http://www.rasi.vr.uff.br
RASI, Volta Redonda/RJ, v. 6, n. 2, pp. 52-70, mai./ago. 2020

The Quintuple Helix Model and the Future of Mobility: The role of Autonomous Vehicles in a Developing Country

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Abstract
This descriptive paper of qualitative approach aimed at understanding whether the Quintuple Helix Model (QHM) can positively foster advancements on urban mobility from AVs' insertion in the society, as well as discuss the dynamic of the QHM in the Brazilian context. Synergy among agents proposed by the model is essential for minimizing the impacts on innovation development. It is necessary to understand AVs' development not only as a technological innovation that will bring comfort to society, but rather to realize that this radical innovation can transform the future of urban mobility worldwide. In a Brazilian context, we observed that the country needs to improve in many aspects in order to carry on the future of urban mobility. Brazilians tend to be early technology adopters and the country has good mobile networks, but it will need to improve on regulations, local innovation and road quality to take advantage of AVs. Finally, QHM can corroborate to such needed improvement and, our proposed theoretical framework could explain how this dynamic works.
Keywords: Quintuple Helix Model; Urban Mobility; Autonomous Vehicles

O modelo da Quíntupla Hélice e o Futuro da Mobilidade Urbana: O Caso dos Veículos Autônomos em um País em Desenvolvimento.

Resumo
Este artigo descritivo, de abordagem qualitativa, teve como objetivo compreender como o Modelo Quíntupla de Hélice (MQH) pode promover avanços positivos na mobilidade urbana a partir da inserção de Veículos Autônomos (VAs) na sociedade, além de discutir a dinâmica do MQH no contexto brasileiro. A sinergia entre os agentes propostos pelo modelo é essencial para minimizar os impactos no desenvolvimento da inovação. É necessário entender o desenvolvimento dos VAs não apenas como uma inovação tecnológica que trará conforto para a sociedade, mas para perceber como essa inovação radical pode transformar o futuro da mobilidade urbana em todo o mundo. No contexto brasileiro, observamos que o país precisa melhorar em muitos aspectos para a inserção dos VAs na mobilidade urbana. Os brasileiros tendem a ser pioneiros na adoção de tecnologia e o país possui boas redes móveis, mas precisará melhorar os regulamentos, a inovação local e a qualidade da estrada para aproveitar os AVs. Por fim, o MQH pode corroborar a melhoria necessária e, nosso arcabouço teórico proposto pode exemplificar como essa dinâmica pode atuar.
Palavras-chave: Modelo de Quintupla Hélice; Mobilidade Urbana; Veículos Autônomos

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Recebido em 03/10/2019
Aceito em 20/01/2020

10.20401/rasi.6.2.410

Avaliado pelo sistema Double Blind Review
Editor: Marcelo G. Amaral

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1 Introduction

In the 21st century, mobility is understood as a major issue and is a focal topic of discussion worldwide. Autonomous Vehicles (AVs) are considered an integral part of the future of mobility and have become a focus of many R&D projects in the automotive industry; in fact, they are considered one of the most popular application of R&D in the recent history of the industry (Fan & Chang, 2016).

Considering the rapid change in the automotive industry and the new players that are ready to shape the automotive industry of tomorrow, there are still a number of legal, ethical, social, environmental and market barriers to overcome. The industry has entered a new era in which value creation relies entirely on dynamic relations in an open ecosystem of innovation, with moving boundaries to be addressed in the long run (Attias, 2016).

AVs are bound to change the future of urban mobility, and this transformation will not only affect means of transport but also society as a whole. Nevertheless, there are many issues that still need to be addressed in the development of AVs, such as the possible impacts of autonomous driving on mobility behaviors and human-machine interactions, as well as related aspects of protection and safety (Schreurs & Steuwer, 2016). AVs will change the structures of our cities (Zakharenko, 2016), and we do not fully understand how our lives will be affected by this automobile revolution.

Although technical developments should be stimulated for the purpose of consolidating this technology, there are several non-technical aspects that have not yet received adequate attention, such as the societal implications of this technology’s advancement (Schreurs & Steuwer, 2016). The timing, scale, and direction of AVs’ impacts are uncertain, and the opportunities to influence investment decisions are limited (Guerra, 2016). In regard to technology and innovation models, one that is very influential among academics is the triple helix. Created by Etzkowitz and Leydesdorff (2000), this model describes the innovation process via government-university-business cooperation. Although widely used, the concept has evolved to include two other main players: society and the environment. Therefore, the concepts of the Quadruple Helix and Quintuple Helix created by Carayannis and Campbell (2009) have also emerged.

The most important element of the Quintuple Helix is the "knowledge" feature, which encompasses the entire system. This model, which can be used both in theory and practice, highlights the exchange of knowledge resources based on five social subsystems in order to promote the sustainable development of society (Carayannis, Barth & Campbell, 2012).

The quest to reduce uncertainties has motivated a number of countries to take significant steps to be at the forefront of AV research (Cavazza et al., 2017). Universities, industries and governments worldwide (especially in the USA, China and the European Union) are studying AVs to determine how this innovation may affect cities and be implemented as part of urban mobility solutions.

