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Research Article

The Adoption of Autonomous Vehicles: A Socio-Technical Transition Perspective

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ABSTRACT

This paper reviews the autonomous vehicle (AV) trials around the world and proposes a socio-technical transition (multi-level perspective) approach for facilitating the adoption of AVs in countries. Built on a comprehensive literature review and a review of ongoing AV trials and tests around the world, this paper utilizes both theoretical and empirical approaches in understanding the dynamics of AV adoption. Three AV transition models (government support, industry push and public transport oriented) are proposed to help countries introduce and adopt AVs as part of their transport systems.

Keywords: Autonomous Vehicles, Socio-Technical Transition, Multi-Level Perspective

1. Introduction

Autonomous vehicles (AVs) offer a unique way of organizing transport and mobility for the cities, regions and countries around the world. They introduce a new perspective of understanding mobility (Howard and Dai, 2014). The transition to AVs presents unprecedented challenges as it is expected to influence the entire transport system. The changes in road infrastructure, user perceptions and preferences, travel demand characteristics, road safety, efficiency of transport operations and emissions necessitate a novel perspective in understanding this transition process. Many countries around the world have been seeking to lay the groundwork for the introduction of AVs with legislative changes and policy documents to guide this transition. While 22 states in the USA have enacted legislation related to AVs (NCSL, 2018), the UK Government has been financially supporting and guiding various AV projects to position itself at the forefront of AV research, development and use (CCAV, 2018). The European Commission has recently drafted a legislative assessment report evaluating the liability rules and insurance for the AVs (EAVS, 2018).

Numerous AV trials and pilots with diverse modes and on diverse settings are being undertaken in many cities around the world. Vehicles being tested for private and public passenger use include automobiles, shuttles, minibuses, pods and buses, whereas vehicles for goods transport include trucks, drones and vans. Tests are being carried out in pedestrianized areas, designated zones and corridors. The local and national governments, the industry and universities are the key actors in those trials, however the lack of collaboration and co-ordination among them may impede the effectiveness of these initiatives. Scarce resources and past experience of innovation diffusion suggest that collaborative policies maximize economies of scale and the dispersion of benefits (Dodgson, 2018). The adoption characteristics of AVs as an innovative mobility option embody the features of the innovation diffusion theories, and categories of the adopters include: innovators, early adopters, early majority, late majority and laggards (Rogers, 2010).

AVs are still in development phase and it is critical to understand the transport policy implications of AV development so that policies can be calibrated early on to guide the desired AV future. Although the future development of AVs has been examined in the literature, a comprehensive perspective taking into account the current state of practice and future pathways is still lacking. A holistic framework is needed to conceptualize the current AV landscape, the transition and adoption processes as well as the future development of AVs. Multi-level perspective (MLP) as a socio-technical transition approach provides such a framework. This study seeks to contribute to the AV literature by proposing an MLP perspective for understanding the transition to AVs and the implications on transport policies.

Section 2 gives a literature review of the AV research as well as socio-technical transition and MLP literature. Section 3 presents the methods and materials used in this study and the current AV landscape. Section 4 proposes an MLP perspective for understanding the adoption of AVs. Section 5 proposes three AV transition models and discusses the role of institutions in AV adoption and its relationship with transport policies. Lastly, Section 6 concludes the paper.

2. Literature Review

In this section, a literature review for AVs, socio-technical transitions and multi-level perspective (MLP) is provided.

2.1. Literature Review for AVs

The literature about AVs has been scarce in previous decades, yet there is an exponential growth in the number of publications since 2013, attracting interest from diverse audiences. There is a wide variety of research themes being focused for the AV literature. The benefits and advantages of AVs along with the concerns and disadvantages are the primary research theme touched upon in almost every study. The barriers for the AV adoption, transition and diffusion of AVs, implementation cases and shared AVs are the other major topics examined in the literature. Table 1 provides an indicative classification of the current literature within the transport domain, based on the AV research themes, which can also help pinpoint the research gaps. The table provides the name of authors, keywords, and AV themes.

Theme	Keywords	Authors
AV Advantages	Increased safety	Fagnant and Kockelman, 2014; Kockelman et al., 2016; Litman, 2017
	Time efficiency	Fagnant and Kockelman, 2015; Santana et al., 2021
	Efficient use of resources	Chen et al., 2016; Zachariah et al., 2014; Fernandes and Nunes, 2010
	Increased comfort	Anderson et al., 2014; Brown et al., 2014; Wadud et al., 2016
	Increased accessibility for disadvantaged groups	Burns, 2013; Lutin et al., 2013; Meyer et al., 2017
	Increase in shared transport options	Haboucha et al., 2017, Lee et al., 2019
AV Concerns	Increased road capacity demands, and vehicle miles travelled	Fagnant and Kockelman, 2014; Childress et al., 2015; Meyer et al., 2017
	Increased urban sprawl	Meyer et al., 2017, Faisal et al., 2019
	High costs of AVs	Fraedrich and Lenz, 2014; Howard and Dai, 2014; Bösch et al., 2017
	Modal shift from public transport	Liu et al., 2017; Meyer et al., 2017
	Safety concerns	Bansal et al., 2016; Zhao et al., 2021
	Legal liability	Howard and Dai, 2014
	Health concerns	Fleetwood, 2017, Rojas-Rueda et al., 2020
	Increased energy consumption	Krueger et al., 2016
	Inconsistencies across states regarding AV regulations and licensing procedures	Fagnant and Kockelman, 2015
Transition, Adoption and Diffusion	User preferences	Haboucha et al., 2017, Saeed et al., 2020, Wang et al., 2020
	Mitigating uncertainties	Todorovic et al., 2017, Saeed et al., 2020
	Facilitating market transition	Fagnant and Kockelman, 2015
	Socio-economic modelling for market penetration	Berrada and Leurent, 2017
	Role of collaboration	Kato et al., 2015
Sharing AVs	Overcoming the initial high costs	Masoud and Jayakrishnan, 2017
	Behavior change from private automobile usage	Fagnant and Kockelman, 2014
	Energy implications	Ross and Guhathakurta, 2017;
	Public/Sharing AVs vs. Private/Individual AVs	Thomopoulos and Givoni, 2015
Other	Levels of Autonomy	SAE, 2014; Favarò et al., 2018
	Impact of AVs on energy consumption and carbon reduction	Wadud et al., 2016
	Impact on fuel economy	Mersky and Samaras, 2016
	Involvement of public health agencies to develop transport policies	Fleetwood, 2017
	Sustainability impacts	Acheampong et al., 2021

