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SPECIAL ISSUE ARTICLE

WILEY

“Make no little plans”: Impactful research to solve the next generation of transportation problems

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Abstract

The transportation science research community has contributed to numerous practical and intellectual innovations and improvements over the last decades. Technological advancements have broadened and amplified the potential impacts of our field. At the same time, the world and its communities are facing greater and more serious challenges than ever before. In this paper, we call upon the transportation science research community to work on a research agenda that addresses some of the most important of these challenges. This agenda is guided by the sustainable development goals outlined by the United Nations and organized into three areas: (1) well-being, (2) infrastructure, and, (3) natural environment. For each area, we identify current and future challenges as well as research directions to address those challenges.

KEYWORDS

health care, infrastructure, optimization, sustainability, transportation, United Nations sustainable development goals

1 | INTRODUCTION

Transportation science researchers have had a significant impact on industrial applications as well as the development of general methods in operations research. For example, Barnhart et al. [1] write about the impact of operations research in the airline industry, “Indeed, it is difficult to think of any single sector, other than perhaps military operations, with which operations research has been linked more closely.” An application in full-truckload trucking offered one of the first large-scale implementations of approximate dynamic programming [2]. Well-documented examples of other successful applications include parcel delivery [3, 4], railway [5], postal services [6], firefighting [7], and bike-sharing [8]. This journal also has a long history of publishing papers making an impact on practice with applications in waste collection, vehicle routing, periodic routing, and school bus routing [9–14].

Methodologically, according to Grötschel and Nemhauser [15], in their work on the traveling salesman problem, Dantzig et al. [16] “… pioneered the idea of employing linear programming relaxation and valid inequalities to solve integer programs by solving (including a proof of optimality) a 49-city TSP.” In addition, Barnhart et al. [17] note, “Routing and scheduling has been a particularly fruitful application area of branch-and-price …” Transportation science has also been a key driver of the development of metaheuristics. Laporte et al. [18] write, “It is fair to say that the study of the Vehicle Routing Problem has stimulated the growth and understanding of several metaheuristic concepts we now know.”

Niels Agatz, Mike Hewitt, and Barrett W. Thomas contributed equally to this study.

With the help of technological advancements that make data more easily available, enhanced vehicle automation, and increased computational power, transportation science continues to make an impact. GPS and smart phone data provide new opportunities to accurately analyze travel times and flows in urban mobility systems [19]. Developments in vehicle automation such as drones, delivery robots, and truck platoons give rise to new challenges and opportunities [20, 21]. Furthermore, over the past few years, there have been significant enhancements in the methods and algorithms that allow us to solve larger problems. In fact, computing speed is now more than a billion times faster than at the time of the first issue of *Networks* [22, 23]. The progress in hardware and methods is clearly illustrated by the increasing scale for which we can find optimal solutions to the traveling salesman problem. Where Dantzig, Fulkerson, and Johnson's pioneering work in 1954 enabled the solution of a traveling salesman problem with 49 cities [16], in 2009, the Concorde TSP solver found the optimal tour through 85 900 cities [24].

Despite these successes, transportation science must not rest on its laurels. Across the operations research community in general, there is growing concern that the field is becoming too insular. In describing the field of operations management, Cachon et al. [25] write, "A high degree of focus on a specific problem or context may provide a spectacular solution for a particular application, but unless the solution generalizes, it is of limited value (i.e., it is a trap)." Furthermore, they claim, "failing to make the effort to travel beyond the comfort zone of our familiar conferences, journals and communities only relegates us to obscurity." Transportation science faces the same risks.

In this paper, we call upon our research community to focus on the big and relevant problems of our times. Similar to the call of Van Wassenhove [26] to the operations management community, we use the United Nation's sustainable development goals (https://sustainabledevelopment.un.org), referred to as SDGs, as a framework for identifying new areas of research where transportation science can make an impact. The SDGs are 17 goals that were adopted by all UN member nations in 2015 with the objective of improving the planet and the people's lives by 2030. Waage et al. [27] categorize the goals into three broad themes: well-being, infrastructure, and the natural environment. We organize this paper around these three themes and explore goals associated with each theme to identify the opportunities that they offer for the future of transportation science research.

