Analysis of Autonomous Vehicle Adoption Through Niche-Level Technology Transitions

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On my honor as a University Student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments

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Introduction

Autonomous vehicles have quickly gone from an imaginative concept to an eventual certainty, with current estimates of highway autopilot and fully automated safety feature capabilities as soon as 2025 ("Automated Vehicles for Safety", n.d.). As these technologies come into reality, it becomes clear that with the correct application they can be utilized to improve daily life. Some foresee autonomous vehicles developing into a large network, communicating to achieve goals such as traffic reduction and improved passenger/pedestrian safety (Gerla et al., 2014). Companies like Tesla Motors are already producing vehicles with features such as lane changing assistance and the ability to summon your car from a parking lot, with more planned for the future ("Autopilot and Full Self-Driving Capability", n.d.).

Just as large companies are devoting time and computing power to the development of automated driving systems, so is the open-source community. Startups like Comma.AI are helping develop open-source software to enable any interested party to outfit their vehicle with autonomous vehicle technology, according to their "Frequently Asked Questions" page. At the same time, some open-source projects are forming partnerships with leading companies and government entities (Autoware, n.d.). These developments, undertaken largely by the individual, are indicative of a grassroots movement towards collective ownership of important software.

A technological transition is defined as a major transformation in the way societal functions such as transportation, communication, housing, or feeding are fulfilled (Geels, 2002). These come in many forms, and the automation of the everyday vehicle certainly fits the criteria. In this paper, I will analyze the role of open-source driver assistance software using the theoretical framework of the multi-level perspective. This framework views technological

transitions as a dynamic interaction between three main components: the grassroots niche, the well-developed regime, and the overall sociotechnical landscape (Geels & Schot, 2007). The paper will give an overview of the multi-level perspective framework, then define the open-source software as a niche-level technology and situate it in the context of its accompanying regime and surrounding landscape. An examination of relevant historical context and a summarizing discussion of perceived influences will follow. My formal objective is to investigate how the development of such open-source systems disrupt the standing regime surrounding autonomous vehicles, and how these disruptions influence the surrounding landscape.

Technology Transitions: The Multi-Level Perspective Framework

Individual technologies, argue Rip & Kemp (1998), cannot simply be valued by the novelty they provide. The authors propose that they are a product of their environment, existing systems that may affect them, and the surrounding sociotechnical landscape. Fig. 1 can be used to help expand on the descriptions of the components of the multi-level perspective framework from the introduction. As Geels & Schot (2007) indicate, the external landscape exists to influence both the standing regime and the developing niche innovations. They then state the regime exists as a collection of well-structured entities that define a given technology as it fits in society. The underlying niche innovations constantly improve, the authors posit, gathering support while waiting for the regime to become destabilized by pressure from the landscape. It is at this point, they conclude, that niche innovations can fill the newly created void in the regime and solidify themselves a lasting role.

