Review Article

Supporting healthier and more resilient communities through investments in mobility: a narrative review of the synergies between mobility options and health through the lens of COVID-19

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Background and Objective: The comfort and advantage that comes from access to immediate, safe, and convenient transportation is underappreciated. The value of such access was perhaps never more apparent than during the COVID-19 pandemic. This paper seeks to identify the critical synergies between access to mobility and health, and identify case studies that support continued focus and investment on this nexus. This paper also begins the conversation around evaluating how emerging technologies such as on-demand mobility, connected and automated vehicles, and unmanned aerial systems can enhance resilience of the transportation system, support emergency response, and strengthen systems for the next public health emergency.

Methods: The paper is a narrative literature review that introduces and connects concepts such as community resilience, or the capacity of a community to respond positively to crises, and related resilience topics in the context of transportation, technology, and health.

Key Content and Findings: This paper finds there are clear connections between land use, connectivity, and health outcomes and transportation is an important player in the public health space. The findings show that transportation measures such as access to transit, walkability, and connectivity will affect directly and indirectly, the health outcomes of people in a community.

Conclusions: Therefore, access to transportation should be considered as a public health, social determinant of health.

Keywords: Resilience; mobility; health; community; transportation

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Introduction

Background

This article will explore the relationship between health and resiliency, and how mobility fits into this relationship. Further, the article contends that transportation is a key cog of community design that can promote community resilience, particularly coming out of COVID-19 and in consideration of emerging mobility solutions that leverage technology and demand responsive transit solutions.

Rationale and knowledge gap

Designing and planning with intention is essential for the future of mobility (1). This is playing out right now with the ongoing build-out of infrastructure to support new

vehicle technology like electric vehicles (EVs). Within the health and well-being context, design approaches for behavioral health environments balance a sense of community with the need for privacy and security (2). The design of spaces affects mental and physical health, and the role of transportation is becoming exceedingly evident in access to health care (2). The word "resilience" has perhaps never been more prevalent. In this article, we will explore the definitions of "resilience" further within the view that "resilience" is centered around making communities stronger at present and in the future. Community health resilience is defined by the U.S. Department of Health and Human Services as "the ability of a community to use its assets to strengthen public health and healthcare systems and to improve the community's physical, behavioral, and social health to withstand, adapt to, and recover from adversity" (3).

Objective

Health is a key cog of resilience as most resilience efforts are made to preserve health at various levels from individual, to community, and even environmental (3). Further, transportation and mobility have been part of resilience initiatives in an effort to connect communities, make their infrastructure stronger, and improve community access to resources (3). Each of these things improves the health of a community and this paper further explores these connections. We present this article in accordance with the Narrative Review reporting checklist (available at https://jphe.amegroups.com/article/view/10.21037/jphe-22-103/rc)

Methods

To establish the concepts of health, mobility, and resilience we searched the literature in public health, transportation, infrastructure and built environment, medicine, disaster preparedness and response, and environmental disasters. We began by searching terms about resilience, then resilience in health contexts such as "resilience", "health resilience", "community resilience", "collective resilience", "individual resilience", and "public health resilience". We then found access to transportation after researching "social determinants of health". Then we searched terms about transportation concepts related to resilience, like "transit-oriented development", "multi-use zoning", "social connectedness", and "social capital". All articles found online were in English, peer-reviewed, from academic institutions, government announcements or reports, and highlighted either health or resilience. The search flowed naturally as the concepts of resilience and health are so commonly linked, and access to transportation fits into this intersection. The analysis then examined connections between health resilience, built environment, and access to transportation. The individual and community context was defined, but community was focused on for resilience analyses. Using this literature and analysis we concluded that transportation fits in the health conversation as a relevant determinant of health.

Key content and findings

The term resilience is increasingly important in public health. A literature review by the Holistic Nursing Practice journal, looking at the historical construct of resilience from a physiological and psychological perspective noted that resilience is considered a vital attribute for some health professionals (4). Historically, in a health context, resilience is rooted in either the psychological aspects of coping or the physiological aspects of stress (4). The construct of resilience developed through observations of individuals coping with stress positively and growing due to adversity, and as a result resilience focuses on positive outcomes (4). Early resilience studies spotlighted intrapersonal and environmental factors that helped individuals thrive from adversity, such as, creativity, humor, belief system, social skills, social support, resources etc. (4). Originally these concepts were described as unconscious defense mechanisms (1800s), homeostasis (1920s), coping (1960s), emotional stress and morbidity (1950s), and eventually the term resilience emerged in the 1990s to encompass all these values (4). During this time resilience models also emerged by researchers Richardson, Rutter, Wolin and Wolin, and Masten all based in psychological and physiological factors (4). Generally, because resilience has had a multitude of definitions, and models there is a lack of empirical instruments to measure resilience, and the trend is to use qualitative students for this concept (4). In an effort to quantify resilience, self-report instruments have become common and are used at the individual level, community level, and elsewhere. Other scales were developed used research literature as a framework, and are discussed below (4). The study noted three major observations about the likely directions for resilience studies in the future, two of which are relevant to this paper: (I) it is important to

have a dynamic, interactive perspective for understanding resilience; and (II) the complexity of resilience requires a holistic perspective. While this study is informative in the history of how resilience and health became intertwined it is limited because it confines resilience to a psychological and physiological context.

A paper by the Glasglow Centre for Population Health researched existing resilience literature to determine its application to public health. The paper is written from a public health perspective and synthesizes multiple understandings of the term resilience in individual and community contexts, further the authors looked at various disciplines (psychology, engineering, ecology) to determine their conclusions. This paper discussed that primary research investigating resilience, from a public health perspective, focused on children and young people to show how these populations responded to stressors such as abusive families, homelessness, chronic illness and disability, teenage mothering and juvenile delinquency, and poverty (5). The research was centered on risk factors, and a criticism of this early research is that it did not expand on "underlying mechanisms and processes of adaptation and protection" (5). This ignores intrinsic (internal characteristics like intelligence or social competence) and extrinsic (environmental characteristics like attachments and parenting styles) factors (5). This criticism applies to modern approaches to resilience in health as well that are focused on narrow views such as "positive thinking" and ignore context specific considerations such as inequity, poverty, and more (5). Further, early studies were limited to children and young populations (5). However, when future studies began highlighting how personality traits and factors relate to interconnectedness of personal and network factors the modern understanding of resilience emerged, and community cohesion, neighborhood social capital, and integration are now recognized as key features of resilience (5). These key features of resilience are also seen as key features of a community with better health outcomes.

Health and resiliency have a synergistic relationship that transportation fits into

Health and resiliency have many definitions and there is not one neat box that these terms fit into. This is helpful to capture the opportunities to include resilient thinking into all projects, but creates a challenge when seeking to measure and quantify the implementation of strategies and tools seeking to enhance resilience in communities. Health is a key foundation of a resilient community, and the purpose behind protecting infrastructure, and preparing for disaster is to preserve health and welfare (3). A resilient community is socially connected and has accessible health systems that can withstand disaster and foster community recovery (3). In the aftermath of COVID-19, it became apparent that a resilient transportation system similarly means ensuring access to safe, convenient, and affordable transportation options that extend beyond personally owned vehicles.

What is resilience?

The paper by the Glasglow Centre for Health, determined there is individual and community resilience, and even resilience of an environment, known as place resilience (5). Though the Glasglow Centre study covers a wide breadth and depth of resilience research, one limitation of the study is that it approaches resilience from so many angles that the researchers' conclusions become confusing and indecisive. While this highlights the complexity of the topic, it is difficult to walk away with a definitive answer as the authors further do not make concrete recommendations but rather have gathered a set of information for readers to utilize to develop their own perspective.

The study highlights the active nature of resilience and comments that, "Resilience is a dynamic interaction between an individual, their stressors, and the resources in their environment" (5). Individual resilience is the "successful adaptation to life tasks in the face of social disadvantage or highly adverse conditions" (5). For the individual, resilience relates to the type of risks and challenges an individual faces, the frequency and intensity of the risks, and the individual's available response (based on environment) to these risks (5). Community or collective resilience, generally, is a community's capacity to respond positively to crises (5). A community can define an individual's resilient outcomes (5). Resilience at the community level is concerned with both the affected population and the environment testing the population's resilience (5). This paper also introduces that increased social connectedness allows communities to withstand disasters more easily resulting in better health outcomes and marking the community as more resilient (5). This key concept is highlighted through this paper to show how mobility can increase that social connectedness and therefore the health and resiliency of a community. The researchers in the Glasglow study categorize pandemics, extreme weather, terrorism, and volcanic ash clouds as events that affect public health as they cause extreme health

emergencies that require community coordination to survive and recover from (5). The ability to survive these disasters is resilience, and a mark of a healthy community is also its ability to respond to these disasters, making resilience a now essential part of public health functions.