Currently, the concept has evolved, and the triad of university-industry-government has been strengthened by new models of knowledge generation that include society (Quadruple Helix) and the environment (Quintuple Helix) as important aspects of innovation dynamics. According to Lombardi et al. (2012), the Quintuple Helix operates in a complex urban environment, where market demand, governance, civic involvement and citizens’

10.20401/rasi.6.2.410

Avaliado pelo sistema Double Blind Review
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characteristics, along with cultural and social capital endowments, shape the relationships among the traditional helices of university, industry and government.

A key reason for policymakers to consider AVs now is that the spatial planning and infrastructure investment decisions that we make today will determine the development of our countries and cities for decades (KPMG, 2018). Thus, adopting this perspective, other countries, especially in Europe, have already begun to design and plan AV-related actions, anticipating the future of mobility by thinking about policies that favor the propagation of this new technology. However, this is far from the reality in Brazil. We realize that there is still a lack of coordination among companies, government, universities and even society – coordination that would enable AVs to promote economic, social and sustainable development for all. In this sense, the QHM can fill the gap among the abovementioned agents. Thus, it remains to be seen "when" and, most importantly "how", this innovation will be disseminated.

In this sense, our research problem can be summarized in the following questions: How can the QHM positively support the implementation of AVs to advance urban mobility? What are the dynamics between the QHM and the Brazilian context? Therefore, this paper aims to understand whether the QHM can positively foster advancements in urban mobility via the insertion of AVs into society. Furthermore, we seek to discuss the dynamics of the QHM in the Brazilian context.

The mobility systems of the future are likely to be very different from what exists in most of the world today. It is therefore important to understand that people are at the center of this evolution (Ramkumar, 2016). In addition to thinking about safety aspects, other issues should be discussed in a coordinated way (Schoitsch, 2016) because increased AV availability increases workers' well-being, displacement distances and the sizes of cities, while also improving traffic coverage and collective transportation (Zakharenko, 2016).

2 Literature Review

2.1 Urban mobility and autonomous vehicles

Considered part of the lifeblood of our cities, mobility is what keeps our urban centers running (McKerracher, 2016). The concept of urban mobility is considered to encompass the characteristics of all transport modes and their relationships with land use, environmental quality and urban planning (Oliveira et al., 2017). Issues related to sustainability and overpopulation, among others, make mobility one of the main concerns of our contemporary society, making it a central topic that is discussed worldwide.

Among the currently available providers of transportation, the automotive industry plays a fundamental role in mobility. In recent years, this industry has been witnessing a transformative evolution into a new ecosystem, known as "intelligent mobility", into which AVs are being inserted. Consequently, this new ecosystem presents several possibilities for new scenarios (Attias & Mira-Bonnardel, 2016). In this sense, it is understood that AVs' development is a disruptive innovation that promises to have a substantial impact on issues of urban mobility.

Hodson (2016) notes that AVs are only a part of a major revolution in urban transport, as there are simultaneous expansions of autonomous technology to other modes of public transport (e.g., metro lines that already operate without drivers in major cities worldwide). Corroborating this, Attias (2016) proposes that in a mid-term perspective, this evolution will not stop with AVs and will open the field for the design of similar technical objects (e.g., trucks, buses) and even boats and autonomous planes.

The convergence process of such dynamic movements between the traditional transport model and intelligent mobility culminates with consumers being even more connected and seeking more accessible mobility solutions at more competitive prices. In this sense, Enoch (2015) proposes that traditional transport models (cars, buses and taxis) will converge to intermediate transport models (centered on sharing), and the author goes further in stating that AVs will accelerate this convergence process due to their various advantages, such as increased mobility, better usage of urban spaces, reduction in congestion costs, increased road safety, user comfort, and reduction in fuel consumption and pollutant emissions (Schoitsch, 2016; U.K. Department for Transport, 2015).

However, negative impacts still surround the development of AV, such as social risks (rebound effects); personal data protection (e.g., hacking attacks); increased insurance costs; loss of revenues related to the reduction in individual traffic (e.g., reduction in parking, speeding and infraction tickets); attraction of passengers from public transport systems, resulting in job losses (e.g., taxi drivers, truck drivers and bus drivers may lose their livelihoods and occupations); possible investments in infrastructure; and rules and regulations, among others (Schoitsch, 2016).

In this sense, it is understood that any positive or negative impacts of this innovation go beyond organizational and governmental limits, affecting many other spheres of our modern society. Therefore, it is important and necessary that the building and execution of this technology contemplate all these spheres (government, companies, society, academy, environment) synergistically to optimize this dynamic process of transformation in contemporary urban mobility.

2.2 From the triple helix to the quintuple helix

Countries' innovation systems have been gaining strength given that knowledge-producing institutions are essential to fighting the issues faced by our modern society. Thus, companies, governments, universities and even the population must work together on trying to curb, or minimize, the negative social consequences of the economic development that has occurred so far.

The main difference between the traditional triple helix model and the newer quintuple helix is in the "innovation ecosystem", which combines and integrates social systems and environments, emphasizing the importance of the diversity of actors and organizations, such as universities, small and medium-sized enterprises, and large corporations, government innovation networks and knowledge clusters (Carayannis & Campbell, 2011).