Table 1. Thematic Classification of the AV Literature.

Since governments at various levels still have the exclusive authority (e.g. USA, UK and Australia) to issue licenses for AVs, they can influence or actively direct the trajectory of AV development through adopted policies and regulations. The National Highway and Transportation Safety Administration (NHTSA) in the USA, for example, released new federal guidelines for AVs which include vehicle performance guidelines, model state policy, regulatory tools and safety standards (NHTSA, 2016). Whether AVs will contribute to a shared or personal mobility options is, to a large extent, dependent on the guidelines and directions provided or allowed by those governments. Therefore, understanding the policies on AV development is crucial. In this respect, a snapshot of current state of practice with a view to forecasting the future trajectory of AVs will help to better understand the role of policies in this transformation process.

The literature is far from giving a systematic analysis of the elements influencing the transition to various modes of AV-based mobility. The models based on travel demand and agent-based modelling are used to predict the adoption of AVs in transport. The impact of current regime elements such as vested interests, user routines or infrastructural inflexibility in hindering the adoption of AVs have not been adequately taken into account. It is assumed that users and markets respond to supply, demand and price signals in a transparent way based on their utility functions, overlooking the role of institutional lock-in and path dependence factors. Interdependence among key transport elements such as road infrastructure, travel habits, user preferences, extant policies may create a lock-in situation, which can impede a smooth transition to AVs. Several studies in the AV adoption literature have these assumptions, often taken implicitly (Haboucha et al., 2017; Todorovic et al., 2017; Berrada and Leurent, 2017).

The literature lacks a holistic and comprehensive framework to conceptualize the current AV landscape, which can help envisage the future transition to AVs. The framework should take into account not only the technical or technological features of this transition, but also the social and economic aspects. Therefore, a socio-technical transition perspective is needed to fill this gap in the literature. The next sub-section proposes the multi-level perspective (MLP) as such a framework.

2.2. Review of the AV Trials

To address the research problem, an extensive review of the current AV landscape around the word was undertaken in addition to the review of the extant literature. The review aimed to create a list of completed, ongoing, and forthcoming AV trials and initiatives. In the second step of the review, all AV trials are classified so that insights about the current AV landscape can be obtained. Table 2 shows the categories used to classify all AV trials and initiatives around the world:

Geographical Location	**Vehicle Features**	**Project Features**	**Testing Features**
Region Country City	Vehicle Type Passengers/ Goods Public/Private Sharing/Non-Sharing Energy Usage Self-Driving Level	Project Status Partners Involved Support Level	Test Setting Public participation AV-Public Engagement

Table 2. Categories of AV Trials

The role of cities in shaping innovation and transition is often underlined in the literature (Marletto, 2014; Bulkeley et al., 2010; Hodson and Marvin, 2010; Smith et al., 2010). Although most AV projects and trials are carried out in city-level, demonstrating a country-level AV state is helpful to have a global perspective. Figure 1 shows the list of all countries undertaking or aspiring to undertake an AV trial:

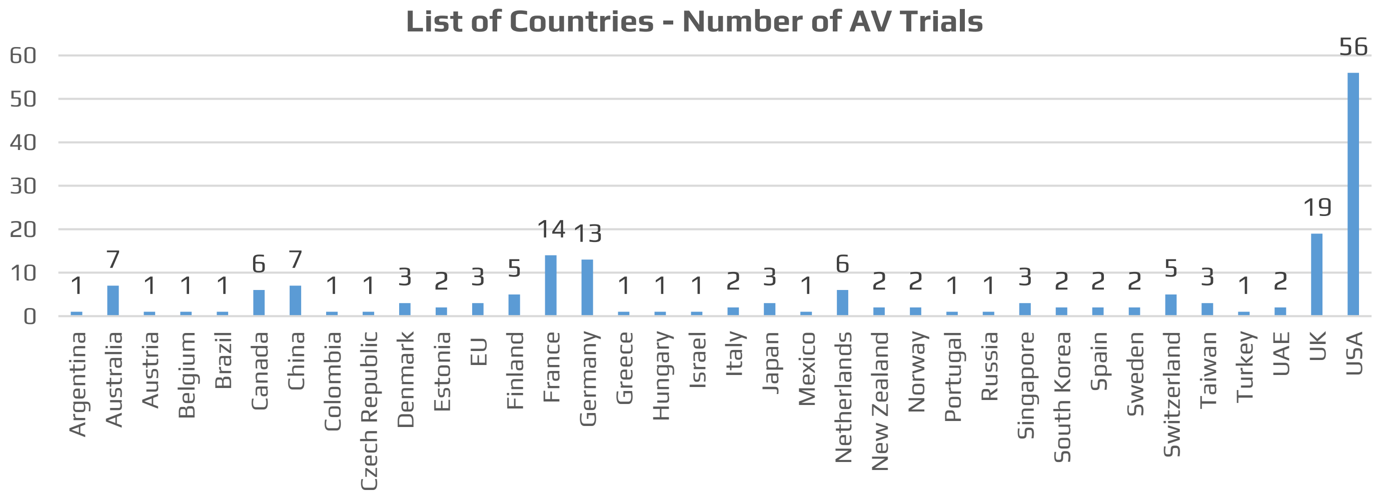


Figure 1. List of countries and corresponding number of AV trials

Table 3 shows the leading countries to emphasize the concentration of AV trials in a few countries. AV trials in USA, UK and France totally make up almost half (48,9 %) of all AV trials in the world and top 7 countries make up two third (67.0 %) of all AV trials in the world. USA and European Union (EU) countries can be argued to be leading the AV development in the world, with 56 and 65 AV trials, respectively (excluding the UK). The USA and Canada in North America and the UK, France and Germany in Europe are the leading countries in those regions.

Whereas in the USA the industry is the main driving actor, in the UK, the government plays a central role, directly supporting 17 out of 19 AV projects. This difference is highlighted in detail in Section 6 where three different transition models are distinguished based on the key driving actors.

Rank	Country	Number of Trials	Percentage (%)
1	USA	56	30,8
2	UK	19	10,4
3	France	14	7,7
4	Germany	13	7,1
5	China	7	3,8
6	Australia	7	3,8
7	Canada	6	3,3
8	Other countries	61	33,1
	TOTAL	183	100

Table 3. Leading Countries

In Turkey, AV trials have been quite recent, and a test has been conducted in the Gebze autonomous vehicle test zone, in partnership with the Automotive Technologies Research and Development Center at Istanbul Technical University (OTAM, 2020). Otokar, a Turkish bus manufacturer company, in partnership with Okan University developed and tested an autonomous bus (AA, 2021). There is no legislation or regulation yet for the use of AVs in Turkey. There is a lack of sufficient data and information in Turkey regarding how to adopt AVs in Turkey.

Figure 2 shows the project status of AV trials by 2020. Most of the AV trials are either ongoing or being planned, showing that it is still in the development phase. Therefore, it is still early to forecast the future of AV development. However, understanding the niche players, regime elements as well as wider landscape factors as suggested by the multi-level perspective can help us make informed predictions about the future. Yet, it is clear that currently it is the right time to shift policy and regulatory focus and formulate relevant transport policies given the increasing number of trials taking place in the near future.

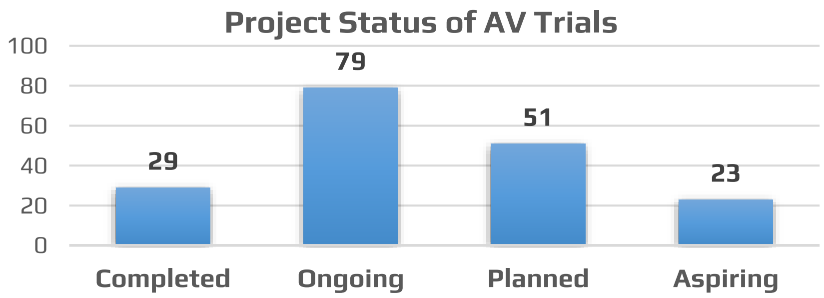
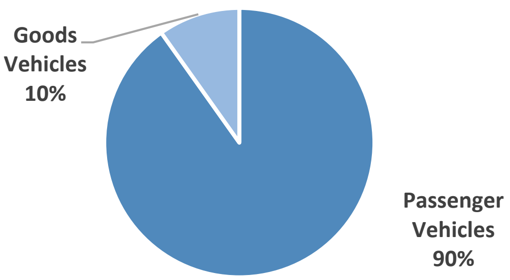
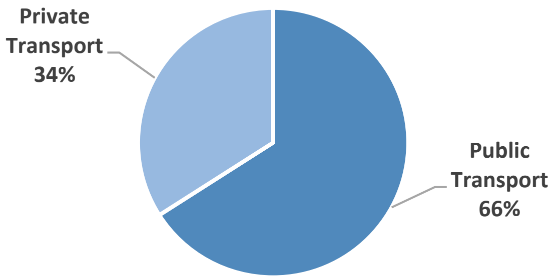