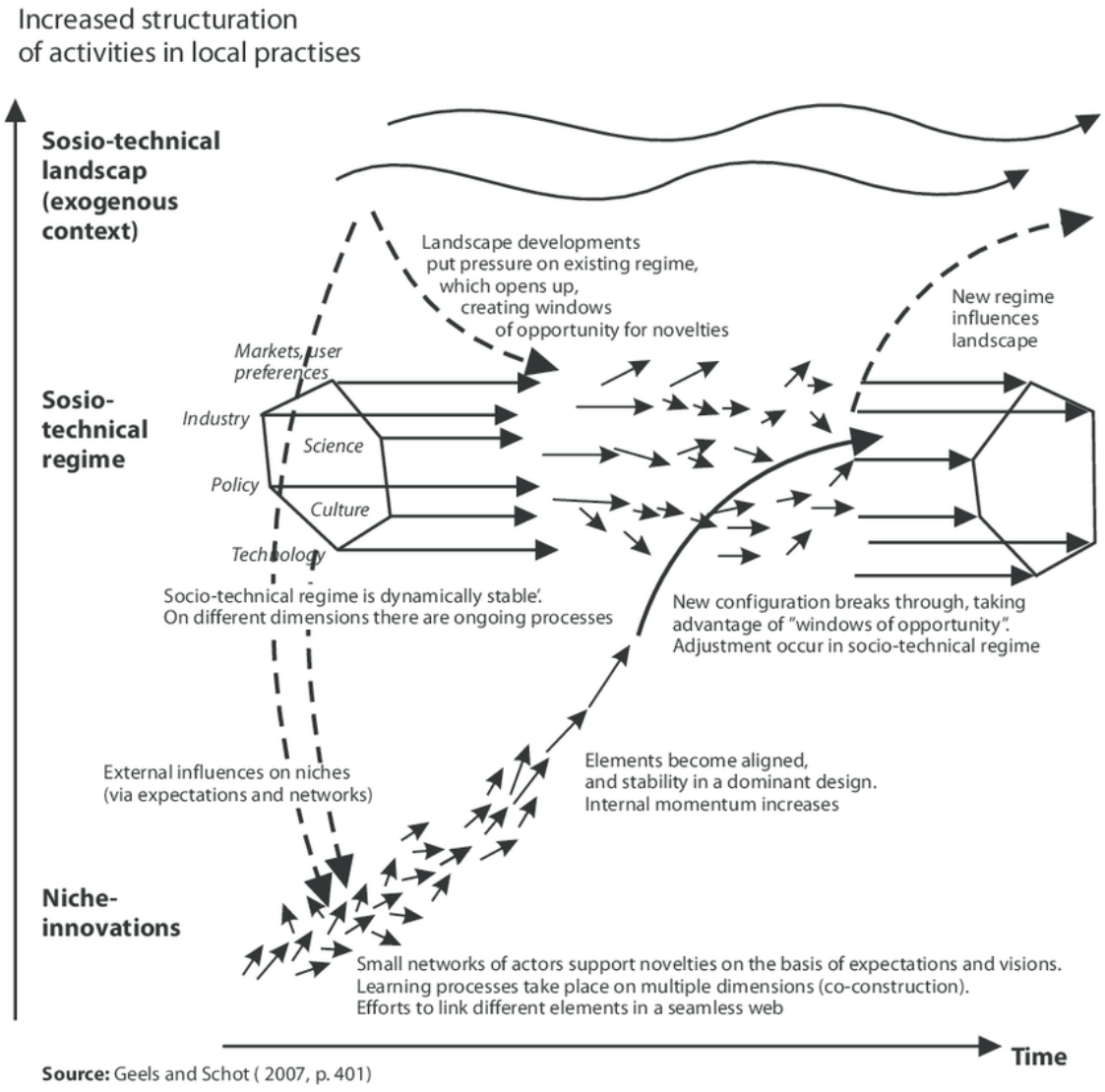

Fig. 1: Multi-level perspective overview (Geels & Schot, 2007)

The Landscape Surrounding Autonomous Vehicles

Globally in 2018, road traffic crashes caused one death about every 24 seconds ("Global status report on road safety", n.d.). In the same year, drivers in cities like Boston, Washington, D.C., and Chicago lost 164, 155, and 138 hours to traffic congestion, respectively

("INRIX 2018 Global Traffic Scorecard", n.d.). These matters of safety and convenience have long been needing a resolution.

However, the same companies sponsoring the research and development into potential solutions have been coming under fire for procedural or ethical violations. Examples include Facebook with their recent mishandling of user data to an analytics firm (Isaak & Hanna, 2018) or the failure of Equifax to address security vulnerabilities, leading to the exposure of half of the United States population to identity theft (Berghel, 2017). Realizations about these practices has in some created a sense of distrust toward the technology giants of today.

