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Advanced Air Mobility, Economic Impacts, and Equity Considerations

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ABSTRACT

Advanced Air Mobility (AAM) may, in the coming decades, result in tens of thousands of new jobs and billions of dollars in additional economic activity. While much of the discussion surrounding AAM focuses on the technical aspects of the nascent industry, estimates of the potential economic impact vary significantly. Much less attention has been paid in the literature to potential externalities, positive and negative, and how these externalities may impact estimates of economic impact. We argue that much work remains to be done before policy advisors and decisions makers can formulate and implement strategies based on the projections of future economic impact of AAM.

KEYWORDS

Air mobility; transport; economic impact; equity; unmanned systems

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1. Introduction

This paper reviews the current knowledge in the literature on the development of Advanced Air Mobility (AAM)[1] and economic growth, whether the projections of economic impact capture potential externalities, and whether discussions of AAM should include an equity dimension.[2] Over the last decade, public and private organizations have developed AAM-oriented strategies, courted AAM-targeted investments, and allocated funds to promote the development of the AAM industry. The interest in AAM as an engine of economic growth has yielded numerous studies that attempt to project the size of the nascent AAM industry, projections that vary significantly in scope and projections of economic impact. Efforts to formulate economic development strategies based on these projections should be aware of potential displacement effects, the lack of coordination of projections across jurisdictional boundaries, and how spillovers may impact social welfare.

The increasing interest in AAM can be grouped into two broad sets of discussions: technical and economic. The technical literature regarding the development of AAM continues to rapidly evolve, focusing on questions of aircraft design, power, transportation networks, and computer algorithms, among others. Our interest lies in the second set of discussions which focus on projections of market sizes and economic impacts. it is no surprise that AAM has captured the attention of decision makers in the public and private sector with projections of total addressable market size reaching $1.5 trillion by 2040 and $9 trillion market by 2050 (Morgan Stanley Research, 2019, 2021). The states of Arkansas and Oklahoma, for example, launched an effort in 2022 to establish an 'advanced air mobility super region' based on estimates that the industry would create up 55,000 new jobs (Oklahoma Center for Advancement of Science & Technology, 2022). Given that other states have commissioned similar studies, it stands to reason that not every state can be the focus on the AAM industry or generate the preponderance of industry employment. If so, then some states that embrace AAM-friendly policies and devote resources toward the development of the industry may be disappointed as jobs and economic activity materialize elsewhere.

We find that there are considerable variations among projections of demand for AAM services and, consequently, projections of economic impact of the AAM industry at the local, state, and national level. We argue that these projections explicitly assume that numerous technologies will mature at the same pace and that regulatory frameworks will evolve rapidly to meet the needs of industry. We also note that many analyses ignore displacement impacts, suggesting that the projections of economic impact overstate the potential impact of the AAM industry in the near- and medium-term. Our contribution highlights these weaknesses and identifies gaps in existing analyses that must be addressed to generate more fulsome estimates of economic impact.

The remainder of this research paper is structured as follows. In the next section, we discuss the lack of a common definition of AAM and how this may contribute the observed heterogeneity in projections of national and subnational economic impact. In the third section, we briefly examine a selection of national and subnational studies that attempt to project the economic impact of AAM. The fourth section discusses how many studies include discussions of additionality while downplaying concerns about displacement. The fifth section argues that equity considerations should be included in future analyses of the AAM industry. The last section concludes and offers recommendations regarding future research.

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1 We use the term Advanced Air Mobility to refer to highly automated (if not fully autonomous) small aircraft and drones that can transport passengers and cargo in and around urban areas.

2 It is not our intention to review the rapidly growing literature on AAM, especially with regards to the design, development, and operation of specific AAM systems. While the literature does include reviews of specific segments, there is an opportunity for a broader review of the literature in future research (Bauranov & Rakas, 2021; Garrow et al., 2022; Sun et al., 2021).