Here, we take the perspective of the transportation optimization/operations research community. Operations research deals with the application of advanced analytical methods to help make better decisions. As such, our community is in a good position to contribute to addressing some of the big global challenges facing the world. However, as most of these challenges are highly complex, broad, and multifaceted, we must collaborate with different disciplines to tackle these issues.

The SDGs are bold and seek solutions to big, global problems. Yet, that is precisely what makes them interesting. Solutions to small problems require only small, incremental changes in our thinking. Rather, we want to think big. As the famous Chicago architect Daniel Burnham said, "Make no little plans; they have no magic to stir men's blood" [28]. Meeting the big targets laid out in the SDGs requires new thinking, thinking that will inspire the next generation of problems and methodology.

The rest of the paper is organized as follows. In Sections 2–4, we discuss the SDGs associated with well-being, infrastructure, and the natural environment. For each of these broad themes, we first present the main challenges related to transportation. Then, we discuss past work and example directions for future research. We provide only general directions and do not intend to propose specific models or solution approaches. Section 5 presents a framework on how to increase research impact. What our exploration of the SDGs and the problems emerging from them identifies is that we need to consider a broader research approach. While we might be able to identify emerging problem areas, the solutions of those problems require us to engage stakeholders, to truly understand the different objectives, constraints and uncertainties. Finally, in Section 6, we provide concluding remarks and perspectives.

2 | WELL-BEING

Waage et al. [27] categorize following SDGs under the category of *well-being* with descriptions from the United Nations [29]:

- Goal 1: No poverty: Economic growth must be inclusive to provide sustainable jobs and promote equality.
- Goal 3: Good health and well-being: Ensuring healthy lives and promoting the well-being for all at all ages.
- Goal 4: Quality education: Obtaining a quality education is the foundation to improving people's lives.
- Goal 5: Gender equality: Gender equality is not only a fundamental human right, but also a necessary foundation for a peaceful, prosperous, and sustainable world.
- Goal 10: Reduced inequalities: To reduce inequalities, policies should be universal in principle, paying attention to the needs of disadvantaged and marginalized populations.
- Goal 16: Peace, justice, and strong institutions: Access to justice for all, and building effective, accountable institutions at all levels.

In this section, we will first discuss the transportation-related challenges to the SDG associated with well-being. These primarily connect to enhancing equality of access to health and education. We will then discuss potential avenues of transportation-related operations research to address those challenges.

2.1 | Challenges and goals for health and equality

Access to quality health care is essential to achieve the health-related SDGs. From a transportation-optimization perspective, this relates to both locating health-care facilities [30] and organizing transportation of patients to and from those facilities. The main challenge is that providing quality care is costly and resources are limited, particularly in developing regions. Global spending on health care continues to rise. It was US$ 7.8 trillion in 2017, or about 10% of GDP and $1080 per capita—up from US$ 7.6 trillion in 2016 [31].

Many people in low and middle income countries lack access to basic health-care services leading to high morbidity and mortality rates. Lack of transportation is one of the most important health-care barriers in this context [32, 33]. The cost of transportation, poor roads, and time taken to reach the health-care facility frequently causes delayed presentations of disease [34]. Diagnosing disease at a later stage has a negative impact on health outcomes. In some regions, heavy rains and flooding can sweep away entire roads, temporarily making access to health-care facilities virtually impossible.

