Article

Making the Car "Platform Ready": How Big Tech Is Driving the Platformization of Automobility

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Abstract

"Big Tech" platform companies like Alphabet (Google), Apple, and Amazon are deeply invested in the future of automobility—from developing car-specific interfaces and self-driving technology to establishing business partnerships with automakers. Far from business-as-usual, we explain how Big Tech is reshaping the traditional automotive industry by making the car "platform ready," as imposed on the web before it. The article considers how this novel transformation of automobility is increasingly significant for critical scholars of social media, platforms, and platformization, as bespoke forms of mediated, datafied, and platformized, sociality emerge. Specifically, we identify six levels upon which this platformization of automobility is unfolding and through which Big Tech is reorganizing the automotive industry according to platform logics concerning programmability, modularity, connectivity, data collection, and developmental partnerships. We do so by analyzing academic and technical literature, industry reports, and initiatives with a stake in *platform automobility*. Finally, we suggest directions for further research into Big Tech's stake in the future of automobility, as these new dynamics begin to reshape the automotive industry at large.

Keywords

platformization, platform automobility, connected and autonomous vehicles (CAVs), self-driving technology, platform studies, Big Tech, automotive industry

Introduction

Now the smartphone race is over, "Big Tech" platform companies are "battling to control how you operate your car" (Nylen, 2021). Google's parent company Alphabet is not only developing integrated digital mapping and navigation software (Google Maps, Waze) and in-car smartphone-reliant interfaces (Android Auto) but whole vehicular operating systems (Android Automotive OS), self-driving technology and vehicles (Waymo), urban infrastructure technology (Sidewalk Labs), and more. Similarly, Apple (Apple Car, Drive.ai), Amazon (AWS Connected Vehicle Solution, Zoox), Lyft, and Uber are likewise investing in and advancing what we refer to in this article as *platform automobility*—that is, the platformization of automobility. In this article, we detail how Big Tech is reshaping the traditional automotive industry by making the car "platform ready" (Helmond, 2015, p. 7) like the web before it.

While connectivity remains central to these automotive initiatives, the platform is emerging as the dominant technological and organizational model, echoing transformational developments across society (Nieborg & Poell, 2018; van Dijck et al., 2018). In short, platform companies have approached the automotive industry as another conquerable domain. As a result, automobility has become increasingly interwoven with platform technology while cars and automakers have become increasingly dependent on platform ecosystems.[1] While the "car as a platform" is set to grow 20% by 2035 (Deloitte, 2020, p. 47), "connectivity as an enabler" (Deloitte, 2020, p. 89) of related services is set to generate far greater global revenues. By articulating how existing automotive companies are reorganized according to the logic of platforms, we highlight the politics of these new emerging "platforms" (cf. Gillespie, 2010), how platforms and infrastructures increasingly converge in cities and in the

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automotive industry (cf. Plantin et al., 2018), and what the societal consequences of these developments are.

In the following, we outline some of the ways in which this "platformisation" (Helmond, 2015; Poell et al., 2019) of automobility has taken place and the emerging significance of the car as an object of study for critical scholars of platforms and platformzation. (Self-driving) cars, we argue, are emblematic of an emerging genre of new, sensor-enabled social media technology, alongside smartphones, consumer drones, domestic robots, wearable technology, virtual assistants, smart homes, urban sensors, and "internet of things" (IoT-)devices more generally (cf. Poell et al., 2019). Cars generate a broad range of data types, from sensors that collect technical data about the vehicle (e.g., speed, position, tire pressure) to embedded infotainment systems that track music listened to, destinations visited, and data generated by Bluetooth-enabled smartphones and watches (e.g., contact lists, photos, messages, call logs).

Yet the specificity of their emergence as new platform types deserves greater attention, as these have modified and expanded prevailing platform logics. In this, we evaluate and synthesize current developments in which a hinterland of automotive engineers, software developers, start-ups, and established companies are transforming automobility according to the logic of platforms. Through an analysis of the various platform "levels" at which platformization is taking place within the automotive industry, we suggest several research foci to further guide and inspire the study of the (self-driving) car, its platformization, and the societal consequences.

We build on prior research on the transformation of the vehicle, including Alvarez León (2019) on how cars became "mobile spatial media," Wilken and Thomas (2019) on the car as a "communication platform," Agre (2001) on the "wired car," and Steinberg (2021) on "automobile platform capitalism" (p. 5). All emphasize how cars have long integrated navigational, communicational, and operational technologies, with the current platformization being but the latest effort to streamline car design and development. In addition, we add to recent work on the infrastructural demands and implications of connected and autonomous vehicles (CAVs) (Gekker & Hind, 2019), considering the privacy and surveillance implications of the platformization of automobility. These prior studies have explored the intersection of cars, media, space, and sociality. We extend the argument that cars became mobile spatial media or communication platforms by suggesting that these dynamic qualities are now subject to, and enabled by, platformization. As such, we contribute to the current debate on the consequences of platformization and the "infrastructuralisation" of platforms, as it is brought to bear on the development of automobiles in 2022 and beyond (e.g., Plantin et al., 2018; van Dijck, 2020).

In the next section, we provide an overview of the literature to make sense of platform automobility. We draw on work on platforms and platformization, media and automobility, and automotive production and organization to situate a debate around platform automobility. In the second section, we consider six platform "levels," drawn from a variety of initiatives with a stake in platform automobility to articulate some of the key trajectories, dimensions, techniques, and implications, of this new dynamic. As we argue, each level offers a different aspect of the platformization of automobility—from how they are built, to how other services are "plugged into" them, and how they serve as drivers of specific infrastructural developments in cities and urban environments. Finally, in acknowledgment of this nascent phenomenon, we propose a research agenda to help study the emerging platformization of automobility and the role of Big Tech.