2. A common definition of AAM has not yet emerged in practice

Advanced Air Mobility (AAM) does not yet have a set definition in the literature; however, the Federal Aviation Administration (FAA) defines Urban Air Mobility (UAM) as a safe, efficient, and effective aviation transportation system that will employ highly automated aircraft to transport passengers and cargo at lower altitudes within urban areas (Federal Aviation Administration, 2022). UAM encompasses a set of potential uses, including airport shuttles, air taxis, and air ambulance services (Goyal et al., 2018). This definition, however, does not explicitly state whether UAM complements existing transportation methods, substitutes for existing transportation alternatives, or increases the set of transportation alternatives for businesses and consumers (Vascik & Hansman, 2018).

In practice, AAM broadens the UAM concept by incorporating exurban uses, to include point-to-point passenger shuttles between urban areas, cargo traffic, and other urban-exurban uses, with cost driving adoption of AAM services (Fu et al., 2019; Peeta et al., 2008). Others argue that AAM is a concept for air transportation to enables people and cargo to move between places not readily served by surface transportation or underserved by existing air transportation (Del Rosario et al., 2021). From this perspective, AAM relies on electric vertical takeoff and landing (e-VTOL) aircraft as well as small unmanned aircraft systems (sUAS) (Goyal et al., 2022). Small UAS provide users the ability to more efficiently monitor infrastructure (Bielawski et al., 2018; Ham et al., 2016; Henrickson et al., 2016), manage agricultural farms (Ubina & Cheng, 2022), conduct search and rescue operations (Karma et al., 2015), perform land administration (Stöcker et al., 2022), and enhance the entertainment experience by providing unique perspectives on sporting and other events (Scheible et al., 2017). A pitfall of the current literature is that the definition of AAM is malleable, changing to suit the needs of the research study instead of providing a foundation upon which comparative analysis can rest.

One challenge in defining AAM is that the technologies which will provide the foundations for the AAM industry are not yet sufficiently mature. Numerous advances must be made in electrification, automation, e-VTOL, UAS, and air traffic management before markets can test the promise of AAM against the hard realities of consumer expectations, demand, and business operations (Vascik, Parker D. & Hansman, R. John, 2017). NASA has proposed a framework, for example, of UAM maturity levels which represent three states (initial, intermediate, and mature) across three dimensions (aircraft, airspace, and community) (Hill et al., 2020). The UAM framework recognizes that challenges exist in safety, security, automation, affordability, noise, and regulations/certification. The UAM framework does not include an equity dimension, a curious omission given the potential externalities associated with AAM.[3] Aircraft noise, for example, may disrupt conversation, sleep, and negatively impact health and property values (Elmenhorst et al., 2019; Pepper et al., 2003; Schmidt et al., 2021). Ignoring equity concerns may result in negative externalities being concentrated in lower-income neighborhoods while benefits accrue to higher-income neighborhoods (Demetillo et al., 2020; Gilderbloom et al., 2020; Grineski et al., 2007; Houston et al., 2004).

Even if technologies mature quickly, the widespread use of AAM requires institutional change at all levels of society, include the public sector. The FAA, for example, has decades of experience regulating passenger and cargo air travel but this experience is unlikely to translate to smaller, autonomous aircraft. Presentation day aircraft separation standards, for example, are clear: two aircraft cannot be separate by less than 5 nautical miles (NM) enroute and 3 or 1.5 NM in the terminal area, depending on the type of air traffic control services available (Bauranov & Rakas, 2021). As AAM matures, the number and density of aircraft will increase, creating organizational strain on the FAA and other regulatory agencies.

It remains an open question whether rigorous aircraft separation standards should be modified for AAM,

[3] We focus here on questions of horizontal and vertical equity, that is, whether agents of similar income receive similar treatment (horizontal equity) and how the burdens and benefits of a system are related to income (vertical equity).

whether standards can be determined algorithmically, whether a human pilot should be in command, or whether UAS should 'self-separate' to ensure sufficient distance exists between aircraft of any type at a given point in time (Geister & Korn, 2018; Lin & Saripalli, 2017; Yu & Zhang, 2015). Requiring human pilots not only imposes additional costs but may also lower safety as AAM technology matures. Simulation results suggest that human-in-the-loop systems are impacted adversely by Detect-Avoid Well Clear (DWC) warnings, a challenge that must be addressed if humans are in the AAM decision loop (Monk et al., 2020). Even if we set aside unmanned urban air systems (sUAS carrying cargo, for example), stringent separation standards akin to those currently required would inhibit the development and operation of AAM. Technology will mature more rapidly than organizations, creating unforeseen tensions between developers and users of AAM and public organizations regulating the industry.