As related to time-critical care, there is usually no formal ambulance-based emergency medical system (EMS) in place in low- and middle-income countries [35]. More than half of the global population lives in areas without formal EMS [36]. This means that patients with critical time-sensitive illnesses and injuries, such as severe infections, dehydration caused by diarrhea, trauma injuries, complication related to child-birth, and acute heart diseases [37] often cannot receive appropriate care in time. In Delhi, India, for example, most trauma victims are transported to the hospital by private cars, taxis, and police vehicles [36]. In several parts of the developing world, we have recently seen initiatives for "Uber-type" dispatching services to better coordinate emergency ride options, based on volunteers, regular taxis, or existing private ambulances services.

Lack of transportation is not only a problem in the developing world. Wallace et al. [38] find that 3.6 million people in the United States do not obtain medical care due to transportation barriers. This finding is reinforced by Grant et al. [39] who note that 3 million children in the United States miss a health-care appointment each year due to lack of transportation. Older adults are particularly at risk. For that population, Fitzpatrick et al. [40] report that transportation is the third most commonly cited barrier to accessing health services. Likewise, Bhatt and Bathija [41] cite transportation as an essential service for ensuring access to quality health care in vulnerable communities.

An emerging strategy to deal with these challenges in a cost-effective manner is to provide home-health-care, in which care providers visit patients in their home and medical transportation that transports patients from their homes to care facilities/providers. While such systems may be seen as a means of increasing access in developing regions, demand for these systems is also expected to grow in developed regions due to aging populations [42]. Relatedly, home-health–care has been seen as a critical component of providing universal access to health care in some countries [43, 44]. On the one hand, home-health-care increases access for those for whom getting to a care provider is challenging. On the other, some studies have shown that providing hospital care at home can reduce costs of the care episode by 52% [45].

Operational planning issues related to both home-health-care and medical transportation have been studied by the operations research community. Planning problems related to home-health-care routing have received increasing attention in recent years [46]. Regarding operational planning for medical transportation, many researchers have studied what is often referred to as the dial-a-ride problem [47]. This problem focuses on designing delivery routes for individuals who specify pickup-and-delivery requests between origins and destinations. The typical objective is to design least-cost routes. However, there are often quality of service issues built into these problems. For example, such problems will often include constraints that prevent an individual having to take too long a ride to get to their destination due to the pickup and delivery of other individuals.

The use of either system often leads to a reduction in overall health-care costs by enabling patients to remain in their homes instead of occupying an in-patient hospital bed [48]. There are many variants of the home-health-care routing problem [49]. A particularly important dimension in providing quality care is ensuring continuity of care [50, 51]. Specifically, by ensuring a patient is always viewed by the same care provider, these variants ensure what is known as the *continuity of relationship* [52]. However, there have also been questions regarding whether all patients equally value continuity of relationship [53, 54]. Differing patient preferences and their impact on patient perception of health-care quality is one of the unique challenges to health-care management.

At the same time, COVID-19 has brought to everyone's attention the role that transportation plays in the spread of disease [55, 56]. Transportation researchers then have a role to play in stopping the spread of disease. For example, existing work has sought to quantify the risks of disease spread through air transport networks [57–59]. Other work shows the role that road [60] and transit [61] networks play in the spread of infectious disease. Researchers have also begun to optimize the mitigation of spread through transit networks [62] and air networks [63–65].

In the context of ensuring inclusive and equitable quality education, researchers at MIT developed an algorithm for school bus routing and scheduling for the Boston Public Schools that could consider multiple objectives (costs, impacts on parent work-day, etc.), with different stakeholder groups focusing on different objectives [66]. In particular, their approach incorporated equity considerations with respect to the start times. They experienced first-hand the challenges associated with using an optimization-based tool to derive operational plans for a transportation system that serves a broad and diverse population. In the end, none of the potential plans produced by the algorithm were adopted, in part because of these conflicting interests among members of the same stakeholder group. Specifically, the impact of changed start times would impact parents from different economic classes differently.