Figure 2. Project Status of AV Trials

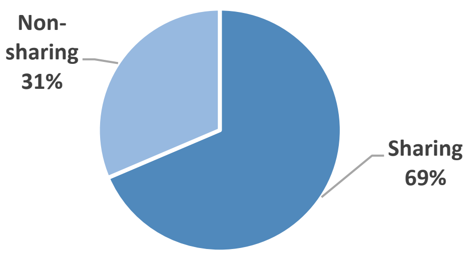
Figure 3 includes a set of graphs illustrating the vehicle features of the collected AV trials, including completed, ongoing, planned and aspiring trials. The majority of AV trials (90 %) target passengers, but goods transport is also developing in certain niches (Figure 3 (a1)). Moreover, the majority of the AVs are tested as a public transport mode (Figure 3 (a2)). Some of the personal automobile AVs are being developed as a sharing (e.g. car-sharing), hence public transport mode. Due to commercial nature of the initiatives, there is a potential bias that private and non-sharing AV trials may not disclose the detailed information regarding their trials. Most of the AVs are developed as a public transport vehicle or a sharing-oriented car (Figure 3 (a3)); therefore, the sharing-based AVs are leading the AV sector for now. If the project explicitly states that they are testing electric vehicles (or other clean propulsion technologies, e.g. hybrid), then it is regarded as electric. Therefore, the AV technology can be said to be developing in an electric-oriented direction (Figure 3 (a4)). Finally, if the AV trial information includes the words "driverless" or "fully autonomous", it is regarded as Level-5. For the measurement of the Self-Driving Level, SAE J3016_201401 standards are considered (SAE, 2014). Although the majority of AV trials target fully driverless (Level-5) autonomy (Figure 3 (a5)), full adaptation of the vehicles to the roads requires extensive infrastructural investments.



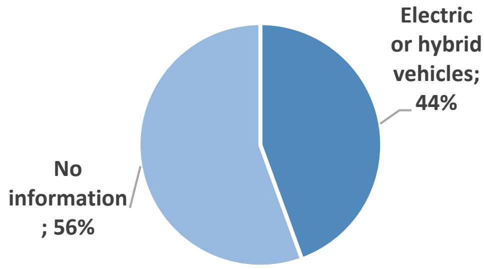
(a1) Passenger vs. Goods Transport



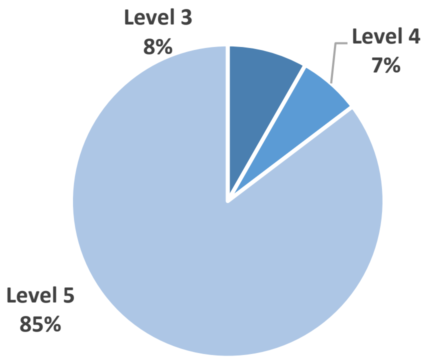
(a2) Public vs. Private Transport



(a3) Sharing vs. Non-Sharing



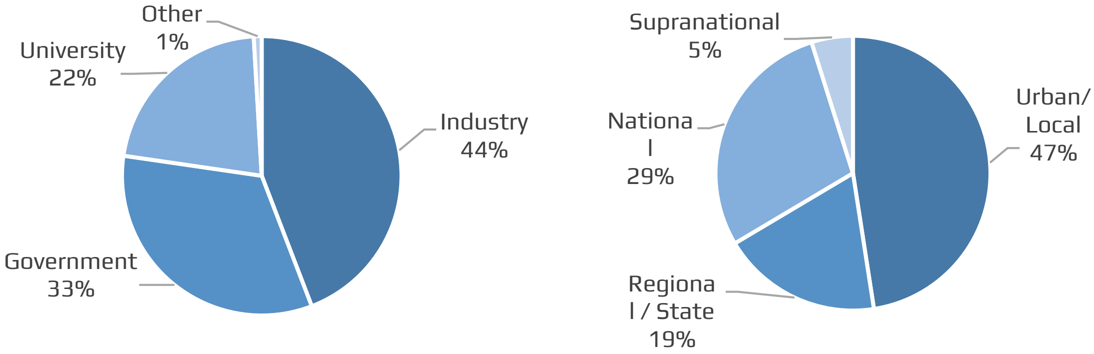
(a4) Energy Usage



(a5) Energy Usage

Figure 3. Vehicle Features of Collected AV Trials

Figure 4 indicates two important project features: the partners involved (e.g. government, industry, university, etc.) and the level of support (e.g. urban/local, regional/state, national or supranational). Industry and government are leading the AV development (Figure 4 (a1)). The UK is the country where government plays a very supporting role, financially as well as regulatory. France, Germany and USA, on the other hand, are the countries where industry plays a leading role. Most of the AV projects are supported either by city governments or being tested in an urban area. National governments are also playing an important role, especially in the UK. State governments are generally active in the USA. EU is the supranational body which supports the AV trials in many European countries (Figure 4 (a2)). The development of AV-based mobility necessitates the sustainable development of knowledge economy, where triple/quadruple or quintuple helix innovation model can be utilized (Etzkowitz and Zhou, 2006; Carayannis et al., 2012; Cavallini et al., 2016). Triple helix innovation model focuses on industry-university-government relations, while quadruple helix model adds media and civil society as a fourth dimension and quintuple helix model adds natural environments of society as a fifth dimension. These dimensions are drivers for knowledge production which is critical in the socio-technical transition to AVs.



(a1) Partners Involved

(a2) Level of Support

Figure 4. Project Features of Collected AV Trials

2.3. Literature Review for Socio-technical Transitions and Multi-Level Perspective (MLP)

Understanding the transition to AVs from a socio-technical transition perspective requires the examination of this approach and socio-technical systems. Socio-technical systems include various domains, such as technology, policies, user practices and markets, cultural and social meaning, infrastructure, maintenance networks and supply chains (Geels, 2005). Various social groups (e.g. private firms, universities and research institutions, public agencies, interest groups and users) constitute the configuration of a socio-technical system. These groups have their own vested interests, problem definitions, value judgments, preferences, actions and strategic resources. Therefore, the socio-technical approach underlines the multi-actor relations between these groups, e.g. business transactions, political struggles, convening coalitions (Geels, 2005).

