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Commentary

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Supporting decarbonization through vehicle rightsizing, automation, and ride-splitting

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Abstract

Vehicle automation and smartphone app-based ride-splitting are commonly discussed topics in the transportation literature. While these technologies have been examined for their role in transportation decarbonization through simulation study, the motivation for such work is rarely made explicit. In this commentary, we provide a motivation for research in this area based on our own simulation research, as well as land use and vehicle operational factors. Specifically, land use factors such as density and the speed of its adjustment make traditional transit operations using large vehicles cost-prohibitive in most U.S. communities (and many other communities around the world). Automation and ride-splitting technologies may offer digitized transportation solutions that can match vehicle size to local land development density and passenger demand. In addition, we highlight a difference in the supply-demand relationship for freight transportation that causes additional challenges for decarbonizing that sector. Finally, we emphasize that fleet ownership is key to ensuring timely vehicle fleet turnover as safer and more efficient technologies enter the market.

Keywords: Transportation decarbonization, digitizing transportation, transportation-land use interactions, supply-demand matching

Transportation surpassed electricity in the United States as the largest economic sector emitter of greenhouse gases (GHGs) in 2018 (assuming electricity for heating is allocated to the electricity sector)[1].

The potential solutions to mitigate these emissions are diverse. The United Nations sees compact urban growth - and associated policies - as central to global climate change mitigation, including for the transportation sector[2]. However, new buildings, neighborhood designs, and land use patterns can take decades to implement at scale[3] and face political and social barriers[4]. At the same time, the U.S. transit share of passenger miles traveled is under 1%[5], and conventional transit is not cost-effective at densities less than about 35 dwelling units per acre[6]. Taken together, these factors raise the question of how to ensure climate goals are met for the transportation sector in a timely manner. In contrast to land use change, digital technology can be adopted at a rapid pace. The transportation sector is currently undergoing a technology transition driven by vehicle electrification, app-based ride-hailing, and vehicle automation. Unfortunately, the potential roles played jointly by automation and ride-hailing in climate change policy are often lost within technical reports and articles. For example, the U.S. Department of Energy SMART (Systems and Modeling for Accelerated Research in Transportation) consortium is a multi-year, multi-laboratory collaboration dedicated to understanding the energy implications and opportunities of the evolving transportation technology ecosystem through simulation and behavioral analyses[7]. We provide a climate mitigation case for digital technologies in transportation based on our own contributions to the SMART consortium and other related research. This commentary contributes to the *Carbon Footprint* Special Issue entitled "Digitizing Carbon Footprint Management" by providing a synthesis of how digital technology (i.e., automation and app-based ride-hailing) might contribute to achieving net-zero climate targets within the transportation sector.

There is a consensus that vehicle electrification is key to transportation GHG mitigation in the U.S., but private-vehicle electrification will be insufficient without lowered vehicle use[8]. Development densification, coupled with transit investments, will be needed to shorten travel distances and encourage more active and shared travel modes. However, as we outline below, traditional transit solutions suffer from a supply-demand mismatch. We argue that vehicle rightsizing, made cost-viable by automation and ride-splitting (We distinguish in this paper between *ride-sharing* as sharing a vehicle (but not a trip) and *ride-splitting* as sharing a trip (or a portion thereof). *Ride-splitting* describes the sharing of travel miles by unaffiliated travelers in a single vehicle along a common route[9]) technologies, is a feasible solution to this mismatch and provides a pathway to transportation decarbonization, given land use and transportation considerations in the U.S.

GHG emissions intensity analyses by travel mode illustrate the relationships between land use, mode choice, and travel distance. Several studies have compared the life-cycle emissions of transit to those of private vehicles[10,11], highlighting the importance of vehicle occupancy (i.e., load factor). Most recently, Soukhov and Mohamed estimate that battery-electric vehicles, relying on Canada's power mix, need to average 2 to 2.4 passengers to be comparable to battery-electric buses carrying 15 passengers[12]. Research by Wang *et al.* in Toronto estimates that bus transit produces higher emissions (per passenger-mile traveled) than private vehicles during the evening off-peak period, owing to low vehicle occupancy[13]. This occupancy dilemma represents a supply-demand mismatch. That is, vehicles cannot be sized to adapt to variable passenger demand. In the U.S., pre-COVID, average bus occupancy varied by state from 3.9 in Wyoming to 15.6 in New Jersey - with an average of 9.2[14].

While larger vehicles' emissions rates per vehicle mile can benefit from economies of scale, this benefit is only true for a loaded vehicle, with most seats occupied - as illustrated by Schipper *et al.* ASIF equation[15]. While larger vehicles' emissions rates per vehicle mile benefit from economies of scale, this benefit is only realized at relatively high vehicle occupancy, with most seats occupied

GHG emissions = travel activity [A] × modal structure [S] × energy intensity [I] × fuel carbon content [F]

Realizing GHG benefits for a full-size bus requires high passenger loadings to mitigate its high energy intensity per vehicle mile. Between the two extremes of large buses and small private vehicles, one can imagine a transit fleet with variously sized vehicles exploiting scale benefits when made feasible by land development density. 4- and 6-seater shared autonomous electric vehicle (SAEV) fleets are a new form of transit, both privately and publicly incentivized for shared rides (with unaffiliated riders, called *dynamic ride-sharing* (DRS), pooling, or splitting). These smaller vehicles would operate in lower-density suburban areas. Larger SAEVs (i.e., autonomous mini-buses) operating in higher-density areas may have attendants on board to serve riders and maintain vehicles. Competition among various SAEV fleet operators - e.g., Waymo, Cruise, and Argo - should also ensure lower service costs than the current U.S. average of $1.70 per passenger mile transit operating costs for bus transit[16]. In summary, a main climate mitigation benefit of SAEVs with DRS arises from the digitization of the driving and passenger matching tasks, facilitating efficient transit operations across a diversity of development densities.