Making Sense of Platform Automobility

Platforms and Platformization

As Helmond (2015) has previously suggested, the "term 'platform' has become the dominant concept for social media companies . . . positioning themselves in the market" (p. 1). In this transition, or transformation, of social media companies (e.g., Facebook) from simple "social network sites" to fully-fledged "social media platforms" (Helmond, 2015, p. 3), they can be said to have *platformized* or undergone *platformization*, ensuring that web data crucial to their operations is made "platform ready" (Helmond, 2015, p. 7) through a number of technical developments. These "levels" or "conditions of programmability" (Helmond, 2015, p. 5), as Helmond writes, usher the platformization of the web itself, allowing web content and its presentation to become uncoupled, content and features to become modularized, and databases to be remotely interfaced with. In terms of specific technical objects, Facebook's "social plug-ins. . .including the ubiquitous Like button" (Helmond, 2015, p. 7) are critical to enabling much of this platformization, allowing Facebook to capture user data from across the web and beyond the Facebook platform itself.

Platforms and the process of platformization have been studied in various domains beyond the web, including mobile apps and games, cultural production, journalism, and the public sector (e.g., Poell et al., 2019; van Dijck et al., 2018). As domains are platformized, they acquire features and characteristics typical of platforms, with similar implications and consequences. Poell et al. (2019), for instance, summarizes that the process of platformization unfolds along three dimensions: data infrastructures, markets, and governance. Together these dimensions of platformization enable a comprehensive understanding of how the process leads to transformation in specific domains, with significant implications for affected stakeholders (Poell et al., 2019). Moreover, the complex and interrelated structure of the platform ecosystems that emerge is increasingly at odds with established legal frameworks, economic models, and public values in countries worldwide (van Dijck, 2020). We argue here that

platformization is taking hold of the automotive industry, which has not yet been fully comprehended, but to which existing literature across media, management, and economic geography is useful.

Platform discourses are important to this process of platformization as it unfolds across society. As Gillespie contends, the use of the term platform is not trivial, but "drawn from the available cultural vocabulary by stakeholders with specific aims, and carefully massaged as so to have particular resonance for particular audiences inside particular discourses" (Gillespie, 2010, p. 359). Gillespie identifies several "discursive positionings" (Gillespie, 2010, p. 349) of the term, including computational, architectural, figurative, and political variants, which together inform its specific meaning and deployment. Others have examined how (web-based social media) platforms organize and redistribute relationships between key stakeholders, typically through data (Gerlitz & Helmond, 2013; Wilken, 2014). These approaches have established the platform as a core unit of analysis for social media scholars and beyond, with varying implications explored, including for public values and governance (e.g., van Dijck, 2020), "platform capitalism" (Srnicek, 2016), and "platform urbanism" (Barns, 2020).

Digital platforms and infrastructures have also been studied extensively by management and information systems researchers. This research examines the architecture designs of platforms and ecosystems as well as their strategy and evolution (e.g., de Reuver et al., 2018; Hein et al., 2020). They cover the technical perspective on software-based platforms that provide core functionality for modular, third-party services. In addition, they also consider the innovation capabilities of digital infrastructures, the mechanisms by which platform owners integrate and govern the ecosystems of connected stakeholders, as well as market-based perspectives on "multi-sided" platforms and market power in the context of network externalities. As such, they provide complementary perspectives on the technical architectures of platforms and platform ecosystems and how they organize and structure platform-based markets. These perspectives are necessary to consider the implications of platform automobility.

Media and Automobility

Despite the current developments in the automotive industry, platform automobility remains largely absent from the media and platform studies literature. While there has been substantial interest in the "on-demand economy" (Chen, 2017) and ride-sharing practices (van Dijck et al., 2018; Wang, 2018), the platformization of transportation, digital labor, or market relations are typically the focus. Further, while there is general research on mobility and mobile practices (e.g., Taipale, 2014), and recently on "smart mobility," and "mobility as a service" (MaaS) (Sourbati & Behrendt, 2020), little of this research evaluates platformization as a dynamic process acting upon, and through, (self-driving)

cars. Instead, transportation networks (e.g., buses, taxi services, e-bikes and scooters), and the integration of transportation systems have taken precedent. While these approaches are relevant in that they analyze technological shifts in mobile labor and transportation, they do not consider the platformization of the automotive domain specifically.

We are, however, not the first in media studies to study the social effects of technological developments within the automotive industry. For instance, cars have been conceptualized as "mobile spatial media" due to the "ongoing computerisation" of vehicles (Alvarez León, 2019, p. 362), long "wired" (Agre, 2001), or "rewired" (Sheller & Urry, 2000, p. 752) to afford mobile technological possibilities. While this has involved the "successive incorporation" of multimedia technologies into cars themselves, it has also entailed the parallel incorporation of "increasingly sophisticated positioning and navigation" (Alvarez León, 2019, p. 363) into vehicles (Brown & Laurier, 2012; Chesher, 2012; Wilken & Thomas, 2019). These developments have yielded different kinds of individual and social activities within, and through the car, from the ability to play music to navigating via "social navigation" apps (Hind & Gekker, 2014). The incorporation of entertainment and navigation features into vehicles is now, we would contend, being driven by platformization in various guises.