Multi-level perspective (MLP) proposes a distinctive epistemological approach, and it is used to examine the complex and uncertain processes such as transitions. Instead of a direct cause and effect relationship, it emphasizes "mutually reinforcing developments, alignments, co-evolution, innovation cascades, knock-on effects, and hype-disappointment cycles" (Geels, 2012). Therefore, MLP approach is well suited to study the transition to AVs as it involves the interrelationships among various social groups, complex processes and multiple socio-technical dimensions.

MLP has been used in various domains including land transport (Geels, 2005), shipping (Geels, 2002), cargo handling (Van Driel and Schot, 2005), sanitation, water supply (Van der Brugge, 2005), aviation, highway systems, and industrial production, and contemporary transitions in electricity systems (Verbong and Geels, 2007), transport and mobility (Canitez, 2019; Nykvist and Whitmarsh, 2008; Whitmarsh et al., 2009; Whitmarsh and Wietschel, 2008), organic food and sustainable housing (Smith, 2007; Bergman et al., 2008), and climate change (Anderson et al., 2005).

Geels (2012) introduces the MLP approach into transport studies and shows its usefulness through an application to the auto-mobility system in the United Kingdom and the Netherlands. This application aims to assess the drivers, barriers and possible pathways for low-carbon transitions. The socio-technical approach to transitions conceptualizes transport systems as a configuration of elements which include technology, policy, markets, consumer practices, infrastructure, cultural meaning and scientific knowledge (Kemp et al., 1998; Elzen et al., 2004; Geels, 2004; Smith et al., 2005; Verbong and Geels, 2007; Smith, 2007). Thus, there is clear potential in employing this framework to review and assess transport policy development focusing on AV.

MLP considers different nested analytical levels: niches (the level where radical innovations occur), socio-technical regimes (the system of practices and rules), and an exogenous socio-technical landscape (macro level trends and contextual drivers) (Rip and Kemp, 1998; Geels, 2002, 2005; Kemp and van Lente, 2011). Managing the transitions is key to adopting AVs, which raise the issue of policy and governance. Hoffman et al. (2017) analyze the governance of socio-technical transitions from a multi-actor perspective. Whitmarsh (2012) suggests improvement of MLP by behavior change perspective, which is useful when behavioral implications of AV transition are considered based on the recent trend to conduct AV trials including selected users.

3. Landscape, Regime and Niche: A Multi-Level Perspective for AV Adoption

The MLP's identification of three levels, namely, landscape, regime and niche within the societal systems can well be utilized for AV adoption. Whereas radical innovation emerges in niches; regimes include prevalent systems, institutions and technologies; and lastly, the landscape incorporates the wider environment influencing drivers and barriers to transitions (Geels, 2005; Nykvist and Whitmarsh, 2008; Kemp and van Lente, 2011). Understanding the tensions and interplays among niche and regime actors together with wider landscape elements facilitates understanding the possible trajectories of AV adoption. MLP approach underlines the complex and multi-dimensional interactions between government, industry, technology, markets, culture and society as suggested by quintuple helix innovation model (Geels and Schot, 2007; Geels and Kemp, 2012; Carayannis et al., 2012). Therefore, examining the context where the interplays of developments in AV take place is crucially important.

Before embarking upon the analysis of levels, it is important to clarify the kind of transition that AV adoption entails. There are three possible transition pathways that AVs can potentially bring about. The first transition is whether AVs will lead to an overthrow of "automobility with drivers" regime. In this case, AVs begin to be widely used on the public roads, irrespective of being automobile-centered or public-transport oriented. The second transition is whether AVs will lead the way for a more public transport or shared transport mobility, bringing an end to the automobility regime itself. Finally, the third transition is about whether AVs will open the way for a low-carbon or sustainable mobility future. Examining the current AV initiatives, actors, objectives, interests and incentives in light of these three transition pathways can provide an understanding of possible mobility futures. In this respect, MLP approach helps us delineate the contours of the AV universe and the relationships between the factors mentioned above. Figure 5 summarizes the potential future pathways of AV.

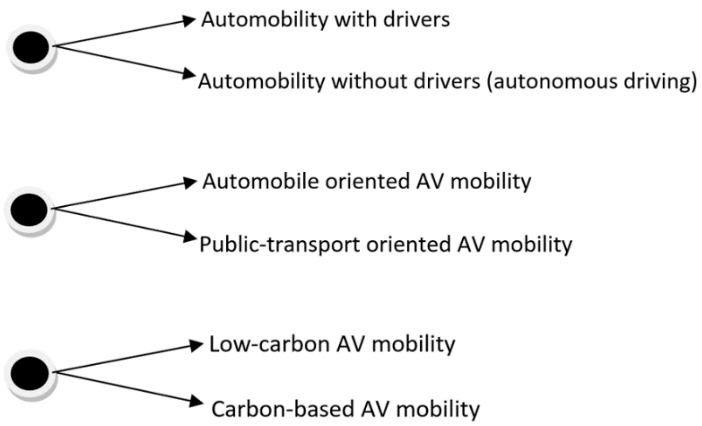


Figure 5. Potential future pathways of AV development

The MLP framework explains the occurrence of transitions through the alignment of processes within and between these three levels. Radical innovations first emerge in niches and can enter the regime level depending on various factors such as cost structures, economies of scale, technological and infrastructural adaptation, support from regime actors and favorable landscape factors. Regime actors can support or resist the changes brought about by the niche elements and develop various strategies to accommodate the forces of change. Diffusion of niche innovation occurs through the windows of opportunity, due to the cracks in the prevalent regime or landscape pressures. Regime level can be transformed if infrastructures, regulations, user practices and lifestyles are adjusted (Geels, 2017). Developments in AVs can lead to a transformation if the niche developments diffuse into the regime by changing the regime elements, therefore this section untangles these notions to illustrate the current policy developments.