Individual and collective resilience can be built through culture, the economy and work, infrastructure, and governance (5). For the purposes of this paper and in the context of providing more transportation options to all users, with a priority on equitable access to transportation services to support mobility and health, one useful approach to measure resiliency is to consider what populations need to enable a different behavior. This approach avoids the trap of homogenizing resiliency measurements, that then cannot be applied cross culturally or in different populations, which would render the measurement moot.

Defining resilience is also a complex task and this term has been operationalized by many disciplines. Dictionary definitions of resilience indicate resilience means an ability to return to pre-crisis conditions; however, the perspective on this has changed and "bouncing-beyond" is indicative of true resilience over "bouncing-back" (5). Creating a measure for resilience has been a challenge and currently there are multiple measurement tools. Examples of resilience tools include (5):

- Resilience Scale for Adults;
- Connor-Davidson Resilience Scale;
- Child and Youth Resilience Measure;
- Resilience Scale of the California Healthy Kids Survey;
- Resilience Scale for Adolescents;
- Youth Resilience: Assessing Developmental Strengths Scale;
- Brief Resilience Scale;
- Resilience Measurement Index.

The Child and Youth Resilience Measure is a self-report measure of social-ecological resilience, used by researchers and practitioners, that defines resilience as an individual's ability to overcome adversity and stay on the path of normal development (6). The Resilience Scale for Adults is a similar self-report measure of protective factors, but it has been criticized for having modest validity in cross-cultural contexts (7). The Brief Resilience Scale is the only scale that identifies the availability of assets and resources to facilitate resilience (5). The Resilience Measurement Index captures fundamental resilience aspects for critical infrastructure in response to all hazards (7). It defines resilience as the ability to reduce the magnitude and/or duration of disruptive events, and effectiveness of a resilience infrastructure depends on ability to anticipate, absorb, adapt to, and rapidly recover from a disruptive event that is either naturally occurring or human caused (7). This definition of resilience is most applicable in the context of this paper.

The diversity in the scales reflects there is no "gold standard" to measure resilience, and the different resilience measurement tools that exist are largely in the early stages of development (5). This is further complicated by the discussion around climate resilience. Scales vary in the type of resilience measured, length and format, whom they are developed for, functions and behaviors assessed, and the number of items they contain [45]. There is no standard resilience measurement even for different types of resilience (collective *vs.* individuals) and it is unlikely that there will be one. The nature of resilience evades having a rigid scale that is cross-culturally applicable for all contexts and types of resilience. While resilience will require multiple measurements, each measurement tool also incorporates different definitions of resilience.

Health, resilience, mobility, and the built environment

People and place resilience are concepts that are considered to fit together because at a community, city, region, or national scale, resilience concerns both the population and the environment (8). This notion is reflected in public health, in which community resilience can be measured by the ability to withstand disasters from threats (8). Further, community health resilience leverages efforts to improve population health and connect communities with each other through stages of a disaster (8). Building resilient community health is important because closely connected communities can better withstand adversity and disasters, and this contributes to the future well-being of communities (8). Community design is a multisectoral effort involving both private and public stakeholders (8). Furthermore, resilience building through community design inherently requires multiple sectors (8). Public health researchers spot examples of resilience and can use these examples to build a resilience framework (8). "A resilience framework provides concrete actions that people, organizations, and institutions can take to promote the sustainable and long-term well-being of communities in the face of adversity and disaster" (8). Resilience frameworks that create communities able to withstand disaster ultimately reduce negative outcomes such as food insecurity, physical health injuries, social isolation, and diminished psychological health (9). These are all

determinants of public health and impact health outcomes. Resilience can directly and indirectly affect these health outcomes.

The built environment is how communities are planned and designed and should be part of a resilience framework, because it has a major influence on health and resiliency (9). Strengthening health systems by promoting social connectedness, and psychological health, encourages actions that promote strong day-to-day systems and address the underlying social determinants of health such as isolation (9). Increasing a community's resilience through the built environment helps create healthier communities, because factors that adversely affect health are reduced while health promoting designs are encouraged (9). Health is impacted by social and economic factors also called social determinants of health which are "conditions in which people grow, learn, work, and live" (10). Access to transportation is a determinant of health (10). A person who has a dependable means of transportation has the easiest access to health care (11). People with dependable automobiles are able to access health care providers easier than someone who must use a bus or walk (10). This has a large influence on health care nationally (10). Missed appointments cost the country's health care system $150 billion annually and medication nonadherence costs an additional $290 billion per year (10). Increased access to transportation can increase the number of patients who go to their appointments and fill their prescriptions (10).

Transportation and the built environment are directly connected to health costs and health outcomes (10). For example, physical activity is a critical factor that influences people's health and the health of a community (10). Walkable, bikeable, and transit-oriented communities are associated with healthier populations (10). The consequences of having a transportation system that relies mainly on motorized transportation are increased traffic-related deaths, air pollution, risk for obesity, cardiovascular disease, and negative health outcomes (10). Investments in sidewalks, bike lanes, trails, public transit, and other infrastructure that supports physical activity can improve individual health and decrease health care costs associated with air pollution, crashes, and physical inactivity (10). Transit oriented communities that are walkable and bikeable are associated with healthy, resilient populations (10). Transit oriented communities also promote mental health through access to social and recreational opportunities by having a foundation built around public transit.

There is a strong link between community design and healthy people. The transportation system shapes community design and operations, and influences how we prioritize investment in the right of way, plan our communities, and determine zoning to influence development (11). Transportation policies can facilitate or stagnate people from healthy lifestyles such as attending regular doctor visits, accessing good jobs, and choosing healthy food (12). Limited access to transportation causes health inequities including decreased access to education, employment, and recreational activities which negatively impact health outcomes (12). This is especially true for households without automobiles and other underserved individuals (12). If health and resiliency are goals of a transportation policy, this can result in reduced air pollution, prevent traffic injury and death, and reduce illnesses like obesity, diabetes, cardiovascular disease, and cancer rates (12). Public officials, planners, and community members should ensure future transportation policies consider health, including the promotion of developments that promote social capital and transit-oriented developments (TOD).

Communities can use mobility policies to promote healthier lifestyles

Social capital policies

Social connectedness helps a community be more resilient and bounce beyond, particularly in emergencies. Social connectedness can be measured through a resilience metric referred to as social capital. Social capital is the way in which people in a community interact with one another, or more specifically, whether a person knows their neighbors, interacts with them, and political participation (13). A study from Finland showed that social capital is associated with healthy behaviors and overall health (14). The study used data from a health survey of an adult population in Finland with an 8,028 value, an 87% response rate for interviews and a 77% response rate for self-administered questionnaires (14). The study examined associations of three dimensions of social capital: social support, social participation and networks, trust and reciprocity and used a logistic regression for health behaviors of smoking, alcohol use, physical activity, vegetable consumption, and sleep (14). The limitations of this study are that in both an interview and self-questionnaire setting there is response bias from participants; however, with a high n number and response percentage, it is likely the results are still reliable (14). The study found that regardless of social status, people with

higher levels of social capital engage in healthier behaviors and feel healthier physically and psychologically (14). The study found social participation and networks created high levels of trust and reciprocity, and robust social networks, which were respectively associated with non-smoking, adequate sleep, and daily vegetable consumption (14). The odds ratio with a 95% confidence interval was 1.10 for non-smoking and moderate social support, versus 1.47 for non-smoking and high social support, similarly odds ratios were 1. Interestingly, for moderate and high social support and non-excessive drinking the odds ratio was 0.98 showing that social support does not change all unhealthy behaviors (14). However, all other statistics (sleep, vegetable consumption) were on trend and importantly, those with moderate social support had an odds ratio of 1.23 versus 1.55 for those with high social support and leisure-time physical activity (14). Social participation and networks also encourage physical activity which contributed to positive health outcomes (14). Importantly, the study found that irrespective of social status people with higher levels of social capital engaged in healthier behaviors and felt healthier both physically and mentally (14).