While these technologies modulate the user experience *in* the car, the contemporary vehicle is still seen as a passive receiver of such technologies, rather than an (autonomous) agent itself. Yet with the promise of CAVs, automobile automation (e.g., Bissell, 2018; Brown, 2017), machine learning (e.g., Ganesh, 2017; Stilgoe, 2017a), autonomous vehicle testing (e.g., Marres, 2020), and the policy implications of self-driving cars (e.g., Stilgoe, 2017b) further expand the idea of the vehicle as a form of social media or a "smart" object *itself*. Others have considered how CAVs require default data collection and processing at the expense of privacy (Gekker & Hind, 2019), or how "future users" of CAVs are enabled or disabled by these advances (Wigley & Rose, 2020). Although approaches that foreground algorithmic and data processes are valuable here, platformization represents a far broader, actualized, tendency within the automotive industry on which automation and datafication are technically reliant.

Likewise, the advent of software-dependent automobility has long foregrounded questions of space, governance, and social inequality. For example, Horvath examined how the rise in the automobile claimed much of our cities as "machine space," restricting access for nonmotorized vehicles (Horvath, 1974). Others have considered how "software-sorting" (Graham, 2005) and "automated management" (Dodge & Kitchin, 2007) have modulated activity inside and outside the vehicle, rendering and reinforcing existing social and geographical inequalities throughout the city (Yeo & Lin, 2020). Yet rather than a scalar, geographical perspective that considers the effect of the platformization of automobility on society

at large, we consider here some key elements of what the ongoing process of platformization actually looks like as it is overcoming automakers and the automotive industry.

Automotive Economies

Recent work by Steinberg (2021) considers the "prehistory" of platform automobility in the shape of Japanese car manufacturer Toyota. Here a "Toyotist" mode of car production (Steinberg, 2021, p. 6) is offered as an automotive inspiration for contemporary digital platforms. Through innovations such as the outsourcing of vehicle part production, the use of just-in-time manufacturing (utilizing *kanban* and *kaizen* systems), and the collection of consumer data from sales partners, Steinberg argues that Toyota constitutes a much earlier model of platform production. Yet while Steinberg argues that Toyotist production methods are "data-intensive" (Steinberg, 2021, p. 8), establishing the company as a "data-gathering intermediary shuttling information about demand throughout [its] entire production network" (Steinberg, 2021, p. 9), he acknowledges that "digital technologies and platforms . . . see an *acceleration* in . . . data-gathering possibilities" (Steinberg, 2021, p. 17, emphasis added). It is this intensification of such possibilities, feeding back into the automotive industry from such digital technologies and platforms, that we focus on at various points throughout this article. In this, we consider the platformization of automobility to not only involve the (ongoing) platformization of production processes but also the novel platformization of data collection, product development, product partnerships, and the like.

Connectedly, Pavlínek (2008, 2020) has examined the restructuring of the European automotive industry over the last 20 to 30 years. As he has contended, manufacturers across this period have sought a range of "fixes" (Pavlínek, 2020, p. 511) (spatiotemporal, technological, and organizational) to secure a necessary rate of profit to fund product development. In the case of German car manufacturer Volkswagen, for example, these fixes have come in the form of foreign acquisitions post-1989 (e.g., buying the formerly Czechoslovakian state-owned Škoda), coupled with securing favorable tax agreements, the suspension of monopoly rules, and the design of modular factory concepts (Henn, 2022; Pavlínek, 2008). In this, we can see how vehicle manufacturers have both (a) long deployed an array of techniques to extract value from the production process while (b) remaining vulnerable to external platformization as high-cost, materially-heavy, locally-embedded, and supplier-dependent firms (Hind, 2021).

Platform automobility then, to summarize, is the transformation in automobile design, development, production, form, and use dependent on greater programmability, modularity, integration, connectivity, and data collection in, from, and between, vehicles. In short, to make the car "platform ready" (Helmond, 2015, p. 7). It is a transformation that is primarily being driven by Big Tech platform companies, and other firms within the automotive industry seeking to emulate these companies' own successful platformization within social media and the consumer electronics market. As we consider platform automobility to be an active process rather than a static state, we therefore discuss the *platformization of automobility* in which platform automobility can be considered an end goal. As we contend here, the nascent platformization of automobility by Big Tech companies is generating new automaking and software development practices, forms of data extraction, types of connectivity, and driving experiences, providing a unique case of platformization in society. In the following, we consider the ways in which this platformization is unfolding.

Levels of Platform Automobility

The platformization of automobility is not, we argue, occurring either singularly (along one trajectory) or in one automotive dimension (design, production, etc.). Instead, it is possible to identify multiple, parallel developments each dependent on a distinct technique or device. In this section, then, we consider six distinct levels on which we are witnessing the platformization of automobility. Each level foregrounds key trajectories, dimensions, techniques, and implications of the platformization of automobility through the advent of CAVs (summarized in Table 1). These levels are not necessarily operationally dependent on each other nor are some more foundational than others. Instead, they should be seen as productive ways of seeing the platformization of automobility, from a platform studies and social media perspective. That is, these levels are neither exhaustive nor mutually exclusive but help to understand how platform automobility is emerging along different paths, using a range of techniques. Our discussion of these levels in this section moves from vehicle *hardware* and material aspects [1, 2] to *software* development and engineering aspects [3, 4] to *connectivity* and urban-infrastructural aspects [5, 6].

