A vision for sustainable mobility through autonomous vehicles in city planning

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Abstract. It is estimated that there will be an increase of more than 2.5 billion in the urban population by 2050 especially in Asia and Africa. Urbanization has a major impact on the transport energy use. Globally the number of vehicles is estimated to double its current volume. Cities need to be designed for safe accessibility and sustainable mobility. Apart From focusing on reduced carbon emissions, well networked transport systems and reduced congestion, creative solutions need to be envisioned for the vital flow of people, goods and services. The main Objective of the study is to understand the potentials of Autonomous vehicles as a key to sustainable mobility and Safe accessibility. The study also examines current trends and future predictions in technological advancements, its importance in safer and cleaner drives through review of literature. The key performance indicators considered are the Economic, Environmental, and social Impacts. The critical challenge lies in forecasting the impact of the paradigm shift to complete autonomous systems by consumers and businesses. Optimization model and simulations are carried out by various researchers to understand the future trends and scope of autonomous mobility. The idea faces numerous criticisms due to technical constraints and user attitudes. Further investigation in this domain will be instrumental in developing a vision focused on autonomous vehicles as a key to sustainable mobility in future cities.

Keywords. Sustainable mobility, Autonomous vehicles, Energy efficiency, Transport systems, Environment, City planning, Future Cities.

1. Introduction

Urbanization is the movement of people from rural to urban areas in search of better economic opportunities and standards of living. The rapid growth in population and change in demographics are major drivers responsible for growth in transport sector. 10% of the world population contribute to 80% of the overall motorized passenger – kilometer. Transportation systems need to fulfill the basic requirement of safe and accessible movement for individuals and organizations. Transport systems are the major contributors to the Greenhouse gas emissions with a 23% contribution to the CO2 emissions. The direct emissions from transport is given by 

\[ \text{Total GHG Emissions} = \sum \text{Modal shares} + \sum \text{Fuels}. \]

Modal shares can be further broken down into urban form, transport infrastructure and choice between modes. Fuel component can be broken down into Carbon Intensity, Energy Intensity and Activity. A
A holistic approach towards Mobility, Energy efficiency, and climate change will help in the development of more sustainable Transport principles[1]. The ideas for sustainable transportation are necessary to ensure clean and healthy living environments. Transportation infrastructure and activities have a significant impact on parameters of sustainability as indicated in Figure 1. [2]

The 2030 Agenda of the United Nations Sustainable Development Goals [SDG] outlines the way forward for sustainable transport systems along with universal accessibility, affordable modes, reliable systems, and resilient cities for all. A good knowledge of different modalities of travel will allow us to understand sustainable concepts in its implementation. Non-motorized transport, Electric vehicles, Clean energy-based systems have been of much interest to many researchers in recent times. The SDG focusses on many such aspects of sustainable transport in which Sustainable mobility has a greater role in achieving the outlined targets.[3]The Technological advancement in areas such as ICT, IOT, Artificial intelligence have kindled the research interests of many in view of future proposals in the domain of sustainable mobility. The 3 major revolutions in the sustainable transport sector can be termed as Alternative fuels, Autonomous vehicles and Shared mobility. One key area of interest is the transition to self-driving systems, that are autonomous in nature. This shift in transport systems to autonomous vehicles has been envisioned as one of the creative solutions to handle the major challenges of the urban form like proximity, traffic congestion, greenhouse gas emissions and climate change. Humans have always been in control of any vehicle they have manned. Over a period, various methods of automation have been incorporated in vehicles along with navigational assistance. Autonomous vehicles and connected vehicle technology use artificial intelligence, cameras, sensors and LIDAR, to gain the control from the direct human interface.[4]

This paper is a discussion on literature towards how these technological innovations can promote sustainable mobility and safe travel for future generations and how it can help in making our cities better and more liveable. Though technological advancements have reached unimaginable heights in the past few decades, there are also some deep rooted uncertainties in the human perceptions of autonomous vehicle systems. The paper also tends to explore future trends and the difficulties that are anticipated when these innovative concepts are implemented. Future research in solving these complex uncertainties will allow us to understand and develop a more efficient, cleaner and greener mobility systems aimed at improving the quality of life.

2. Methodology
The methodology adopted is the literature review of key areas connecting sustainable mobility and autonomous vehicles. A systematic analysis and review of past literature was conducted in 4 parts as indicated in Figure 2.

Figure 2: Flow chart indicates the methodology adopted to focus on key areas of interest.

