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AI in emerging mobility systems: On disruptive change, ethics and resilience

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Society is facing a multitude of wicked problems. Climate change, scarcity of resources, social, economic, and spatial inequalities and divides are too complex to define from a single perspective, too broad to contextualize within a sole geography, and too relevant to overlook in terms of their short- and long-term impacts. Artificial Intelligence has the potential to assist humankind with such problems by improving the efficiency and optimization of data/driven processes towards measurable outcomes. In this brief, we discuss autonomous vehicles (AVs) and urban air mobility (UAM) as two emerging mobility systems enabled by the advancements made in AI. These systems are two examples that display the inherent complexity and disruptive nature of AI-enabled systems to urban mobility. The impacts of such systems relate to the (1) reshaping of cities, (2) advancing technologies to further support innovation, and (3) steering urban development trajectories.

There is a plethora of wicked problems affecting our pluralistic society. Indeed, all planning problems are inherently wicked. This does not mean that they cannot be specific or identified - it means that they cannot be translated into, nor solved, as a mathematical problem. Rather they touch upon many aspects simultaneously, including social ones. Therefore, wicked problems are ill-defined, and their resolution relies upon elusive judgment. This applies to issues such as the location of a freeway, the adjustment of a tax rate, the confrontation of crime, as well as climate change or population growth, and scarcity of resources (Rittel & Webber, 1973).

Wicked problems have thus the potential to disrupt trajectories that have been sustained on established sociotechnical systems. Moreover, reliance on technological innovation has become a common way to address wicked problems. The attempts to respond to these problems through innovation and technological advancements entail yet another sequence of disruptive changes.

Disruption is understood as a large magnitude and rapid change, as a discontinuity that stretches and transforms a sociotechnical system. While disruptions can be the result of gradual change of large magnitude, a form of disruption in transitions progressively reconfigures the whole system. Therefore, the effects are critical for the stability and operation of incumbent technology and entities such as infrastructure, markets and business models, regulations and policy, actors, networks and ownership structures and/or practices, behavior, and cultural models. Conversely, incremental change, sustaining the existing system's set-up, has a non-disruptive nature. The rapid change that only affects one dimension might translate into disruptive innovation, affecting fit-and-confirm strategies but not compromising the stability of a socio technical system (Kivimaa et al., 2021).

Emerging mobility systems have been framed as potentially leading to disruptive change in the transport sector, as well as society, at a broader level. Such systems are often depicted by embodying at least one of the current strands of innovation i.e., vehicle electrification, vehicle automation, shared service provision, and urban air mobility (Akar & Erhardt, 2018; Skeete, 2018; Sprei, 2018; Sovacool et al., 2019; Chatziioanno et al., 2020; Yigitcanlar et al., 2020; Al Haddad et al., 2020). The advancements made are creating new opportunities for the reorganization of established transportation systems and mobility solutions while aiming to reduce externalities associated with the transportation sector.

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At the same time, they are creating new challenges for urban mobility and exposing users and society to paradigm shifts linked to the interaction between humans and machines. While envisioning the use of other energy sources and the overall reduction of vehicles, as well as the reduction of privately owned vehicles, autonomous mobility is challenging established socio-political and economic structures. Autonomous machines embodied by AI[1] will force humans to increasingly rely on and delegate control to machines with amplified complexities for shared responsibility and accountability in the event of harm. Sociotechnical systems characterized by stability will consequently be

Source Title Page Image: Tokyo with flying cars. Source: AI-generated image retrieved from Midjourney.

shaken and challenged to respond and adjust as unresolved societal impacts are unveiled.

Wicked problems, wicked solutions?

The complexity of an AI system is often overlooked due first to the attempt to isolate components and detach the system from the environment where it operates. The algorithms, the models, the outputs, the hardware, the sensing infrastructure, the data, the data subjects etc.… It can be quite a task mapping out the components and costs of an AI system (see for example Crawford, 2021 and Bommasani et al., 2021).

