WORKING PAPER / AUGUST 27, 2015

AUTONOMOUS VEHICLES AND THEIR FUTURE IN LOW- AND MIDDLE-INCOME COUNTRIES

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ABSTRACT

If you do a literature search for autonomous or driverless vehicles you will find very few references before the year 2005. This is interesting because beginning in the late 1980s, many driverless experimental platforms have been built dealing with lane centering, distance keeping, obstacle avoidance, lane changing and intersection handling (Junqing et al. 2013). Robert W. Lucky writing in the IEEE Spectrum Magazine informs us that at the turn of the millennium he was a member of a committee of the National Academy of Engineering (USA) whose task was to select most outstanding engineering achievements of the 20th century and among others they selected the development of the automobile as it 'profoundly changed where we lived and how we lived' (Lucky 2014). But, he goes on to say that 'At about the same time, people were making lists of important future achievements for the 21st century—grand challenges with social impacts. But as far as I know, driverless cars were not on any of those lists'.

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INTRODUCTION

If you do a literature search for autonomous or driverless vehicles you will find very few references before the year 2005. This is interesting because beginning in the late 1980s, many driverless experimental platforms have been built dealing with lane centering, distance keeping, obstacle avoidance, lane changing and intersection handling (Junqing et al. 2013). Robert W. Lucky writing in the IEEE Spectrum Magazine informs us that at the turn of the millennium he was a member of a committee of the National Academy of Engineering (USA) whose task was to select most outstanding engineering achievements of the 20th century and among others they selected the development of the automobile as it 'profoundly changed where we lived and how we lived' (Lucky 2014). But, he goes on to say that 'At about the same time, people were making lists of important future achievements for the 21st century—grand challenges with social impacts. But as far as I know, driverless cars were not on any of those lists'.

It is quite amazing that within a short period of time the autonomous vehicle (AV) has caught everyone's imagination all over the globe as something that is not only possible but also expected to be our roads in the near future. Many cities have already announced intentions for putting such vehicles on the road. For example the Transport Minister of U.K recently announced that projects in Greenwich, Bristol, Milton Keynes and Coventry will backed by £19 million worth of funding to test prototype driverless vehicles on dedicated lanes (Topham 2015). With these investments they expect to 'keep the UK at the cutting edge of automotive technology and bring more highly-skilled jobs to the UK' and 'be world-leaders in this field and able to benefit from what is expected to be a £900 billion industry by 2025'. Prototypes of two vehicles that are expected to be introduced are shown in Figure 1.

Figure 1. Prototypes of driverless vehicles proposed to be introduced in Greenwich, Bristol, Milton Keynes and Coventry, U.K. (Source: Topham 2015).

While many cities are preparing to introduce AVs for limited use, a number of vehicle manufacturers have announced their intention to make commercial AVs available for sale within a decade. Google, BMW, Ford, GM, Toyota, Nissan, Volvo and Audi have all demonstrated prototypes of AVs in the past couple of years and laws are already being changed in many countries to allow use of such vehicles in the public space (Lucky 2014, Schultz 2014, Naughton 2015, Knight 2013). Even in India a vehicle manufacturer (Mahindra & Mahindra Ltd.) has launched an all India competition for design and fabrication of AV.[1] Out of 670 applicants 9 have been selected for the final phase and are expected to be ready with their entries for the prize by October 2016.

While there are some sceptics who do not believe that such cars will be a normal feature on public roads 'in our lifetime' (Knight 2013, Luettel, Himmelsbach and Wuensche 2012), others including many manufacturers have no doubt that we'll see AV on our highways in some countries in the near future. However, it is quite clear that some kind of AVs will be on the roads in some parts of the world within a decade.

In this paper we indulge in a thought exercise to understand the possible role of AVs in low and middle-income countries like India by 2030. For this purpose we assume that a fully functional AV will be available around 2025. The issues we examine are:

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[1] Rise Prise, Driverless Car Challenge, http://www.sparktherise.com/program-detail/driverless-car-challenge

- The composition of the probable vehicle fleet in India in 2030 and the possibilities of AV penetration in that fleet.
- Operational issues concerning AV in the projected modal shares on urban streets in the Indian future.
- Influence of AVs on urban form, transit, and labour markets.

PERSONAL VEHICLES IN INDIA

Ownership of personal motor vehicles – national trends

Figure 2 shows the growth of personal motor vehicles registered in India by year (Transport Research Wing 2014). The official registration data over represent the number of vehicles in actual operation because vehicles that go off the road due to age or other reasons do not get removed from the records. This is because personal vehicle owners pay a lifetime tax when they buy a car and do not de-register their vehicles when they junk them. The actual number of vehicles on the road is estimated to be 55%-70% of those on the records (Expert Committee on Auto Fuel Policy 2002, Mohan et al. 2014, Goel et al. 2015). The number of cars and