The summary of the readings were directed towards two components – Opportunities and risks of Implementing Autonomous vehicles and Its impact on the future of city planning. The conclusions arrived gives a brief description of both the positive and negative aspects of autonomous vehicles and addresses the gap in the research and possibilities to innovate further.

3. Sustainable mobility
Sustainable development was conceived as an effective method to sustain any ecosystem by itself over a long period of time. With reference to transport is defines the construction of a new ‘sustainable mobility area’ [SMA]. Early studies in 1992, responded to the sustainable challenge by introducing the term ‘sustainable mobility’. It encompassed the guidelines for environmental standards, emissions from vehicles, promoting eco friendly modes of commuting and regulation of transport infrastructure. In the years between 1992 – 2000 the major issues revolved around the need to reduce use of motorized vehicles. A thesis by Karl Georg Hoyer [2000] identifies 7 measures to promote sustainable mobility. They are – Reducing mobility, reducing infrastructure, reducing pollution,change in modalities, alternative fuels, and energy efficiency. Between the years 2000 – 2005, Dependance on cars created social problems and patterns of unsustainable transport. Policy decisions were required to sensitise use of transport systems, pedestrian safety and accessibility of the road for all users. The studies focussed more on improving the quality of life. The three approaches outlined were Efficiency, alteration and Reduction as indicated in Table :1.[5]
Table 1 – The three approaches towards sustainable mobility.[5]

| Policy Orientation | Information | Regulation | Technology |
|--------------------|-------------|------------|-------------|
| Efficiency         | Adapt energy efficient vehicles. | Regulating the use of efficient vehicles, by more inspection, maintenance and retirement of existing vehicles. | Develop energy efficient vehicles. |
| Alteration         | Adapt use of NMT and Public Transport – efficient modes of commuting. | Encourage alternative modes through Reduction in passenger fares, providing subsidies, incentives for Public transport. | Efficient system through Automatically guided vehicles. |
| Reduction          | Reduce Travel kilometres and travel time. | Reduce travel through Efficient land use planning and smarter logistics. | Development of Information and communication technologies. |

Figure 3: Relationship between various elements that contribute to sustainable mobility [5]

$$SM = f \{(TE+PT+GA+LU) + [(TE*PT)+(TE*GA)+(TE*LU)] + ... + [TE*PT*GA*LU]\}.$$
[TE – effects of technology, PT – Use of public transport, GA -Green attitudes, LU – Land use, SM – Sustainable mobility]. The formula is only an illustration that indicates the complexity of the relationship between the elements to achieve sustainable mobility as indicated in Figure 3. [5]

3.1 Inclusive mobility and Safe accessibility

Much more growth in the passenger transport in the following decades are expected to occur in the cities, especially in developing countries. This will have a major impact on air pollution, climate change, congestion and passenger safety. To create a transformation in the transport sector and provide inclusive access there has to be a paradigm shift to design for people. Good access to amenities, employment and services should be strategically employed. The design of transport infrastructure can be should be guided by 3 approaches i.e avoiding unwanted trips, shifting to efficient modes, and improving environmental performance through technology.

![Figure 4: Illustration indicating the application of Avoid - Shift - Improve concepts][6]

The illustration in figure 4 demonstrates varied solutions that can bring about inclusive designs. These solutions provide multiple benefits in combining other environmental needs. Safety of the passengers becomes a primary factor in inclusive design. Current global trends suggest that road accident deaths will be the 5th major cause of fatalities by 2030. Road safety in developing nations are a cause of concern due to poor design, poor maintenance and poor governance. The UN General Assembly proclaimed to stabilise the increasing fatalities by following action of safety for a decade. An improvement in quality of transport, personal safety, accessibility to remote areas are highly necessary. Comfortable and convenient transport solutions are the key to principles of accessibility. This in turn will help in designing secure urban zones that can promote use of public transport, walking, cycling, NMT which can have a positive impact on the lives of people.[6]

3.2 Intelligent transportation systems

ITS Applications have enabled for dynamic management of traffic including electronic automated tolling, navigation systems, automated parking guidance, warning systems etc. Real time mapping of Traffic details help the drivers to avoid congestion zones and reroute themselves. Future innovation may allow Vehicles to interact with each other and the infrastructure [7]. In this lineage autonomous vehicle (AV) can be considered as a creative solution to modern day traffic problems. They follow the avoid-
shift-improve approach discussed in the section 3.1. They are connected with each other and can communicate amongst themselves. Though certain risk factors like conflicting data hacking and cyber security are associated with them, needs to be addressed their appeal has improved significantly. With an increased focus on affordable, secure global networking to improve social and economical progress technological advancements can pave the way to future advancement in sustainable transport mobility.[8]