Landscape

The landscape level includes environmental and demographic changes, cultural trends, changes in political preferences, economic climate, emerging social movements and changing technological and scientific methods (Smith et al., 2010). Technological developments in visual object recognition, artificial intelligence, big data analysis, deep learning, advanced control systems, real-time locating systems and mapping algorithms are the major landscape elements driving the testing and adoption of AVs. Coupled with the prevalence of a techno-optimistic culture (Huesemann and Huesemann, 2011), the AVs are often portrayed in mass media as a savior for the mobility problems (Dubai's Autonomous Transportation Strategy, 2018; Kalra and Groves, 2017). Increasing concern with safety, desire for convenience and leisure time, search for diversified mobility markets by the automotive industry are the other landscape factors fostering the adoption of AVs. On the other hand, growing societal concerns with the shrinking employment opportunities jeopardized by the digital transformation and the ongoing COVID-19 pandemic is a major landscape factor playing as a barrier role in the adoption of AVs. Actors at the niche level respond to these landscape developments and weaken the boundaries of the regime. When niche actors and regime players cooperate to accept new the AV developments or niche actors overcome the regime resistance, regime change becomes a possibility, leading to the socio-technical transition.

Regime

At the next level, the regime is defined through the incumbent actors' beliefs, capabilities, infrastructures, technologies, competencies, user practices and lifestyles (Kompella, 2017). Prevalent regulations, institutions and cognitive models are other regime elements. Rules and routines orient actors' behaviors and interactions. The regime is structured through the institutionalization of those elements, hence providing the stability which is dynamic with incremental innovations (Geels and Schot, 2007). The regime is affected by the landscape pressures as well as niche actors' innovations. While normal innovation patterns are the way of innovation in the regime level, the radical or disruptive innovation characterizes the innovation patterns in niche levels (Smith et al., 2010). The regime selects, retains or dismisses the inroads from the niche level. The regime stability is dependent on the alignment or tension between rules and actors (Geels, 2005). Vested interests in the regime level can act as barriers to the innovations threating the regime.

There are various regime level socio-technical barriers hindering the transition to AVs. Regulations concerning road safety and road use around the world take for granted that drivers control the vehicle. For example, many states in the USA (e.g. Arizona, Washington D.C., South Carolina) have introduced legislation regarding autonomous vehicles. The National Highway and Transportation Safety Administration (NHTSA) released new federal guidance for the Automated Driving Systems (NHTSA, 2016). The fundamental requirement for AVs is that their use in the roads must be permitted by law. Germany has recently adopted a law setting out the legal framework for AVs and allows testing on German roads (German AV Bill, 2017). It is the first EU member state having passed a detailed regulation, aiming to eliminate the legal uncertainty around testing. In 2018, The UK government commissioned a 3-year program to review its current driving laws to pave the way for developing, testing and using AVs in UK roads (UK, 2018). These regulations address the safety, liability, insurance models, impact and risk issues. The regulations as one of the major regime elements have to be adjusted according to the landscape developments mentioned in the previous section. The regulatory changes also make possible the testing of AVs, hence fostering the niche development. Therefore, the close cooperation between incumbent regime factors and aspiring niche actors is crucial to open windows of opportunity for the adoption of AVs.

Actors' beliefs are another regime element which can potentially drive the adoption of AVs. Governments who anticipate an AV-based mobility future change their perceptions and beliefs and adjust their strategies. The UK government, for example, (UK Smart Mobility Living Lab, 2018) established a new joint policy unit – the Centre for Connected and Autonomous Vehicles (CCAV)- with a view to becoming a world leader in developing and testing AVs. Through Innovate UK program, it plans to invest up to £200 million, by delivering a program of research, development, demonstration, and deployment activity. Belief in the future development of AV is an important driving factor in the regime level. On the other hand, users' acceptance of AV-based mobility is another determinant of AV adoption. Towards this end, AV trials and initiatives also engage with the public to better understand the users' reactions and attitudes to the AV adoption. For instance, the GATEway project in Greenwich (UK), which involves the testing of driverless pods includes understanding the public acceptance of and attitudes towards driverless vehicles through surveys and trials (GATEway, 2018). Travelling experience in a vehicle having no control of a real driver changes the perception of safety from the users' perspectives. If the safety concerns override the increased sense of safety from users' side, it can act as a barrier in the adoption of AVs. For example, accidents during AV tests, with the help of media publicity, can create sense of unsafety around AVs as incidents have showcased (Guardian, 2018), which can hinder the adoption from both user and government sides. This is why, government and industry should engage with the public and users in a way to facilitate the psychological adoption of AVs. User segments also play an important role here. Whereas Generation Y as digital natives can easily adapt to the new AV technology, it can take a longer time for senior people to get used to the idea of being driven in a vehicle having no driver control.