In the triple helix model, the relationships are overlapping, creating hybrid environments, leading to dilution of barriers and enabling greater cooperation (Silva et al., 2019). For this, the government has the role of elaborating public policies that foster innovation processes, and the government is also responsible for regulating and normalizing economic activity. Companies must concentrate on their productive activities in a cooperative sense, and the production, dissemination and transfer of knowledge are reserved for universities (Vieira et al, 2015).

The above actors are pressured by the accelerating pace of change and innovation in both scientific and technological environments. Thus, in the process of manufacturing autonomous cars, even cutting-edge companies are facing ethical, moral, technological, and urban mobility challenges because evidence of the long-run impact of AVs is not yet clear and well mapped.

The first step to be stimulated within this innovation system begins with the introduction of education inputs. Because more investments flowing into the helix of the education system means the production of new equipment, new locations for scientists and teachers, and greater opportunities for research, a greater outlet for innovations in science and research can be created (Carayannis, Barth & Campbell, 2012).

For this to happen in an integrated way, the other helices must be interconnected via the input of knowledge. The second step begins with human capital in the helix of the economic system, represented by companies. Any investment in knowledge and in promoting the production of knowledge brings new impulses crucial to innovation, know-how and the advancement of society (Carayannis, Barth & Campbell, 2012).

Leydesdorff (2012) argued that to go further – i.e., towards the fourth or fifth helix – would require greater specification, operationalization in terms of potentially relevant data, and sometimes additional development of relevant indicators. To do this, companies must focus on their productive activities in a cooperative sense, and the university reserves its role in constructing, disseminating and transferring knowledge (Vieira et al, 2015).

The "fourth helix" of the model refers to the culture and values of society. In this way, innovation policies and strategies must recognize the important role culture plays in promoting a knowledge-based economy. The politics of knowledge and innovation should be inclined to reflect the dynamics of "media-based democracy" and their role in the elaboration of strategies. The goal is to develop a policy of innovation to generate economic performance and thus link the whole system of innovation in a country (Carayannis & Campbell, 2009).

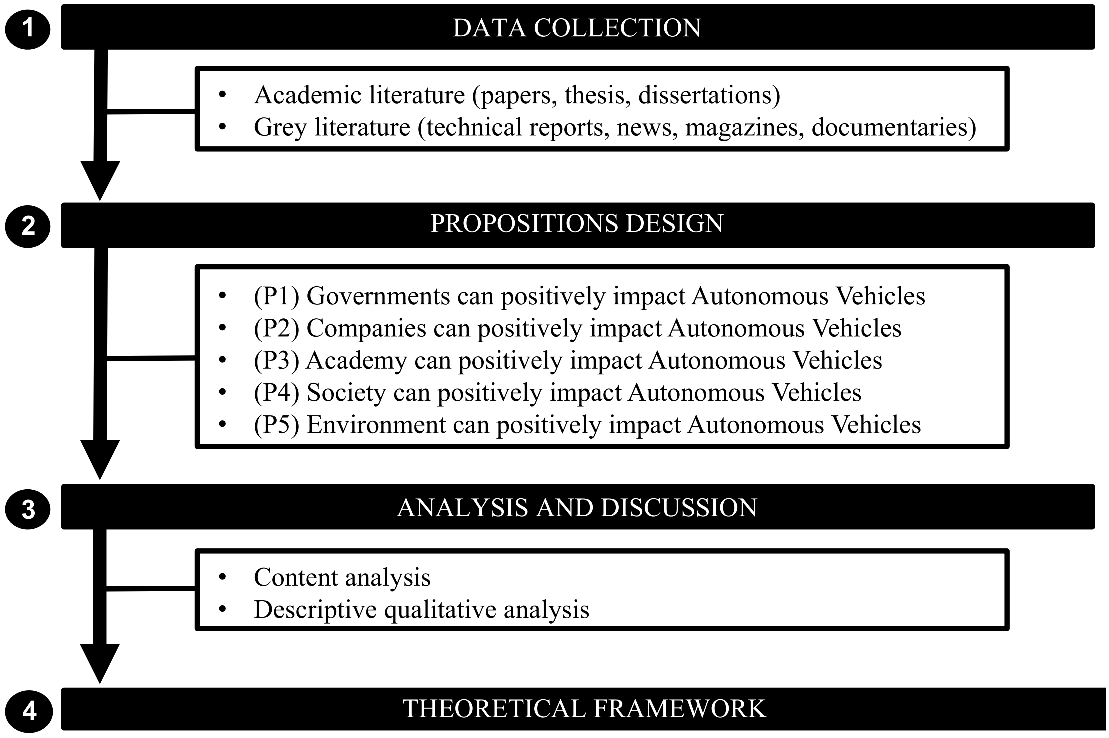
By adding the fifth helix to the model, the model becomes more comprehensive because, in addition to the analytical and explanatory approach it already possessed, the "natural environments of society" are added in the macro analysis (Carayannis & Campbell, 2010). Now, the socio-ecological environment is taken into account, that is, the Quintuple Helix's innovation system is ecologically reliable because it is based on the understanding of the production of knowledge (research) and the application of knowledge (innovation), both of which consider environmental issues (Carayannis, Campbel & Rehman, 2016).