As an emerging industry, the lack of a clear, concise, and commonly accepted definition of AAM and its projected scope of activities can inhibit the comparison of studies projecting the economic impact of AAM. Differences in services can significantly impact the number of potential users and applications, differences that can lead to wide variations in projections of economic activity. We argue that studies attempting to project the future economic impact of AAM should clearly and objectively state the scope of potential activities to allow for the transparent replication of results. Definitionally, future studies should specify what North American Industry Classification System (NAICS) codes are employed to generate projections of future employment and economic impact.[4] State, metropolitan, and county level studies should account for the possibility of competition among these jurisdictions instead of assuming that the gains will be predominately located in the geographical area of analysis.

3. Existing measures of demand and economic impact

The literature is replete with studies projecting that AAM will have a transformative impact on economic activity. By 2040, the total addressable market for autonomous flying aircraft is projected to be between $1.5 and $2.9 trillion (Morgan Stanley Research, 2018; UAM Geomatics, 2019). For the United States, the annual AAM market is projected to reach $115 billion by 2035 (Hussian, Aijaz & Silver, David, 2021). In Canada, AAM is projected to increase the GDP of British Columbia by almost $700 million by 2035 (Canadian Advanced Air Mobility Consortium, 2020). Air taxis may account for 12 million passenger enplanements by the 2030s and more than 400 million by 2050 (Mayor, Tom & Anderson, Jono, 2019). Another estimate for 2035 envisions a passenger market of 23,000 aircraft and a market worth approximately $32 billion (Al Haddad et al., 2020). These (and other) projections vary widely because of differences in assumptions regarding technological maturity, organizational change, market adoption, military applications, and whether AAM will complement or substitute for existing transportation alternatives.

National level studies, however, typically ignore questions regarding subnational tax, expenditure, and regulatory policies with regards to emerging AAM industry. Intergovernmental Institutional arrangements may influence the process of urban development (Feng et al., 2015; Millimet, 2013; Oates, 2004; Potoski, 2001; Yuan et al., 2019). The context within which institutions operate also matters (Bardhan, 2002, 2006). Institutions may be prone to capture, which, in turn, may lead to the overstatement of costs, corruption, or the understatement of demand to lower tax requirements. The development of the AAM industry may be impeded if firms must navigate a multitude of local and state regulatory regimes for the operation of AAM vehicles and services.

We argue that projecting future employment gains at the subnational level for a nascent industry is a difficult challenge, at best, and is complicated by the fact that states and localities have not yet fully formed economic

[4] We recognize that some studies may use IMPLAN, REMI, or other proprietary software to generate economic impacts and industry classifications may not exactly align with the NAICS system. In these cases, analyses should include the industry codes from these systems to increase the likelihood of replication.

development policies in attempts attract and retain AAM-investment and jobs. Whether or not such incentives are effective furthermore remains a matter of debate in the literature (Buss, 1999, 2001; J. L. Hall & Kanaan, 2021; Kang et al., 2016). While subnational governments may engage in a 'race to the bottom' to attract the AAM industry, there is evidence to suggest that such competition is unlikely to affect the efficiency of firm location (Mast, 2020). Firms may also base the location and investment decisions on the actions of other firms, and such peer effects appear to be stronger in more concentrated markets (Bustamante & Frésard, 2021).

Subnational projections of the potential economic impact of AAM in the United States also appear to be formed independently, implicitly assuming gains are concentrated in the study area. A sample of studies suggests that the sum of employment gains from the subnational studies in the United States may be larger than the projected gains from national-level studies. New Jersey could add 25,679 additional jobs over the next 15 years from commercial and cargo AAM operations (Deloitte Consulting, 2022). In Ohio, AAM could generate up to 15,000 new jobs and have an economic impact of $13 billion from 2021 to 2045 (Del Rosario et al., 2021). The development of AAM operations as well as electric vertical take-off and landing (eVTOL) manufacturing in Arkansas could generate approximately 16,000 jobs from 2020 to 2045 (Gatling, 2022).