Another barrier to the adoption of one of the proposed plans was the view that the algorithm was too much of a "black box." The Boston Public Schools did take some steps to avoid such concerns; before publicizing the plan proposed by the algorithm, they laid out the algorithm's four guiding principles in designing new routes and schedules. However, they did not fully prepare families for how dramatic the changes would be, including changing the start times for some schools by nearly 2 h. It is reasonable to conclude that greater engagement with parents and families would have increased the likelihood of the algorithm producing a plan that was implemented and impactful.

At the same, as highlighted in the United Nations goals, equality can be considered along different dimensions, including age, geography, health, and income. In general, considering multiple equity objectives in a multiobjective manner has received some attention [67]. In addition, Cardoso et al. [68] consider three equity-motivated objectives with a multiobjective approach in the context of tactical planning for a long term health-care system. However, there is little to no other research that considers multiple equity objectives in transportation settings.

2.2 | New research directions to promote well-being

Many of the SDGs related to well-being aim to improve access to quality health care and education in an equitable way. The transportation optimization community can contribute to these goals as they involve locating facilities and transportation.

We see multiple opportunities for more transportation-optimization research that takes into account the specific challenges that are relevant when operating in the developing world. One important example relates to emergency care systems. So far, the transportation optimization community has mostly focused on location planning [69, 70] and real-time dispatching of ambulances [71] in the context of centralized emergency response systems. As developing countries often lack such a system, they typically rely on creative ad hoc solutions. We are aware of only two recent papers [72, 73] that look at the associated challenges from a transportation optimization perspective.

Non-governmental organizations play an important role in providing health-care services in low income countries. Their operations typically involve facility location challenges. North Star Alliance, for example, seeks to "build a network of primary health clinics supported by targeted preventive programs to stop the spread of disease" (https://www.northstar-alliance.org). Determining where to best locate different types of roadside health-care facilities gives rise to complex trade-offs between different objectives related to patient volume and the effectiveness of the offered care, see Ares et al. [74] and de Vries et al. [75]. Additional challenges arise when incorporating the uncertainty and risk [76]. We believe there are many more research opportunities in this space related to transportation optimization.

Novel transportation technologies also give rise to new opportunities and challenges in health care as well as new research opportunities. We have seen the use of drones for various medical purposes. By not being hampered by poor infrastructure, drone delivery service Zipline has performed 2700 blood transports in Rwanda and increased the access to rare blood products by 175% [77]. Other examples include the use of drones to deliver defibrillators to victims of out-of-hospital cardiac arrest in rural areas [78]. As drone technologies develop and people devise new applications for them in health care, there will be a need for new problem formulations and methodologies to optimize their use.

Effectively serving public goals, as opposed to economic goals, is challenging as it involves multiple stakeholder groups. Patients, providers, and administrators may nominally share the goal of providing universal access to quality health care in a cost-effective manner. However, in reality, each stakeholder group likely focuses on a subset of those three objectives (access, cost, and quality), and there are trade-offs between them. For example, in home-health-care, there can be a trade-off between quality and access when quality is achieved by having a provider spend more time with each patient. While patients and providers may prioritize quality, and thus providers spend more time with patients, doing so would necessarily reduce provider capacity and thus access. An administrator may instead prioritize access and instead ask providers to spend less time with patients.

School bus routing and the determination of school start times are similar. School district administrators may focus on costs and thus spread out school start times so as to leverage the same bus fleet for multiple school districts. However, parents may prefer early start times to facilitate their commutes to work, and children may prefer later start times so they can get more sleep. Equality concerns further compound the challenges as children from different neighborhoods may face different travel distances.

Regarding new research directions, it is clear that the optimization problems solved to equitably address the SDGs on well-being require multiple objectives. Multiobjective optimization has been studied in both general [79] and transportation [80] contexts. However, much if not all of that literature considers problems with a small number (e.g., two or three) of objectives that are functions of system-level statistics. In health care, an emphasis on quality that is achieved through patient-centered care and recognition of individual patient preferences may necessitate consideration of tens, if not hundreds of objectives, one for each patient's individual assessment of the quality of the care they receive. To the best of our knowledge, no methods have been shown to be effective in such settings. We anticipate that large numbers of objective functions will greatly add to the computational complexity of optimization methods that seek to populate the set of Pareto efficient solutions.