A second level of complexity derives from data dependency. What data is then good and plentiful enough to ensure reliable outputs? The answer seems to be “the more the merrier.” Indeed, AI might steer society not only to ubiquitous computing but also to legitimating and naturalizing surveillance by overstating the need to continuously generate and collect data (Helbing et al., 2019; Helbing, 2021). Furthermore, the data required is also based on individuals’ emotions, behavior, and social interactions. However, that is not the end of the toll for society. Biased data can hardly be avoided, as data subjects are the source of the stereotypes rendering it. Thereby AI is merely replicating and maybe overemphasizing biases in unanticipated ways. Recent advancements show that biases can be detected, assessed, and mitigated. The question is whether it can always happen before certain individuals or groups become exposed to obscure and unfair forms of discrimination. If not, then the question becomes how can AI pave a better future for society while relying on and exploiting biased data sources?

A third level of complexity relates to the opacity of the processes that lead to an output. This means that it might be impossible to trace the chain of decisions and rationale enabling a certain output, the so-called black-box. Even with the efforts to make AI explainable and transparent, humans are only able to deal with limited information. Therefore, making AI explainable means that humans will probably rely on AI to filter it down to a size we can handle. Perhaps there will be a way out of this vicious cycle where humans can actually take back control before abiding by opacity by default. Yet, there is the risk that opacity becomes a feature in order to mask underlying purposes for implementation, endorsing the idea of a back box society (Pasquale, 2015; Helbing, 2021).

A fourth level of complexity refers to the current limitations of AI in dealing with wicked problems. AI systems are mainly goal-directed, which means they are designed to achieve a defined goal by using specified techniques. However, not every problem can be translated by employing such a simplistic approach. AI systems struggle to deal with uncertainty, inasmuch as some facets of reality are hardly quantifiable or representable in ways from which an AI could currently interpret or learn. Conversely, being goal-oriented does not necessarily mean that it can only be applied for specific purposes. As AI-based systems become more complex by interacting with more subsystems and converging with other technologies (for instance, AI has been coupled with edge computing, and foundation models are being used in innumerable applications), possible adverse effects generated by AI might be displayed at several points in the process. In the aftermath, there might be an escalation of impacts and a heightened difficulty in identifying and tracing back the roots of the problems (Bommasani et al., 2021).

AI in emerging mobility systems

Autonomous Vehicles represent a big promise for innovating transportation systems, with the goal of overcoming crucial problems in the transport sector linked to negative externalities such as traffic congestion, safety issues, resources consumed, and environmental impacts (Zakharenko, 2016; Chatziioanno et al., 2020).

When embodied in vehicles, AI already enables (semi-)automated driving concepts, the so-called advanced driver assistance systems (ADAS). These systems are not yet set to replace human drivers; rather, they are intended to improve some of the vehicle's systems for enhanced safety. This concerns, for instance, lane departure and blind spot alerting. A fully autonomous vehicle is, however, expected to be self-driving under all environmental circumstances (Ma et al., 2020; Biswas & Wang, 2023).

AI and AVs cohesiveness has been moving forward by, for instance, leveraging deep learning to accurately recognize and locate obstacles on roads, assisting in decision making (i.e., controlling steering wheel, acceleration/deceleration), and optimizing transport operations such as congestion, parking, and safety (Skeete, 2018). Data is paramount, deriving from IoT (Internet of Things) to share information vehicle to vehicle (V2V), vehicle to infrastructure (V2I), and across the complete network (V2X) (Biswas & Wang, 2023).

Even if the automotive industry is considered the frontrunner to implement AVs, urban air mobility is a second use case. Just like AVs, to some extent, urban air mobility is already possible. Helicopter-based passenger transportation is possible on a charter basis in many cities. Helicopters and drones are supporting in operations such as emergency response, logistics, or surveillance (Postorino & Sarné, 2020; Straubinger et al., 2020). However, what urban air mobility entails is naturalizing the use of transportation services via air. This can mean both air taxis to transport passengers and cargo or unnamed air vehicles (UAV) to deliver goods. It has been pointed out that the adoption of emerging urban air mobility systems can pave the way towards resolving some of the current challenges in the transport sector by, for instance, significantly reducing the travel time and delivery time, decreasing traffic congestion on the ground and mitigating environmental impacts (Postorino & Sarné, 2020; Çetin et al., 2022).