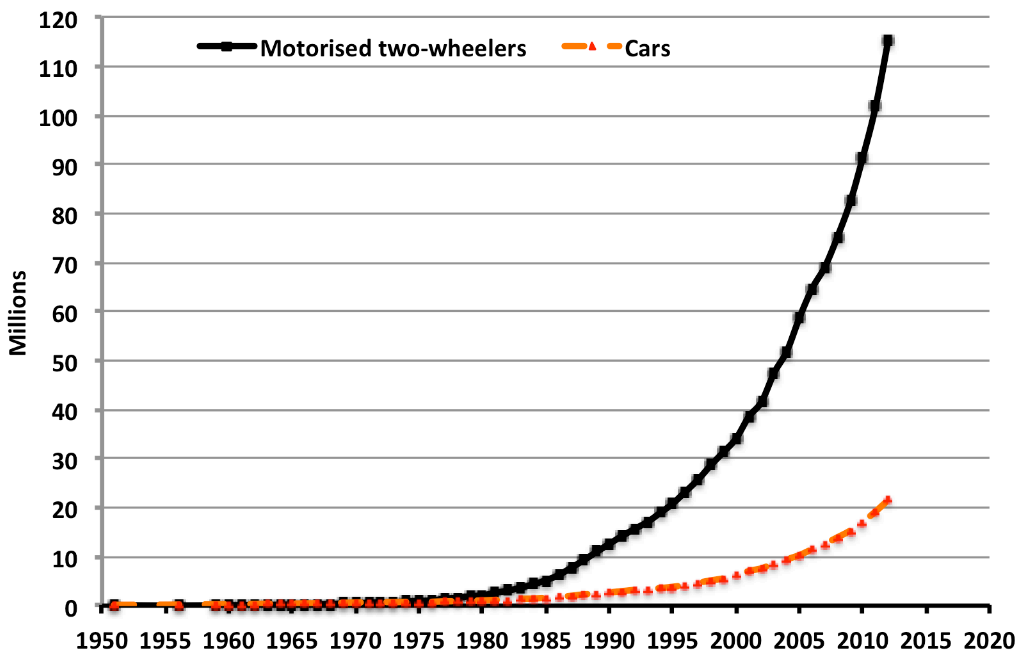

Figure 2. Cars and MTW registered in India by year (Source: Transport Research Wing 2014).
Note: Actual numbers on the road would be considerably less, see text.

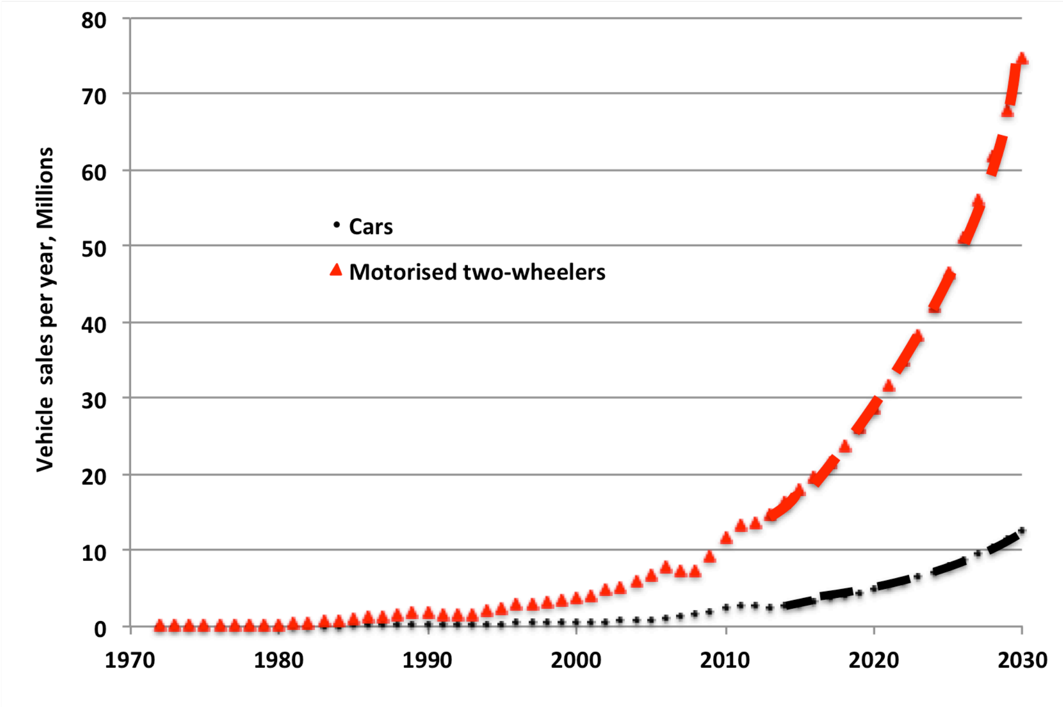

Figure 3. Personal motor vehicle sales in India 1972-2013 (Source: Society for Indian Automobile Manufacturers) and projections to 2030 at growth rate of 10% per year.

motorised two-wheelers (MTW) registered in 2012 was 21,568,000 and 115,419,000 respectively. If we assume that 70% of them were actually on the road, then car and MTW ownership per 1,000 persons was 13 and 67 respectively in 2012.