In fact, in a 2017 survey conducted by Axios, 40% of US internet users surveyed were concerned about lack of regulation of technology companies (Benes, 2018). Benes points out in the article that the results of the same survey from 2018 show an increase to 55% of respondents. A 2015 study conducted showed that only 50.4% of Americans surveyed were comfortable with their vehicles transmitting data to other vehicles, and only 42.9% were comfortable sending data to the manufacturer (Bansal & Kockelman, 2017). Despite the concern of a portion of the population, an argument can be made that this emotion has not translated to any sort of pushback from consumers (Benes, 2018). Total revenue from companies like Facebook, Equifax, and Google have risen steadily in the past five years, and their respective stock prices, while dipping at times of scandal, have either broken even (Facebook) or increased (Equifax, Google) during the same timeframe ("Macrotrends – The Premier Research Platform for Long Term Investors ", n.d.). All of this information points to the average American consumer being entrenched but wary, supplying the pressure needed according to Geels & Schot (2007) to open windows of opportunity for innovation.

The Regime: Policy and Stakeholders

As with many other cutting-edge technologies, the policy regarding autonomous vehicles is outpaced by the development of the technology itself (Pinto, 2012). However, in the United States, many policymakers are trying to set what guidelines they can for these systems as they expand. The "Safely Ensuring Live Future Deployment and Research In Vehicle Evolution Act", or "SELF DRIVE Act", which most recently passed the House of Representatives in 2017, aims to solidify the NHTSA as the leading authority on autonomous vehicle regulation, establish an advisory council for highly automated vehicles, and requiring manufacturers to develop cybersecurity plans before introducing their vehicles (H.R. 3388, 2017). Since 2012, 41 states and the District of Columbia have enacted legislation regarding autonomous vehicles, many of which handle baseline tasks such as defining key terms and establishing new committees or task forces to handle future automated vehicle-related issues ("Automated Vehicles | Self-Driving Vehicles Enacted Legislation", 2019). This shows that despite rapidly advancing technology, a majority of states are eager to follow the direction of the NHTSA and prepare for increased levels of vehicular autonomy in the near future.

Many well-established companies are also following the roadmap of the NHTSA and pushing to make automated vehicles a reality sooner rather than later (CB Insights, 2019). The same report authored by CBS Insights lists the tenured Alphabet (Waymo) and Tesla initiatives, but also includes manufacturing powerhouses like Volkswagen, Ford, Toyota, and Honda who are making their own investments into the tech. These companies will need to work together, and especially with academia at the research level, in order to introduce technology with sensible policy, however (Beiker, 2012). And partnerships are already starting to form, including BMW, Intel, and Mobileye developing an open standards platform and GM, Honda, and Lyft pooling

billions in investments in pursuit of an autonomous ride-hailing service (CB Insights, 2019). This signifies an important shift away from the copyright-focused norms to a more collaborative environment, perhaps paving the way for more progressive, niche changes.

Niche-Level Developments

The concept of creating software at the community level has existed for almost as long as the modern computer itself. In 1985, Richard M. Stallman founded the Free Software Foundation, a nonprofit whose mission is to advocate and educate on behalf of computer users around the world (Free Software Foundation, n.d.). This organization fostered the development of computer programs such as the GNU operating system, flavors of which are still widely used today (Free Software Foundation, n.d.). Eric von Hippel (2001), an MIT professor specializing in the economics of free innovation, attributes the success of a user community (like those creating free software) to be the realization of three conditions: Some of the users having sufficient incentive to innovate, some of the users having incentive to voluntarily reveal their innovations and the means to do so, and the ability of user-led diffusion of innovations to compete with commercial production and distribution.

Openpilot is an open-source driver assistance system that performs functions like adaptive cruise control, automated lane centering, lane departure warnings, and more (Comma.ai, n.d.). This software is now maintained and expanded by the open-source community under the MIT license, which allows for commercial use, modification, and distribution without any warranty or liability to the provider ("*Comma.ai/openpilot: open source driving agent*", n.d.). Comma.ai then sells an accompanying hardware kit on which the software is run (Comma.ai,

n.d.). With respect to von Hippel's conditions for success, this separation of legal responsibility between hardware and software gives comma.ai the incentive to innovate and continue to reveal their findings.