Creating autonomous vehicles able to undertake transportation in urban areas via air is also envisioned by the industry. Nonetheless, the phased implementation points to starting with piloted vehicles, later migrating to a remotely piloted version until the system can be completely operated by autonomous systems. While 5G and AI are enabling autonomous vehicles on the ground, some studies advocate that 6G and edge intelligence will unlock the next generation of autonomous vehicles (Ansari et al., 2021; Biswas & Wang, 2023).

Given the complexities associated with the use of AI, the question is whether problems related to urban mobility can be formulated in ways that justify the value of AI as part of the solution?

Disruptive change, ethics, and resilience

The value of AI for endowing mobility systems with certain levels of autonomy is clear from the examples above. However, given the complexities associated with the use of AI, the question is whether problems related to urban mobility can be formulated in ways that justify the value of AI as part of the solution? We have pointed out that problems related to urban mobility are intertwined with many other problems, such as the unsustainable ecological footprint, scarcity of resources, growth of population, and urbanization. Urban mobility is a construct of solutions facilitating the movement of people and transportation of goods, encompassing, however, wicked problems deriving from the nature of their planning (Rittel & Webber, 1973). Urban mobility exists in wicked environments and deals with ill-formulated problems, where the goals and judgment of resolution are influenced by conflicting values and innumerable uncertainties. Thus, designing processes and systems to improve urban mobility entails finding ways to address the overlapping and intersections with other problems, namely those of a contextual, social, and socio-technical nature.

Moreover, emerging mobility systems enabled by AI attempt to deal with complexity by adding even more complexity. This approach will force a paradigm shift. This is hardly the first wave of disruptive change stemming from the transport sector. However, if emerging technologies are solely perceived through a technical and operational lens, there is the risk that many dimensions of unintended impacts for society will be overlooked and consequently the prevention of potential harms will not be realized.

Figures 1-2. Future cities and autonomous vehicles
Source: AI-generated images retrieved from Midjourey

The transformation of urban environments, including some aspects of urban life, is part of urban development processes. However, some changes challenge stabilized paradigms shaping urban life (see, for instance, how the use of biometric identification systems might impact the meanings of public space (Fontes & Lütge, 2021)). We will focus on three dimensions showcasing how emerging mobility systems represent disruptive change impacting cities and urban life, reshaping cities, advancing technologies, and steering urban development trajectories.

Reshaping cities to accommodate emerging mobility systems

The restructuring of existing infrastructures to accommodate AVs and UAM entails reshaping urban landscapes at the physical and digital level while laying the ground for further innovation.

Sci-fi movies have been inspiring technical innovation; thus it is expectable that this will be the case as well for AI-generated images. While delving into the transformation of urban landscapes, it is worth noting how generative AI has been intensively used to project images about future cities and the future of urban mobility (Figures 2-4 illustrate this reality).

Figures 3. Future cities and autonomous vehicles
Source: AI-generated images retrieved from Midjourney

On the one hand, using a couple of words or a longer text to prompt a generative AI program instantly delivers a series of visuals on how cities would look like, driving the conception of urban futures.

However, the question remains to what extent generative AI will hamper or replace human imagination and creativity? As a result, cities may look more and more similar. Whereas increasingly similar cities are not necessarily a problem, the situation is another manifestation of how AI is reproducing certain stereotypes by mainstreaming some values while suppressing pluralism (Bommasani et al, 2021). Generated images depend on the prompt and yet be completely distinct while generated simultaneously. The first studies on the topic already demonstrate how biases are part of the outputs[2].

Midjourney for instance can present very enticing imaginaries on how AVs and UAM will be integrated in future cities. However, the request for future cities and future mobility is harmonized with vertical cities, favoring artificial artifacts over organic elements, and where humans, if present, are a side element of the built landscape, rather than a defining condition of urban environments (Figures 1-3). In another example, AI fails to acknowledge how African architecture has moved away from rudimentary forms of sheltering[3].