Figure 3 shows the sales of cars and MTW in India from 1972 to 2013. The average growth rate in the 10 year period 2004-2013 was 11% per year for cars and 10% per year for MTW. The average growth rate of the GDP in the same period was about 7% per year.[2] This gives us an income elasticity of demand (motor vehicles) of about 1.4-1.5 for India. In non OECD countries this ratio varies between 1.4 and 2.2 with an average of 1.61 (Dargay et al. 2007). The growth rate of vehicles in India seems to be lower than that in many other non-OECD countries. The projection of vehicle sales to 2030 is shown Figure 3 by dashed lines assuming a growth rate of 10% per year for the period 2013-2030. We use the projected sales figures for estimating vehicle population in India in 2030. Assuming a life expectancy of 17 years for cars and 10 years for MTW (Goel et al. 2015) in India, we get a total of 111,660,000 cars and 534,650,000 in 2030. For an expected population of 1.4 billion

[2] Planning Commission, http://planningcommission.nic.in/data/datatable/data_2312/DatabookDec2014%2016.pdf. Accessed 20 March 2015.

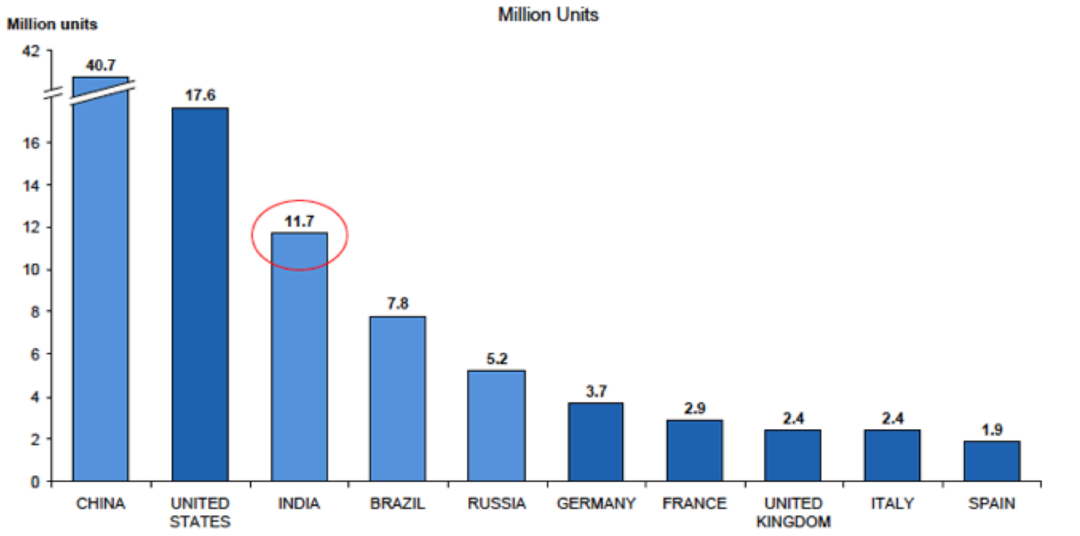

Figure 4. Estimates of light passenger vehicle sales for different countries in 2030 (Source: Sehgal 2011).

in India in 2030, we get ownership per thousand persons of 80 for cars and 380 for MTW in 2030.

Figure 4 shows that our projected number for car sales in 2030 in India is similar to that estimated by Booz & Company Inc. (Sehgal 2011). In 2030 the per capita income in India should reach around US$ 6,000 (at 2012-13 prices), similar to the present per capita income of China and Thailand now (National Transport Development Policy Committee 2014). At this income our estimates suggest car ownership of 80 per thousand persons. Figure 5 shows vehicle ownership and per-capita income, historical and projected, for 8 large countries (Dargay et al. 2007). Dargay et al.'s estimates for India suggest vehicle ownership for India in 2030 at a little more than

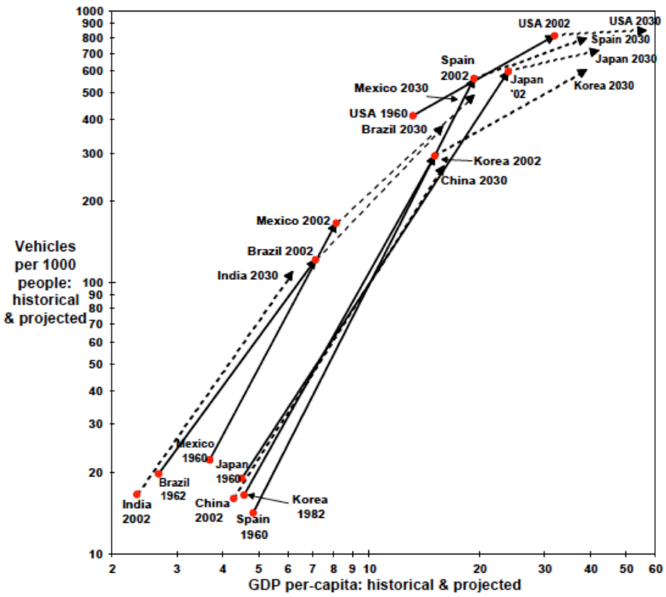

Figure 5. Vehicle ownership and per-capita income, historical and projected, for 8 large countries : (Dargay, Gately and Sommer 2007)

100 per thousand persons. Their estimate for India would be higher than our number because they would have used the official numbers for vehicle ownership in India that our overestimates the vehicle population.

Therefore, car ownership in India in 2030 at 80 per thousand persons would be less than that in most of the large countries today and certainly much less than that in high-income countries (500-800). The experience from counties like Thailand, Taiwan and Columbia show that at per capita incomes of around US$ 6,000 per year, MTWs can still remain a significant proportion of the vehicle share on the roads. Our projection for India in 2030 suggests MTW ownership at 380 per thousand persons. However, it is possible that with rising incomes penetration of MTWs may reduce. At even half the projected number, MTWs will still outnumber cars by a factor of 2.4.