In addition, those objectives are likely to be nonlinear. Patient satisfaction, and hence perceived quality, likely exhibits diminishing marginal returns as a function of time spent with the provider. Similarly, in many public services (e.g., hospitals), access to the services provided by a location is measured by the Euclidean distance individuals must travel to reach that location [81]. The overall objective then attempts to reconcile these different individual (nonlinear) distances in an equitable manner.

To date, many of the algorithms proposed [79] for solving multiobjective optimization problems are genetic algorithms. While such algorithms are generally amenable to nonlinear objective functions, they also lack the optimality-type guarantees provided by branch-and-bound-based methods. However, as branch-and-bound-based methods rely on repeatedly solving relaxations of the original optimization problem, they may be ineffective at solving problems that incorporate multiple non-linear functions. Future research will need to address this methodological challenge.

Last, because human preferences are rarely fully known or revealed, and are likely to change, functional models of those preferences are subject to uncertainty. There has been some work [82–84] on multiobjective optimization problems where there is uncertainty in how objective functions map solutions to value. However, much of that is inspired by engineering settings wherein uncertainty is driven by noise in sensor data. To the best of our knowledge, there has been no work done on multiobjective optimization problems in a transportation context that exhibit uncertainty in objective function values. In addition, we are unaware of any methods that seek to jointly optimize multiple objective functions whose values are uncertain in an equitable manner.

3 | INFRASTRUCTURE

The second category of goals defined by Waage et al. [27] refer to the development of infrastructure. These are:

- Goal 6: Clean water and sanitation: Ensure availability and sustainable management of water and sanitation for all.
- Goal 7: Affordable and clean energy: Ensure access to affordable, reliable, sustainable, and modern energy for all.
- Goal 8: Decent work and economic growth: Promote sustained, inclusive and sustainable economic growth, full and productive employment, and decent work for all.
- Goal 9: Industry, innovation, and infrastructure: Build resilient infrastructure, promote inclusive, and sustainable industrialization and foster innovation.
- Goal 11: Sustainable cities and communities: Make cities and human settlements inclusive, safe, resilient, and sustainable.
- Goal 12: Responsible consumption and production: Ensure sustainable consumption and production patterns.

These goals are broad, but throughout, the concepts of sustaining rapid population growth and urbanization emerge. In this section, we highlight the challenges with both rapid growth and urbanization and then describe how these can fuel new research directions in transportation science.

3.1 | Challenges of population growth and urbanization

More than half of today's world population lives in cities, and this number is projected to grow to two-thirds by 2050 [85]. This rapid increase will mostly take place in developing countries with Africa and Asia having the fastest urban growth rates. The number of megacities, cities with more than 10 million inhabitants, is expected to grow from 33 to 43 in 2030 [86]. While urbanization has the potential to greatly contribute to prosperity through economies of scale and richer market structures [87], it also creates important challenges.

One of these challenges is providing the appropriate levels of infrastructure, such as road, water, electricity, and telecommunications, to support the large populations. Most cities grow by means of spatial expansion, and these expansions require the development of new infrastructure. Without careful planning, these urban expansions may lead to fragmentation, congestion, poverty, health risks, and social unrest. Unplanned growth, particularly the formation and proliferation of slums, is especially common in the developing world where (local) governments often have insufficient funds for the required infrastructure investments [31]. As a result, many people in the poorest countries still do not have access to safe water, electricity, and internet.

