and Measurement 69 (9), 7306-7316, 2020
27. “Data Adaptive Compressed Sensing using deep neural network for Image recognition” R Gupta, A Kumar, S Chaudhury, B Lall, V Kaushik 2020 National Conference on Communications (NCC), 1-5, 2020
28. “Blind Channel Coding Identification of Convolutional encoder and Reed-Solomon encoder using Neural Networks” N Gautam, B Lall 2020 National Conference on Communications (NCC), 1-6, 2020

29. “Aerial multi-object tracking by detection using deep association networks” A Jadhav, P Mukherjee, V Kaushik, B Lall 2020 National Conference on Communications (NCC), 1-6, 2020
30. “Analysis of underwater acoustic channel based on angle of arrival distribution M Rawat, B Lall, S Srirangarajan 2020 International Conference on Communication Systems & Networks, 2020 “Automatically optimized gradient boosting trees for classifying large volume high cardinality data streams under concept drift” J Wilson, AK Meher, BV Bindu, S Chaudhury, B Lall, M Sharma, V Pareek The NeurIPS'18 Competition, 317-335, 2020
31. “Theoretical Characterization of Deep Neural Networks” P Kaul, B Lall Deep Learning: Concepts and Architectures, 25-63, 2020
32. “Activation Functions” M Goyal, R Goyal, PV Reddy, B Lall Deep Learning: Algorithms and Applications, 1-30, 2020

b. List of Investigators from Industry – EcoAutoMo Pvt Ltd

Investigator	Name	Designation	Signature
Principal	Anupam Vibhuti		
Co-Principal	Adarsha Kapoor		
Co-Principal	Manraj Bains		
Co-Principal	Sanjay Arora		
Co-Principal	Prof. Kannan Laxminarayan		

Anupam Vibhuti

- Founder Director at EcoAutoMo Pvt Ltd
- Director Tranxit Mobility Logistics Pvt Ltd
- Director Worxpace Consulting Pvt Ltd

Anupam Vibhuti graduated from the School of Planning & Architecture as an Architect & Town Planner with a specialization in Urban Transport Planning. He has a rich experience of over 28 years of practicing in the field of planning & design in architectural and transportation domains. Over the years of practice has developed core expertise in transport planning, town planning, infrastructure developmental planning & management, and the use of IT tools for related applications.

His enduring interest in computers & technology applications and solutions specifically towards integrated transportation systems efficiency has helped him identify appropriate business cases in the transportation domain and conceive applications to address the same. He initiated and built a demonstration application for a mobile device based 'on field' traffic violation information system for the Traffic Police and a mobile-centric application for 'on-demand' scheduling of autorickshaws besides a full-fledged Pod Taxi system, christened 'AutoBots'.

He has written papers that have been published and presented at ORF, IIT Chennai, IIT Mumbai, and Urban Mobility India Conferences on planning policy aspects related to 'Mass Transit Systems', 'PRT Applications for Indian Requirements' and 'ITS Applications for Indian Business Cases'. He has also contributed to UTTIPEC, Delhi with the agenda for applying micro-simulation techniques for evaluating transportation infrastructure projects.

Education

- Bachelor of Architecture, 1985-1992 School of Planning & Architecture, New Delhi
- Masters of Planning Specialisation in Transport Planning, 1999-2002 School of Planning & Architecture, New Delhi

Technical Experience

- Architecture & Facility Design
- Transportation Planning

- Solution Architecture & Feasibility Studies
- Modeling & Microsimulation of Traffic
- Transit & Urban Mobility Applications
- Business Case Analysis & Value Engineering
- Transportation Systems Planning

Memberships

- TED 28 Intelligent Transport Systems, Bureau of Indian Standards, GOI
- Institute of Town Planners India
- Institute of Urban Transport
- Council of Architecture
- American Society of Civil Engineers

Positions Held

Duration	Institution	Nature of Work done
2019 - Present	EcoAutoMo Pvt Ltd	Founder Director, AutoBots
2008 - Present	Tranxit Mobility Logistics Pvt Ltd.	Founder Director, Urban Mobility Applications
2005 - Present	School of Planning & Architecture	Visiting Faculty, Thesis Guide
2003 - Present	Worxpace Consulting Pvt. Ltd	Founder Director, Transport Planning Consultant
1994 - 2003	MODES, Studio Square One	Architecture & Design
2018- 2019	Indian Institute of Technology Madras	Professor of Practice