Ownership of personal motor vehicles – urban trends

Figure 6 shows the car and MTW ownership levels in Indian cities with population greater than 1 million persons. There is a wide scatter for ownership levels especially in the smaller cities. This is probably because there would be a

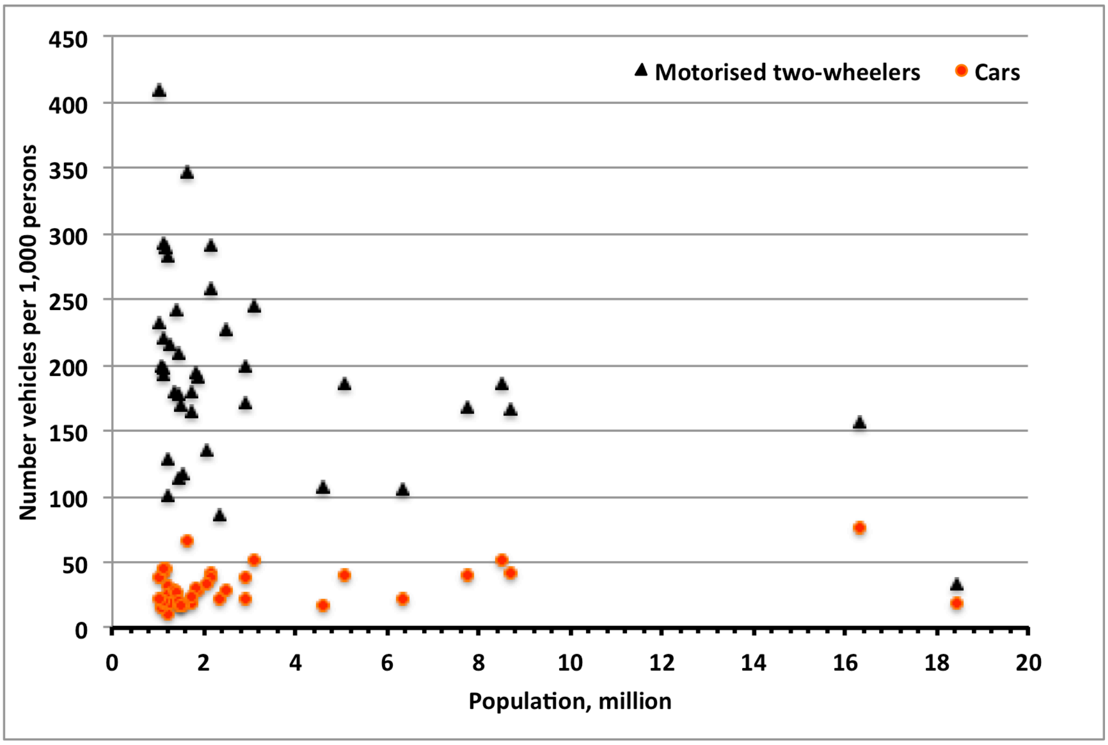

Figure 6. Personal vehicle ownership in cities with population > 1 million in 2012 in India (Source: Transport Research Wing 2014).

Note: Numbers from the source document have been adjusted downward to account for over representation in the official numbers.

variation in the income levels for these cities. The proportion of MTWs to cars seems to decrease in cities with populations greater than about 5 million. This would reflect the greater prosperity levels in the megacities. The average ownership per thousand persons in large urban areas is 31 for cars and 194 for MTWs. This shows that the average urban vehicle ownership is a little more than double national average.

Therefore, if the average urban car ownership in 2030 is double that of the national average, it would amount to 160 cars per thousand persons. In megacities, the MTW population is about 2-3 times the car population, and this trend may continue up to 2030. These estimates suggest that in most large cities in India car ownership levels may still be significantly lower in 2030 than those prevailing in the high income cities of today, and MTWs will continue to have significant presence on our roads.

Income and its influence on car sales

At present A (mini), B (compact), and C (Sedan) category cars constitute about 80% of the sales and non-luxury SUVs about 15% of the sales in India.[3] All these vehicles cost less than US$ 20,000. Vehicles costing more than US$ 20,000 have a sales share of less than 3% . India has one of the largest shares of A and B category cars among all the large countries in the world (Cather 2007). Figure 7 shows Indian household income & car sales distribution in 2030 (Sehgal 2011). Even in 2030, D (large sedans), E (executive sedans) and F (luxury cars) category vehicles comprise less than 3% of the sales. Among the sports utility vehicles (SUV) and multi-purpose vehicles (MPV) those costing more than US$ 20,000 are likely to be a small proportion. It appears that in 2030, cars costing more than US$ 20,000 may constitute less than 5% of the vehicle sales. The affordability of cars will have an important influence on the level of penetration of AV in the post 2025 period in India.

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[3] Indian Car Sales Figures & Analysis http://www.team-bhp.com/forum/indian-car-scene/160444-january-2015-indian-car-sales-figures-analysis.html.03. Accessed 13 March 2015.