We believe that the model has the advantage of aggregating new knowledge, helping in the creation and development of creative innovations and new learning methods. At the same time, innovation in AVs is still characterized by lack of coordination among OEMs, governments, universities and even society; such coordination is necessary if these vehicles are to effectively support economic, social and sustainable development overall.

3 Methodological Approach

With the dual aim of understanding whether the QHM can positively foster advancements in urban mobility as a result of AV insertion into society and discussing the dynamics of the model in the Brazilian context, the adopted research design (Figure 01) was characterized as a qualitative approach of a descriptive and exploratory nature.

Figure 1: Study design.



Source: developed by the authors.

On **Step 1**, the data collection was performed in both academic and grey literature by using the saturation criteria as a stopping point (Fontanella; Ricas & Turato, 2008; Guerra, 2006). Through this literature review it was possible to define parameters to contextualize the insertion of AVs in Brazil instead of other countries. Moreover, it was observed that the alignment between the helix proposed by the QHM model could propose statements for the insertion of these vehicles in a country and the theoretical establishment of these propositions had not yet been realized.

In this sense, on **Step 2** we created five propositions based on QHM that could positively impact AVs. These propositions not only sought to establish isolated relationships between the impacts of each stakeholder but also to highlight interrelationships between the helix and the impact of this connection on the insertion of AVs in Brazil (presented as the theoretical framework). In order to achieve our aim, on **Step 3**, we used categorical content analysis and descriptive qualitative analysis (Bardin, 2010; Vergara, 2005). The information collected was categorized in order to establish parameters so that the analyzes could be established as close as possible to the reality found.

Last but not least, on **Step 4**, we created a theoretical framework based not only on isolated analysis of the helices but on the interrelationship between the propositions. Our idea was to bring the results and practical implications together to illustrate the theoretical contribution of the QHM to urban mobility in Brazil based on AVs' insertion.

4 Results and Discuss

Automotive companies, suppliers, government, regulators, legal authorities, rating agencies, road operators, and the general public have been prepared for what is the greatest inflection point for the automotive industry since the introduction of the assembly line (Mosquet et al, 2015). In this session, we tried to show the impact that the Quintuple Helix could have on AVs and the impact on each of the 05 helices: (P1) government; (P2) companies; (P3) academy; (P4) society and; (P5) environment.

(P1) Governments can positively impact autonomous vehicles

The relations among the institutional spheres of university, industry, and government can help generate solid strategies for economic growth and societal transformation. From a political perspective, national innovation systems can be defined as a relevant reference framework for governmental interventions, which are aimed at the economic growth of different industries (Etzkowitz & Leydesdorff, 2000). In this sense, the organization of the political system is of crucial importance because it formulates the "will" of the state, that is, where the state is directed both in the present and the future and how it organizes the general conditions of the nation. Therefore, this helix has active political and legal capital through incentives, ideas, laws, plans, and partnerships that can benefit companies and the population, as well as emerging sectors (Carayannis, Barth, & Campbell, 2012).

An issue that is already on the agenda in some European governments concerns AVs' regulation and encouragement of the motor vehicle industry. Regulation should ensure safety and accompany the development of the emerging AV industry, avoiding any market failures. Different countries have created rules on prototypes allowing testing, licensing and operation of this technology on public roads (Frisoni et al., 2016).

For instance, in Germany in 2015, the federal government started a round table on vehicular automation where industry, academia and government met to define specific areas of action to support the introduction of autonomous driving in the country. Discussions included topics such as infrastructure, legislation, innovation, and interconnectivity (Frisoni et al., 2016).

Sweden is supporting a national program to promote alliances among the various stakeholders. In 2009, the country established a partnership with the automotive industry, called "Strategic Vehicle Research and Innovation", with the aim of investigating innovative solutions for the climate, environment and safety. This report involves R&D activities worth approximately €100 million per year (half of this amount is publicly funded), including research in AVs and connected transport systems (Frisoni et al., 2016).

France is encouraging a new strategic alliance among the main French automotive companies to favor the development of AVs in the country. This industrial strategy is called "*La Nouvelle France Industrielle*" and was promoted by the Ministry of Economy and Finance beginning in 2014. AVs are mentioned as a key point of technological development in France.

Based on the above reports, we see that the discussions between government and industry in the aforementioned European countries are moving towards partnerships. Despite the progress initiated by some countries, there seems to be little coordination of the actions taken by different jurisdictions; the jurisdictions are restricted to targeting their own individual actions (Frisoni et al., 2016).

The analysis of the Brazilian context points to the Government helix as the weakest link. Undoubtedly, the Brazilian government has several issues and problems that need to be overcome so that the implementation of AVs can be made feasible. According to the KPMG (2018) report "*Autonomous Vehicles Readiness Index,*" which seeks to access countries' openness and readiness for AVs, Brazil "has the weakest scores of the 20 surveyed countries for policy and legislation".