Another study investigated the relationship between neighborhood design and individual levels of social capital (15). The study used a household survey to measure social capital of citizens in various neighborhoods in Ireland from mixed-use, traditional, pedestrian-oriented, to car-dependent suburbs (15). The limitation of this study is the response bias that may exist in a household survey that participants answer, and the surveys had a response rate of 37.2% (279/750 surveys) (15). The study results indicate that people living in walkable, mixed-use neighborhoods were more likely to know their neighbors, trust others, be socially engaged, and participate politically (15). The researchers calculated t tests to compute P values and means for measures related to social capital (15). In a mixed-use, walkable neighborhood with an n value of 163, the mean for neighborhood walkability was 7.35, feeling connected to community 2.94, knowing neighbors 2.67, trust index 2.32, contacting elected officials 0.32, and ability to walk to work 0.51 (15). For comparison, in a car-dependent suburban neighborhood these values were respectively 4.72, 2.39, 2.22, 2.09, 0.17, and 0.19 (15). These are all measures of social capital, and higher levels of social capital often correlate with better public health (15). The study results also indicate that when a neighborhood is walkable, social capital increases, and this will also correlate with better health outcomes (15). Social capital is measured at the collective and individual level, with the former examined in communities as a collective property and the latter a personal resource emerging from social networks (15). The benefit of both is improved health (15). Increased social connectedness results in individuals who access transportation more easily, interact with their community, exercise, and as a result avoid negative health outcomes that come from decreased access, lack of exercise, and psychological stress from isolation.

Building social capital is also used as a response to emergencies such as natural disasters and technology can play a significant role in this process (16). After Hurricane Sandy, a public-private partnership resulted in a collaboration that created wi-fi networks for shelters and disaster recovery centers (16). These networks allowed survivors to connect with their social networks and seek help (16). Further, preparedness apps such as, bReddi Facebook App and American Red Cross Hurricane App, help users identify friends and connect with their community during an emergency by designating friends for ensuring their well-being in the event of a disaster (16). These services provide users with psychological support during an emergency (16). Similarly, Geographic Information System technology-based social vulnerability maps can identify which communities are most vulnerable to disasters based on a variety of factors (16). These maps are used by policymakers to determine which communities to focus on during a disaster and help with emergency preparedness (16). These apps increase social connectedness which has been shown to improve health outcomes.

TOD, what is it and how does it encourage active travel?

TOD is a form of urban development that maximizes the number of walkable destinations from public transport (17). This type of development aims to increase public transport ridership and reduce the use of private cars (17). TOD encourages high-density, mixed-use, areas with a central transit stop in the center of the area (17). A mixed-use development has a mix of commercial, residential, office, and entertainment land uses (17). A successful TOD has multiple easy-to-use access points to a transit station and has many frequently visited locations walkable from the transit station (17).

The core value of a TOD is to reduce dependence on driving single-occupancy vehicles; therefore, increasing use of transit and creating a community that supports walkability (18). Though over 80% of public space in a city

consists of streets, often there is not ample space for citizens to walk, bicycle, drive, and take transit (18). For example, in Phoenix, Arizona, the Light Rail began service in 2008 and increased transit ridership by 487% and connected residents and visitors to attractions, jobs, schools, services, and other cities (19). Phoenix is a city that transformed during the auto boom and prioritization of automobiles resulted in a sprawl development pattern when street cars were replaced with buses and personal automobiles (19). The sprawl development also reduced walking and biking. However, the Light Rail is transforming the city once again to be a TOD focused city, particularly in downtown Phoenix (19).

TOD additionally increases active travel or active transportation. Active transportation is physical activity used for transportation, that also acts as exercise methods that decrease obesity, diabetes, and risk of heart disease (11). Though active travel is often used to describe walking and biking, the term encompasses more than these two activities, and can include any mode of transportation involving physical movement, such as micromobility (20). The term active travel is part of two disciplines, transportation and health (20). It is a growing field and while public health literature reflects a focus on the results of active travel, transportation is focused on the process and planning of active travel (20).

A systematic review of the health benefits of active travel reviewed non-randomized and randomized trials, and observational studies to examine the effects of active travel interventions and the association between active travel and health outcomes (21). The comprehensive study looked at 22 studies from 11 countries, a limitation of the study however is that 16 of the 22 studies did not evaluate impact of a specific intervention and were prospective cohort studies (21). The study noted the established link between physical activity and health, that is reflected in statistics from countries in which obesity increases n settings where active travel declines (21). The study hypothesized active travel may be a feasible approach to increase level of physical activity, and as a result increase positive health outcomes (21). The study found there is accumulating evidence that active travel may have positive effects on health outcomes including obesity (21). Previous systematic reviews and meta-analyses found non-vigorous physical activity reduces all-cause mortality while active commuting alone does not have a positive effect on health (21). Active travel has been linked to positive impacts on health conditions including obesity, cardiovascular health, diabetes, and more (21). However, there are many factors that contribute to active travel, from distance to frequented destinations, psychological meaning of activity, and culture and this leads to existing studies having varying results (21). For example, a study in the UK did not find cardiovascular mortality risk among active travelers to be reduced by active travel, whereas a study in Finland found it to be significantly lower [adjusted hazard ratio 0.78 (CI: 0.62–0.97)], and a study in Japan found a statistically significant reduced risk of hypertension in participants who engaged in active travel for longer periods [adjusted relative risk =0.70 (CI: 0.59–0.95)] (21). The systematic review sheds light on the various cross-sectional studies in the active travel area and highlight that active travel's effect on health is determined largely by contexts such as pollution, terrain, etc. and studies in this sector should put active travel in context. This paper is distinguishing its conclusion by focusing on active travel that increases access to transportation having a positive effect on health outcomes.

Further, TOD isn't without its challenges. Historically, cities and transportation were co-dependent and mutually influential; however, today there is explosive urban growth, and this complicates the relationship between the two (22). While TOD is a solution for improving urban infrastructure, many TOD proposals don't make it past the planning stage (22). There are several barriers to implementation including: economic, social, environmental and planning, regulatory barriers like permits, stakeholder commitment, land acquisition, design framework, and community involvement among other things (22). Additionally, the success of a TOD ultimately depends on public- private partnerships, such as collaboration between governments, land-use agencies, and businesses (22). Enhanced accessibility to housing and transportation can also cause inflated prices on land and result in "transit-induced gentrification" (22). There are also practical challenges TODs must grapple with, for example, towns planning for a TOD struggled with balancing either limiting or removing parking, or developing parking minimum standards for the new development (23). One in four adults report they do not engage in any physical activity outside of their employment, a statistic reflective of the sedentary lifestyle that contributes to two of every three adults in the United States being overweight (24). Public transportation close to bicycle and pedestrian facilities, facilitates multi-modal trips and increases active transportation (24). Transportation agencies can invest in mixed-use neighborhoods where there are multiple frequently visited destinations within walking distance of

each other and close to public transportation (24). Investing in these facilities allows people more opportunities to exercise, and in turn reduces obesity and risk of chronic conditions such as cardiovascular disease and diabetes (24). Further, active transportation facilities are integral to low-income and minority communities where residents are less likely to own personal vehicles and unsafe streets create a barrier to using active and public transportation (24). This concept is gaining momentum with the growing integration of mobility hubs into communities.

While the cost of transit facilities and the build-out of transit systems is high, when connected with the health benefits described above, the overall return on investment is high. Investing in transit systems and mixed-use dense communities will increase health over time, and create long-lasting health communities. Rather than putting a band-aid on health issues or treating outcomes, this style of community investment can eliminate sources of health issues. Such multi-modal focused facilities also align well with emerging transportation technologies, including electric and automated vehicles, especially if the shared mobility conversation picks up momentum again post-COVID.

Resilience in climate change, an emerging topic

This concept can be seen through the lens of climate resilience and recovery from extreme weather events. Climate change events are becoming a global challenge, periods of extreme weather such as heat, heavy downpours, floods, fires, and droughts cause decreased food production, population shifts, physical injuries, and psychological impacts from disasters (9). These are negative effects on public health that will contribute to negative health outcomes, and being able to successfully navigate climate change disasters will require community resilience, which strong built environm ent and transportation systems can help build.

Climate resilience is successfully navigating and coping with the impacts of climate change while simultaneously curbing the impacts from worsening (25). Climate resilience strategies are based in mitigation and adaptation (25). In mitigation, harmful activities such as heat-trapping emissions are mitigated by shutting down coal and gas plants and shifting to renewable energy sources (25). In adaptation, communities protect against threats that currently exist, such as by planting trees to reduce extreme heat or investing in infrastructure to protect against flooding in areas where the sea level is rising (8).

