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On-Demand Mobility: Autonomy for Future Air Transportation
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The Future: On-Demand Mobility System

Imagine a fully integrated, multi-modal air-ground transportation system flexible enough to accommodate the optimal operational characteristics of an evolving mix of heterogeneous vehicles. A distributed, rule-based, open architecture more similar to today's highway system than to today's NAS will provide a safe transportation infrastructure for diverse mobility demands. For example, consider dropping children off at school a few blocks away from home before attending a meeting 200 miles away without necessarily changing vehicles or losing the entire workday to commuting. Similar on-demand mobility is enjoyed today by a few elite early adopters who can afford the vehicles, the training, and the specialized staff required to participate in today's air transportation system. Through technologies employing cyber-physical systems (CPS) and economies of scale, our airspace will be democratized (like the automobile into society) and participants will source from all socioeconomic strata. Participants can vary in skill level as well as desire to interact with the vehicle and transportation system, adapting and moving continuously between self-operated and autonomous modes.

Today's Landscape:

The general consensus among the American public is that our transportation system is broken and unlikely to improve in the near future. The average one-way daily commute for workers across the country is 25.5 minutes [1] and congestion forces travelers to allow for 60 minutes to make a trip that takes 20 minutes in light traffic [2]. The frustration among domestic air travelers is so great that many are avoiding air travel altogether with 2009 estimates [3] of approximately 40 million avoided trips a year at a cost of more than $26B to the US economy. Juxtaposed with this consumer frustration is a recent FAA projection that airline passenger travel is still expected to nearly double in the next twenty years [4]. Add in the inevitable integration of unmanned vehicles and we are faced with a significant demand challenge that is being partially addressed through NextGen and the JPDO via communication capabilities such as ADS-B and the integration of automated *decision support* tools. Beyond NextGen, this increase in demand will come from "digital natives" in the form of innovative vehicles and the integration of autonomous *decision-making* capabilities. Digital Natives are those who were born into the "information age" where libraries and bookstores are passé and information is only a click away. These new users (digital natives) who have information available at their fingertips will bring this "on-demand" expectation to mobility. Today, this is evident in the success of cost-sharing solutions like ZipCar [5] and on-demand ridesharing like Lyft and Uber [6] for ground transportation. Eventually, the public will demand this type of access to the sky [7] and intelligent cyber-physical systems will

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enable the transition from today's cost-prohibitive point of entry and skilled pilot model to an affordable and usable (across a continuum of skill levels from passenger in an autonomous vehicle to skilled aviator) system with access points from any point on the planet. Mobility solutions that include fixed flight schedules, limited origin-destination pairs, unreliable trip performance, etc. that result in limited personal autonomy will be even less palatable to the coming generation of transportation consumers than it is today. In addition, we know that today's centralized NAS is brittle and not capable of accommodating significantly increased traffic density, new heterogeneous vehicles (PAVs, UAVs, novel solutions, commercial, scientific, public), and the evolving needs of the nation.

Tomorrow's Horizon:

The transportation system of tomorrow will be very different from today's. The evolutionary automation currently implemented in new decision support tools to aid humans in the system is essential to the implementation of NextGen but will not transform the underlying architecture of today's system to solve the problems of tomorrow (beyond NextGen). Tomorrow's solutions will include intelligent systems (as opposed to simply more automation) that make decisions on their own and replace or team with humans. The solution must also scale to many different types of vehicles as well as many more vehicles on the road and in the sky. A scalable transportation system, like the internet in the information age, should accommodate unforeseen on-demand mobility requirements. The introduction of new classes of vehicles, such as UAVs and PAVs, should not force redesign and restructuring. This suggests a distributed system with responsibility and authority moving away from human-centric centralized control to vehicle-centric responsibility and authority, not unlike today's highway transportation system, and with CPS-based enablers such as traffic flow management, self-separation, collision avoidance, safety-assured resilient and autonomous control capabilities to address loss-of-control [13], autonomous landing functions that prevent Controlled Flight Into Terrain [8], and adaptive user interfaces. Analogous to the way we drive today, file-and-fly will be just "fly" and multi-modal transportation will be just "go" with no "Mother, May I?" component as we strive to maximize personal independence and autonomy at the individual level. Tomorrow's transportation system is not only gate-to-gate, it's door-to-door.

The Path to Tomorrow:

The new On-Demand Mobility System (ODMS) cannot be designed from the top. Because we cannot know the initial conditions of the ODMS, we must design a system that is flexible and scalable without converging on a point design. We must also look beyond our historical stakeholders (e.g., industry, airlines, service providers) and reach out directly to the public in the same way that DARPA is using crowdsourcing to design and manufacture a new armored vehicle with "Adaptive Vehicle Make" [9]. To determine what the ODMS must accommodate, we need only look to the mainstream public who are excited about the idea of Personal Air Vehicles (PAV) like Terrafugia's TF-X [10] and specialists (e.g., realtors, photographers, scientists, hobbyists) already flying

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UAVs to for surveillance and sport as well as DoD who are investing heavily in CPS for the theater in the form of autonomous helicopters like ONR's Autonomous Aerial Cargo/Utility System (AACUS) [11] and autonomous carrier-based aircraft like X-47B [12] who will eventually be bringing these capabilities into civil airspace.

In this model, the needs and wants of new users/providers will inform new vehicle capabilities and, in-turn, demand a new operational infrastructure solution space which directly enables both the vehicle and user expectations and desires for On Demand Mobility. From user expectations come desirements, first impacting vehicle design and capabilities. New vehicle technologies will allow passengers to "personalize" travel through the use of an on-demand, highly-distributed transportation system. As new vehicles and their associated operations mature, the ODMS must accommodate many and more participants. Much like today's highway system, rules and the infrastructure vs. the positive control imposed in today's NAS will enable conformance and CPS will ensure safety, efficiency and mobility. The new transportation system architecture is driven by user needs and vehicles, not designed in a vacuum without feedback loops to the vehicles/users and the desired system constraints of reliability, affordability, usability, and accessibility. These "ilities" will be achieved through the safety-assured fusion of human and machine intelligence with transparent integration of the cyber and physical worlds.

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