Recently, the Brazilian government inaugurated the new automative sector regulation, called "Route 2030". The program, launched more than a year late, aims to replace and broaden the scope of its predecessor, "Inovar Auto" as well as to set rules for the manufacture of automobiles produced and marketed in Brazil over the next 15 years.

The expectation around this new government program is high, investments in the areas of electric mobility, energy efficiency, manufacturing 4.0, internet of things, production digitization and connectivity have already been announced.

Although initiatives such as the Rota 2030 are already beginning to develop in the national context, there is still a lack of articulation and more tangible advances regarding new developments in the Brazilian automotive industry. Specifically, these results clearly state the deficiency of the Brazilian government concerning the legislation and incentives surrounding AV technology. Thus, there is still a large chasm to be overcome so that Brazil can really be ready for the imminent arrival of AVs.

(P2) Companies can positively impact autonomous vehicles

We observed that the governments of some countries offer tax support and create public policies to strengthen their relationships with universities and industries. For example, some European countries are already addressing the regulation of incentives for the AV industry. Regulation should ensure safety and monitor the development of this emerging industry, avoiding any market failures. These nations have created rules regarding prototypes that allow testing, licensing and operation of this technology on public roads. These changes, in turn, directly impact manufacturers in the automotive industry, as all actors must work together to implement a "common language" solution.

Moonzur (2012, p. 12) also mentions the likely disappearance of driving schools. "In case the vehicle would be completely autonomous and not require driver intervention, the vehicle that will be in sole command". Morally, the relevant decisions would have been made by the developer of the underlying algorithm. In any case, the automatic system would act, and the consequences cannot be considered accidental because they are determined beforehand. In many cases, different interested parties should cooperate to advance such solutions.

It is important to emphasize that it is not only vehicle manufacturers that are benefitting from advancements in AVs but also the economic system as a whole. The main stakeholders of this advancement are described as telecommunication companies, shared vehicle services, and technology and insurance companies (European Parliament, 2016), and it is expected that they will all have new services and demands as a result of the synergy generated by the QHM.

Botelho, Carrijo and Kamasaki (2007) say that this helix concentrates "economic capital" (e.g., entrepreneurship, machines, products, technology, money). Given this concentration, relations with customers and suppliers, with companies competing with research institutes and/or universities, appear to be one of the most important issues (Leydesdorff & Zawdie, 2010).

To ensure strong and sustained public support, the industry will need to engage with the general public and be direct about the limitations and benefits of the technology (BCG, 2015). To accelerate AVs' adoption and, consequently, urban mobility, industry players must collaborate to overcome technology challenges (Mosquet et al., 2015).

In this sense, actors in the private sector should consider partnerships that go beyond traditional sectorial boundaries (many of which have already begun to blur). Consumers will judge the vehicles by how they are integrated with the services they provide: from in-car entertainment to on-demand rental platforms. Those players in the industry who can unlock new partnerships between technology and service providers will have the best chance of avoiding marginalization (McKerracher, 2016). According to the European Automobile Manufacturers Association, the European car industry annually invests € 41.5 billion in R&D, approximately 5% of its total turnover. Although this amount is spent on a variety of research and testing programs, it is undeniable that the development and implementation of AVs represents one of the major interests of car manufacturers (Tan et al., 2016).

Although the automotive industry has strong relevance on the national scene, it is worth noting that Brazil is a "technology importer and commodity exporter," and this fact demonstrates certain weaknesses in our OEM industry. According to the KPMG report, Brazil "received the lowest scores on R&D hubs, AV technology company headquarters, patents and investments" (KPMG, 2018, p.33).

In this context, it is worth highlighting one of the main actions of the Rota 2030 program, which enables the automotive chain industries to invest the money that would be spent on import duties and taxes in R&D programs. Initiatives like this can be important in fostering new partnerships between industry and academia, significantly increasing the industry's innovative capacity.

The Brazilian industrial scenario is paradoxical: on the one hand, we see growing interest and investment in some companies, e.g., Uber operation has been authorized in large cities in the country since 2016, and Brazil is considered one of the largest Uber markets globally (KPMG, p. 33, 2018). On the other hand, we know that there are many problems related to infrastructure and legislation that need to be addressed. The same report notes that Brazil "gets the lowest rating for people's use of technology."

(P3) The Academy can positively impact autonomous vehicles

The convergence between basic and applied research is an opportunity for universities to transfer their knowledge to other spheres. In this regard, the academy plays a central role between the government and industry, especially car manufacturers. It was observed that universities from different countries are now cooperating with large programs involving both public and private actors for the development and application of automated mobility systems.

Technical aspects that permeate AVs were research fields in earlier decades. During the 1990s, the USA Defense Department promoted the development of self-driving vehicles for military purposes by financing projects across academia and automotive companies (U.K. Department for Transport, 2015). Nevertheless, non-technical aspects are still an incipient knowledge field (Gandia et al., 2017).

In this sense, Cavaza et al. (2017) identified five knowledge categories that could contribute to the dissemination of AVs: policy issues (law); ethics, moral issues, liability; transport planning; consumer behavior and business models. It should be highlighted that even with the academy's efforts in projects that stimulate synergy among the spheres, there is still a gap that affects all the interested parties as proposed by the QHM.