A 2023 study for Virginia estimates the AAM industry will generate $16 billion in new business activity through 2045 and create over 17,000 new full-time aerospace and other jobs in (Virginia Innovation Partnership Corporation, 2023). This study argues that by the 2041 – 2045 period, approximately 7.7 million passengers will travel annually using eVTOL services. For comparison purposes, we note there were 7.2 million total passenger enplanements (domestic and international) at Washington-Dulles International Airport in 2022. These, and other studies, assume that the AAM industry will mature rapidly, and that consumers and businesses will shift a non-trivial amount of travel into eVTOL and similar services.

Finally, unconstrained studies assume that the underlying technologies are sufficiently mature and negative externalities that would hinder the adoption and operation of AAM platforms are limited or not germane to the analysis. Concerns about affordability, safety, privacy, and equity remain in the background even while studies assume that AAM will complement and replace existing forms of travel (Bauranov & Rakas, 2021; Goyal et al., 2022). Even if one implicitly assumes these concerns do not significantly influence AAM adoption, there remains the open question of whether AAM supply chains will mature sufficiently and at the approximately the same time to allow for the realization of economies of scale and scope.

4. What should we examine when projecting economic impact?

When considering the economic impact of a policy, economists focus on two broad effects: additionality and displacement (Lenihan, 1999; Senior & Danson, 1998). Additionality occurs when a policy change causes economic agents to engage in behavior that they would not have taken in absence of the policy (Larsson et al., 2019; Orlic et al., 2019; Prowse & Snilstveit, 2010). Public subsidies for research and development (R&D) are often motivated by the argument that R&D investment is non-rival in consumption and excludable in the short-run (Archibugi & Filippetti, 2015; Arrow, 1962; Hall & Lerner, 2010). Public subsidies may incentivize firms to engage in uncertain R&D Investments, that Is, creating additional spending that would have not occurred otherwise. Of course, there Is also the possibility that public investment will crowd out private investment as firms simply substitute public for private R&D spending. Jurisdictions considering public investments in the nascent AAM industry should structure these investments to avoid crowding out, to what extent is possible.

Displacement occurs when a shift in policy causes economic agents to shift consumption from one good or service to another. Displacement may also occur when a new good or service crowds out the ability of economic agents to consume existing goods or services (Crompton, 2006). While the transportation literature does consider the question of displacement, this discussion often focuses on the movement of individuals due air pollution, encroachment of transportation networks, or other factors (Badami, 2005; Mouratidis et al., 2021). If, as argued by some, UAM and AAM could be used for the transportation and delivery of goods to consumers and businesses, then it stands to reason that the shift In transport modalities towards AAM could result In a decline In other modalities (Cohen et al., 2020; Mouratidis et al., 2021). There is a paucity of peer-reviewed discussion regarding the potential impact of UAM and AAM on transport modalities and how these shifts could, if UAM and AAM are relatively more autonomous than existing modalities, reduce overall employment.

If AAM becomes sufficiently mature, proponents argue that it will expand the ability of consumers to travel to, from, and within a region (Goyal et al., 2018, 2022). Personal air vehicles, with sufficient technological progress and lower prices, have the potential to disrupt urban transport markets (Balać et al., 2019). However, projections of UAM demand note the sensitivity of consumer demand to price and vertiport location. An agent-based simulation analysis of the Munich metropolitan area estimated that 84% of UAM trips would be for distances under 40 kilometers and 55% of all demand was for trips less than 10 kilometers (Ploetner et al., 2020). Total estimated market share for UAM was 1%, increasing to 3% to 4% for distances over 30 kilometers. A similar study of the Munich region found that, for a region with a mature transportation system, traveling by UAM does not offer significant time savings and projected mode share was only 0.61% (Pukhova et al., 2021). For northern California, increasing the cost per passenger mile from $1 to $1.20 was projected to reduce UAM round trip demand per day by 34%, that is, demand was price-elastic. Passenger demand was sensitive to the number of vertiports, although overall demand was concentrated in a small number of vertiports much like the current passenger airport system in the United States (Rimjha et al., 2021).

We argue that many of the current studies touting gains in employment and increases in economic activity implicitly or explicitly ignore potential displacement impacts. We examined several recent state level studies and found little or no discussion of how displacement could reduce the net economic impact of the AAM industry. The focus on additionality biases projections upwards and likely overstates the net economic impact of AAM, even if projections of technological maturation and market adoption turn out to be reasonable.