An example of a city that exemplifies the importance of climate resilience is New Orleans, Louisiana (26). In 2005, hurricane Katrina caused dramatic floods which tragically left 1,000 people dead and 600,000 displaced from their homes (26). The city was underwater for weeks after the hurricane, causing disease and dirty water to sit in the city, surrounding swamps to rise, and alligators and bears to come into the city (26). Black and economically disadvantaged communities were hit harder by the hurricane and experienced more difficulty in recovering from the natural disaster (26). Researchers noted a change in perception in the New Orleans community and residents went from wanting to go back to how things were in July 2005 to wanting things to be even better than they were in 2005, a correlation with the "bouncing beyond" mentality that describes resiliency (26). The city became a testing ground for innovative water management projects such as constructing river gates to mimic flooding and create sediment (26). For example, the Lake Borgne Surge Barrier (Great Wall of Louisiana) was constructed to block lake surges. Canals were also built beneath the streets to improve the city's resiliency towards future natural disaster events (26). The result is New Orleans now has a better water management program than it did prior to Katrina (26). Following the city getting a grasp on its environmental vulnerabilities, there has also been a surge of investments in youth projects, reductions in crime, and a significant improvement in the city's education system—indicating the city is bouncing beyond (26). Reduced crime, increased access to education, and less negative impact of climate disasters are all determinants of public health and improvements in these determinants will improve health outcomes and reduce negative influences on health.

Following trends seen in cities like New Orleans, the current Biden administration is putting resilience concepts into action through different programs. One is the Thriving Communities Program (TCP) which looks to build community capacity to ensure disadvantaged communities or communities disproportionately affected by environmental, climate, and human health policy have the tools and capacity to build infrastructure that allows their community to thrive (27). TCP will facilitate planning and development of transportation and community revitalization activities to help under-resourced communities (27). The TCP program is focused on helping communities develop comprehensive transportation, housing, and community revitalization activities (27). The program's goals are to

increase mobility, reduce pollution, expand affordable transportation, improve health outcomes, improve housing conditions, facilitate land use, and expand jobs (27). Pollution, access to transportation, affordable housing, and increased mobility will increase residents ability to exercise, move around, access health and more and contributed to improved health outcomes (27). This improves a community's overall public health measurements.

Another is the Reconnecting Communities Program (RCP) which seeks to reconnect communities that historically were cut off from economic opportunities in transportation infrastructure (28). The scope of the program is broad and will encompass building pedestrian walkways, building a transit line, and creating more ways to travel around a neighborhood (28). The RCP will work with the TCP to provide technical assistance and support to disadvantaged communities for transformative infrastructure projects (28). Further U.S. Department of Housing and Urban Development will complement these efforts to coordinate housing and transportation planning to improve access to housing (28). The RCP has a similar strong focus on equity, environmental justice, and strong community engagement (28). Similarly, community engagement and equity will improve social connectedness and improve health outcomes.

The connection between the built environment, transportation, and health is not an idea, but a reality that has shown real world connections and implications. The Biden administration's funding structure that focuses on equity and programs that, like TCP and RCP, invest in infrastructure with the goal of improving health outcomes and building resiliency are reflective of that, in addition to addressing and mitigating climate change impacts. The Biden administration sees the value of investing to create resilient communities that can create permanent changes to health and welfare. Continued investment in programs that view and leverage mobility as an opportunity to connect users to their community and services, will allow communities to focus on the value of transportation and its strong, direct connection to health. It also provides an opportunity for communities to "bounce beyond" and design and implement next generation infrastructure that both improves mobility and addresses climate change.

How do connected and automated vehicles fit into TOD

Smart growth principles emphasize land use mixing, supporting public transportation, and encouraging active travel (29). Dense, mixed-use communities that reduce auto dependence and encourage active travel are based on smart growth principles and many urban planning researchers are studying these principles (29). The United States Environmental Protection Agency projects that smart growth can promote public health and a clean and safe environment, through access to daily necessities, preserving community features such as cultural landmarks and green space, and providing transportation options among other things (29). Smart growth additionally considers novel technology that can transform transportation and create healthy, resilient communities. One such technology is connected and automated vehicles (C/AVs). Connected vehicles are vehicles that use communication technology to communicate with the driver, other cars on the road, roadside infrastructure, or cloud technology (30). Automated vehicles are vehicles that operate without direct driver input, in which a driver is not expected to continually monitor the vehicle (30). A vehicle can be a combination of the two technologies or contain only one of the technologies (30). The levels of automation are based on the SAE International scale that ranges from 0 to 5, with 0–2 being driver support features in which a human is driving and 3–5 being automated driving features in which a human is not driving (30), though there may still be an expectation that a human be ready to intervene, especially with SAE Level 3. This technology can improve vehicle safety and efficiency, and reduce commute times (30). However, as promising as this technology is, there are significant equity concerns surrounding its deployment. Many experts are worried about C/AV deployment following existing patterns of racial and socioeconomic inequity, that transportation planning has created. There are also concerns that C/AVs will lead to increased vehicles miles travel and congestion thereby reducing their positive social benefits (31).

Transportation planning in the United States has contributed to socioeconomic and racial inequities (31). Moreover, racism has guided the development of transportation policy and played a role in decision making (31). Hazardous facilities and infrastructure, such as highways, have historically and intentionally been located in disadvantaged communities causing residents to be exposed to elevated levels of air, water, and noise pollution (31). Further, recent evidence reflects that state and municipal transportation planners have not delivered in providing equitable access to transportation services (31). To remedy these trends, *Title VI of the 1964 Civil Rights Act and Executive Order 12,898* mandates transportation agencies

and departments of transportation conduct analyses to evaluate if planned infrastructure will negatively affect disadvantaged communities (31).

These practices make C/AV deployment particularly controversial, because this technology should not add to this trend, but rather be part of its remedy (32). In a study by the University of Minnesota, researchers studied transportation needs of disadvantaged communities, and C/AVs can meet some of these needs (32). In the study, the researchers note that transportation networks are significantly more robust in urban than rural areas, and additionally rural areas have more mobility challenges (32). C/AVs can reduce urban sprawl and encourage population dispersal depending on the type of C/AV policies adopted (32). Currently, at the municipal level, there is a lack of preparation for C/AV policy, and the C/AV policies that do exist vary greatly from region to region (32). C/AVs can expand mobility options and improve mobility for disadvantaged populations; however, the shift to C/AV transit options can also constrain limited bicycle, pedestrian, and transit resources (32). Another issue surrounding C/AVs is social constraints of the transit system (32). From language barriers to lack of understanding about how to use the transit system, to restrictions on groups like refugees, access by those with disabilities, including physical and sensory, there are many social barriers to transit (32). Additionally, there are many unanswered questions and undiscovered risks surrounding C/AVs. Regardless of these concerns, C/AVs can still have a very productive place in the transportation system.

An article in the Annual Review of Public Health Journal conducted a literature review of C/AV reports, literature, and studies showing potential effects of their introduction and compiled C/AV effect on public health (33). The limitation of the study is it does not cite empirical evidence, most studies looked at are for potential future impact not current impact (33). C/AV impacts on public health can vary and will be dependent on automation level, use case, ownership models, and engine type (33). There will be both direct and indirect impacts from C/AV implementation (33). The direct impacts include traffic safety as C/AVs are expected to reduce accidents, increase physical activity, reduced air pollution emissions if electric vehicles are promoted alongside C/AVs, reduced noise, and potentially improved work conditions as C/AVs reduce commute times (33). Indirect negative impacts could be increased traffic congestion if personal ownership models for C/AVs are promoted versus fleet ownership, and potentially decreased use of public transportation (33). Indirect positive impacts include increasing accessibility to transportation by modifying land use and urban design practices, and increased use of clean energy (33). C/AV, specifically as fleets, can positively impact urban land use by potentially reducing urban parking space, permit relocation of public space from automobile infrastructure to other activities such as green space, and increase accessibility to transportation which would reduce urban sprawl and commute times (33). Further, the transportation sector is pushing for C/AVs to employ electric vehicle technology or similar engines that do not require fossil fuels, which will decrease emissions from the vehicles (33). C/AVs used for public transportation, such as an automated shuttle, can also help those without access to a car, access destinations such as health services, employment, education, and more (33). These indirect impacts will increase physical activity and have a positive effect on health outcomes such as obesity, cardiovascular disease, pollution and climate change related health outcomes like lung disease, and reduce psychological stress by increasing socialization opportunities. C/AVs likely will have a positive impact on health outcomes, through the mechanisms described, and can even have a space in emergency response procedures.