As for the academic area, Brazil does not have an impressive percentage of

10.20401/rasi.6.2.410

Avaliado pelo sistema Double Blind Review
Editor: Marcelo G. Amaral

publications according to information extracted from the Web of Science database. Regarding the field of AVs, the country ranks 17th in publications worldwide. Although it ranks first in Latin America, the discrepancy in numbers of publications is huge (95 publications for Brazil versus 1796 for the first-place country); Brazil is responsible for just 1.41% of all publications in the world (Gandia et al., 2017).

If we consider the business and management fields, the results are even worse. According to a previous investigation in the 3 main international databases, of the 644 papers found (244 from Scopus, 56 from WoS and 344 from SD), there was no single paper originally from Brazil (Cavazza et al., 2017).

It is important to highlight that this lack of academic knowledge in our country regarding this object of study (Gandia et al., 2017; Cavazza et al., 2017) has a direct impact on AVs' development, as academia is a valuable actor as a provider and manager of information and knowledge for other helices.

(P4) Society can positively impact autonomous vehicles

In an era where innovation is blooming, in which social innovation and ecological innovation imply behavioral changes at both individual and social levels, the challenges of health, poverty and climate change, and especially the future of cities, must be addressed. The regional governance system and companies should be open to new groups in society that are capable of promoting a culture of challenge.

This new era also includes perceptions of consumption that are different in each country; for instance, in emerging economies (e.g., Brazil), the ownership of a car is perceived as conveying status, independence and power. In this sense, it is also worth understanding consumers' needs (Attias, 2016).

While consumers expect automakers to produce reliable, high-quality and safe vehicles, they also believe that technology companies must bring in their expertise. Apple and Google are top-of-mind possibilities. Consumers in India, in the United States, and China are more likely to see a technology company as an ideal coordinator of the entire chain. One reason may be the importance and visibility of the technology industry in these economies (Mosquet et al., 2015).

A survey conducted by the Boston Consulting Group and the World Economic Forum with 5500 consumers in 10 countries (North America, Europe, Middle East and Asia) highlighted the fact that users who adhere most to the AVs are more numerous in emerging countries such as India (85 %) and the United Arab Emirates (70 %) than in France (60%) and Germany (44 %) or Japan (36 %). Another point to note in this survey is that traditional manufacturers are by far those that consumers consider the most reliable (between 50 and 58% of reliability), and they think about other technology players such as Apple and Google as bringing "relevant, but complementary expertise" (Mosquet et al., 2015; WEF, 2015).

On the other hand, social pressure can be an obstacle. Generally, audiences who are very keen on new technologies may change their minds quickly. If, for example, a horrible accident involving an AV occurs in the early stages (market introduction), regulators could face pressure to take a strong position against such vehicles. To ensure strong and sustained public support, the industry will need to engage with the general public and be direct about the limitations and benefits of this technology (Lang et al., 2015).

Clearly, societal acceptance is very crucial to AVs' adoption, especially considering that stakeholders must address the interests and concerns of consumers and policy makers.

Overcoming this challenge requires strong collaboration among the parties involved, especially industry and government, to address concerns adequately (e.g., by establishing stringent safety standards) and to transparently provide economic alternatives to those who are adversely affected (Lang et al., 2015).

Contrary to the government helix, the societal one emerges as the strongest link in the Brazilian context. First, it is important to note that the Brazilian auto market stands out on the world stage and can be considered the gateway to Latin America (ICCT, 2015; SEBRAE, 2015). Another important factor is the Brazilian consumer profile:

> Brazilians are the keenest of all 20 countries on AV technology, mobile phone penetration is more than 100% of the population and Brazilians are known for being early adopters of new technologies. Despite this, the country gets the lowest rating for people's use of technology (KPMG, 2018, p.33)

When analyzing the profile and the behavior of the Brazilian consumer, we can observe great acceptance potential for AVs in our country. Such characteristics, which are linked to the size and potential of the Brazilian market, have attracted attention from researchers and industries worldwide and serve as a counterpoint to the shortcomings presented by other helices.

(P5) Environment can positively impact autonomous vehicles

One could argue that concepts such as "sustainability", "sustainable development" or "social ecology" are already, *per se,* interdisciplinary and transdisciplinary, as they are now fundamental to the conception of products and to academic research. Research questions and problem-solving in relation to ecology, the environment, environmental changes and environmental protection increasingly depend on interdisciplinary and transdisciplinary network configurations of different knowledge and innovation modes. Cross-linking human rights, human development and the environment already bridges analytically into sustainable development, clearly including features of social ecology (Carayannis & Campbell, 2010).

In this context, AVs can reduce fuel consumption and pollution; moreover, this emerging technology promises several potential benefits, such as reducing collisions and deaths, reducing traffic congestion, improving mobility for people incapable of driving and mitigating environmental impacts. Sustainability is a crucial desideratum for engineers and policy makers considering vehicle design, public versus private transportation, and infrastructure manufacturing (Mladenovic & McPherson, 2016).