4. Potentials of Autonomous Vehicles

Autonomous vehicle is capable operating without human involvement by sensing its environment. A human is not required to drive the vehicle. Society of Automotive Engineers (SAE) has defined 6 levels of driving automation.

| Automation Level | Description |
|------------------|-------------|
| Level 0          | No automation                                      |
| Level 1          | Autonomy of one primary control function, e.g., adaptive cruise control, self-parking, lane-keep assist, or autonomous braking |
| Level 2          | Autonomy of two or more primary control functions “designed to work in unison to relieve the driver of control of those functions” |
| Level 3          | Limited self-driving; driver may “cede full control of all safety-critical functions under certain traffic or environmental conditions,” but it is “expected to be available for occasional control” with adequate warning |
| Level 4          | Full self-driving; driver “is not expected to be available for control at any time during the trip” (includes unoccupied vehicles) |
| Level 5          | Full self-driving without human controls |

Autonomous vehicles work by collecting data from sensors, camera, lidar, ultrasonic then process them with complex algorithms, hard-coded rules, machine learning systems, predictive modelling, software and powerful computer. Computer directs the actuators which intern drives the vehicle. [10]

Figure 5. Technologies in Self-Driving Car. [12]
Autonomous vehicles have advantages such as a higher safety level, reduce accident, reduced emissions due to optimized speed, car-to-car/car-to-infrastructure communication, more mobility options for disabled or older people, use the drive time for other activities, ease congestion, reduce parking needs etc.. [12]

5. Performance Indicators
Autonomous vehicles are poised to shake up multiple industries including vehicle manufacturing, shipping, public transportation, and emergency transportation. [11]. Author of Smart Urban Mobility Report Sustainable Mobility Project 2.0 (SMP2.0) described 22 indicators to be used by cities to identify their sustainable mobility performance. (Example indicators such as congestion and delays, commuting travel time, mobility space usage, access to mobility services, traffic safety, comfort and pleasure, intermodal connectivity and occupancy rate). [12]. Success of the autonomous vehicles and its infrastructure ecosystem can be judged by following broadly classified indicators

5.1. Economic impacts
It is been predicted that autonomous vehicles will contribute about $800 billion saving annually when it is fully deployed. The economic benefits will come from cost savings related to following points - reduced crashes, fuel efficiency, better access to transportation, reduced cost of labor (drivers), reduced travel time, less infrastructure expansion, reduced health care by preventing accidents, new economy, new job opportunities,[13] reduced accident probability, reduces vehicle insurance premium cost and reduced cost per kilometer for consumer and business. While the economic benefits and cost saving is more, there is also negative impact in terms of temporary job loss, additional investment in smart city technologies and continuous research for improvement.

5.2. Environmental Impacts
While there is great potential to reduce environmental impact of road vehicles, environmental impact of autonomous vehicles depends vastly on implementation method. Advantage of autonomous vehicle like less fuel consumption, less cost per kilometer, time efficiency reduces the impact on environment.

Air quality can be improved by use of better power train technology like battery electric vehicles (BEVs) or hydrogen fuel cell vehicles (HFCVs), Land use reduced by autonomous vehicles by increased road use and decreased parking requirements. Even though larger, more luxurious vehicles or higher average speeds would also increase energy use overall environmental impact should be reduced if autonomous vehicles are widely used. [14] Autonomous Electric Vehicles have zero tailpipe emissions. In countries that use relatively low polluting energy sources for electricity generation, EVs would have low emissions than similar conventional powertrain vehicles. [16]

5.3. Social Impacts
Autonomous vehicles have the potential for shared mobility service (one car used by many separately) which in turn makes autonomous cars availability for personal mobility much easier. This will enable common man and make the personal transport available for all evenly. With shared mobility people inside small autonomous vehicles can socialize more, bringing more people together. People can concentrate on more family time, creative time and work time inside autonomous cars.

5.3.1. Accepting Autonomy. Currently the prospect of autonomous vehicle driving itself around might seem terrifying because of lack of trust, but we have to keep in mind that world is already filled with numerous automated systems that make our lives easier, safer, and more enjoyable. We trust the human driver who is driving the car similarly we have to learn to trust the autonomous vehicles in smart city environment since the probability of accident is projected is very less or negligible when comparing to current scenario. Also, we have to remember, that in airplane majority of flight time is with plane’s autopilot system and pilots primarily focus on navigation, system monitoring, and communication. [11]
Also, there is a fear that autonomous vehicle mobility may hinder on the human right to freedom of mobility by giving control to smart city systems.

