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Designing Robo-Taxis to Promote Ride-Pooling

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Abstract. Robo-taxis (automated vehicles operating in a ride-hailing model) have the potential to improve mobility while reducing traffic, emissions, and energy use. However, such outcomes depend largely on increasing riders per vehicle. Public policy that incentivizes industry to design robo-taxis to support ride-pooling may be critical to achieving positive outcomes. This research reviews current shared automated vehicle designs and literature related to potential consumer risks and benefits of ride-pooling in robo-taxis in order to articulate potential design solutions to promote pooling.

Keywords: Automated Vehicles · Ride-Sharing · Ride-Pooling · Design

1 Introduction

Projections of the future of urban transportation suggest the convergence of "three revolutions"—vehicle electrification, automation, and shared mobility—could halve global CO2 emissions by 2050 [1]. This estimate reflects a "dream scenario" in which consumers relinquish private car ownership in favor of pooling rides in shared automated vehicles (SAVs), resulting in a reduced vehicle-miles-travelled (VMT), traffic, energy use, and emissions [2]. Achieving this dream scenario thus depends largely on consumers' willingness to share part or all of their ride with others.

Early deployments of SAVs have primarily been short, fixed-route, higher occupancy shuttles for first-and-last-mile travel, with pooling as the only option. SAVs are now expanding into ride-hailing services (such as Waymo)—called "robo-taxis." Little is known regarding consumer willingness to pool in this context of lower occupancy shared vehicles where there may be the option to take a private ride instead of pool.

This paper reviews innovative SAV designs and relevant research in order to articulate features of robo-taxi vehicle and service design that might promote ride-pooling (Figure 1 introduces our concept design). The SAV design review explored innovative design features in deployed SAVs, conceptual designs and prototypes identified via online searches. The literature review focused on social and environmental psychology theory and consumer research regarding SAV deployments and analogous modes (e.g., pooled ride-hailing, public transit).

Fig. 1. Electric, shared, and automated RoboTaxi concept with flexible seating and separation screen guards. Image: B. Ferguson, D. Swindle, 2020

2 SAV Design Review

We reviewed 12 SAV designs, including 6 high-occupancy and 6 lower-occupancy (more comparable to the idea of robo-taxis). The most prevalent innovative SAV design feature is larger windows than conventional vehicles. Other common features include tall frames and large, sliding curbside doors, facilitating easy, safe and fast ingress and egress. High-occupancy SAVs tend to be more utilitarian, maximizing seating and standing room for shorter, slower trips, e.g., in dense urban areas. In contrast, lower occupancy SAV designs tend to provide more comfort and amenities, e.g., bucket seats and extra (interior) storage space so passengers can quickly store and retrieve their belongings upon entry and exit. Features like tables and wood floors resemble living and working spaces. We also see personal lighting and climate controls, charging ports for personal electronics, and even noise-canceling technology and screens to create private spaces. Other interior features include innovative safety measures (e.g., emergency stop buttons, cameras, and intercoms) and infotainment (e.g., digital screens). Unique exterior features include murals and colored lights or screens to communicate with pedestrians and passengers outside the vehicle.

Table 1. SAVs reviewed

Vehicle	Occupancy	Special Feature(s)
IDEO	4	Private pods
Volkswagen Sedric	4	Augmented reality
Yanfeng	4	Interior storage
Zoox	4	Augmented reality
Navya Autonom Cab	6	Infotainment
Renault EZ-GO	6	Wood floors
MOIA Volkswagen	7	Interior storage
Continental CUbE	8	Standing room
Olli	8	Video surveillance
Mercedes-Benz URBANETIC	12	Augmented reality
EasyMile EZ10	15	Standing room
Navya Autonom Shuttle	15	Video surveillance

3 Literature Review and Design Recommendations

The next sections summarize our literature review and design recommendations, organized into two main categories: risks and benefits of ride-pooling in robo-taxis. Risks and benefits are further organized according to five key theoretical themes: personal space, defensible space and perceived control (related to risks), and restorative environments and social capital (related to benefits).

3.1 (Mitigating) Risks of Ride-Pooling in Robo-Taxis

Personal Space. One risk of ride-pooling in robo-taxis is infringement of personal space that causes discomfort and stress. Personal space is "the emotionally-tinged zone around the human body that people feel is 'their space'" [3]. To cope with personal space infringement, we rely on defense mechanisms such as avoiding eye contact, also called "civil inattention". However, these strategies do not eliminate the stress response to personal space infringement in public transportation [4].