Research/training experience (in reverse chronological order):

2008-Current

Research & development as principal investigator & solution architect at Tranxit Mobility Logistics Pvt Ltd. Producing intelligent transportation applications and systems using state-of-the-art technologies for typical Indian ‘use cases’ including the following:

- AutoGo - OLA/ UBER type application suite for on-demand auto-rickshaw services in India.
- TrackETA -360-degree Student tracing & tracking application including backend operations and control center management, solution sold to Indian Air Force, MT Division.
- AutoBots - On-demand automated transit system with in-depth use case analysis, solution architecture, and system design.

2003-Current

Consultancy practice as Principal Consultant at Worxpace Consulting Pvt Ltd.

Town Planning aspects largely centered around transportation issues including the following:

- Feasibility studies for automated parking Infrastructure in Delhi
- Traffic impact studies of Infrastructure projects
- Feasibility studies for toll plaza locations on highways
- Township-level traffic & transportation master plans
- ROW Infrastructure planning & streetscapes
- Terminal designs for the bus system/trucking industry
- Metro station property development feasibility studies
- Metro station design conforming to NFPA130 focusing on pedestrian movement using simulation
- Multimodal Integration design for at-grade transfers & feeder system studies
- Design of automated vehicle testing centers
- ITS enablement planning for bus transport services.

1999-2002

Sabbatical to pursue a full-time Masters course in Town Planning with specialization in Transportation from the School of Planning & Architecture, New Delhi

1994-1999

Practiced Architecture as lead architect, designed Nepal's first-ever Cricket Stadium for ZEE TV Network. Worked on a variety of projects like corporate interiors, factories, and commercial complexes, including a truck and bus parking terminal.

List of publications/Patents relevant to this Project

1. Paper Publication: Best Practices to Relieve Congestion on Mixed-Traffic Urban Streets In Developing Countries – BPRCM 2008 IIT Chennai (Theme: Transportation System & Role of Government): Selection Methodology & Pphpd as an 'Incomplete' Unit of Comparison for Public Transit Systems
2. Paper Publication: Transportation Planning and Implementation Methodologies For Developing Countries -TPMDC 2008 IIT Mumbai (Theme: Transportation Infrastructure Planning b. Transit Systems Planning): Concept of 'Mass' in Mass Public Transit Systems
3. 'Personal Rapid Transit' A Suitable Mass Transit Alternative for India - Technical Note published in the IUT(MoUD) Journal December 2009
4. Paper Publication: Research Symposium - Urban Transport Planning and Management: Emerging Challenges –Urban Mobility India 2010 – IUT, MoUD, GOI (Theme: Demand Management Measures 'Mobile Centric Application for On-Demand Response System for Autorickshaws as key IPT Mode in Indian Cities
5. Poster Presentation: Transport Research Board 2013: Dynamic Model for Benchmarking of Personal Rapid Transit for Indian Cities.

6. Paper Publication: Transport Research Board 2013: Impact of Personal Rapid Transit System on Accessibility Index
7. Paper Publication: ORF Issue Brief No 140, May 2016: Transporting Masses in Urban India: Policy & Fact Disconnect,
8. Paper Publication: International Journal for Traffic and Transport Engineering, 2016, 6(3): 313 – 324: Potential of Personal Rapid System to Meet the Urban Transport Deficit.
9. Patent: High Throughput Transportation System with seamless carriage switching between track along the vertical plane" vide Patent Application No. 202011021745 dated May 23, 2020 (Granted)
10. Patent: Method for Trajectory shift of a vehicle unit in a transport system" vide Divisional Patent Application no.: 202112052782 dated November 17, 2021 (Granted)

Annexure 4: Background IP & Representations

1. Relevant Published Papers

a. Anupam Vibhuti, 'Transporting Masses in Urban India: Policy & Fact Disconnect', Observer Research Foundation, ORF Issue Brief No. 140, 2016
b. Tranxit Mobility Logistics Pvt Ltd 2016, AutoBots- Technology Demonstration System | V1 | TRL 4 – TRL 7.
c. Tranxit Mobility Logistics Pvt Ltd 2017, AutoBots Urban Deployment – Crowded Indian City.