Another instance of grassroots mobilization in the autonomous vehicle industry is the Autoware Foundation. The core product they maintain, Autoware.AI, allows for driving assistance with 3D map data and LIDAR sensors (Autoware.AI, n.d.). Like openpilot, the project is open-source and open to contributions from anyone. The project developed out of Nagoya University in 2015, before ownership transferred to a single company, and then to the foundation as it stands currently (Autoware, n.d.). The Autoware Foundation is partnered with academic, private and public sector backers who help advise the direction of the product, including LG, Huawei, and Intel (Autoware, n.d.). This is an example of a niche development experiencing self-organization and alignment with the help of powerful actors, an important step in the transition process (Geels & Schot, 2007). Additionally, the involvement of these actors, each having their own network of influence, can help satisfy von Hippel's third condition of competition with commercial production.

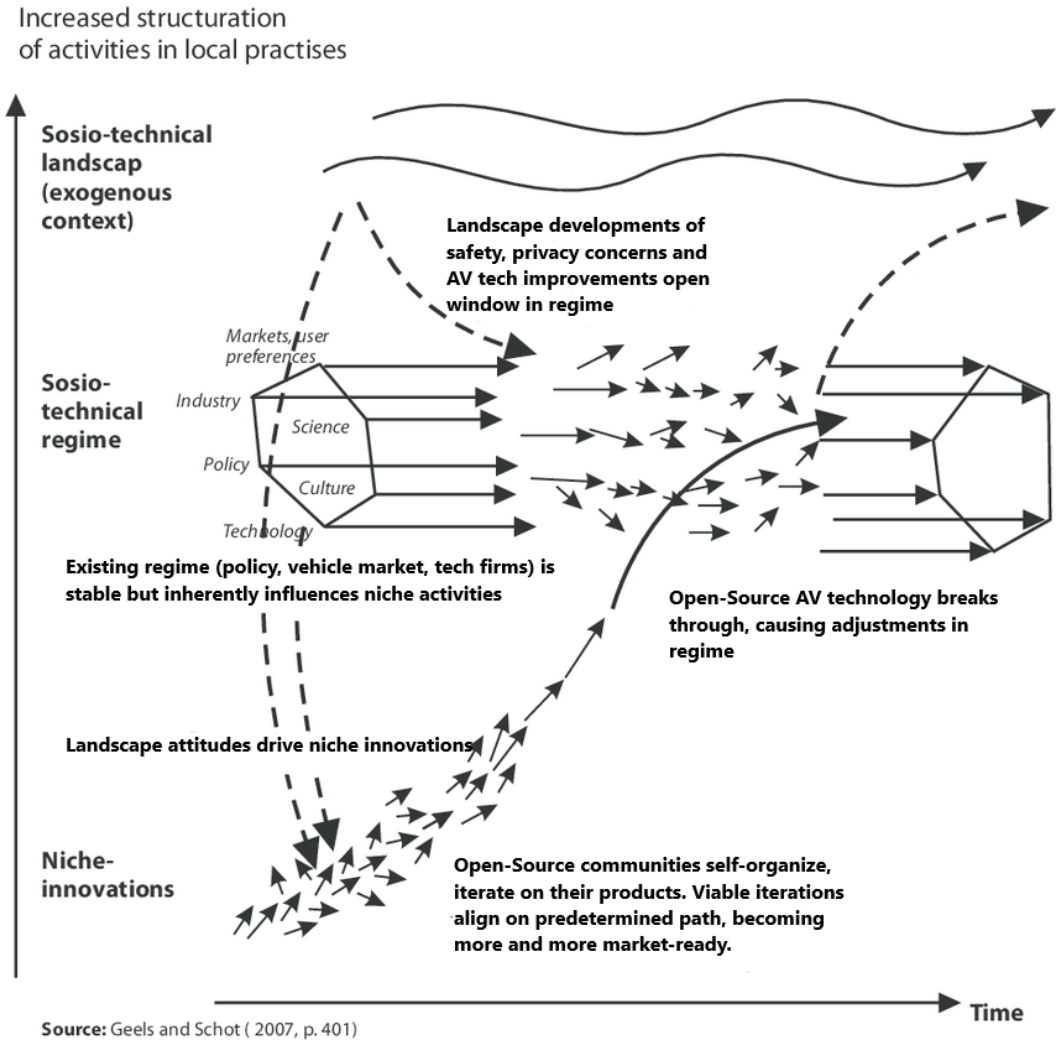

Fig. 2: MLP Diagram of Open-Source AV Technology. Template from Geels & Schot, 2007.

Technology Transition in Practice

The following section will outline a historical instance of technology transition that has to do with the automobile in order to offer an example of this framework in practice and draw

parallels to the research in context of autonomous vehicles. Thus, it should be considered for these parallels rather than a definite, fully-researched case study.

Example: The Original Automobile

Geels (2005) examines the birth of the automobile in America from 1860-1930 using the multi-level perspective framework. In his paper, he divides these 70 years into distinct time periods, each with different landscape, regime, and niche developments. 1860-1885 was a period of regime stabilization for horse-drawn transport such as horse trams, with large systems of stables and stable hands being employed, for example (Geels, 2005). The surrounding landscape encouraged this as cities expanded, creating the pressure for more transportation infrastructure (Geels, 2005). During this time, niche movements like the bicycle began emerging as "fascinating novelties", mainly being used as toys for the rich (Geels, 2005). Geels (2005) then describes the period from 1885-1903 as one with landscape actions of immigration and expansion of the middle class. Existing horse regimes encounter problems of safety, cost, congestion, and pollution, and new niches like the electric tram and the gas automobile emerge to try to solve them (Geels, 2005). Geels describes the period from 1903-1914 and 1914-1930s separately, however they will be discussed jointly in this paper for brevity. During these time periods, gas automobiles and electric trams captured different