Seating configuration and territorial props in robo-taxis can influence perceived personal space. For example, a redesign of the San Francisco Bay Area Rapid Transit (BART) trains replaced seats that faced each other with forward-facing ones, making it easier to avoid eye contact [5]. Territorial props, such as armrests, tables, and other demarcations and barriers between passengers, can increase perceptions of personal space and are underutilized in SAVs to-date [6].

Proxemics interacts with time to impact perceptions of personal space in public transit. It is much easier for riders to tolerate short periods of crowding, and stops give momentary relief from crowding as passengers get off and others get on. Perception of crowding may be more likely when sharing space with strangers in a robo-taxi, particularly for prolonged periods of time. One solution is to offer more personal space to each passenger than you would find in larger public transit vehicles. Increasing vehicle size might reduce vehicle efficiency and fleet owner profits, but a more desirable robo-taxi service might be more efficient and profitable overall.

Defensible Space. Safety concerns will likely be a significant barrier for ride-pooling in robo-taxis, similar to safety concerns with the current ride-hailing industry and with automated buses [7-8]. The theory of defensible space can suggest strategies to mitigate these risks. Defensible space enables people to monitor their own security; it includes the concepts of territoriality, image, natural surveillance, and safe adjoining spaces [9].

Territoriality (feeling a space is one's own) is associated with vigilance and incidence reporting, and could be fostered in robo-taxis by assigning a particular car or fleet to a certain group of people (e.g., women-only). Passenger rating systems could also increase users' sense of ownership via control of who they ride with (though this may create equity issues). Territoriality over other spaces, such as a user's home and workplace, should also be considered, with provisions to protect privacy. For example, a robo-taxi service could give users the option to enter "private" pick-up and drop-off locations near their actual origin and destination [10].

Robo-taxis would not require a human operator, but riders may require one to feel at ease [7]. This relates to the concept of image; a vehicle without a driver, particular with the prospect of sharing with strangers, may not appear safe. Video surveillance may be sufficient for some and other possibilities include a remote human administrator that riders can see on a screen and speak to (and vice versa) [11].

Large windows in current SAV designs support natural surveillance, creating visibility into and out of the vehicle, which early SAV users report mitigates perceived safety risks [6]. Windows should not be heavily tinted and interiors and adjacent spaces during ingress/egress should be well lit. Along with the presence of security cameras and a remote administrator, these visible features can create an image of safety.

Proximity and access to safe adjoining spaces is a challenge for robo-taxis since they are mobile. In the context of bustling city traffic, robo-taxis could offer plenty of safe adjoining spaces (e.g. sidewalks, commercial buildings); but in rural areas and high-speed freeways, there would be a need to create virtual safe adjoining spaces, such as access to a remote human administrator and an emergency button or hotline [6].

Perceived Control. Perceived control over environmental conditions—feeling you have the ability to control something, whether or not you act on it— can mitigate the stress responses to aversive stimuli [12]. This concept relates to personal and defensible space, and to issues around convenience, comfort and cleanliness. Perceived control can be enhanced by providing personal climate controls, lighting and ports for personal electronics. Perceived control over timing can be supported by a real-time navigation display, keeping passengers informed of their location and scheduled arrival, and designing for quick ingress/egress (e.g., minimal height difference between the car floor and curb). Flip-up seating and other accommodations that can be reliably reserved for riders with varying physical abilities and needs (e.g. those with wheelchairs, walkers, or strollers) would give them the kinds of control they would need. Interior storage space would also aid in timing as well as perceived control and security.

The current COVID-19 global pandemic is having overwhelming immediate impacts on ride-pooling, including for the currently limited shared automated vehicle deployments and more common modes such as public transit and conventional ride-hailing. There may be long-term ramifications for shared and pooled modes, including consumer demand and possibly regulations for new norms aimed at creating the most hygienic conditions possible. Design solutions will likely become even more critical to promoting pooled travel across all these modes. Non-porous and easy-to-clean surface materials and physical barriers (e.g., clear acrylic barriers) can promote hygiene and related perceived control. Services may adopt practices of providing hand sanitizer and disinfectant wipes, and apps can allow users to report when cleaning is needed.

3.2 (Promoting) Benefits of Ride-Pooling in Robo-Taxis

Restorative Environments. Robo-taxis could serve as restorative environments, or sites that provide relief from stress and accumulated strains on attention. Restorative environments have four key qualities: Being Away, Fascination, Extent, and Compatibility [13]. Some AV design concepts and other services are already moving in this direction. Examples include lots of wood surfaces and natural elements [14], thematic designs [15], and augmented reality windshield for AVs [16]. These features could promote pooling if they were *not* also offered for private ride-hailing trips.