Cars typically use a lot of urban space, both in terms of road infrastructure and parking spaces. To increase the sustainability and livability, cities across the globe are trying to reduce their inhabitants' dependence on cars and reclaim space for pedestrians, cyclists, and public transport. Hamburg, Oslo, Helsinki, and Madrid have recently announced plans to ban cars from large parts of the city [88]. Others are reshaping the urban space to promote active travel behavior. For example, Barcelona introduced a so-called superblock model [89] in which the interior streets of groups of city blocks are primarily accessible by pedestrians and cyclists [90]. While these initiatives improve the living conditions of the urban population, they can hamper the supply of goods and food into the cities.

Urbanization also leads to increasing transportation flows to supply goods and move people. In most megacities in emerging markets, the supply of retail stores is very fragmented due to the informal nature of many small "mom and pop" or nanostores [91]. While transportation is essential for most economic and social activities in urban areas, it is also associated with negative externalities such as congestion, emissions, and noise. Air pollution levels in most urban areas around the globe are well above healthy air quality standards. In 2019, for example, Delhi reached pollution levels that were almost 40 times the amount deemed healthy in 2019 [92]. This means urbanization has an impact on well-being as air pollution, especially particulate matter, nitrogen dioxide, and ground-level ozone, has significant negative consequences on human health [93]. A recent article in the *Lancet* states that " … pollution is the largest environmental cause of disease and premature death in the world today. Diseases caused by pollution were responsible for an estimated 9 million premature deaths in 2015—16% of all deaths worldwide—three times more deaths than from AIDS, tuberculosis, and malaria combined and 15 times more than from all wars and other forms of violence" [94].

Many cities are also finding that their waste management strategies cannot keep up with increasing consumption. Hong Kong has only 10% of its landfill space remaining with no room left for more after having used up 13 other landfills [95]. China may not be far behind. While it has limited imports of foreign waste, until recently big business, China is now the largest producer of waste in the world and could soon overcome its existing infrastructure [96]. Furthermore, with China limiting imports of foreign waste, the United States and many countries in Europe are now struggling to deal with even recyclable material [97]. Determining how to best use the available landfills and where to open up new ones gives rise to many new transportation optimization problems related to facility location and waste-collection routing.

Because of traffic congestion and limited public transit options, enabling people to conveniently and quickly travel within urban areas also presents a huge challenge. The proportion of urban residents who have access to public transport remains low (as low as 18% in sub-Saharan Africa), particularly in developing countries (UN). Most car-focused mobility systems do not scale well and are close to collapse with traffic congestion increasing year after year. By 2050, the average time people spend in traffic jams will be 106 h per year, three times more than today [98]. To reduce individual transport, it is important to both use financial mechanisms and extended public transport coverage. For example, New York City is the first in the U.S. to impose congestion pricing, charging drivers to enter the most crowded parts of Manhattan, planning to use the additional revenues to update its subway network. Improving the efficiency and effectiveness of the public transit systems with limited budgets is challenging. This specifically relates to the first- and last-mile problem of getting travellers to and from the transit stations [99], using minibuses, taxis, shared bikes, and e-scooters [100] as well as ride-shares [101, 102] or autonomous vehicles.

Ride-hailing services like Uber and Lyft may amplify the problem of congestion and pollution in urban areas. While ride-hailing can provide first- and last-mile services and connect suburban areas that are not adequately served by public transit, they may also substitute for more sustainable transit trips. Moreover, the empty relocation trips between paid trips can also contribute to extra vehicle miles. Indeed, several recent studies suggest that ride-hailing services increase traffic congestion by replacing more sustainable transit trips [103].

In addition, triggered by global warming and air pollution, we see a shift towards alternative fuel sources in the motor vehicle industry. Most car makers have started including electric vehicles in their product portfolios. Developments in the area of freight transit take more time. However, we now also see important initiatives to help electrify corporate vehicle fleets. This year, for example, Amazon ordered 100 000 new electric delivery vehicles [104]. In addition, car sharing services are increasingly moving towards electric cars in urban areas. One of the main challenges with the use of electric vehicles is their limited battery capacity and associated range. Supporting the shift to a fully electric system would require significant infrastructural investments in terms of loading stations. Another challenge is that electric cars are still more expensive than gasoline cars which means they are not affordable for low and middle income families. Government incentives can help to create a more equitable electric-car transition.