5. Existing measures of demand and economic impact

Assuming that the technological and regulatory challenges can be surmounted in the coming decades, the economic impact literature largely focuses on the potential benefits of AAM. However, AAM may generate costs external to its production process and these positive and negative externalities may result in a lower (higher) marginal social costs relative to the marginal costs associated with AAM. While negative externalities were discussed in a recent analysis of AAM vertiport considerations, the preponderance of the analyses focused on costs to the public and private sector instead of the potential externalities associated with the widespread use of AAM (Mendonca et al., 2022; Shaheen et al., 2018; Zhao et al., 2022).

There is consensus in the literature that for AAM to generate significant economic benefits, AAM vehicles must have access to urban areas. AAM will increase air traffic and will require the proliferation of vertiports or similar facilities in urban areas. However, proximity to airports has been casually associated with higher levels of air and noise pollution (Wolfe et al., 2014), decreased levels of subjective well-being (Lawton & Fujiwara, 2016), and lower residential property values (Espey & Lopez, 2000; Salvi, 2008; Trojanek et al., 2017). These costs are more concentrated among households in proximity to airports while the benefits of airports are widely spread among the population. When the Hong Kong Kai Tak Airport closed in 1998, for example, the reduction in airport traffic noise increased housing prices by approximately 24.3% for homes surrounding the airport from 1998 to 2006 when compared to the control group in the study (Zheng et al., 2020). In other words, if closing an airport increases home values, adding numerous (though smaller) vertiports is likely to negatively influence existing home values (Tuchen et al., 2022). The open question that remains is not whether one eVTOL or sUAS is relatively quiet but whether tens (if not hundreds) operating at the same time produce a significant amount of noise, visual pollution, and ground traffic around the vertiports.

Transportation equity, however, encompasses more than the externalities associated with a specific transportation system (Karner et al., 2020). Transportation equity research examines how the benefits and costs of transportation infrastructure and services are distributed across populations and geographies. From this perspective, transportation equity focuses on a combination of positive and normative questions. From the positive perspective, transportation equity examines how transportation infrastructure and goods are distributed and consumed across the population (Karner, 2016; Lewis et al., 2021). Extant analyses of AAM are largely focused on these positive questions, that is, where will AAM vehicles and services be produced and who will consume these goods and services? Normative analyses typically focus on whether these services are distributed fairly, with value judgements being made regarding what is considered a fair distribution of goods and services. We focus on positive analyses of horizontal and vertical equity as discussions of transportation justice are beyond the scope of this paper.

5.1. Horizontal equity considerations

From a positive perspective, we argue that projections of AAM's impact should include analyses of horizontal equity. Horizontal equity suggests that taxpayers with similar income should face similar tax burdens (Musgrave, 1990). From a transportation perspective, horizontal equity implies that revenues should be remitted to transport owners, net of external costs (Litman, 1996; Shirmohammadli et al., 2016). If planning processes favor systems based on speed, for example, over slower but more affordable means of transport, the resulting transportation system may increase horizontal inequity (Karner et al., 2020; Verlinghieri & Schwanen, 2020). Instead of investing in slower modalities that may be more accessible, the focus on AAM may divert resources to the building of vertiports and other facets of the transportation system that do not equally benefit taxpayers of similar means.

We would be remiss if we did not note that AAM may also exacerbate existing racial and ethnic inequities. There is now consensus that transportation planning in the past focused primarily on the benefits to automobile drivers, leading to the construction of highways that displaced established urban neighborhoods (Brown et al., 2009; Podagrosi & Vojnovic, 2008). This consensus has led to efforts to remove urban highways in some cities, though one must also recognize that displacement has already occurred and one cannot recreate the neighborhoods that once existed in these locations (Taylor et al., 2023). Furthermore, including the social costs of transportation systems may reduce the projected benefits significantly. Automobiles, for example, impose significant social costs in terms of congestion, noise, pollution, and risk. Individuals who drive more than average impose costs on individuals who drive less than average (or not at all) (Roll et al., 2021). We argue that efforts to attract and develop AAM largely ignore these considerations of horizontal equity. If AAM planning focuses on speed and accessibility to urban consumers and businesses, then it will likely negatively impact consumers and businesses that prefer (or can only afford) other forms of transportation.