market areas and competed directly, with automobiles ultimately winning due to standardization of design and technical improvements (Geels, 2005). In addition, perception of electric tram companies as money-hungry actors and limited room for fare-based income stopped the niche's progress (Geels, 2005). Geels (2005) then posits that as automobiles fulfilled a landscape pressure of suburbanization their sales increased rapidly, and they established a new regime of their own.

Many parallels exist between the birth of the original automobile and the diffusion of vehicle automation. The problems with the horse transportation regime that Geels identifies in 1885-1903 still exist in the transportation regime today (although in the context of this paper, these were discussed as the surrounding landscape). In particular, safety concerns as a driving force are prevalent in both areas. Additionally, Geels' (2005) classification of gas automobiles as being toys for the rich up until their mass production in the 1910-1930 period aligns with the current status of vehicular automation. The discussed open-source automation technologies involve a considerable capital investment and technical knowledge, or both (Comma.ai, n.d.) (Autoware.AI, n.d.). Companies like Tesla have driven the cost of vehicles with automation technology down, however ("Design Your Model 3", n.d.). These movements will improve much like the original automobile as related technology advances.

Discussion

Using the contextual definitions of landscape, regime, and niche defined above, it is evident that a potential technology transition is in the making. In particular, this can meet the definition of a technology de-alignment and re-alignment as outlined by Geels & Schot. This transition type concerns large, divergent, and sudden change in landscape along with loss of faith in regime actors. This causes the earlier explained drive for actualization of niche technologies, except that in this case the niche technologies are still undergoing research and development. This leaves the niches to grow and compete until one becomes the dominant, shaping form to fill the gap (2007).

In this case, the landscape of intertwined technology growth and desire for improvements in long-standing vehicular issues supplies the pressure. The distrust in technology giants of the day has been made poignant by mounting privacy and misuse examples is rocking the standing regime. Alternatives like Openpilot and Autoware.AI may not be in position to replace regime technologies at present, but they are working towards an end goal that will directly appease the change of landscape. If these opinions hold and the development of aforementioned open-source solutions reaches a point of stability, then the transition will be realized. These interactions are visualized in Fig. 2 above.