C/AVs can be used for non-passenger uses in emergency situations such as snow removal. Automated snowplows can augment snow removal efforts by public agencies. Further, C/AVs have a use case for deliveries, including goods, groceries, and medical supplies. This provides the important opportunity to overcome food deserts that impact low-income and aging populations, and increase access to prescription drugs and other medical services. During COVID-19, deliveries became particularly important as people could not encounter one another. With that in mind, C/AVs can contribute to delivery services and even deliver to areas that are difficult to reach by human drivers. This is especially true when considering opportunities with advanced air mobility. Currently, North Carolina has a pilot project ongoing around the use of unmanned aerial vehicles for package delivery in rural, suburban, and urban areas including medical package and food delivery (34-36). The program also completes transportation infrastructure inspection (34-36). The North Carolina Department of Transportation was able to serve thousands of patients and customers through this pilot program (34-36). This being said, it is necessary to note the potential negative social impacts from an overreliance on automated technologies and decrease in human interaction. Mental health issues resulting from the isolation of the COVID-19 pandemic

Table 1 C/AV themes (32)

Theme	Existing issues	Future issues
Reliability and reliance	The "transportation disadvantaged" do not have reliable access to a car, and are reliant on transit and other modes of transportation that have limitations (network extent service hours, etc.)	Will C/AVs provide a reliable transportation mode to address unmet transportation needs?
Equity	Limited income, ability level, language barriers, employment made more challenging by limited transit network/service hours	Cost considerations; inequities from poorer access to transportation
Accessibility	Spatial mismatch of residents and jobs, physical accessibility	Same as existing plus technology access
Vehicle ownership	Structural barriers—driver license documentation restrictions; limited financial capacity to buy a car	Private ownership *vs*. shared ownership reiterating existing socioeconomic/spatial disparities
Safety	Vehicle crashes, policing	Pedestrian detection, trust without drivers

C/AV, connected and automated vehicles.

provides an important case study around this (34-36).

C/AVs can also be employed to enhance and expand the transit system by connecting underserved areas to main transit lines (32). This is often referred to as "first/last mile" opportunities (30). Further C/AV transit may reduce transportation costs; however, there are also important workforce considerations to keep in mind. An interesting concept surrounding C/AVs is that by buying a personal vehicle, an individual is buying transportation reliability; using C/AVs to expand the transit system would allow lower-income riders to buy demand responsive transit and not be "priced out" of C/AV access like they may be for personally owned vehicles, especially with supply chain and inflation increasing the cost of vehicles (32). The incorporation of automation into the transit system is currently being researched by the Federal Transit Administration (FTA) through its Strategic Transit Automation Research Plan. This includes funding for the use of automated and electric buses to support bus rapid transit by the Connecticut Department of Transportation (37,38).

Other issues about C/AVs can also be addressed, for example, to reduce social barriers C/AV operators must be intentional about the communities they are engaging in and how they can reach these communities (see *Table 1*) (32,39). Moreover, increasing access to AVs will likely be dependent upon programs that subsidize deployments in low-income, underserved, and rural areas where market share is lower (24,39). However, this is likely no different than ongoing investments into transit systems offering free transit. For example, Olympia, Washington began offering free bus service starting in 2020 (39). Previously the cost of a ride was $1.25 for an adult ride and $3 for an express bus, but the Zero-Fare Demonstration Project was affected on January 1, 2020 and bus ridership is now free (39). The program was created after two and a half years of strategic planning and will be evaluated in 2025 (39). The city began by passing a ballot measure to approve an additional sales tax for public transportation purposes and after this transitioning to being fare-free became Olympia's most cost-effective option (39). The pilot program saw returns quickly and 60,000 additional riders joined the program just one month after it began, or a 20% increase in ridership (39). Similarly, in Corvallis, Oregon which houses Oregon State University a fare-less public transportation system was implemented (39). This program increased public transit ridership by two-thirds over time (39). Kansas City, Missouri also implemented a systemwide, universal, fare-free payment scheme through a unanimous city council vote (39). In Kansas City, the increased access to public transportation has allowed for easier access to employment, education, and increased quality of life (39).

Pilot programs that offer free public transportation should continue to be explored as part of transportation planning in a community and goals around increasing system resilience (39). Transit is a necessity to reach activities critical to livelihood such as doctors' appointments, grocery stores, school, and work (39). Further, most cars are single occupancy vehicles and only transport one individual at a time while buses, trains, subways, gondolas, and other public transportation options can move dozens of people at once. This improves the efficiency of the transportation system (39), in addition to reducing impacts on infrastructure, thus leading to a higher long-term return on investment despite higher initial costs for building out a transit system. Using these pilot projects as blueprints to increase equity and combat negative trends is important not

only for future transportation planning, but also for future C/AV deployment. C/AV deployment can be modeled on pilot projects such as the ones in Kansas City and Olympia to effectively combat negative historical transportation trends and overcome existing transportation gaps.

Mobility has a role in emergency response

Transportation may seem like an afterthought to health; however, it can be used to remedy emergency situations. A disaster route is a freeway, highway, or arterial route that is pre-assigned as a designated route in a time of crisis (40,41). The route is utilized to bring emergency personnel, equipment, and supplies in emergency areas to minimize impact, save lives, protect property and more (40,41). Most importantly, such routes also support the evacuation of people that may be in harm's way due to natural disasters or other public emergencies in an area (40,41). Accordingly, these routes are also given priority for cleaning, repairs, and restoration over other non-designated routes (40,41). Emergencies significantly affect transportation networks and establishing strong, resilient networks is critical to saving lives, protecting infrastructure, and distributing necessary goods and supplies (40,41). Disaster routes are designated by emergency personnel and "activated" by authorities during disasters (40,41). A challenge for such routes is that they can become congested, thus slowing down critical evacuations (42). This is one opportunity that is talked about with automated and connected vehicles—such vehicles can help lead to efficiencies for such evacuations (42). On the other hand, such disaster routes also need to be modernized to support new mobility innovations like electric vehicles (42).

Entities like NASA use sensor and satellite technology to capture measurements such as land surface temperature, thermal anomalies, nighttime imagery, clouds, elevation, soil moisture, and more (43). These measurements are used to produce models for projections and forecasts, and create datasets to track natural disasters and other climate changes (43). The technology used is primarily imaging sensor technology (43). C/AVs could have a role in assisting with this process. C/AV technology already employs sensors, and can be deployed at the ground level to measure changes in the environment. C/AVs can also take the process a step further, and beyond sensing changes for a disaster, can assist with maintaining connectivity through the natural disaster. Though each state and local government will have its own methods for designating such routes, communication and connectivity are central to any planning process (43). C/AVs can be used to signal emergency responders and coordinate a response to an emergency, by communicating with authorities and responders.

What are lessons learned from COVID-19?

As tragically experienced during the COVID-19 pandemic, transportation also leads to the spread of illnesses. Passenger compartments on various forms of transportation contaminate people and surfaces that act as sources of further contamination (44). Transportation modes can be vulnerable to biological release events (the spread of disease) (44). Enclosed spaces, number of passengers, and difficulty of decontamination are some factors that make transportation more vulnerable to biological release of particles; this causes transportation services to be disrupted, and is what happened during COVID-19 (44). While transportation modes can be major sources of contamination, emergency response plans often do not involve transportation officials (44). Rather these officials are usually responsible for following directions from incident command and emergency operations centers (44). Likely, transportation officials should be included in these plans moving forward (44). Additionally, despite initial concerns around transportation and virus spread, new technologies including air filters and ultraviolet lights have proven to work for planes and buses (44).

The role of transportation in supporting resilience during health emergencies

When there is a biological threat, any mode of transportation can be used in evacuating people, transporting emergency personnel, and providing emergency supplies (44). Further, we want to be ready for the next pandemic by instilling resilience in our transportation system to ensure safe, affordable, convenient, and accessible transportation options are available to all those with transportation needs.