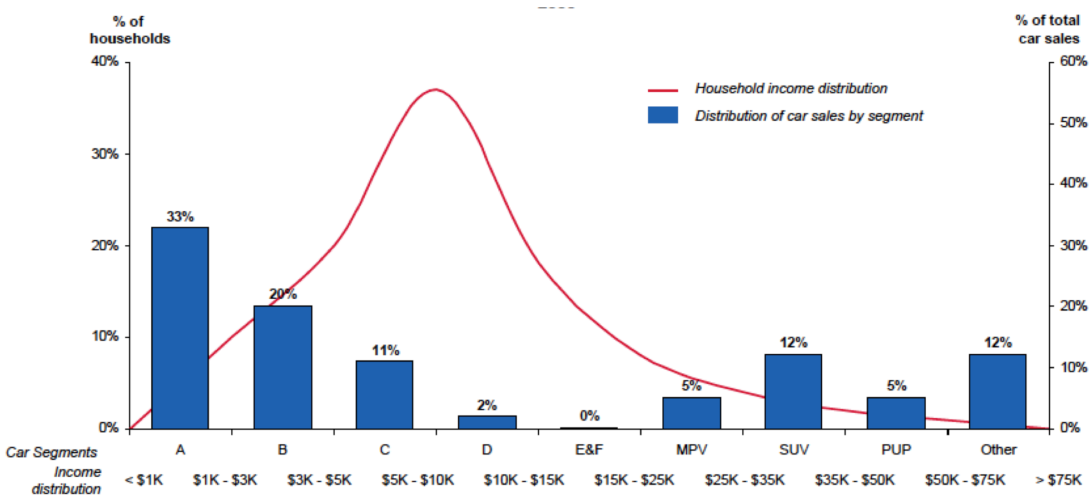

Figure 7. Estimate of Indian household income & car sales distribution in 2003 (Source: Sehgal 2011).

THE ROLE OF AV IN URBAN INDIA OF 2025-2030

Expected modal share of AVs

One of the important technologies necessary for the operation of AV is a system that creates a map of the car's surroundings, including other moving and stationary objects, and integrates the information with existing maps and other sensors as the vehicle moves. In the Google car this mapping is done by LIDAR systems that include a large number of lasers and receivers (Luettel et al. 2012). The present cost of this technology alone is estimated to be US$ 75,000-100,000. However, costs of these technologies are expected to reduce over the next decade. The most optimistic estimate for extra cost necessary for producing general use AVs is about US$ 10,000 (Schultz 2014). At present costs, the basic AV would then sell for more than US$ 20,000.

The cost criterion may remain an important issue. In a survey of public opinion about self-driving vehicles done across 6 countries Schoettle and Sivak (2014) report that, "…the respondents in the six countries surveyed, while expressing high levels of concern about riding in vehicles equipped with this technology, mostly feel positive about self-driving vehicles, have optimistic expectations of the benefits, and generally desire self-driving-vehicle technology (though a majority in four out of the six countries surveyed are not willing to pay extra for such technology at this time)”. The Indian respondents were willing to pay less US$ 1,600 extra for such technology.

The cost component would restrict AV use only to upper class families, as households earning more than US$ 35,000/year will be les than 5%. In large urban areas this proportion may be about 10%. At these income levels penetration of fully functioning AVs in large Indian cities is not likely to be more than 5%-10% in 2030. At this price the AV is unlikely to replace the lower end taxi service as chauffeurs cost less than US$ 4,000/year at current prices and vehicles used generally less than US$ 8,000. However, it possible that the AV might become economical for running shared taxi services with vehicle capacities more than 10 persons.

Chauffeurs vs AVs

One way to understand the role of AVs in the future is to examine the role a chauffeur plays in the mobility of upper class citizens in Indian cities. The car owner is able to issue instructions on the mobile phone and have the following functions performed by the car (driven by a chauffeur):

- Have children and disabled members of the family taken to their destinations without other members of the family accompanying them.
- Pick up guests from airports, etc.
- Run errands (including shopping) and make deliveries.
- Transport owners to their destinations and then park and wait at a location distance away where parking is available.
- Cruise around if no parking available while the owner does some shopping.

It appears that the chauffeur driven car is providing the same benefits to the owner as an AV would, except that the AV would not be able perform the functions that require human interaction (e.g. shopping). However, it is possible that the AV would provide a safer alternative to the chauffeur driven car.

Mobility in large Indian urban areas

Indian cities changed form when the British established a new city for themselves in most district headquarters of the country. They lived and worked in this new city which included the ‘Civil Lines’ (where all the civil service officers living quarters and offices were located) and Cantonments. This city (B in Figure 8) was physically separated from the old city where the 'natives' lived (A in Figure 1). For the next century the old city (A) was neglected, did not get adequate municipal services and decayed physically. After independence in 1947, the Indian elite took over the British city (B) but the decay of the old city continued. When Indian cities expanded after 1950s, it was not easy for most people to settle in the bureaucratic city and they did not want to live on the old congested 'dirty' city. A third city came into being (C) which surrounded the earlier two. This historical development of Indian cities has to be to be taken into account to understand the difference in mobility patterns between Indian cities and mature European cities.