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At a more specific level, and in regards to the adaptation of physical ground infrastructure, required changes are particularly disruptive for the case of UAM. If the construction of places for vertical take-off and landing (VTOL) – vertiports - is fundamental, one approach envisions vertiports as built additions to existing infrastructure (e.g., upgraded rooftops) (Straubinger et al., 2020; Schweiger & Preis, 2022). This approach might limit the resources spent and counteract the lack of vacant areas within consolidated cities to accommodate completely new infrastructures. On the other hand, AVs might initiate urban growth and a redefinition of urban centralities and land uses (Zakharenko, 2016). Vertical take-off and landing and flying at lower altitude amplifies the visual and sound impacts within cities, considering that the point of vertiports, unlike airports, is to integrate the core neighborhoods of a city, enabling urban routes.

Further adaptations will be needed in terms of requirements for vehicle certifications and air traffic management, given that UAMs are expected to fly at much lower elevations (Schweiger & Preis, 2022). As for AVs on the ground, preliminary experiments tested enclosed infrastructures, working towards nullifying uncertainties (Cugurullo, 2020). ADAS are already sharing the road with non-autonomous vehicles. Yet to implement more advanced levels of autonomy, self-driving cars will need to share and exchange information with the infrastructure and other vehicles so that the system can operate as a whole in order to optimize safety (Biswas & Wang, 2023).

Advancing technologies to further support innovation

AI is also seen as an enabler of sustainable transportation by contributing to efficiency and optimization (Yigitcanlar et al., 2020). Reducing the number of vehicle kilometers traveled (VKT) should contribute to a reduction in energy consumption and, in turn, lower air and noise pollution and traffic congestion. With regards to optimization, by analyzing data in real time, AI can support adjusting routes and balancing out availability and demand, thus, resulting in considerable reductions in travel time, energy savings, and overall improved management of resources (Skeete, 2018; Straubinger et al., 2020; Yigitcanlar et al., 2020; Schweiger & Preis, 2022; Biswas & Wang, 2023). Nevertheless, the infrastructure that needs to be in place behind the scenes is and will be consuming resources and entails externalities that might be overlooked or underestimated if the adoption of emerging

[2] Generative AI Takes Stereotypes and Bias From Bad to Worse (bloomberg.com)

[3] The AI Image Generator: The Limits of the Algorithm and Human Biases | ArchDaily

mobility solutions is not addressed as a process of change. For instance, the data collection apparatus will expose individuals to forms of surveillance that society might not be prepared to accept. In another example, as AI orients towards the optimization of certain sustainability indicators, it might aggravate social and spatial divides. Some routes might be unstainable from a demand or topologic perspective but serve as key factors for the social inclusion of certain communities.

To accommodate AVs and in particular UAM, there is a need to advance connectivity toward 6G Airborne Wireless Networks. AI is seen as a crucial feature and enabler of the 6G mobile network at many levels, including radio planning, network orchestration, user experience, and operator policies (Ansari et al., 2021). While still at an early stage of implementation, 5G enables Connected and Autonomous Vehicles (CAVs) on the ground by resolving issues of low-latency and ubiquitous coverage and allowing vehicles to exchange data across the complete system. Indeed, Intelligent Transport Systems also refer to resulting applications for traffic management and road safety (Ansari et al., 2021; Biswas & Wang, 2023). In extension, milestones are being achieved towards the Internet of Everything (IoE) and ubiquitous computing. We can ask ourselves whether it is possible to maintain the current standards for privacy under such conditions and whether human autonomy can be preserved if there is no possibility to evade exposure to such a pervasive data collection apparatus.

Steering urban development trajectories

Naturalizing data collection and data-driven decision-making

The pervasiveness of sensors integrating urban landscapes entails the datafication of our environments. In this case, there would be a ubiquitous surveillance system in place, measuring, recording, and decoding, and all that possibly in real-time. The data generated is at the grassroots of a data-driven science (Kitchin, 2014) that relies on the aggregation of data harvested from different sources and delivers outputs governing certain aspects of urban life or assisting in certain aspects of urban governance.