5.2. Vertical equity considerations

If horizontal equity examines whether equals are treated alike, vertical equity asks whether individuals of unequal means are treated appropriately relative to their means (McDaniel & Repetti, 1992). Here, the question is whether the incidence of taxation changes with income, that is, does the burden of taxation increase or decrease as income rises? From a public finance perspective, a progressive tax system would feature marginal tax rates that rise with income, while a regressive tax system would result in a relatively higher tax burden for individuals with lower incomes. From a transportation perspective, equity considerations are often addressed *ex post*, with subsidies and other interventions to promote equity, thus there is an argument to be made that transportation planning should address equity concerns (Camporeale et al., 2017; van Wee & Mouter, 2021).

Including transportation equity in AAM analyses and planning would likely increase the complexity of such efforts, however, ignoring vertical equity concerns may produce a transportation system that is regressive. Given that automobile usage is positively correlated with income, the social costs of driving are disproportionately borne by individuals with relatively lower incomes. However, since transportation networks are often funded by a blend of fuel taxes and user charges as well as revenues from sales and use taxes, the vertical equity of existing transportation systems may be difficult to gauge and there may be an implicit assumption that the existing systems are equitable (Lindsey et al., 2023).

With regards to AAM, this discussion suggests that incorporating equity concerns now, before networks are formed and technologies have matured, will likely be more resource efficient (and possibly effective) than if equity concerns are addressed *ex post*. Planning and development efforts should examine the placement of vertiports and whether the nascent industry will impose social costs on neighborhoods that are less likely to consume AAM services. AAM passenger transportation services are likely to be tightly correlated with income and the exclusion of vertical equity considerations is likely to impose social costs on lower income individuals while benefits will primarily accrue to individuals of higher incomes. One only need examine the history of urban transportation networks to envision a possible analogue with the development of AAM transportation systems if insufficient consideration is given to horizontal and vertical equity.

If there is a modicum of good news, it is the advances in smartphone and smartcard tracking have reduced the burden of tracking public transport usage (Hörcher & Tirachini, 2021). Given AAM service consumption requires geolocation services, a similar effort could be undertaken in the future to examine who are consuming these services and how median household income in a influences the propensity to consume. For now, simulations of traffic demand and supply should employ empirical evidence from analyses of automobile consumption to seed models of traffic design and consumption and the potential spillovers associated with AAM consumption.

6. Conclusions and recommendations

There are considerable variations among projections of demand for AAM services and, consequently, projections of economic impact of the AAM industry at the local, state, and national level. These projections explicitly assume that several technological advances will not only occur but will be sufficiently mature to provide passenger and cargo services. In many cases, there is an implicit assumption that the current regulatory framework will adapt sufficiently to help, rather than hinder, the development of the AAM industry. Several analyses appear to rely on a form of Say's Law, that is, the production of a product or service will serve as the source of demand. In other words, if you can build AAM industry, the demand for AAM services will emerge and displace existing transportation modalities. Supply, to paraphrase Say, will create its own demand.

We argue that future efforts to ascertain the economic impact of the nascent AAM industry address the questions of displacement. How will the emergence of AAM urban cargo delivery services impact transportation service companies and employment? Will the shift of passengers to AAM passenger services impact bus, rail, and more current forms of air passenger travel? How closely will AAM service consumption be related to household income and, if the disparities mirror automobile transportation, how will this influence transportation equity?

The consequences of addressing these (and other) flaws in the current slate of studies is clear: a misallocation of public resources in expectation of employment and income gains that are unlikely to materialize. Developing estimates that not only account for displacement impacts but also address questions regarding horizontal and vertical equity may not directly align with the interests of those promoting the industry, but further insight is needed with respect to these impacts. Otherwise, we will continue to observe the production of optimistic estimates of employment and income gains; gains that when summed at the subnational level significantly exceed projections at the national level. We conclude that much like the AAM industry, projections of its economic impact will take time, effort, and transparency to reflect its future economic impacts more accurately.

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Conflict of interest

The author claims that the manuscript is completely original. The author also declares no conflict of interest.

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