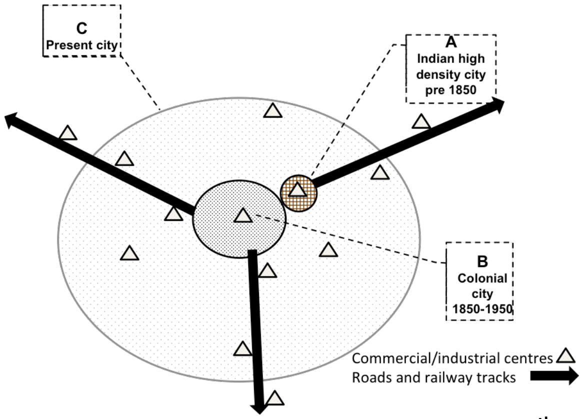

Figure 8. Development of the Indian city, 19th century to the present.

Most cities in high-income countries have important central business districts (CBD) with thriving city centres that are also the pride of the city. This is not true for most cities in low and middle-income countries. Most of these cities expanded after 1960 and planned for multiple business districts. The old city generally includes wholesale markets and older trades (A), the British city government offices (B), and all the new development has taken place in the third city (C). This has a significant influence on mobility patterns and where people live and work.

Modern Indian cities have multiple business districts distributed around the city and along the roads leading out if the city. This is one of the factors that do not favour very high capacity radial transit systems bringing people to the centre. These cities have developed urban forms that encourage "sprawl" in the form of relatively dense cities within cities. Low and middle-income people do not require a very large pool of activities to find work. If businesses are mixed with residential areas, and the lower income people allowed to live everywhere, then the less skilled persons are more likely find work closer to home. All Indian cities now have polycentric forms with most of the new development taking place on the periphery.

Recent studies suggest that in Indian firms doing research and development work appear to locate in larger metropolitan areas while mass production of standard items in non-metropolitan areas. As development proceeds manufacturing decentralizes form large cities and moves to the periphery or to smaller cities. But in India this may be happening prematurely as expensive land, lack of infrastructure and power force organisations to move to the periphery where they can establish their own facilities. While many of the principles on how and why cities grow may be common across the world, Ejaz Ghani and Ravi Kanbur inform us that unlike the west, with increasing incomes and urbanization the availability of formal jobs has slowed down in the developing countries, especially in India (Ghani and Kanbur 2015). It appears that for the time being there is going to be urbanisation of the informal sector and deurbanisation of the organized sector.

Because of the reasons cited above, low income levels, wide availability of MTWs and relatively low cost para-transit facilities, Indian cities demonstrate the following characteristics (Mohan 2013, Goel et al. 2015, Mohan et al. 2014):

- *Estimated modal share in urban trips*
  - Cars: ~5-15%
  - MTW: ~15-25%
  - Paratransit: ~10-20%
  - Bus and metro transit: ~5-20%
  - Walk and cycle ~30-60%
- *Annual average kilometres for cars and MTW*

City	**MTW (km)**	**Car (km)**
Delhi (16.7 million)	12,804 ± 349	12,199 ± 435
Visakhapatnam (1.7milllion)	9,238 ± 576	-
Rajkot (1.5 million)	7,255 ± 325	-

These data indicate that:

- Vehicles in megacity like Delhi average only ~12,000 km per/year and in cities 10 times smaller in population ~7,000-9,000 km per/year. The Delhi values are only 50% higher than much smaller cities. Therefore, the ‘sprawl’ of Delhi seems to be different in nature than that of Los Angeles, and does not increase travel distances as much as one would expect.

People appear to find places to live closer to work. As mentioned earlier, Delhi may be functioning as a combination of many small cities in close proximity without an important CBD forcing long commutes.

  - The average distance travelled per year by car in Delhi is less than in most large US and European urban areas (~18,000 km/year).
  - Annual distance travelled by cars and MTW is similar in Delhi probably because the owners of both vehicles live and work in similar locations and their trip distances are not too long.

- All Indian cities have average densities greater than 100 persons per hectare which is much greater than large cities in high income countries (< 50 persons per hectare). This makes it easier to plan for sustaining non-motorised and public transport mode shares in the future.

Influence of urban settlement and mobility patterns on future AV use

The future urban transport scenario in large urban areas may have the following characteristics:

1. Relatively high density sprawling cities with polycentric activity nodes enabling relatively short trips
2. Car use limited to less than 20% of all trips, and non-motorised trips may remain in the range of 30%-40%.
3. At least 90% of all cars and taxis costing less than US$ 20,000. This will limit the penetration of fully AVs to less than 5% of the fleet.
4. Public transit will probably comprise medium capacity (< 20,000 passengers per hour per direction), high-density (lines per square kilometre) systems. These arrangements will need dedicated lanes for buses, and route taxi systems.
5. With greater provision of route and shared taxis, MTW share may reduce in urban areas.

If the above scenario plays out in 2030, then the role of AVs may be predicted as follows:

1. Since AVs may mimic chauffeur driven private vehicles of today, they are not likely to reduce vehicle use or kilometres driven.

2. Penetration of AVs may be less than 5% of the vehicle fleet.
3. Because of high cost and low penetration levels, high degree of informality in trade and business, multicentric city structure, small AV will probably not influence urban labour markets, land use, and transit significantly in Indian urban areas in 2030.
4. AV may find and important role as large shared taxis operating on dedicated corridors for public transit.
5. AV may have a niche role for last mile connectivity between public transit nodes and large business/industrial establishments.
6. AV technology will probably be introduced in many areas of public transport and other niche functions in India.