To derive these levels, we draw upon a variety of empirical materials, including scientific and technical literature from across fields and disciplines, industry reports and white papers, product and development reference documentation, promotional materials, and online videos. In this, we employ a "technographic" approach (Bucher, 2018; Rieder & Skop, 2021) to draw out the critical techniques and devices through which platformization is occurring. In some cases, platform discourse is used by some of the actors themselves (e.g., scientists, engineers, and companies) while in other cases, we encounter more subtle technological or material characteristics that can be identified as part of platformization. The historical development of some of these levels suggests that the platformization of automobility has been ongoing for some time. Others present themselves as newer and emerging developments. In these, the "platform" variously manifests as a discrete technical object, an established operational

Table 1. Levels of Platform Automobility and Summary of Key Themes.

Level		Key themes
(1)	(Hardware) "skateboard" platform	Modular and layered hardware platform architecture design (e.g., to enable customization and personalization); Integrated hardware and software functions (e.g., to ensure optimal functioning and system security, as in Apple's iPhone/iOS platform).
(2)	(Mobile) sensing platform	Importance of real-time sensor-based data collection to control and manage system operations; Extraction and accumulation of driving data for remote testing and "permanent beta" products; Machine-based "learning" processes organized through product usage analytics for CAV decision-making.
(3)	(Modular) app/product development platform	Generativity and value creation in the platform ecosystem organized through third-party development (e.g., with APIs, SDKs); Testing outsourced to users (conducted as "aftersale" feature); Partnership strategies (e.g., with car manufacturers, cities) used to "mature" platforms and integrate technology in cars.
(4)	(Developmental) partnership platform	"Big Tech" platform companies leading development of self-driving technology, along with their partners, third-party developers, and open source communities; (Access to) driving data obtained through deployed vehicles as a key strategic asset to evolve self-driving technology; Performance is unevenly distributed, resulting in an increase in inequality (e.g., to "CAV ready" areas).
(5)	(Connective) platform ecosystem	Requirement of open interoperability standards (e.g., vehicle-to-vehicle [V2V] communication); Self-driving technology as a "game of partnerships" (Marshall, 2020) (e.g., connecting stakeholders in the automotive industry/connected car ecosystem); Trade-offs between generativity, usability, and dependency (e.g., mutual partnership relationships may become unequal, asymmetric, or extractive).
(6)	(Embedded) urban platform	CAVs inspire significant infrastructure development to meet their particular requirements (e.g., 5G connectivity, roadside infrastructure); Tension between private platforms and public values in regard to infrastructure development (e.g., public investments, private gains); Urban renewal processes become key sites of politics and contestation (cf. Raetzsch et al., 2019).

CAV = connected and autonomous vehicles; V2V = vehicle-to-vehicle.

discourse, a coalescence of relevant categories, an emergent market structure, or a set of novel supply chain relations.

(Hardware) "Skateboard" Platform

First, the car is undergoing platformization as alternative, more cost-effective, propulsion methods are developed. Vehicles with an internal combustion engine typically possess a chassis, a metal frame upon which the vehicle "body" sits, and components are attached. While "building multiple models of cars from a single base or standard" (Steinberg, 2021, p. 7) is not in itself new, with the Ford Model T quickly coming to be "called a platform in industry lexicon" (Sherman, 2020, p. 407), electric vehicles are constructed differently. Here, large batteries are placed along the length of the vehicle, creating a single, flat surface commonly called a "skateboard." As electric vehicles have no need for a bulky engine, nor extensive mechanical connections or parts (like an exhaust), most of the electric components are placed at either end of the skateboard. As such, electric vehicles are lighter, quicker to assemble, and provide more room for occupants.

The first example of an electric vehicle using a skateboard platform was General Motors' "Hy-Wire" concept car (Morris, 2020), featuring a "removable vehicle body that [was] easily interchangeable with a dockable skateboard housing all the propulsion, energy storage, and control systems."[2] This platform style also underpins Tesla vehicles, all of which are electric models built, from scratch, using skateboard hardware platforms.

Other skateboard manufacturers include Arrival and Rivian, two electric van/truck start-ups. Ordered by the likes of UPS (Tomlinson, 2020), Arrival electric vans have "batteries in the floor, motors by the wheel" and a modular "platform architecture upon which [to] quickly build different body types" to help the company flexibly address the needs of clients.[3] Furthermore, that the "platform architecture exists to facilitate multiple products really quickly" enabling

Arrival to deliver "new configurations" upon demand. Thus, the skateboard provides an (electric) modular hardware platform upon which to add further customizable and personalized elements and features, such as different body types and new control systems. In its modularity, the skateboard platform bears a striking resemblance to many other (hardware and software) platforms. Nonetheless, the level of platformization witnessed here is directly connected to the development of electric vehicles, and to the specific operational capacities of electric motors and battery technologies. Without these shifts, this kind of platformization would arguably not be taking place, with battles over the building of battery manufacturing facilities a sign of their growing significance (Jolly, 2019).

(Mobile) Sensing Platform

Second, the car is undergoing platformization as new modes of data collection are built into them. Vehicles have long had the capacity to transmit data (Dodge & Kitchin, 2007; Wilken & Thomas, 2019), with components able to communicate using established protocols. However, CAVs carry a broader variety of onboard sensor technologies to collect and process real-time data of the local environment, constituting a newly "'datafied' driving experience" (Hind, 2021). Contemporary luxury vehicles now possess between 100 and 150 electronic control units (ECUs) (Hind, 2021; Stoltzfus, 2020; Winning, 2019), required to transmit and store data.