To address transportation challenges before and during an emergency, mobility managers can do a few things. First, they can engage stakeholders in the emergency planning process by building relationships with emergency management professionals, transportation providers, and local elected officials (45). For example, what do citizens with special needs such as disabilities or English language barriers need during an emergency (45). How can directions for evacuation be modified for these special populations (45). Mobility

managers are also advised to determine what resources could be used during an emergency by individuals and the community at large through a Resource Capabilities Assessment (45). There are organizations that have already made significant impacts during emergency situations (45).

Supporting case studies linking mobility and emergency response

Hopelink Mobility Management is a community action agency with a mission to promote self-sufficiency for community members and reduce poverty (45). Hopelink provides staff for the Regional Alliance for Resilient and Equitable Transportation (RARET) workgroup (45). RARET's purpose is to increase critical transportation services available to older adults, people with disabilities, low-income, and other disadvantaged populations (45). RARET is a nexus of emergency planning and transportation, and uses its position to incorporate transportation planning into emergency management plans (45). An example of what RARET does is exemplified by its work preparing for the Cascadia Subduction Zone Earthquake (45). RARET works with King County Mobility Coalition (Washington, USA) to develop emergency transportation plans, specifically a One-Call system that will streamline emergency efforts by acting as a 211 for transportation booking (45). RARET is now looking for a transportation provider alliance to develop the technology necessary to create the coordinated emergency response (45). During COVID-19, RARET obtained updates from transportation providers to compile weekly impact summaries (45).

The Ohio Department of Transportation (ODOT) partnered with the Ohio Emergency Management Agency (EMA) during COVID-19 (from March 2020 to June 2020) to convey real-time information on transportation resources (45). ODOT also worked with the Ohio Department of Health (ODH) to coordinate transportation and site location for COVID-19 testing sites, and mobility managers partnered with ODH to bring face masks to agencies serving vulnerable populations (45). Distributing face masks reduced shipping costs for ODH and helped develop a partnership between the agencies that did not exist prior to the pandemic (45). Since then, ODOT created an online database of transportation services accessible by the public, that shows transportation providers in Ohio and the capacity they operated at while Ohio transitioned out of the stay in place order (45).

Des Moines Area Regional Transit Authority (DART) partnered with Des Moines Area Religious Council (DMARC) to offer mobile food pantries to local senior centers and apartment complexes (45). DART also works with Polk County in Iowa to respond to emergencies by providing transportation during fires and floods, setting up warming centers during winter, and cooling centers during the summer (45). During COVID-19 DMARC began food delivery and DART assisted them via their paratransit fleet for deliveries to increase delivery services (45). Also, during the pandemic, DART worked with the county to route buses from the hospital to isolation centers for homeless residents (45). Further, DART worked with the Iowa Cancer Consortium to provide paratransit services to cancer patients and provided over 60 safe transport trips over two months (45).

These partnerships exemplify what transportation can do to create resiliency and health. COVID-19 put a spotlight on why these partnerships are so important and how technology innovation can transform how emergencies are approached.

COVID-19 impacted mobility and subsequently mental health and access to health services

COVID-19 reduced individual mobility due to a lack of transportation options, social distancing guidelines, and closing frequently visited places such as shops and schools. A study of twelve European countries showed that social distancing policies and closing frequented places, such as schools, was associated with a sharp decline in observed mobility patterns in each country (46). Specifically, closing frequently visited shops was strongly associated with reduced ridership and use of all forms of mobility (46). The study found that restrictions on non-essential movement reduced all forms of mobility and increased time spent at home (46). Further, while restrictions such as school closures and distancing also had a significant negative impact on all mobility forms, the study found that people responded to the pandemic by reducing mobility habits beyond what was required by formal distancing policies (46). Similarly, when the COVID-19 pandemic became front and center in the United States in mid-March 2020, many public transit agencies experienced a reduction in ridership (47). From 2019–2020, ridership fell by over 60% (47). Transportation network companies (Lyft, Uber) experienced ridership drops in Summer 2020 from 54–75% (47). This is also ended focus on pooled rides by such companies. Micromobility experienced both increases and decreases in ridership based

on geography and trip purpose (47). Conversely, delivery services became profitable during this time (47), but gig economy workers quickly became front line workers risking health for the need to make a living.

The restrictive measures implemented during COVID-19, including isolation, also triggered massive changes in travel behaviors. A study by Barbieri *et al*, examined individual mobility patterns in ten countries, including the United States, for all transportation modes via a survey (48). Across all countries, avoidance of public transport was a consistent finding (48). Further, restrictive measures massively impacted individual mobility patterns for both commuting and non-commuting travel (48). Use of all transport models dropped and correspondingly the amount of people reporting they never used bus, car, shared a ride, airplane, or train increased drastically (48). Even the number of people sharing that they did not walk during the pandemic increased by 15.5% (48). The pandemic had a negative relationship with travel for both work or recreational purposes (48). There was also a reduction in the number of people leaving their home to purchase goods, visit relatives, and join social gatherings (48). Further, transportation operators experienced disproportionately high rates of infection and morbidity in addition to suffering emotional, psychological, social, and economic stress from the pandemic (48). In fact, the pandemic worsened psychological distress at all ages due to isolation, impact on local economy, unemployment, and related trends (49). While psychological health worsened, physical health was impacted by COVID-19 itself and decreased access to healthcare.

While many factors emerged during COVID-19 that affected access to healthcare, such as income reduction, unemployment, and more, lack of transportation and fear of exposure contributed to the decline of in-person visits to physician practices (49,50). Solutions such as telehealth appointments fell short and physician practices still experienced financial losses from missed appointments, while patients felt telehealth didn't address their concerns the way in-person visits do (49,50). For example, telehealth does not allow for physical exams or lab tests (50). Telehealth also presents its own challenges such as lack of access to technology, digital literacy, and reliable internet coverage, all of which disproportionately affected disadvantaged and rural communities (50). COVID-19 and its associated trends (disruption to economy, access to transportation, isolation) contributed to a lack of access to healthcare and access to transportation was a factor of this decline. The aforementioned partnerships between health care organizations and transportation highlight how transportation can be used to combat public health emergencies, and the next section explores how transportation technology solutions helped alleviate some of the burdens created by COVID-19.

Overall, the lessons learned from the COVID-19 pandemic confirm the following correlations between mobility and health and offer the following opportunities moving forward:

- Mobility supports different layers of health—mental health through community connections and socialization; nutritional health by providing access to groceries; physical health by providing opportunities for recreation through active transportation or accessing recreational opportunities.
- The value of access to safe, affordable, convenient, and accessible transportation is underappreciated.
- Mobility is a key economic driver and a foundational cornerstone for healthy communities.

Despite the pandemic, emerging mobility trends and innovations support better health

There are novel transportation solutions that are already being deployed to remedy mobility problems that emerged during COVID-19. Though there was a decrease in ridership during COVID-19, innovative mobility solutions demonstrated that these mobility trends can be combated.

Ride sourcing is a transportation solution that can help access to care for people in rural areas and bridge the access to care gap created by socioeconomic divides (51). Access to health care is a recurring problem that will be prevalent as long as rural areas and socioeconomic divides exist. The ride sourcing industry has captured a significant share of the non-emergency transportation healthcare market (51). Health care providers leverage ride sourcing to book patient trips (51). The booking process involved a HIPAA-compliance step to be tailored to the ride sourcing industry to ensure compliance with privacy requirements around healthcare records (51). An alternate way to use ride sourcing is an insurer or health plans can partner with a ride sourcing company to expand transportation options to beneficiaries or add these services to its plan for the first time (51). Adjacent to ride sourcing are delivery companies such as DoorDash, which can be leveraged to support access to healthy food options or even meals to aging populations.

Following initiatives from the Biden-Harris administration's Call to Action to Reduce Maternal Mortality and Morbidity, TNC's such as DoorDash and Lyft created partnerships to positively impact maternal health trends (52). DoorDash, partnered with CARE and the Homeless Prenatal Program to deliver food and essential items to unhoused and unstably housed pregnant mothers (52). Lyft partnered with CareSource to analyze the impact of safe, reliable transportation on healthy pregnancies (52). Rides will be provided for to the grocery store, maternity appointments, general healthcare appointments, pharmacies, and educational classes (52). Lyft and CareSource will publish a report on its data collection (52). Uber is conducting a Rides for Moms initiative with Surgo Ventures, Community of Hope, and Mary's Center. This initiative will provide free transportation for prenatal and postnatal care appointments for up to 1,000 pregnant people in the D.C. area, and the program will close at the end 2022 (52). These partnerships show the potential that TNCs can offer for non-emergent transportation solutions. This can fill a significant gap for people who do not have a private vehicle or adequate public transit in their communities. While TNCs can assist with non-emergency medical transport, transportation technology solutions such as C/AVs and unmanned aircraft systems (UAS) can transform emergency care and offer novel ways to transport medical supplies. However, as noted above, concerns around equitable access and reducing impacts from increased vehicles miles traveled and congestion will need to be addressed to ensure holistic positive benefits.