6. Current Research Trends

- **Cameras**: Camera spots things like lane lines on the highway, speed signs, and traffic lights.
- **Lidars (light detection and ranging)**: Lidar fires millions of laser beams every second, measures time taken by the laser to bounce back, and uses the data to build a 3D map that is precise and easier for a computer to understand than a 2D camera image.
- **Machine Learning**: Artificial intelligence tool trains computers to do things like detect lane lines and identify cyclists and pedestrian by showing them millions of examples of the subject at hand. It is key for vehicles to learn from experience and figure out how to navigate on their own.
- **Maps**: Autonomous vehicles use existing detailed maps as reference document to verify its sensor readings, it is key for autonomous vehicle looking to know its own location down to the centimetre.
- **Radars**: Radars bounce radio waves around to see their surrounding and are especially good at spotting big metallic objects such as other vehicles. Radars work in fog, rain, snow so they are reliable. [15]
- **Green Powertrain**: Currently Lithium Ion battery and Hydrogen powered powertrain vehicles are being used as alternative to internal combustible engine.

7. Future Research Trends

7.1. **Vehicle to Vehicle (V2V) Communication**
Seamless, fast & latency-free high-speed network allows autonomous cars to communicate with one another and exchange information about their current position, route, and hazards on the road. This information can be relayed to the car behind so that it can begin braking and adjusting its route.

7.2. **Interconnected Vehicles**:
Network of interconnected vehicles could alleviate traffic congestion since vehicles will be able to make intelligent decisions about their current route to maintain a steady rate of vehicle flow.

7.3. **Vehicle to Infrastructure (V2I)**
Self-driving vehicles connected to high speed network will be able to communicate with different infrastructure elements that make up our roads and other transportation systems helps in finding reserving vacant parking, plan route in advance.

7.4. **Vehicle to Pedestrian (V2P)**
By communicating with pedestrian personal devices autonomous vehicle will be able to react dynamically to the pedestrian with collision prevention measures like braking and automatic steering, which makes sure our streets are much safer to travel by foot.

7.5. **5G Network**
Advent of 5G is the most crucial development for autonomous vehicles. The technology allows vehicles to effectively communicate to one another, collaborate. 5G promises to be close to 1000% faster than 4G LTE which is currently available, which will make connection woes such as high latency and long response times a thing of the past. We are fast approaching a world dominated by IoT devices, where everything, be it a motorized vehicle or a traffic light, will be connected to a high-speed network of some sort, enabling all sorts of new and exciting functionality. [15]
7.6. Sensor Fusion
Data from the key sensors in autonomous vehicles: camera, radar, and lidar is fused together for 3D object detection, moving object detection, tracking system and occupancy grid mapping used for navigation and localization in dynamic environments. Including more sensors into sensor fusion system benefits with better performance and the robustness of the solution, improves the perceived model of the environment. Sensor fusion has a crucial role in autonomous systems overall.

7.7. Mobility Patterns
The monitoring of mobility patterns can be used to study driving behaviour for improving traffic flow through a reduction of traffic congestion and an increase in road safety. Mobility patterns are the big-picture sets of information that show people’s habits and routes. Therefore, mobility pattern information is crucial in providing personal multimodal mobility services as it can guide technological applications in suggesting travel routes and creating new habits. [12]

7.8. Improvement to Energy Technology
Currently the research focus is on improving the efficiency of lithium ion battery to reduce recharging time and increase range of the electric powered cars. Also, research focus to increase solar, wind and wave power generation capacity and efficiency, thereby reducing greenhouse gas emission from the source.