Social Capital. Social capital (SC) refers to the social networks characterized by mutual trust, cooperation, and reciprocity that contribute to community, culture, and economy [17]. Casual social interactions on public transit have been noted as "society's most extensive opportunities to interact with people outside the individual's common social circles" [18]. A recent study found that nearly a third of the users of pooled ride-hailing services (e.g.,UberPool and Lyft Line) reported making a useful social connection on a pooled ride [19]. Robo-taxis can provide a similar opportunity.

Some AV designs are envisioning sociopetal seating orientations where passengers face each other, which is conducive to social interaction, or swivel seats that allow for flexibility, though practical concerns with orienting seats different ways include a probable higher level of car sickness and need to reconfigure airbags and seatbelts [20]. Environmental psychology theories are helpful in identifying other ways to promote social interaction. For example, the concept of triangulation refers to a shared stimulus in small urban spaces, such as art, that could prompt strangers to interact [21]. The stimulus could also reinforce community identity, e.g., community-relevant art and local trivia games or conversation prompts.

The theory of third places (public spaces where social interaction occurs) is also relevant and provides a set of requirements for fostering social capital [22]. Third places provide a welcoming and comfortable atmosphere for all, often with a playful tone. Accessibility is crucial, to ensure diversity; pricing schemes should not create or exacerbate equity issues. Warm lighting, comfortable seats, accommodations for food and drink (cup holders at minimum, mobile coffee shops as an extreme case), as well as themed designs celebrating local culture, could all help make robo-taxis welcoming.

4 Conclusion

This research identified factors, categorized as risks and benefits, that may influence consumers' willingness to ride-pool in robo-taxis, and developed hypotheses about robo-taxi design features that might promote pooling. Figure 1 depicts many of these features. Future research should attempt to quantify the relative impacts of these different design features on consumer willingness to ride-pool in robo-taxis.

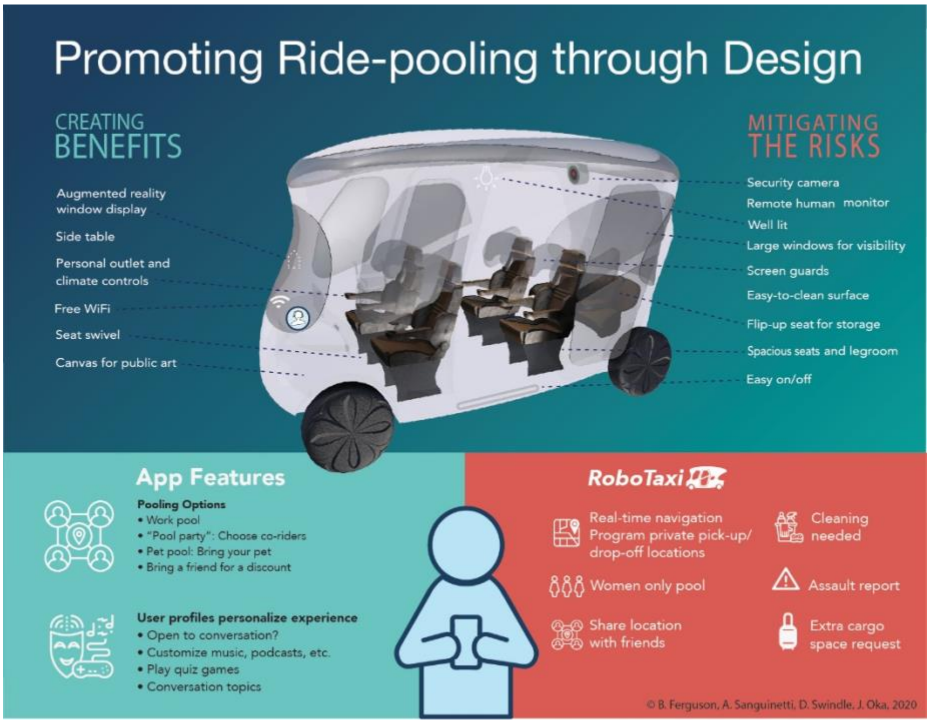

Fig. 2. Robo-Taxi design features to promote ride pooling. Image: B. Ferguson, A. Sanguinetti, D. Swindle, J. Oka, 2020

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