Regime-Level Changes

Insertion of open-source technologies into the regime level would be a new turn in the realm of commercial assisted driving, however the process itself has been done before to great success in other applications. The Apache Software Foundation, not unlike the Free Software Foundation described earlier, is a nonprofit overseeing a large number of open-source software projects (Severance, 2012). Formalized in 1999, the ASF releases software like the Tomcat web server under their Apache license, which allows anyone to modify and release proprietary versions of their software (Severance, 2012). In turn, engineers from technology companies who employ this software contribute to it in their free time, adding changes from their proprietary versions as they lose commercial edge (Severance, 2012). The continued success of this organization sets an important example for how vehicle manufacturers can adopt a similar business model to advance the arrival of higher levels of vehicular autonomy.

To this effect, in 2014 Tesla Motors CEO Elon Musk announced that the company would not take legal action against anyone who uses their patented technologies, as long as they are acting in good faith (Musk, 2014). Their definition of "good faith" is restricting to most interested business parties, however (Collura, 2018) ("Patent Pledge", n.d.). Companies like Tesla Motors making these acts of goodwill for the autonomous vehicle community can take it a step further. Modeling after innovative open-source software innovations like Apache, these companies can move to open-source portions of their software while still enjoying profit from selling their vehicle chassis and other hardware. This also models after startups like comma.ai, who have made progress under the same business model. Doing so would allow the development of cutting edge autonomous vehicle software to be put first on all fronts, while still catering to the traditional vehicle markets of today with manufacturer-specific features.

At the policy level, Congress must continue to follow the eagerness of many states in preparing for the onset of these vehicles. Currently, the Senate has a committee on Commerce, Science, and Transportation with relevant subcommittees being Transportation and Safety, and Communications, Technology, Innovation, and the Internet ("Congressional Committees", n.d.). The House of Representatives has committees on both Science, Space, and Technology and Transportation and Infrastructure relevant subcommittees include Research and Technology and Highways and Transit, respectively. Given that the onset of increased levels of vehicular autonomy is projected in the near future ("Automated Vehicles for Safety", n.d.) (Litman, 2020), both the House and Senate should at least dedicate a new subcommittee to the pursuit of autonomous vehicles. A group of policymakers tasked with keeping up with the rapid pace of innovation and articulating advancements to the rest of Congress can only serve to ease the inevitable transition.

Landscape Influences

Assuming that these regime-level changes actualize, the surrounding landscape will react accordingly. The use of open-source initiatives in more established, industry contexts will lead to an increased collective consideration of accountability and transparency when choosing products. When the algorithms by which an individual's vehicle operates are auditable and freely available, that individual will care more about what they are able to do. If the individual is technology-literate, they can see for themselves; advocacy groups will help those interested who are unable to navigate the details themselves. As law professor Eben Moglen (2004) states, "In the twenty-first century, power is the ability to change the behavior of computers. If you cannot change the behavior of computers, you live within a Skinner box created by the people who can change the behavior of computers.".

Additionally, once these freely available open-source systems have become ingrained in the regime, the currently ongoing discussions of ethics surrounding autonomous vehicles will turn a new chapter. A simple illustration of a potential issue arises in the form of what is known as the Trolley problem (Thompson, 1985). In this case, the problem consists of an autonomous vehicle encountering a choice, either swerve left and strike a young girl, swerve right and strike an old grandmother, or do nothing and strike them both (Lin, 2016). The ethical dilemma is thus apparent. The twist that this technology transition creates is, if the average technically-literate user is able to modify the software on which their vehicle runs, they theoretically may be able to influence these controversial decision making processes. The question of whether or not a user is able to impose their personal moral inclinations on such a potentially dangerous technology is one that will be hotly debated in years to come.

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