Yet most recently, attempts have been made to extract even greater amounts of data from vehicles. In this, the car is seen to have "the potential to make a breakthrough transition from a single sensing probe to a veritable mobile sensing platform" (Massaro et al., 2017, p. 4). Thus, as opposed to simply being able to *optionally* collect GPS data to determine a vehicle's location and movements, the increase in the volume of sensor-based components within modern vehicles enables, even demands, the continuous *operational* collection of a much broader array of data from both internal (e.g., engine temperature, breaking activity, fuel consumption) and external sources (e.g., air temperature, moisture, other road users) (Martens & Zhao, 2021). Tesla Autopilot, for instance, employs a suite of eight external cameras, a radar, twelve ultrasonic sensors, and an onboard computer to assist drivers.[4] This active data collection from sensors physically attached to the exterior of the vehicle is critical to its operation under certain conditions, as images are fed into driver-assist systems. At this level, platformization enables the manifold capture of sensor data, both inside and outside the car, both optionally and operationally, which is increasingly important to the functioning of the vehicle. A recent global semiconductor chip shortage in the automotive industry, causing leading automakers to reduce factory production capacity, only emphasizes the significance of sensor technology and sensor data (Gitlin, 2021).

(Modular) App/Product Development Platform

Third, vehicle manufacturing is undergoing platformization as modular apps (i.e., tools, products, and services) are built "on top of" vehicles by third-party developers and businesses. To reduce complexity and to accommodate external contributions by developers and businesses, platforms commonly have a modular architecture design, where interoperable modules such as apps and services are interconnected with the platform through standardized programming interfaces (APIs) (e.g., de Reuver et al., 2018). As a result, with the same chassis (base frame) or hardware components, it is possible to offer a variety of customization options, thus following the modular architecture design of the hardware platform on the software level.

Google's Android Auto platform continues to expand with more apps, supported hardware, and, increasingly, by offering a "secondary interface" for other cars.[5] While Android Auto has long supported Google Maps, it has only recently opened up to the social navigation app Waze (also by Google/Alphabet). The platform has also begun working with early access partners such as navigation companies TomTom[6] and MapFactor[7] and other partners in the areas of parking and electric vehicle charging, such as SpotHero (Schoon, 2020).[8] Drivers may find and install those apps via the familiar Google Play Store,[9] turning the car into just another mobile user device alongside the smartphone, tablet, and smartwatch. The Polestar 2 announced itself as the "First car with Google built in" as it is integrated with an array of Google apps and services,[10] including Google-powered voice-activation capabilities.

In addition, Google has also developed the Android Automotive operating system (AAOS; not to be confused with Android Auto), which will underpin millions of Ford vehicles as part of a partnership with Google (Korosec, 2021a).[11] AAOS is not merely a layer atop of the vehicle but constitutes its actual operating system and runs directly on in-vehicle hardware. As such, it extends Android's reach. Moreover, Ford has chosen Google Cloud as a preferred cloud provider (Lardinois, 2021) to find ways of datafying, commercializing, and "personalising" (Hind, 2021, p. 10) the CAV driving experience.

In addition to Android for cars, map apps also embody this level of platformization. Mercedes-Benz has integrated what3words, an external addressing and voice navigation system that is embedded into model-specific infotainment systems.[12] As platforms for mobile app development, CAVs extend, as well as modify, the value of these various services. Rather than being used within the car on mobile devices, they become part of the vehicle, with special versions of these products generating novel, interactive experiences.

(Developmental) Partnership Platform

In addition, the car is also undergoing platformization through developmental alliances and partnerships. Following

a platform logic, technological scale and economic growth are in part accomplished through early access partnerships and development work conducted by, and with, third-party developers and businesses (Helmond et al., 2019). In the automotive industry, such partnerships are plentiful: Aptiv has teamed up with Hyundai, Waymo with Jaguar vehicles, and GM's self-driving operation Cruise (previously a start-up itself) has been supported by a $2.75 billion investment by Honda (Hawkins, 2018).[13] Car consortia have also purchased mapping companies (Santus, 2015), and Big Tech companies have poached personnel from robotics labs (Lowensohn, 2015) such that the nascent self-driving industry is itself "becoming a game of partnerships" (Marshall, 2020). These partnerships are structurally different from typical car industry relationships forged between Original Equipment Manufacturers (OEMs) and suppliers, in which vehicle production networks are typically dictated by car manufacturers (Pavlínek & Janák, 2007), operating alone.

In addition to partnerships, companies with access to capital make self-driving tech acquisitions. Amazon acquired Zoox, an autonomous vehicle company ($1.1 billion), and Intel acquired Mobileye ($15.3 billion), a self-driving technology firm, and Moovit, a MaaS app ($900 million). The larger a company's market valuation, the easier it is to access investment and acquisition capital. In late 2021, the market valuation of Tesla surpassed the $1 trillion mark (Korosec, 2021b), on a par only with other Big Tech firms.

In addition to these companies, open-source developer communities and informal video-based testing communities have expanded the societal interest in platform cars. For example, Comma's openpilot is an open-source driver-assist system,[14] which performs similar to the Tesla Autopilot and GM's Super Cruise.[15] It also offers a web dashboard of recent drives, where developers can annotate vehicle "disengagements" to help improve the system.[16] Here, self-driving technology development is supported through volunteer participation on web forums and wikis,[17] offering the allure of a grassroots, "bottom-up" project in sharp opposition to higher level strategic alliances. At this level, platformization inculcates new vehicle developer roles and relations (Blanke & Pybus, 2020; Dieter et al., 2019; Partin, 2020), contributing to the rapid accrual of knowledge, talent and skill, and experience within communities and between partners.