Whereas such a complex and intertwined system aims to support other systems and promises to exhaustively capture a whole domain, not all dimensions of a city frame can be measured and mirrored, in particular those that relate to social interactions and human behavior. Thus, the result of such ubiquitous surveillance supported by ubiquitous computing is rather a representation and a sample of segmented views from certain vantage points, using particular tools and hardly living up to the expectations of providing full resolution (Kitchin, 2014). Resultant data gaps are the product of a selection and priorities decided by the most empowered actors in play, usually demonstrating the vulnerability of certain communities unable to influence decision-making processes.

Many of the most important societal values remain difficult to measure or even to describe in terms of standards, such as happiness and well-being

Moreover, a downside to relying on measurements becomes clear when defining how data should be used to assist in decision-making. By extension, it is aggravated by the limitations of AI to deal with multi-dimensional frameworks encompassing multi-level perspectives (Geels, 2007). AI might be able to cover certain decisions that refer to efficiency and optimization and adapt to specific requirements and indicators. However, many of maybe the most important societal values remain difficult to measure or even to describe in terms of standards, such as happiness and well-being.

Conversely, data is reproducing biases embedded in society (as mentioned above in the case of AI-generated images) and projecting the future based on the past (historical or real-time data). Thus, data science might be a formula to steer urban development trajectories, but it has limitations, just like many other theories and tools that have been informing policymaking (Kitchin, 2014).

Finally, ubiquitous surveillance, even if confined to public spaces, introduces serious concerns for individual privacy while it becomes increasingly difficult to distinguish and separate what personal data is and whether anonymization is possible. To contain and respond to the potential disruptions to European democracies and the violation of fundamental rights, the EU has been progressively attempting to regulate the intrusive collection and the abuse and misuse of personal data. For example, in the GDPR (EU, 2016), biometric data is defined as personal data, and it includes physical, physiological, or behavioral characteristics of a natural person as long as they allow or confirm the unique identification of that natural person. Indeed, behavioral data can equally be used to target groups or individuals, namely by influencing decision-making through nudging and tailored advertisement. The EU AI Act (COM, 2021) bans the use of biometric data within remote biometric identification systems if conducted in real-time in publicly accessible spaces and for the purpose of law enforcement, endorsing the expectation of remaining anonymous in public space (see also Fontes et al., 2022). The Act further acknowledges that AI can be misused for manipulative, exploitative, and social control practices, contravening the values of human dignity, freedom, equality, democracy and the rule of law and fundamental rights, including the right to non-discrimination, data protection, and privacy and the rights of the child.

Shared mobility and mobility as a service

Over the past few years, the new paradigm of sharing economy has been on the rise, leveraging advances in information technology and access to improved internet and telecommunication services. This has facilitated the distribution, sharing, and reuse of goods and services, often through mobile apps. The sharing economy has affected the mobility scene, with shared mobility being at the forefront, encompassing carsharing systems, ride-hailing systems, carpooling, bike-sharing, scooter-sharing, etc. The main principle is to promote the shared use of a vehicle for completing a trip.

Shared mobility is often grouped under the umbrella of sustainable mobility, as it encourages vehicle sharing, leading to a longer-term decrease in vehicle ownership. There is an epistemological discussion positioning ownership in relation to responsibility and attachment versus access, translating a utilitarian view of goods or services (Bardhi & Eckhardt, 2012). However, shared mobility goes beyond sharing a vehicle. When compared to an autonomous carsharing system, an autonomous ride/sharing system results in lower VMT/VKT (Narayanan et al., 2020). In this sense, mobility as a service has a clear entry point to the discussion on shared mobility.