Maintenance of the road infrastructure equipped with the new connected and autonomous technology requires different skills, capabilities and organizational structure than the current one. All of the road infrastructure (e.g. junctions, barriers, traffic lights etc.) should be supported with IT systems which closely monitors the operating status of those systems. Increased interoperability between these systems necessitates more complex and interlinked maintenance systems, hence increased cooperation between various entities (e.g. IT systems, maintenance agencies). Therefore; more complex arrangements of infrastructure and maintenance can delay the adoption of AVs. Fragmented governance structures and incompatible AV standards between different cities, regions and countries act as a major regime barrier to the adoption of AVs.

The transition to connected and autonomous vehicles on the roads requiring a complete and, once and for all transformation for all vehicles is an important barrier to overcome. This is why, many of the AV tests have been carried out in dedicated corridors and zones. Until the full adoption of AVs, an interim period when both vehicles with drivers and AVs mix together on the roads is required. In this case, however; disparate logic of regulations for vehicles with drivers and AVs, management of discordant traffic rules and different information and communication technologies (ICT) and infrastructures necessitate an all or none principle for the adoption of AVs. A complete change of system elements in the regime level requires a radical transformation and disruption of the current regime. This is one of the reasons why full AV adoption can take a much longer time than anticipated. Socio-technical systems are composed of sub-systems, and a change in one sub-system triggers changes in its constituent elements as well as other sub-systems (Geels, 2002). Due to the complex interlinks between regime elements, disentangling all those links and then paving the way for a completely new system can expectedly prolong the full transition to AV. This combination of factors creates risk and uncertainty for governments, industry and users which can further delay the transition. Focusing separately on AV technology, regulations and vehicle prices without addressing the complex links between them can act as a major barrier for the AV adoption.

Niche

The niche level is where actors have more space to experiment with alternative and innovative practices and processes. It is protected from the regime's selective and eliminative environment. Radical innovations often occur in this level, and in case of windows of opportunities, diffuse into the regime level. Niche level actors can cooperate with regime level actors or clash with them if exposed to the regime environment. Developing interoperation capabilities (Kompella, 2017) is important to diffuse into the practices, systems and routines of the regime. Innovative ideas in technology, business models or processes are nurtured by the niche players before launching their ideas into the marketplace, which is the domain of the regime. Innovations at this level do not necessarily replace the existing technologies, sometimes they go through a hybridization process (Geels, 2002).

AV trials and initiatives are carried out by both niche and regime players. On a niche level, industry players such as Tesla, Google, UBER develop and test AVs in protected spaces like testing facilities; universities develop AV technologies in laboratories and test the AVs in their campuses. To reduce the interference of the current road regime with its infrastructure and rules in the testing and piloting, designated testing areas are being built to provide a niche environment where innovations can be tested in a protected environment. Governments as regime actors can support niche developments through funding, regulatory changes, giving permits, infrastructural investments, as in the US, UK and many European countries (Bloomberg, 2017). The AV trials of GATEway, Venturer, DRIVEN in UK; MCity Driverless Shuttles, CityNow and and GAToRS trials in USA and AUTOPILOT, L3Pilot and HAVEit trials in the EU are some examples where governments (national or supranational) play an active role. Adoption of AV depends not only on government permits but also on favorable regulations and infrastructural investments. Therefore, without a cooperation between niche actors and government, transition to AVs is not possible. The active cooperation of industry as the main niche actor and government as the main regime actor is necessary but not a sufficient condition for the AV transition. Coevolution of entities is essential to manage the transitions (Kompella, 2017). Another important regime actor is the automotive industry itself. By diversifying their manufacturing portfolio in a way to include AVs, they are trying to adapt to the changing landscape. Some of the regime players from the automotive industry have been pushing for the introduction of AVs into their product offerings.

Since current systems in the regime are locked-in and path dependent, AVs bring about disruptions of prevailing technologies, driving experience and user practices, markets, infrastructure, transport policies and cultural meanings (Geels, 2017). User practices are linked with existing technologies, which are dependent on the current infrastructure, which shapes the cultural meaning of mobility. While transport policies take the current skills, infrastructures, capabilities and meanings for granted, markets struggle for catering for the demands and needs of this system. All in all, even though AV trials are successful in niche spaces, it is completely another issue whether these vehicles diffuse into the mainstream mobility landscape. Interlinkages of these regime elements make it harder for the diffusion to take place. Transport policies are particularly crucial to enable this diffusion as they can coordinate regime elements to make way for the accommodation of AV developments.

4. Three Transition Models: Government Support, Industry Push and Public Transport Oriented

Three different AV transition models can be proposed to facilitate the adoption of AVs. The first one involves a very strong government support beyond giving AV testing permits. It involves directly funding projects, supporting research and development and setting regulations. As shown in Table 4, the UK is the only country where there is a strong government involvement in AV development. Out of 19 AV initiatives, 18 are directly supported by the UK Government. Industry players as well as universities form partnerships under the umbrella of government support. The Center for Connected and Autonomous Vehicles is a government agency in the Department of Transport which directly coordinates AV initiatives and support AV research and development projects. Its objective is to make the UK a global leader in the AV sector, and many projects (e.g. Venturer, GATEway, DRIVEN, FLOURISH, Capri) are directly supported by the UK Government. Government is collaborating with the industry to create an effective AV testing ecosystem, integrating them with existing roads and automotive sector and coordinating the capabilities of the regime and niche players. The UK Government aims to gain economic, social and environmental benefits through its direct support and has invested nearly £100 million since 2014 (CCAV, 2018).