8. Discussions

8.1. Opportunities and Risks
- Autonomous vehicles may become prone to cyberattacks and humans may be one of primary carriers of the attach. One point of failure may jam the completed network or worst create pile up of accident. Hackers may take control of the individual vehicles or complete network which may lead to total catastrophe. Here is an opportunity to improve security of autonomous vehicles. [9]
- People and vehicles share the same road space which leads to accidents. The smart city technologies and autonomous vehicles in combination can better visualize the presence of humans and animals on road and take preventive action to prevent human and animal loss of life.
- Vehilces to vehicle location awareness could be used to improve travel time, reduce greenhouse gas emission, environmentally friendly, reduce vehicle to vehicle accident and improve safety.
- Traffic Data collected from Urban Cooperative Systems can be used to collect travel time which in turn can be used to effectively manage traffic, control and flow optimization reducing costs related to logistics.
- There is a question how autonomous vehicle sense weather (rain, snow, storm..) and how it will react to more adverse weather condition autonomously. And also, in case of water, oil, ice, debris….
- Whether new law needed in case there is an accident involving the autonomous vehicle, this creates an opportunity to study and start formation of draft law. Also, there are more open question, who will be liable for accidents by autonomous cars.
- With autonomous vehicle bringing in less travel space that is less space required in road due to its time efficiency, cost of future infrastructure upgrade could be reduced.
- Fuel consumption is reduced in autonomous vehicle because of uniform style of driving, less time in signal stop, less time of travel... which ultimately helps in conserving energy
- Passengers in autonomous cars will have more time which can be used for personal productivity, more reading time, more sleep or work while travelling. More importantly you are not tired of driving while driving to office which may increase your productivity at the office.
- Autonomous vehicles and smart city systems can take trauma care patients to hospital quickly by prioritising the emergency vehicle space which will save more human life. [11]
- Using battery operated autonomous cars would reduce Greenhouse gas emission in the urban streets which in turn would lead to reduced air pollution related health problems and improve urban environment in the cities.

8.2. Impact of AV on The Future of City Planning

Land use and Transport systems are intrinsically connected. In the previous sections we have seen the how technological advancement and innovations can help in reducing travel time, passenger safety and accessibility. The advent of Autonomous vehicles and connected technology can help in conceptualizing better cities for the future. Planners and Designers need to re visit the fundamentals of land use planning and how efficiently it can be utilized to plan and develop future cities. The primary idea of these connected transport technology is to reduce congestion and improve safe travel. Urban planners can combine the different data sets to integrate sustainable mobility solutions and examine the need to attain socio economic and environmental objectives.[17]. A complete autonomous experience needs to work on all road conditions and should be supported by existing and future infrastructure. [18]. The major shift in planning aspects will be focussed on mixed use development, which will resolve the need to travel more and save fuel consumption. As the amenities are available at shorter distances, a smaller number of vehicles will be active on the road. Less number of vehicles in turn indicate reduced carbon emissions and reduced levels of air pollution. The connectivity between the vehicles can be tracked real time and the data can support creation of junction or traffic signals to relieve the congestion again reducing fuel consumptions and pollution. Some of the major changes anticipated in the future of city planning are conversion of parking lots to greener lung spaces, change in land use to mixed use development, Narrower ROW for automobiles and exclusive lanes for cyclists, pedestrians and NMT. Shared mobility systems will also cut down on individual garage spaces in the housing sector, allowing for more private spaces in the total built up area. Another point of debate involving AV is urban sprawl. Though accessible mobility will be a prime reward of AV, it is still not very clear how it will impact the spread of the urban area into the rural regions. With relevance to impact on city and town planning there is a definite scope to improve traffic management and control systems. Compact and dense settlements would be another outcome of these sustainable mobility concepts. [19] Further investigations needs to be carried out to understand the impact, autonomous vehicles will have on urban sprawl trends and growth dynamics. But overall, we are expected to see a paradigm shift in the design of cities, from being vehicle centric to more human – centric in the coming years.

8.3. Conclusion

After the initial review of available literature in this domain certain key points could be focused upon before implementation of autonomous vehicles & related systems. It is important to understand and predict all the methods and probabilities of cyber-attack and take preventive measure and develop policy before allowing autonomous vehicle on the road. As a standard rule there could be a manual override switch for all vehicle systems even at level 5 autonomy. The basic right to mobility could be kept in mind while creating policy for Autonomous vehicles and these should be designed in such a way that it is 100% in line with human rights to free mobility. Humans should cooperate with autonomous systems to realize its full potential. Autonomous system should be biggest aid for human passenger driver and humans should have always have the power to take over.
The source quality of electricity is directly proportional to effect of the emissions from electric vehicle on environment, so it is also important to move towards greener energy source to reduce effect on the environment. True economic and environmental benefit of autonomous vehicle could be realised only by implementing alternative and greener power train technology along with autonomous technology. These would be hot topics of interest especially when more research could be focussed on less energy consumption and reduced emission of greenhouse gases, which in turn can assist in moving towards sustainable mobility. Huge gains in energy can be anticipated with lesser trips and compact city planning concepts. This could be a potential area in the research of alternate modes of transport systems and mitigate the energy crisis due to depletion of the available natural resources.

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