Though there are some concerns surrounding C/AVs, there are also promising uses. For example, during the pandemic Nuro used a small fleet of road delivery robots to transport medical supplies around two stadiums in California that are used as treatment facilities for COVID-19. Nuro employed R2 prototype vehicles to deliver goods to health care workers (53). The R2 prototypes are low speed (under 25 mph), lightweight EVs that are completely driverless and can eventually provide contactless delivery (53). The R2 prototypes delivered food, personal protective equipment, clean linens, and similar supplies (53). The only point of human contact is when the human workers load and unload vehicles at the beginning and end of the route (53). The vehicles are on fixed, preplanned routes and operate on private roads (53). They operate at 5 mph when outdoors and 2.5 mph indoors (53). The automated delivery robots allowed contactless transportation of essential medical supplies, posed a low safety risk to workers because of their size and low speed, and exemplify how C/AVs can be implemented during emergency situations. Similarly, UASs were very effective in contactless delivery during COVID-19.

In China UASs have been an integral method of combating the COVID-19 pandemic, and were used in three distinct roles (54). First, agricultural UASs that are normally used to spray pesticides, were used to spray disinfecting chemicals in public spaces and on epidemic prevention vehicles that travel between impacted areas (54). UAS spray is significantly more efficient and consistent than hand spray (54). Second, UASs were used to deliver medical samples (54). A UAS carrying medical supplies traveled three kilometers from a province to the Chinese Center for Disease Control and Prevention in six minutes, a journey that would have taken twenty minutes using ground transport (54). Using UAS delivery to transport medical samples and supplies not only reduced human contact, but also sped up the transport process and saved ground transport resources (54). While this process required diligent coordination between the government, health department, and aviation administration, once this hurdle was overcome, over twenty flights a day were completed (55). Third, UAS delivery was used to ensure citizens had access to consumer items such as food (54). China has challenging landscapes and a large population, making it difficult for ground transport to navigate rugged terrain or crowded streets (54). UASs were able to replace an hour-long drive with a two-kilometer flight that could be completed in ten minutes (54). While UAS delivery for consumer goods was primarily pursued by private companies, they were able to coordinate with local governments and the aviation administration to deploy UASs which further highlights the importance of public-private partnerships (54).

UAS also have uses outside of the ones mentioned for COVID-19. They can improve mobility of health care transportation because they can navigate spaces that traditional automobiles cannot, such as ambulances unable to navigate in a crowded area or an area with heavy traffic. UAS can also be used to transport medical tools, organs, and blood samples (55,56). UAS have the capacity to carry loads and transport them quickly to a destination because they can circumvent road conditions, traffic, terrain, even war-torn territory (55,56). At Delft University in the Netherlands an UAS was designed to deliver a defibrillator and other essential medical equipment in emergency situations (55,56). Timely arrival after an emergency is essential to saving lives (55,56). For example,

after cardiac arrest there is 4–6 min before brain death (legally considered dead), and emergency services have an average response time of 10 min and are strained to reach a person in this very short time frame (55,56). An UAS could positively impact survival rates by delivering a defibrillator to a first responder on site, or a person close to the patient who can be instructed via a webcam on the UAS (55,56). Technical University in Greece is also researching how UASs can be used to deliver insulin to someone in diabetic shock via a smart phone app (55,56). Researchers at Johns Hopkins University in the United States found that blood samples and other sensitive materials can be safely transported by UASs (55,56). The Hopkins research group tested samples flown over the Arizona desert stored in a temperature-controlled chamber on the UAS, and found flown samples were comparable in quality to non-flown samples (55,56). Further, UASs can also be used to save people in difficult to reach areas. UASs can be used to replace medevac helicopters in areas that helicopters have difficulty landing (55,56). For example, the United Nations Institute for Training and Research used UASs in 2010 to analyze earthquake damage (55,56). This minimized the risk of a person flying out to evaluate earthquake damage and potentially being hurt (55,56). Eventually UASs could also be used to rescue a person from an earthquake or a similar situation. UASs are emerging technology like C/AVs; however, both have hopeful futures in transportation and can address issues that the industry is grappling with. Like many of the emerging mobility innovations discussed in this paper, a coordinated effort between public and private industry with federal backing will be needed to overcome governance and regulatory hurdles, while also supporting continued testing in real operational environments.

Conclusions

Reliable and accessible transportation options can position a community to be resilient and healthy. The mobility partnerships that emerged during COVID-19 and those that existed prior show that mobility has a definite impact on health and resiliency and should be a constant counterpart to the two disciplines. This literature review is different from the studies mentioned because it focuses on the link between health and mobility, and within mobility highlights access to transportation and emergency response preparedness. The scope of this paper is narrower because in doing the literature review we noticed one limitation with other studies is an overly broad scope that requires readers to make assumptions about the transportation system as having far reaching health benefits. The public health implications of this paper are focused on that access to transportation can have a positive impact on health outcomes, and that emerging technology in the transportation sector can improve this access and can help build resilient communities that have better health outcomes.

From the research and analysis completed as part of this paper, the following recommendations can be put forward:

- Connecting policies and incentives that link mobility and housing can lead to positive health and social benefits, including reduced dependence on vehicle ownership and increased active transportation. Modernizing TOD policies to incorporate demand responsive transit and mobility hubs presents a near-term opportunity.
- Government leaders and those in the private sector should continue to focus on partnerships that leverage emerging on-demand mobility technologies with specific use cases that support access to transportation, particularly around healthcare.
- As we continue to come out of the COVID-19 pandemic, finding opportunities to modernize and support public transportation is important for ensuring an equitable, resilient, and accessible transportation system when the next disruption comes.
- While automated technologies have been highly scrutinized, there are specific use cases that can support healthier communities, including through access to healthy foods, prescriptions and supplies, and emergency response where continued investment is warranted.

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References

1. Rodriguez G. A Smart(ER) Mobility Approach. 2022 [cited 2022 March]. Available online: https://www.stantec.com/en/markets/transportation/smart-mobility
2. Healing communities by design. 2022 [cited 2022 March]. Available online: https://www.stantec.com/en/markets/health/behavioral-health
3. Public health emergency. 2015 [cited 2022 Oct 16]. Available online: https://www.phe.gov/Preparedness/planning/abc/Pages/community-resilience.aspx
4. Tusaie K, Dyer J. Resilience: a historical review of the construct. Holist Nurs Pract 2004;18:3-8; quiz 9-10.
5. Seaman P, McNeice V, Yates G, et al. Resilience for public health: supporting transformation in people and communities. Glasgow Centre for Population Health. 2014 Feb. Available online: https://www.gcph.co.uk/latest/news/481_resilience_for_public_health_supporting_transformation_in_people_and_communities
6. Child and Youth Resilience Measure & Adult Resilience Measure. Resilience Research Centre. 2022 [cited 2022 Oct. 14]. Available online: https://cyrm.resilienceresearch.org/
7. Hjemdal O, Roazzi A, Dias Mda G, et al. The cross-cultural validity of the Resilience Scale for Adults: a comparison between Norway and Brazil. BMC Psychol 2015;3:18.
8. Petit FD, Basset GW, Black RA, et al. Resilience measurement index: an indicator of critical infrastructure resilience. Available online: https://publications.anl.gov/anlpubs/2013/07/76797.pdf
9. Wulff K, Donato D, Lurie N. What is health resilience and how can we build it. Annu Rev Public Health 2015;36:361-74.
10. Mahalingam S. An unlikely connection – how transportation affects health. 2019 [cited 2022 Sept 3]. Available online: https://cmopp.web.unc.edu/2019/07/an-unlikely-connection-how-transportation-affects-health/
11. Robert Wood Johnson Foundation. Built environment and health. 2022 [cited 2022 Sept 3]. Available online: https://www.rwjf.org/en/insights/collections/built-environment-and-health-library.html?o=0&us=1
12. Raynault E, Christopher E. How does transportation affect public health. June 2013 [cited 2022 September 5]. Available online: https://highways.dot.gov/public-roads/mayjune-2013/how-does-transportation-affect-public-health
13. Center for Disease Control. Transportation health impact assessment toolkit. 2011 [cited 2022 Sept 4]. Available online: https://www.cdc.gov/healthyplaces/transportation/hia_toolkit.htm
14. Nieminen T, Prättälä R, Martelin T, et al. Social capital, health behaviours and health: a population-based associational study. BMC Public Health 2013;13:613.
15. Agampodi TC, Agampodi SB, Glozier N, et al. Measurement of social capital in rela-tion to health in low- and middle-income countries: a systemic review. Soc Sci Med 2015;128:95-104.
16. Morton MJ, Lurie N. Community resilience and public health practice. Am J Public Health 2013;103:1158-60.
17. Leyden KM. Social capital and the built environment: the importance of walkable neighborhoods. Am J Public Health 2003;93:1546-51.