(Connective) Platform Ecosystem

Fifth, the car is undergoing platformization as it becomes connected to roadside infrastructures (e.g., traffic lights, tolling, and congestion charging systems) as well as other vehicles on the road network. Beyond thinking about the vehicle as a (mobile) sensing platform, the more vehicles become autonomous, the more they become dependent on other types of systems for their operation. As Wilken and Thomas (2019, p. 2717) contend, "[t]he importance of infrastructural support to autonomous vehicles, and communications between

them, cannot be overemphasized." In addition to cloud-based services, such communications are necessary for purposes of coordination between vehicles (i.e., "vehicle-to-vehicle"), with entire car fleets, as well as between cars and their environments (e.g., "vehicle-to-infrastructure").

To enable vehicles to communicate and interact with other vehicles and roadside infrastructure in close proximity requires common standards. Here, envisioned seamlessness is only possible when APIs and other protocols are standardized for the entire automotive industry (Raetzsch et al., 2019). Aside from who sets these standards and whether they are open or private, it is at least as important to consider whether they are adopted at all, or become failed attempts to streamline development. Examples include SENSORIS,[18] a "sensor interface specification" designed to become a global standard for "vehicle-to-cloud" connectivity (Gekker & Hind, 2019), and Responsibility-Sensitive Safety (RSS), a standardized driving policy developed by Mobileye, intended for all autonomous vehicles (Shalev-Shwartz et al., 2017).[19]

Self-driving cars connect (or redistribute the relationships between) stakeholders in the automotive industry, including through aforementioned partnership strategies, and mergers and acquisitions. The car is the core of the connected car ecosystem and, as such, mediates the connections and interactions between the platform's multiple "sides," akin to how social media platforms foster relations between ordinary users and other market actors. Companies, developers, manufacturers, and others take part in those ecosystems to access or share data and tools, products, and services enabled by those data. For this all to work, the vehicle requires continuous speedy access to reliable and secure computing infrastructure—and these requirements may further increase as vehicles become more dependent.

(Embedded) Urban Platform

Finally, automobility is undergoing platformization as wider investments are made in supporting infrastructure, integrating the car with a variety of smart systems within the "computational city" (Luque-Ayala & Marvin, 2020), such as by modular, "plug-and-play" energy storage start-ups.[20]

While transport and mobility infrastructure are traditionally a core tenet of public infrastructure development, it is increasingly the case that private platforms like Google adopt those tasks to maintain firm infrastructural control over the entire vehicle platform "stack." As a consequence, CAVs may put additional pressure on long-standing public values in the governance of cities and societies (e.g., Plantin et al., 2018; van der Graaf, 2018; van Dijck et al., 2018), as they are tracked, and managed, by private interests with a stake in the development, and maintenance, of urban infrastructures. Moreover, through networks and digital infrastructure, CAVs "connect, in functionally interdependent ways" (Alvarez León, 2019, p. 371), the spaces *inside* vehicles with the environment *outside*, exacerbating tensions

between network rich (urban) areas and infrastructure poor (rural) areas.

At the same time, Raetzsch et al. (2019) note that urban infrastructure developments, such as the weaving of an "urban fabric" with city APIs, reveal how urban renewal processes turn into key sites of politics and contestation between city governance and urban management, technological development, data science, and civic participation. For instance, the apparent seamlessness of integrated urban mobility—as advertised by Sidewalk Labs' Coord platform (by Alphabet)—is only possible when APIs are standardized for the entire industry.[21] This underlines "the centrality of API design and governance for new kinds of civic and commercial services developed within and for cities" (Raetzsch et al., 2019, p. 1) but also Alphabet's key role in developing these API standards. The car then becomes the critical "urban platform" (Hodson et al., 2020) on which other initiatives rely, generating a "structural dependency" (van Doorn et al., 2021, p. 721) that can be leveraged by vehicle operators/manufacturers. Thus, platformization in this guise only further entrenches automotive "machine space" (Horvath, 1974) within the city, generating insights that purport to help manage traffic flows, support urban advertising, and foster economic development.

Studying the Future of Platform Automobility

Based on the levels of platform automobility we have identified, we now offer six propositions for further research to address these bespoke dynamics of platform automobility—from new forms of vehicle control and data accumulation to automotive expertise and driving experiences. We do so in acknowledgment of the comparative novelty of the phenomena explored, from a media perspective. Here, each of the levels covers new ground that social media researchers, and platform studies scholars, may be less familiar with. For instance, in how car production processes, vehicle data transmission, or the specificity of OEM-supplier relations offer these bespoke platform dynamics. These propositions are loosely aligned with the levels we have identified but they may also be used to test the validity of each or to propose new levels altogether. Indeed, as the platformization of automobility matures, it is likely that further rounds of consolidation will occur, foreclosing existing levels, merging others, or establishing new ones altogether. We argue that these developments should be of interest to those studying (social, mobile) media and automobility, particularly in respect to how platformization processes are transforming the automotive industry.

Account for Interoperable Vehicle Power

A suite of data processing issues arises with platform automobiles, where sensor data inputs are used to enable and/or enhance vehicle operations. In these operations, software

engineers work to optimize image rendering processes from on-board cameras (Li et al., 2020), or learn how to segment point cloud data generated by LIDAR (Hu et al., 2020). Here, we identify the need to focus attention on two distinct layers of interoperability. First, vehicular *system interoperability* concerned with the integration of components ([modular] app/product development platform, 3), the exchange of sensor data, and ensuring the "non-conflicting" control of individual vehicles. Second, vehicular *ecosystem interoperability*, concerned with the aggregation of driving data by connected partners ([connective] platform ecosystem, 5), across an ecosystem of connected vehicles. To get to grips with questions of power that arise through the platformization of automobility, it is important to study both the technical features enabling "vehicle power" and the key stakeholders driving these developments.[22]