There is an expectation that AVs can reduce fuel use and pollution (because they will be electric) by strictly following hypermiling strategies. They may position themselves closely behind other cars because AVs have a faster reaction response and do not need to have the same safety margin as humans (Spieser et al., 2014). In the future, the progressive replacement of fleets of combustion vehicles by electric vehicles will also be positive in this regard.

In a study carried out by Fagnant and Kockelman (2014), the authors found that a single shared AV has the potential to replace approximately 11 private vehicles. In addition, reductions in energy consumption and emissions of air pollutants can be expected when the AV system begins to be used by 5% of the population.

Sustainability is also an important element in the pursuit of social justice: institutions that ensure fair relations between people and reduce harm to future generations are

10.20401/rasi.6.2.410

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Editor: Marcelo G. Amaral

unquestionably important. For these reasons, sustainability is a crucial point for engineers and policy makers who consider vehicle design, public transport vs. private transport, and infrastructure manufacturing (Mladenovic & McPherson, 2016).

Perhaps this is the helix with fewer inputs to discuss in the national scenario. The Brazilian population in July 2016 comprised 206,081,432 inhabitants (IBGE, 2016), and it is possible to calculate an average of 4 inhabitants per car (automobile). This is a relevant environmental impact, especially considering the impressive number of people using private transportation. A study from the Institute of Applied Economics Research (IPEA, 2011) showed that 65% of the population of Brazilian capitals uses public transportation to commute, and this number drops to 36% in non-capital cities. Only 2.85% of capital populations commute by foot, while in other cities, this percentage rises to 16.63%. On average, in all Brazilian cities, 23% of the population uses a car as a means of transportation.

Once again, if we consider the new technologies, the image is not promising: “Brazil shares the bottom spot with Russia on market share of electric cars which are not generally available, although hybrid cars are starting to be imported” (KPMG, 2018, p.33).

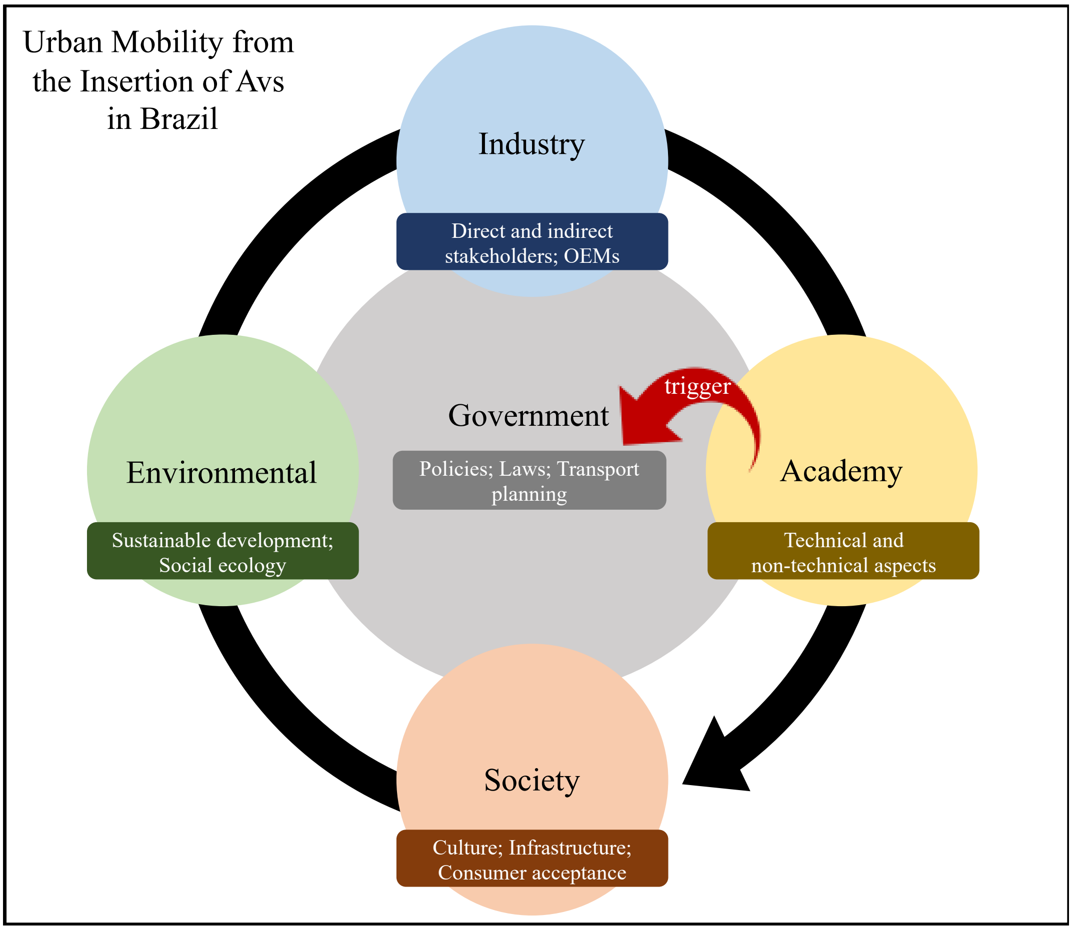
4.1 Triggering AVs via Academy Helix in Brazil

In order to summarize the main analyzes and implications generated by the propositions presented in the previous topics, we used the theoretical model of the Quintuple Helix to establish positive relations between urban mobility and the introduction of AVs (Figure 2). It was observed that the helices present synergetic relations, which should act in consonance so that a positive development of AVs is established and, consequently, AVs contribute to urban mobility.