AV ISSUES IN URBAN TRAFFIC

Safety and ease of movement

In addition to the urban mobility and affordability issues there are few other concerns that we must consider. The AV is expected to make our roads much safer as the route guidance technology does not allow it come into conflict with other vehicles and objects on the road. However, many experts are not so sure. A recent report sates, "The expectation of zero fatalities with self-driving vehicles is not realistic. It is not a foregone conclusion that a self-driving vehicle would ever perform more safely than an experienced, middle-aged driver. During the transition period when conventional and self-driving vehicles would share the road, safety might actually worsen, at least for the conventional vehicles" (Sivak and Schoettle 2015b). The last point would be especially true for Indian roads where the AV would have to share the road with MTWs, non-motorised vehicles and bicyclists. Figure 9 shows traffic in present day Beijing where per-capita income is more than two times that in Delhi. In 2030

Figure 9. Traffic at a junction in Beijing, China.

it is likely that Delhi may be similar in a business as usual scenario.

The safety characteristics of the AV make it unforgivingly polite. It has to stop if it senses that it might impact another vehicle or object. With pedestrians, bicyclists and MTWs weaving their way around vehicles on urban roads an AV might find it difficult to move. Pedestrians and bicyclists could stop them from moving by just stepping in front of the vehicle.

The AV needs to keep specific longitudinal and lateral distances from adjacent vehicles to ensure safety. These distances increase with speed and remain fixed as specified in the software. With MTW weaving around the AV it is possible that the AV will slow down and to maintain the appropriate distances and brake very frequently. This could have adverse consequences on the safety on non-AV MTWs and slow down traffic.

Motion sickness in AVs

Many individuals, especially passengers, experience motion sickness in vehicles because of conflict between vestibular and visual inputs, inability to anticipate the direction of motion, and lack of control over the direction of motion. A report calculates the expected frequency and severity of motion sickness in fully self-driving vehicles and estimates that 6%-12% of adults would be expected to experience moderate or severe motion sickness at some time (Sivak and Schoettle 2015a). This is because none of the passengers would be driving the vehicle, and therefore, have greater dissonance between vestibular and visual inputs.

While the issue of motion sickness is not a major issue, in a limited marked in India it is possible that it may reduce the penetration of AV in the market share.

Increase in vehicle use

AV in high-income countries are expected to increase shared vehicle use, but this may not result in reduce in total vehicle distance travelled. Preliminary results indicate that each AV can replace around eleven conventional vehicles, but adds up to 10% more travel distance than comparable non-AV trips (Fagnant and Kockelman 2014). Since AV in personal use in India may replace chauffeur driven cars that probably do higher annual mileage than self-driven cars, the increase in annual

Figure 10. Children in crowded vans and auto-rickshas being transported to school.

mileage by AV may not have a significant effect in India. Actual figures for car sharing in India are not available, but anecdotal evidence suggests that this may be much higher than in US and Europe. Young professionals form car pools, private buses and cars run shared taxi systems, government and private employers provide shared car and bus facilities for transport to work, and many children go to school in crowded auto-rickshas and vans (Figure 10). In light of the current scenario it is unlikely that expensive AV will replace the current sharing systems in any significant numbers.

ROLE OF AV TECHNOLOGIES IN INDIA

The fully functional AV will be able to automatically generate a route from the user's current location to a desired destination. To be able to do this The AV includes a host of sophisticated technologies which include: advanced driving system sensors, system to produce optimal estimates of the braking system, computer control of turn signals, hazard lights, dim bright headlights, door locks, ignition, and the horn, controllers that allow the lateral tracking error to be limited to within 30cm even for sharp turns and high-speed driving, work zone detection and three-layer safety system. It is almost certain that some of these technologies will be used in vehicles other than cars. Some of these applications may be very useful and find wider coverage than in cars alone.

Surface public transport systems

Surface transport systems are likely to remain the main stay of urban mobility for a long time. These systems will need to combine the flexibility of buses and vans and the efficiency of metro transit systems. As mentioned earlier, Indian cities are unlikely to redevelop high-density central business districts and will

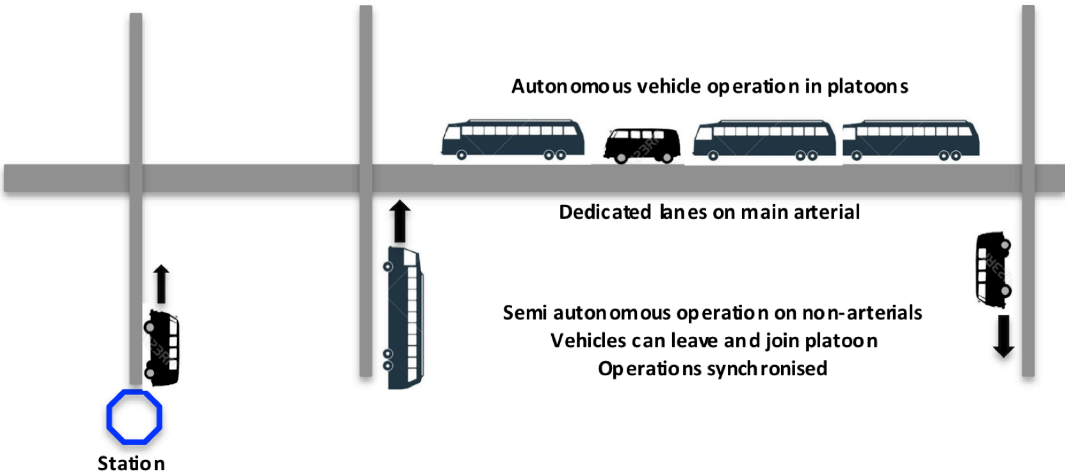

Figure 11. Autonomous and semi-autonomous vehicles participating in a citywide synchronised public transport system.

continue to develop as multi-nodal cities with large populations. Such cities will need dense medium capacity multi-modal transport systems that are flexible and able to run vehicles in platoons. The technologies being developed for the AV can be used to great effect in such systems.