Simulation analyses suggest that DRS services can reduce vehicle miles traveled (VMT) and GHG emissions by as much as 20% relative to private vehicle use[17-21]. There are also potential synergies with the electrical grid using vehicles as mobile storage devices (through vehicle-to-grid discharging) or as mobile energy consumers to absorb excess power generation[19,21]. As a complement to land use reform, SAEVs with DRS could reduce parking demand by 90%, freeing up land for other uses, including less expensive housing[22,23]. However, without price signals set by carbon taxes, congestion fees, and other policies, privately owned autonomous vehicles may increase total VMT by as much as 30% relative to their current levels[24,25]. Fleets of SAEVs can facilitate ride-splitting, even in places such as sprawling Orlando, Florida, where nearly 60% of person trips could be feasibly shared with a “stranger” at less than 5 min of added travel time[26].

A final set of benefits associated with SAEVs with DRS stems from its fleet ownership model. By one estimate, the introduction of managed charging for battery electric buses (BEBs) would save operators 22% of their daily costs relative to current diesel fleets[27]. Fleet operators are well situated to assess and act on these lifetime investment costs relative to individual homeowners. An understudied implication of DRS deployment is the impact of reduced private fleet size on emissions. The benefit does not come from a reduction in embodied emissions - the expectation being that higher vehicle turnover will not reduce long-run vehicle requirements. Instead, benefits are of a technological nature. By reducing the time to vehicle turnover, new technologies would quickly penetrate the fleet. SAEVs with DRS vehicles are expected to travel 230-430 miles per day[28] - or roughly 100,000 miles per year, much like a commercial truck or traditional taxi, but with empty travel under 20% or 25% of VMT (and effectively zero with DRS). Assume an average vehicle lifetime of 200,000 miles[29] and that the average private vehicle is driven 10,200 miles per year[30]. With these assumptions, a DRS vehicle will be replaced every approximately 2 years, rather than every 15 or more years, for private vehicles. More efficient vehicles, with longer battery lives, and fewer crash-related losses due to continually improving algorithms, cameras, and sensors will enter the vehicle fleet under this shared ownership model than under a continuation of the current private ownership model.

Thus far, we have focused on short-distance passenger travel. Long-distance passenger travel and freight transport are more difficult to decarbonize the components of the transportation system[31]. We leave this discussion for other venues but will highlight one difference between technology-based decarbonization pathways in passenger and freight transportation. Vehicle rightsizing in the freight context exhibits a non-monotonic relationship that is not present in the passenger case [Figure 1]. Delivery cost efficiency tends to be highest at middling densities, with increasing density leading to inefficiencies because smaller vehicles must be used for delivery. The solutions for freight will differ from those outlined in this commentary.

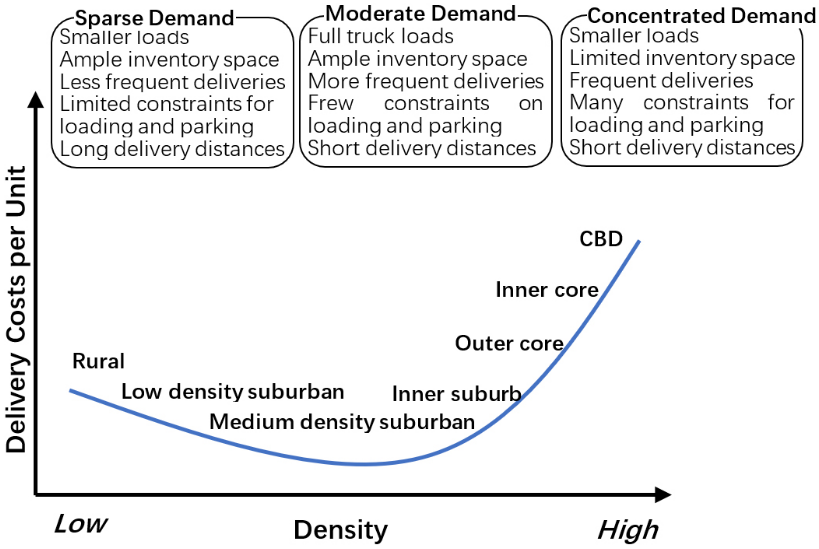

Figure 1. Relationship between density and commercial freight delivery unit costs.

Vehicle electrification and automation rely on individual and industry actions through technology development and deployment. Government and community policies such as credit-based congestion pricing[31] can help ensure those actions deliver climate mitigation, by promoting SAEV rides in right-sized vehicles, land use mixing at higher densities, and active modes of travel, while prohibiting empty travel by privately owned autonomous vehicles (AVs) and limiting empty travel by SAEV fleets. Private technological advances are often at odds with public policy, but private innovation in vehicle technology (i.e., electrification and automation) can complement and support land use and public transport policies. On the path to net zero, fleet automation facilitates vehicle rightsizing to match passenger loads and travel demands, while denser and more varied land use patterns remain fundamental to long-term urban sustainability. Vehicle fleets benefit from scale economies in both vehicle sizing and contracting, and higher rates of fleet-vehicle replacement can ensure faster adoption of more efficient transportation technologies.

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Authors' contributions

Made substantial contributions to the conception and design of the study: Hawkins J, Kockelman K
Performed data analysis and interpretation: Hawkins J
Made substantial contributions to the drafting and editing of the manuscript: Hawkins J, Kockelman K

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Conflicts of interest

Both authors declared that there are no conflicts of interest.

Ethical approval and consent to participate
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Not applicable.

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