It is noted that the government can exert a direct influence on all helices (from political stimuli to transport plans and laws), and such influence can determine the positive or negative paths along which the devices inherent to the development of AVs and the future of mobility will be established. The academy must act on both the technical and non-technical fronts of this development; it should act like a trigger by identifying the demands of other spheres to point out scenarios that allow orchestrated thought among government, industry, society and the environment.

The social sphere presents cultural, consumer and infrastructure-related specificities, and these factors must be taken into account as the global regulatory aspects of AVs are developed (e.g., automotive technology imports from other countries to Brazil must take into account the cultural aspects of Brazilian consumers). Regarding the environmental sphere, it is important to emphasize the strong interface between AVs and sustainability issues. Several studies point to the gains generated by these vehicles with regard to sustainable development and social ecology.

Figure 2: Theoretical framework – the QHM positively assists with advancements in urban mobility as a result of the insertion of AVs into society.



Source: Developed by the authors.

According to Santos and Benneworth (2019) the collaboration academy-industry is increasingly important. In this context, it is important to highlight the role that the industry (including the entire network of stakeholders, OEMs and companies and businesses that will be indirectly impacted) will play in the articulation, deployment and dissemination of AVs. However, in order to achieve the technical and non-technical features of this new technology the industry will need to work together to the academy. Only in this way will the government helix have subsidies to implement regulatory actions for the insertion of AVs in Brazil with a lower risk of rebound effects.

Among several examples of the dynamics of this model as a trigger for insertion of AVs, we can cite the industry's efforts to understand, based on studies conducted by the academy, the consumer's perspective in their acceptance of the use of autonomous shuttles over conventional buses in public transportation. Based on the results of these academic efforts, governments could establish regulatory guidelines and / or transportation planning programs that would best suit the replacement of a conventional road line with, for example, an autonomous shuttle.

5 Concluding Remarks

This study has sought to understand the contribution that the QHM can make to the future of urban mobility via the insertion of Autonomous Vehicles. We observed that the QHM contributes favorably to the future of urban mobility, in which AV-related innovation plays a crucial role. It is noteworthy that among projections and scenarios of the future of mobility (Lang 2016; McKerracher, 2016; PWC, 2016; Mosquet, 2015; Lang et al., 2015), AVs are a key factor, even though this innovation is still surrounded by uncertainties.

According to the QHM, the synergy among agents is essential if the impacts of the development of this innovation are to be minimized, and although we observed a need for action by all agents, this was observed in a fragmented way in the documents and studies analyzed. It is understood that the technological development of AVs can be considered at a global level; however, in the case of urban mobility, local specificities should be taken into account, considering social and governmental particularities as determining factors for AV dissemination. This study opens discussions on the topic by demonstrating the importance of establishing AV innovation in a synergistic way. Among the stakeholders responsible for the development of AVs, the academy will be responsible for the search for a suitable model.

Second, it is necessary not only to understand AVs development as a technological innovation that will bring comfort to society but also to realize that this radical innovation can change the future of urban mobility around the world. Thus, developing this technology without looking at all the helices proposed by the QHM would be like “driving with one eye closed”. Governments should be aware of this, but this paper agrees that the academy has an important role to play in stimulating this line of thought; the academy must help the government ensure that this revolution happens with minimum negative impacts.

In the Brazilian context, it was observed that the country needs to improve many aspects of the way it is preparing for the future of urban mobility. Brazilians tend to be early technology adopters, and the country has good mobile networks, but it will need to improve its regulations, local innovation and road quality to take advantage of AVs (KPMG, 2018). The QHM can corroborate those needed improvements, and the theoretical framework can explain how this dynamic works.

In this sense, we proposed a concept in which Industry, Academy, Government Society, and Environment (Quintuple Helix Model) has synergetic relations, which should act in consonance for a positive development of AVs. As the government can exert a direct influence on all helices (from political stimuli to transport plans and laws), such influence can determine the positive or negative paths along which the devices inherent to the development of AVs. At the same time, the academy must act on both the technical and non-technical fronts of this development. The Academy-Industry outputs should act as a trigger for the positive transport planning pathway considering the future of AVs in the Brazilian context.

In addition, this is a theoretical paper; therefore, interviews or surveys have not been conducted. Regarding future research, we suggest practical studies that generate data in order to validate our theoretical framework. We also suggest deeper studies for each helix to determine the importance of each to the QHM. Finally, it is important to highlight that this study represents a starting point for analyses involving AVs and the spheres of the QHM and that it can contribute to advances and future studies on the issues of mobility, eco-innovation, sustainable innovation, smart cities, industry 4.0 and more.

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