The concept proposes integrating the broad variety of transportation options from a utilitarian perspective and has been coupled with the discourse on sustainable integrated alternatives for non-motorized transport, public transport, and shared mobility. While shared mobility and mobility as a service promote diversifying the options for moving in urban contexts, they entail that end users will depend on service providers to be able to reach a destination within a desired timeframe. If public transportation is designed to promote fair access across a city, the question is if mobility services are increasingly transferred to private companies, will the coverage meet demand or will it impose social and spatial divides by restricting mobility options in certain areas and for certain communities.

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Shared mobility has been discussed in relation to emerging transportation modes, including autonomous vehicles (Narayanan et al., 2020) or urban air mobility (Michelmann et al., 2020). In both cases, concerns have been raised in relation to potential misuses and ethical gaps, given their disruptive nature, and how the perception of risks impacts trust in the system and public acceptance (Al Haddad et al., 2020).

Moral machines

From an overarching perspective, moving towards autonomous technologies encompasses transferring the responsibility of decisions and actions from individuals to machines and their governing structures, raising questions about moral responsibility and accountability. AI will embody and animate vehicles and machines so that they are able to interact within and with environments while keeping humans out of the loop. This will serve to drive smart cities towards autonomous cities (Cugurullo, 2020). This means that machines might be exposed to situations that entail decisions over the life and death of humans while being constrained by uncertainties and probabilistic models, whereas humans would rely on a moral compass. In such situations, the individual's accountability is lower, as the outcome is beyond one's control, given that it is hardly possible to decipher a chain of casualties and moral values at play.

Machines, however, rely on predictions, simulations, and rules. Thus, such events, even if rare, are crucial and defining for how AI can integrate everyday life as an autonomous force in permanent interaction with humans. This is the case of dilemmatic situations if the agency of end users is no longer required. Instead, AI will, hopefully, be able to identify and correctly assess the dilemma according to probabilistic models and apply certain rules guiding it to perform in alignment with core values governing societies. While AI will probably not develop consciousness and the ability to act intentionally (who knows what this would lead us to?) (Remmers, 2020), machines need to be moral in the sense that they must be designed to perform in alignment with ethical principles and standards, in compliance with the law and in open dialogue with participatory processes (Geisslinger et al., 2021).

It is not a question that the need to embed rules guided by moral values and adhere to ethics as a condition for the development of AI goes beyond the rare situations where AVs will face a trolley problem (Luetge, 2017; Kochupillai et al., 2020). In fact, it includes all situations where decisions prompted by AI-based machines can be at the cause of physical or any other kind of harm inflicted on individuals, groups in society, or even humankind when applying proportionally to respond to other harms. AI might need more personal data to deliver more accurate or personalized results, yet we might prefer to minimize the intrusion and pervasiveness and opt for anonymization. AI might help us tackle the wicked problem of the climate crisis, but if we are not able to grasp the impacts of other disruptions and allow AI to choose how to distribute inevitable harm, this might be just the beginning of another wicked problem.

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Final thoughts

AI is now able to embody urban artifacts and allows machines to perform autonomously. While navigating the literature on AVs and UAM, complexity has been underestimated at the same time as narrow disciplinary perspectives have been adopted. As a result, the architecture of such AI-enabled systems is reduced to a simple component, they appear detached from the environment where they will need to perform, and/or the context surrounding the introduction of disruptive systems has been oversimplified. The path towards autonomous machines started before the more recent advancements in AI. IoT, connectivity networks, and the accumulation of big data, among many other technological innovations, have paved the way to what may be, in the end, just a transition to something that we cannot yet fully grasp.

Nonetheless, these technology-based innovations entail disruptive changes for society that should not be overlooked. In this brief, we depicted a few facets of potential disruption concerning the supporting infrastructure, the obsolescence of some skills, and the need for conformity and adherence to a new paradigm where data and code might be dictating the rule of law.

To start an alternative path for humankind that leverages AI, we should approach the problems we are trying to fix by embracing the inherent complexity of both the problems and designed solutions. This approach should move us away from technology-driven segmental solutions to smaller problems that in turn could lead to new, aggravating, or additional wicked problems.[4]

[4] This Brief is based on research from the IEAI project Ethics for the Smart City

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