Consider the Commercialization of Driving Data

It is worth extending our approach to understand the significance of data generated by or extracted from CAVs as a continuation of critical work on the political economy of data and platforms. The framing of such data processes considers the extent to which "data is capital" (Sadowski, 2019), forming an ever more significant source of profit for car manufacturers, for instance, through subscription-style, "X-as-a-service" models (e.g., MaaS). Here, the vehicle simply becomes another device for extracting personal data. Further, as long as driving data is critical for training machine learning models, it will remain commercially siloed. One example can be found in the insurance industry, in which various devices are used to generate personalized products (Meyers & Van Hoyweghen, 2020). Other examples concern the privacy implications of vehicles with multiple, external cameras (Humbs & Weller, 2020), providing a challenge for data protection laws, especially in densely populated environments ([embedded] urban platform, 6) as footage of other road users is collected without permission ([mobile] sensing platform, 2).

Explore Automotive Data Multiplicities

Furthermore, as the vehicle becomes a sensing platform [2], it becomes important to understand the "multivalence" (Gerlitz, 2016) of automotive data. While other platform approaches have sought to understand how personal data is used in, and by, apps and related services (Blanke & Pybus, 2020; Dieter et al., 2019), similar efforts have only tentatively been made with respect to automobility (e.g., Fugiglando et al., 2019; Massaro et al., 2017). Similarities might be found between approaches in app studies, where "performative usage" of such technologies might yield a greater understanding of the multiplicity of data but so might "using data flows originally designed for machine reading" (Dieter et al., 2019, p. 2). As manufacturers enroll

external researchers in the development of new machine learning models, initiatives such as Waymo Open Dataset and Google-Landmarks provide a valuable resource for future research.[23] Accordingly, it becomes important to approach the vehicle as a platform both "with the grain" (i.e., as a typical user) and "against the grain" (i.e., as an atypical, or more inquisitive, user). As social media research has shown, the development of platforms also entails the development of new standards and protocols [3] to manage the collection and circulation of novel streams of big data with implications for society and culture (Puschmann & Ausserhofer, 2017).

Contextualize Automotive Modularity

As argued by Steinberg (2021, p. 6), "automobile manufacturer and its organization are the basis for the digital media artefacts we call platforms." But while the automotive assembly line offered a 20th-century version of modularity, it is not entirely clear how Big Tech platformization will affect 21st-century modularity. For commercial vehicle start-ups such as Arrival, this has meant championing "small-footprint, low-cost microfactories" using "cell-based assembly" rather than a "traditional automotive production line."[24] Likewise, with electric vehicles, production processes are increasingly reliant on battery production facilities (e.g., Tesla or Volkswagen "Gigafactories"),[25] which may or may not lie outside of the platform firm, but are nonetheless integral to the vehicle as a connective [5] or urban platform [6]. Indeed, that such facilities might become as critical to manufacturers as data centers are to the cloud and platform companies more generally.

Understand the Driving Experience

As platform operations proliferate, they disrupt and redistribute existing relations between drivers, passengers, vehicles, and manufacturers. On one hand, established social practices are subtly reformatted, while on the other, entirely new driving experiences are cultivated. Voice-activated navigation systems, such as with the aforementioned Android Auto and what3words, swap typed inputs for vocal utterances (Hind, 2021). Lane-changing or self-parking systems, as machine operations, render human involvement minimal. Thus, it becomes critical to explore how the "social road" is changing (Brown & Laurier, 2017). While some of the changes are directly observable, many are hidden behind technological interfaces. Most importantly, driving becomes another digital practice that is continuously monitored, analyzed, and tweaked (Marres & Stark, 2020), serving as a basis for further data-driven design and development. Thus, understanding how the use of skateboard platforms in electric vehicles [1] or how developmental partnerships [4] cultivate new (personalized) driving experiences, is important.

Evaluate Machine Vision

The (automated) decision-making capabilities of CAVs heavily rely on forms of machine vision, both in the sense of repurposed sensor technologies such as LIDAR and the process of "automating" vision itself (McCosker & Wilken, 2020). Images produced by CAVs take an operational form, enabled by an assortment of connective hardware (e.g., sensor units) and software (e.g., algorithmic object recognition). As these "operative images" (Farocki, 2004) are used extensively, both as tools during development and testing stages of CAVs as well as promotional devices, they are vital to understanding the car as a connective platform ecosystem for partnerships [4] and associated urban platform imaginaries [6]. They also represent one of the only ways in which critics, regulators, and policymakers may gain insight into the sense-making and decision-making processes at all,[26] and thus the effects of platform automobility more generally.

Conclusion

With this article, we have aimed to show three things. First, that automobility is on the cusp of being transformed through platformization. Second, that established platform logics, like data generation, interoperability, vertical/horizontal integration, and multisided market relations, are not simply being applied "off the shelf" in the automotive industry but are driving bespoke forms of platformization within it. Then third, that this platformization process is occurring on at least six recognizable levels, reorganizing relationships throughout the automotive industry. To navigate these entangled platformization processes, we have proposed six priorities for future research into platform automobility.

The platformization of automobility is significant because it upends traditional relationships within, and across, the automotive industry. These have typically relied on partnerships between automotive manufacturers and technology suppliers, with the former typically able to dictate terms of these arrangements with the latter. The entry of Big Tech platform companies into the automotive industry poses a significant challenge to these relationships, as automotive manufacturers are no longer (sole) senior partners, and technology suppliers no longer offer unique technological products or expertise.