18. Transit-oriented development. 2022 [cited 2022 Sept 10]. Available online: https://www.transit.dot.gov/TOD
19. National Association of City Transportation Officials. Urban street design guide. 2022 [cited 2022 Sept 10]. Available online: https://nacto.org/publication/urban-street-design-guide/
20. Transit oriented development. 2022 [cited 2022 Sept 10]. Available online: https://www.phoenix.gov/pdd/tod
21. Saunders L, Green J, Petticrew M, et al. Systematic review of health benefits of active travel. NIHR Journals Library. Available online: https://www.ncbi.nlm.nih.gov/books/NBK263971/
22. Cook S, Stevenson L, Aldred R, et al. More than walking and cycling: what is active travel. Transport Policy 2022;126:151-61.
23. Masjutina S. Benefits and challenges of transit oriented development. 2016 April [cited 2022 November 20]. Available online: https://www.linkedin.com/pulse/benefits-challenges-transport-oriented-development-svetlana-masjutina
24. Transit Oriented Development Challenges and Opportunities. 2021 August [cited 2022 November 20]. Available online: https://resilientconnecticut.uconn.edu/tod/
25. What is climate resilience? 2022 Jun [cited 2022 Oct 20]. Available online: https://www.ucsusa.org/resources/what-climate-resilience
26. Fuller-Love H. Resilience in New Orleans. 08/23/2016 [cited Oct 14]. Available online: https://www.dw.com/en/recovering-from-katrina-will-new-orleans-become-the-worlds-climate-beacon/a-19443437
27. Thriving communities program. 2022 [cited 2022 Oct 15]. Available online: https://www.transportation.gov/grants/thriving-communities
28. Biden administration announces first-ever funding program dedicated to recon-necting American communities. June 30, 2022 [cited 2022 Oct 15]. Available online: https://www.transportation.gov/briefing-room/biden-administration-announces-first-ever-funding-program-dedicated-reconnecting
29. Gehrke S. Land use and active travel: a complex relationship. Project Brief 2016-973. Portland, OR: Transportation Research and Education Center (TREC), 2017.
30. Connected and automated vehicles. 2010 [cited 2022 Sept 5]. Available online: http://autocaat.org/Technologies/Automated_and_Connected_Vehicles/
31. Velasco G. How Transportation Planners Can Advance Racial Equity and Environmental Justice. 2020 [cited 2022 Oct 15]. Available online: https://www.urban.org/urban-wire/how-transportation-planners-can-advance-racial-equity-and-environmental-justice
32. Shephard E, Napoline K, Douma F, et al. Opportunities and challenges for de-ploying connected and automated vehicles to address transportation disparities in urban areas. J L Mob 2022;3. Available online: https://repository.law.umich.edu/jlm/vol2022/iss1/3
33. Rojas-Rueda D, Nieuwenhuijsen MJ, Khreis H, et al. Autonomous Vehicles and Public Health. Annu Rev Public Health 2020;41:329-45.
34. BEYOND lead participants. 2022 [cited Oct 16]. Available online: https://www.faa.gov/uas/programs_partnerships/beyond/lead_participants
35. Beyond. 2022 [cited 2022 Oct 16]. Available online: https://www.faa.gov/uas/programs_partnerships/beyond
36. Unmanned aircraft systems program. 2021 [cited 2022 Oct 16]. Available online: https://www.faa.gov/uas/programs_partnerships/completed
37. Transit automation research. 2022 [cited 2022 November 21]. Available online: https://www.transit.dot.gov/automation-research
38. FTA transit bus automation factsheet: FTfastrak. 2022 [cited 2022 No-vember 21]. Available online: https://www.transit.dot.gov/research-innovation/fta-transit-bus-automation-factsheet-ctfastrak
39. Hess AJ. Americans spend over 15% of their budgets on transportation costs – these US cities are trying to make it free. 2020 [cited 2022 Oct 16]. Available online: https://www.cnbc.com/2020/03/02/free-public-transportation-is-a-reality-in-100-citiesheres-why.html
40. Disaster response routes. 2022 [cited 2022 September 13]. Available online: https://www2.gov.bc.ca/gov/content/transportation/driving-and-cycling/traveller-information/routes-and-driving-conditions/disaster-response-routes?
41. Disaster routes. 2022 [cited 2022 September 13]. Available online: https://pw.lacounty.gov/dsg/disasterroutes/
42. Stranded drivers are free after 24-hour snowy ordeal on I-95 in Virginia. 2022 [cited 2022 December 4]. Available online: https://www.nytimes.com/2022/01/04/us/i-95-closed-snowstorm-winter.html
43. Disasters data pathfinder. 2022 [cited 2022 September 13]. Available online: https://www.earthdata.nasa.gov/learn/pathfinders/disasters
44. Transportation response to CBR events. In: NCHRP Report 525. Transportation Research Board; 2006:6-33. Available online: https://nap.nationalacademies.org/

read/13944/chapter/4
45. National Center for Mobility Management. Integrating emergency management and mobility management. 2020 July [cited 2022 October 6]. Available online: https://nationalcenterformobilitymanagement.org/wp-content/uploads/2021/06/Integrating-Emergency-Management-and-Mobility-Management-07.10.2020.pdf
46. Marcus S, Kahanec M, Laffers L. The impact of COVID-19 restrictions on indi-vidual mobility. 2020 [cited 2022 Sept 4]. Available online: https://www.bruegel.org/blog-post/impact-covid-19-restrictions-individual-mobility
47. Shaheen S, Wong S. Future of public transit and shared mobility: scenario plan-ning for COVID-19 recovery. Inst of transp studies reports. 2021 Jan; 58. doi: 10.7922/G2NC5ZGR
48. Barbieri DM, Lou B, Passavanti M, et al. Impact of COVID-19 pandemic on mobil-ity in ten countries and associated perceived risk for all transport modes. PLoS One 2021;16:e0245886.
49. Núñez A, Sreeganga SD, Ramaprasad A. Access to Healthcare during COVID-19. Int J Environ Res Public Health 2021;18:2980.
50. Cole B. The impact of the COVID-19 pandemic on access to health care. 2020 July. Available online: https://www.nasi.org/research/medicare-health-policy/the-impact-of-the-covid-19-pandemic-on-access-to-health-care/
51. Wolfe MK, McDonald NC. Innovative health care mobility services in the US. BMC Public Health 2020;20:906.
52. Initial external contributions in response to vice president Kamala Harris's call to action to reduce maternal mortality and morbidity. 2021 December 7 [cited 2022 April 30]. Available online: https://www.whitehouse.gov/briefing-room/statements-releases/2021/12/07/initial-external-contributions-in-response-to-vice-president-kamala-harriss-call-to-action-to-reduce-maternal-mortality-and-morbidity/
53. Hawkins AJ. Nuro is using delivery robots to help health care workers fighting COVID-19. 2020 April 22 [cited 2022 April 30]. Available online: https://www.theverge.com/2020/4/22/21231466/nuro-delivery-robot-health-care-workers-food-supplies-california
54. Yang J, Reuter T. 3 ways China is using drones to fight coronavirus. 2020 March 16 [cited 2022 Oct 16]. Available online: https://www.weforum.org/agenda/2020/03/three-ways-china-is-using-drones-to-fight-coronavirus/
55. Konert A, Smereka J, Szarpak L. The use of drones in emergency medicine: prac-tical and legal aspects. Emerg Med Int 2019;2019:3589792.
56. Rucker M. The potential of drones providing health services. 2022 April 25 [cited 2022 April 30]. Available online: https://www.healthplaning.com/blog/the-potential-of-drones-providing-health-services.html

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