2. Patents

a. Patent 1 - High Throughput Transportation System with seamless carriage switching between track along the vertical plane" vide Patent Application No. 202011021745 dated May 23, 2020 (Granted by Indian Patent Office)
b. Patent 2 - Method for Trajectory shift of a vehicle unit in a transport system" vide Divisional Patent Application no.: 202112052782 dated November 17, 2021 (Granted by Indian Patent Office)
c. Patents filed in Jurisdictions of
    - United States of America
    - United Arab Emirates
    - European Union

3. Representations

a. Niti Ayog AutoBots Review Minutes of 2016.
b. Niti Ayog Advisory to growing pod taxi Industry of 2017.

Annexure 5: Market-related Press Clippings in Reverse Chronology

a. Jewar Greater NOIDA Podtaxi

https://www.hindustantimes.com/cities/noida-news/pod-taxi-project-to-connect-noida-airport-with-film-city-will-cost-862-crore-says-dpr-101626201534640.html

b. Reliance buys majority stake in Skytran

https://www.business-standard.com/article/companies/ril-arm-acquires-majority-stake-in-us-tech-firm-skytran-for-27-mn-121022800740_1.html

c. Reliance pilot project announcement

https://www.digit.in/car-tech/reliance-aims-to-foster-pilot-implementation-of-personal-rapid-transit-systems-based-on-magnetic-lev-44191.html

d. Haridwar Tender Bid - PNC Infra

https://themetrorailguy.com/2021/04/06/pnc-infra-only-bidder-for-haridwars-prt-system/

e. Soon, you can go around Dubai on 'Sky pods'

https://m.khaleejtimes.com/nation/dubai/soon-you-can-go-around-dubai-using-sky-pods-1

f. World's largest electric vehicle transport at Ajman
https://www.sentinelassam.com/news/fairwood-to-build-worlds-largest-electric-vehicle-transport-system-in-ajman/amp/

g. India's 1st pod taxi on the way, to follow U.S. safety norms

https://www.thehindu.com/news/national/indias-1st-pod-taxi-on-the-way-to-follow-us-safety-norms/article22282385.ece

https://timesofindia.indiatimes.com/business/india-business/indias-1st-pod-taxi-on-the-way-to-follow-us-safety-norms/articleshow/62254487.cms

h. Gurgaon Pod Taxi

https://www.businessinsider.in/say-goodbye-to-traffic-pod-taxis-to-debut-in-gurgaon/articleshow/51483035.cms

i. Amritsar Pod Taxi

http://www.sunday-guardian.com/news/amritsar-all-set-to-get-rapid-pod-cars

M. Abbreviations & Definitions

a. PRT Personal Rapid Transport
b. TMLPL Tranxit Mobility Logistics Pvt. Ltd
c. FITT Foundation for Innovation & Technology Transfer
d. IITD Indian Institute of Technology Delhi
e. NUTP National Urban Transport Policy
f. SPV Special Purpose Vehicle
g. MRTS Mass Rapid Transit System
h. BRTS Bus Rapid Transit System
i. IPT Intermediate Para Transit
j. NMT Non-Motorized Transport
k. RoW Road Right of Way is the space legally allocated for the movement of people, goods or vehicle defined by site boundaries of the adjoining properties.
l. Road 'Roads' are legally sanctified spaces allocated for the movement of people and vehicles (not considering airports, Railway tracks, and waterways, as their medium of transport is different).
m. EV Electric Vehicle
n. ICE Internal combustion Engine
o. IP Intellectual Property
p. IPO Indian Patent Office
q. PCT Patent Cooperation Treaty
r. USD United States Dollar
s. OEM Original Equipment Manufacturers
t. TRL Technology Readiness Level
u. SRL System Readiness Levels
v. YOY Year on Year
w. RIL Reliance India Limited
x. CAPEX Capital Expense
y. OPEX Operational Expense
z. Pphpd person per hour per direction
aa. LCA Life-cycle Analysis
bb. INR Indian Rupees

Notes