The second dominant AV transition model is the strong industry push, as is prevalent in the USA, Germany and China, as shown in Table 4. Both niche players such as Google, Tesla, UBER (USA) and Baidu (China) and regime players such as Mercedes and BMW (Germany) play an important role in developing, testing and introducing the AVs. Although local or national governments give permits or amend regulations for those AV tests, the investment and development are only undertaken by the industry players. As mentioned above, the regime elements need to be coordinated due to interlinkages among them, weak government coordination can be a barrier for full transition in this model. On the other hand, niche players have more freedom to experiment with new ideas, technologies and testing features without a possible blocking of free initiative by government interference. The dominance of a well-established automotive sector in Germany, on the other hand, present advantages as well as barriers for the AV transition. Being locked-in by the current “automobile with drivers” regime and its practices, skills and cognitive models, it can hinder the innovative ideas and practices to flourish. On the other hand, their power in the national scale can pave the way for a faster transition. Collaboration and sharing are key dimensions which have to be allowed to grow naturally to enable niches to become dominant regimes.

Finally, a public transport-oriented AV transition can be distinguished in the initiatives of countries such as Denmark, Norway, France and Switzerland, as shown in Table 4. Most of the projects involve testing public transport vehicles such as autonomous shuttles, minibuses, pods and buses. Both government and industry can play an important role in those tests; however, there is a clear orientation towards adoption of AV as a public transport vehicle. In this case, it can arguably be easier to ensure transition to AV as there will be less resistance from the automobility regime with its user practices, maintenance and infrastructure capabilities and market characteristics. In the case of an automobile-oriented AV transition, the tension with the current automobility regime would be higher due to conflicting claims on the mobility system elements (e.g. regulations, infrastructure, user habits). Using those autonomous public transport vehicles on designated roads or lanes creates an even milder transition path. Another important characteristic of this transition model is the focus on environmental or green ways of mobility objectives. Electric AVs are supported as a new public transport type to promote a flexible and sustainable transport model. Therefore, this AV transition model can facilitate the transition to low-carbon or sustainable mobility future. Increased convenience, satisfaction and safety of autonomous public transport can increase the image of public transport, triggering a weakening of automobility regime. Moreover, using electric battery in AVs carrying goods can contribute to the transition to green logistics.

AV Adoption Models	**Countries**	**Number of AV Trials**	**Partners Involved**		**Vehicle Types**	
			Government Involved	**Only Industry**	**Automobile / Personal Car**	**Public Transport**
Strong Government Support						
	UK	19	18	-	8	11
Strong Industry Push						
	USA	56	15	34	22	24
	Germany	13	5	8	10	3
	China	7	2	5	6	1
Public Transport Oriented						
	Denmark	3	3	-	-	3
	Norway	2	1	1	-	2
	France	14	8	4	4	10
	Switzerland	5	3	1	1	4

Table 4. AV Adoption/ Transition Models

5. Conclusion

The future of AV-Based mobility is predicated by the interplay of niche, regime and landscape forces acting in the wider socio-technical environment. Transport policies and strategies, both interurban and urban, play a very critical role in directing the development of AV to the possible futures explained in this paper. Legislation, regulations and policies are critical in facilitating the transition to the AV-based mobility. The transport policies can range from issuing permits to AV tests in dedicated zones to complete reconfiguration of the transport system for AVs. National transport policies and strategies influence the mode of adoption in the local context due to interconnectedness of the road network. The consistency of those policies is important to transition to a clear AV path. Since the adoption of AVs involve a complete reconfiguration of the entire mobility system, having a clear AV vision and setting out strategies and policies accordingly gives consistent signals to the actors in the system so that they can adjust their long-term objectives and actions. In this respect, the UK Government seems to give a clearer message through its AV-oriented policies and strategies. Developing countries, which are still new at adopting AVs, need to formulate a clear pathway and roadmap for adoption of AVs taking into account the socio-technical factors explained in this paper.

It is still early to tell whether this AV oriented future will involve an automobile oriented or public transport-oriented AV mobility. An increase in autonomous automobile usage, for example, can create conflicts with the transport policies of many cities which aim to reduce the mode share of cars, and promote public transport. It is essential to consider AV adoption not only as a new transport option such as car sharing, ride pooling or private hire services, but as a new mobility phenomenon requiring complete reorganization of the current mobility system. Without adapting and adjusting the transport policies and strategies in a way that can tackle all the elements of the current socio-technical system (e.g. user practices, cultural and symbolic meanings, infrastructure, maintenance networks, industry structure, and vehicle technologies involving vehicles with drivers), it is not likely to set out a consistent roadmap for the transition to AV-based mobility even if the niche players come up with innovative vehicle technologies.

The countries where socio-technical factors are not taken into account might be lagging behind the other countries pushing forward for the introduction of AVs, in any form, in their transport systems. The transition to AVs requires an open, democratic, diverse and inclusive approach, which brings about major challenges for the developing countries to cope with. In order to familiarize the public with AVs through public engagement programs, showcases and surveys are critical to bring about a perception and behavior change in the users. The introduction of funding schemes, government support programs, infrastructural investments to ensure connectivity between road elements, collaborations involving government, industry and research centers, legislative amendments aiming the current regulations and policies are all important to set "the rules of the game" right so that both regime and niche actors can adjust their objectives and actions accordingly.

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