Figure 11 demonstrates the concept where semi-autonomous vehicles (buses and vans) operate in platoons on dedicated public transport lanes on the main arterials of city. These vehicles would be able to operate with very small gaps and move at speeds of metro systems safely. Vehicles will be able to leave or join the platoon on the main arterial from non-arterial roads and move with driver assist systems on the minor roads. The future technologies would enable these movements to be synchronised so that the platoons can keep moving smoothly and efficiently.

This system should make it possible to directly link origins and destinations so that most commuters do not have to change buses/vans in a journey. The flexibility of the system will allow changes to suit transportation demand and changes in land use over time. It is possible that such systems may have efficiencies greater than present rail based grade separated metro systems at a fraction of the cost. The money saved on expensive infrastructure would more then offset extra cost of autonomous vehicle systems. Use of AV technologies could integrate high occupancy shared vehicle/taxi systems with transport systems and provide very efficient mobility options round the clock in low and middle-income polycentric cities at relatively low cost.

Freight delivery systems

The availability of dedicated lanes and automated transit technology would make it possible to design very flexible freight delivery system especially during off-peak hours. Many reports suggest that freight trips may account for almost one-third of all trips in a city (VREF 2012, Dablanc 2007). Large manufacturing centres and permanent logistic installations are moving away from urban territories and movement of freight vehicles in major cities poses particular problems for residents and commerce. In megacities with major ports, airports, distribution centres, and multi centric business centres this is becoming a major problem. Freight movement activities are important contributors to the local economy, but at the same time generate significant externalities in the form of pollution, traffic accidents, congestion and noise. Because of these problems over the years, large truck movement has deteriorated in many cities, and paratransit in the form of small trucks/vans and non-motorised goods carriers have filled the gap (VREF 2012, Sadhu, Tiwari and Jain 2014) .

More dense development and mixed land use in large multinodal megacities has further complicated the movement of freight. It is possible that intelligent use of AV technologies to coordinate freight movement during the night utilizing the automated public transit network may solve dome of these problems very efficiently. Such solutions may become essential in Asian megacities as the volume of internet based home deliveries become a large proportion of fright movement all over the city.

Niche applications

There will also be a number of situations where AV application would be justified as their use would replace more expensive less flexible systems or operations in hazardous and polluted zones. Some of these possibilities are listed below:

- Operations in mines and quarries.

- Transfer between airport terminals and other mass transit centres.
- Commuter dispersion from large transit centres and inside large commercial/industrial complexes.

CONCLUSIONS

Large Indian cities are likely to remain high-density sprawling cities with polycentric activity nodes enabling relatively short trips with car use limited to less than 20% of all trips, and non-motorised trips may remain in the range of 30%-40%. Even in 2030 at least 90% of all cars and taxis sold may cost less than US$ 20,000 and this will probably limit the penetration of fully AV to less than 5% of the fleet.

One way to imagine the role of AV in the future is to examine how personal chauffeur driven cars and taxis are used today. For the owner these vehicles perform similar roles as the AV of the future. Like chauffeur driven cars AV are not likely to reduce miles driven or number of trips per day. In addition, current wisdom suggests that people have similar time budgets across incomes and countries and they don't save time if given faster mode of transport (Crozet 2009, Hupkes 1982, Kent 2014, Schafer 2000, Kung et al. 2014, Metz 2008). The average number of trips per day (including all walk and bicycle trips) also seems to remain relatively constant in the range 3-4 (Knoflacher 2007, Giuliano and Narayan 2003, Hupkes 1982, Santos et al. 2011, Zegras 2010, Transport for London 2011). Therefore, it is unlikely that AV will have a significant influence on the way personal vehicles are used in India in 2030.

Public transit will probably comprise medium capacity (< 20,000 passengers per hour per direction), high-density (lines per square kilometre) systems. These systems will need dedicated lanes for buses, and route taxi systems. With clever adaptation AV technology may play an important role making surface transit systems much more efficient, convenient and reliable at costs lower than expensive metro systems of today. These systems may also provide some relief for movement of freight efficiently with use of AV during off peak hours. There is also a great deal of hope that AV might provide accident free transport on our roads in the future. However, since their penetration is likely to be very limited in the low and middle income countries it is unlikely that we will see much safety benefits overall.

Therefore, it is very necessary that we continue to develop and implement safer designs of vehicles, roads and infrastructure for the foreseeable future.

We do not see fully functional autonomous vehicles to have a major influence on urban labour markets and land use in the future because of their low penetration in the market. However, it is possible that AV technologies will make commuting by public transit more efficient and thus maintain personal vehicle use at present low levels. This should bring greater overall efficiencies in matching job supply and demand, and promoting social interaction and trade in the city.

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