Aside from these economic concerns, in their nascent platformization of automobility, Big Tech platform companies are also transforming how cars—and especially CAVs—are designed, developed, built, and used. As we have discussed in this article, the platformization of automobility can certainly be seen as an extension of existing notions of the car as a mobile media space, or social media object in itself, equipped for auto-mobility and also for forms of mediated sociality, communication, and navigation (Agre, 2001; Alvarez León, 2019; Brown & Laurier, 2012; Hind & Gekker, 2014; Sheller & Urry, 2000; Wilken & Thomas,

2019). Yet platform automobility, as we have hopefully articulated, does not simply concern the ability to use Google Maps or play Spotify through a vehicle dashboard, but the wholesale restructuring of relations throughout, and beyond, the car itself; between vehicle manufacturers, technology suppliers, sensing systems, cloud providers, and embedded infrastructures.

In this, we have argued that the platformization of automobility can be witnessed, and addressed, across six levels. Drawing on literature from across the industry, we have considered how platform automobility is occurring at the level of vehicle hardware [1, 2], software [3, 4], and wider infrastructural connectivity [5, 6], offering multiple trajectories, dimensions, techniques, and implications to, and through, the platformization of automobility. However, what is important to address here is that this platformization process is neither inevitable, nor somehow already "complete." Instead, the article has offered a heuristic lens with which to evaluate the ways in which platform automobility might be coming into being. Naturally, by foregrounding the role of Big Tech platform companies in orchestrating such an effort, we have backgrounded a host of other actors within (and beyond) the automotive industry who likewise have a stake in the future of automobility.

While these companies may not operate at the same scale as Big Tech firms, offer niche products within the industry, or possess far less capital to dictate the direction of the industry, they nonetheless have the potential to steer platformization. Companies such as Mobileye (chip, driver assist device manufacturer), Bosch (engineering and technology company), or Velodyne (lidar device manufacturer) may or may not offer a different insight into the future of the automotive industry, with this suite of "Lesser Tech" actors likely to continue to play a part. Indeed, that while we have emphasized the platformization of automobility as being undertaken by global platform companies, it is entirely possible that other automotive actors are able to emulate their efforts within the automotive industry itself.

Likewise, despite our implicit suggestion in this article that vehicle manufacturers will become usurped by Big Tech, it is also plausible that the former will continue to be able to dictate terms within the industry, including those with platform companies. The sale of Uber ATG to self-driving start-up Aurora (Korosec, 2020), in return for a minority stake in a combined company, strongly suggests that platform companies are finding automotive innovation challenging, and that the multitude of strategic partnerships between manufacturers suggests a desire, and need, to spread associated costs and risk.

Nevertheless, as this article has sought to show, the platformization of automobility is very much in evidence, already judged to be "Big Tech's next monopoly game" (Nylen, 2021). Considering how other industries have become platformized, it is distinctly possible that the same will happen to the automotive industry, just to greater or lesser degrees. As a recent assessment of the future of the automotive industry has suggested, vehicle manufacturers risk being "unable to realise most of the revenues" (Deloitte, 2020, p. 89) connected to platformization, precisely because Big Tech platform companies have greater control over the applications, products, and (eco)systems needed to harness it. It is these emerging battles around the nascent platformization of automobility that this article has attempted to narrate.

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Notes

1. Consider, for example, the relationship between traditional manufacturers (e.g., Ford, General Motors, Mercedes-Benz, Nissan), component providers (e.g., Bosch, NVIDIA [DRIVE Mapping]), mapping companies (e.g., HERE, what3words), self-driving start-ups (e.g., Argo AI, Aurora, Aptiv), and university research departments (e.g., https://labs.ri.cmu.edu/argo-ai-center/).
2. https://www.adrianchernoff.com/project/hy-wire/
3. https://youtu.be/I781itRPJH8
4. https://www.tesla.com/support/autopilot
5. https://www.android.com/auto/ and https://developer.android.com/cars
6. https://play.google.com/store/apps/details?id=com.tomtom.gplay.navapp
7. https://play.google.com/store/apps/details?id=com.mapfactor.navigator
8. https://play.google.com/store/apps/details?id=com.spothero.spothero
9. For a list of Android apps for Android Auto, see http://g.co/androidauto.
10. https://www.polestar.com/uk/firstcarwithgooglebuiltin/
11. https://source.android.com/devices/automotive/start/what_automotive

12. https://what3words.com/
13. https://media.gm.com/media/us/en/gm/home.detail.html/content/Pages/news/us/en/2018/oct/1003-gm.html
14. https://comma.ai/
15. https://www.tesla.com/autopilot and https://www.cadillac.com/world-of-cadillac/innovation/super-cruise
16. https://connect.comma.ai/
17. https://discord.com/invite/avCJxEX and https://github.com/commaai
18. https://sensor-is.org/
19. https://www.mobileye.com/responsibility-sensitive-safety/
20. E.g., https://www.plugandplaytechcenter.com/energy/startups/
21. https://www.sidewalklabs.com/blog/announcing-coord-the-integration-platform-for-mobility-providers-navigation-tools-and-urban-infrastructure/ and https://www.coord.com/
22. E.g., International Data Space (by the Fraunhofer-Gesellchaft), https://www.mobility-data-space.de/en.html
23. https://waymo.com/open/ and https://ai.googleblog.com/2019/05/announcing-google-landmarks-v2-improved.html
24. https://arrival.com/?id=4
25. https://www.volkswagen-newsroom.com/en/press-releases/volkswagen-enters-into-strategic-partnerships-for-the-industrialization-of-battery-technology-7680
26. E.g., https://waymo.com/safety/

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