Parallel to the electrification of the transportation sector, we see the increase use of renewable energy such as wind and solar energy. Several European countries are expanding their share of renewable to replace older coal plants. The construction and maintenance of renewable energy infrastructure give rise to transportation planning issues. For example, several researchers have already started to work on maintenance scheduling problems in off-shore wind farms [105–107].

Equity must also be considered. Chetty et al. [108] find that one's access to transportation and particularly the length of one's commute is an important factor in rising out of poverty. Yet, more public transportation does not offer a simple fix. For example, as the city of Seattle sought to add more light rail options, *The Seattle Times* reported, "If you want to live near a transit hub, you will likely have to pay up" [109]. Furthermore, in their zeal to attract talent, companies can exacerbate the problem. Shoe company New Balance bought a transit stop near its headquarters rather than waiting for the city of Boston to build the station [110]. While private investment in public infrastructure is a good thing, in this case, it is likely wealthier citizens who benefit. Some, such as Trulia's Chief Economist, believe that new technologies such as self-driving cars will only exacerbate the inequality due to transportation [111]. Not only are the wealthy more likely to be able to afford the cars, but with them, commutes will be less taxing and more productive, pushing the wealthy to more segregated, ex-urban living.

Given the role that access to transportation has in social mobility [108], transit design is an area that can have significant impact. The challenge is to balance the needs of various stakeholders. Veeneman [112] notes, "From an equity perspective, authorities quite reasonably want to provide sufficient coverage to connect all communities within their jurisdiction. From an economic reductionist/business perspective, offering services in areas with low demand is need [sic] as undesirable, but have been justified on equity grounds." Currently, the economic undesirability has taken precedence in the literature. In addition to their own, Camporeale et al. [113] identify only two papers explicitly addressing equity issues in transit design. Camporeale et al. [113] find that the challenge is that equity goals "… are not adequately translated into specific objectives, and it seems to be a lack of quantitative indicators able to assess the related achievements." There is a particular opportunity to combat transportation inequality as we see the implementation of new models of mobility, most notably bike- and scooter-sharing networks. Yet, Caggiani et al. [114] find that, if issues of equity are even acknowledged, the literature on bike-sharing network design does so only with post hoc measures.

As highlighted earlier, one of the key opportunities and challenges related to transportation and equality in the coming decades is the design of urban transportation systems in the face of autonomous vehicles. Autonomous vehicles will change patterns and frequency of movement. Obviously, transportation researchers will need to revisit transit models to incorporate the new technology. They will also need to pay particular attention to the structure of these models if they want to serve citizens equally. In recent work, Pinto et al. [115] explore the design of transit networks in the presence of autonomous vehicle fleets. The results show that "While overall wait times decrease, not all transit users benefit, as reduced frequencies on certain lines result in much reduced service levels." With the autonomous vehicles most accessible to the wealthy, the reduced service levels will disproportionately impact the poor. As a remedy, Pinto et al. [115] note, "This suggests that agencies may wish to explore the impact of additional design constraints in the formulation." The form of such constraints is an open question as is the setting of their parameters. These kinds of questions offer the opportunity of tremendous societal impact.

At the same time, the results such as those reported by Pinto et al. [115] can be the result of the choice of objective. The default in much of the transportation literature is to minimize costs or maximize profit. Yet, doing so can have unintentional effects. For example, Banerjee and Smilowitz [116] find that simply minimizing busing costs leads to disparate impacts in the setting of individual school start times. Essentially, costs can be minimized by using fewer buses, but doing so means that some students must start extremely early or late in the morning. Analogously, results in Chen et al. [117] show that maximizing service in same-day delivery will lead to certain customers being less likely to receive service, a result that has been reported in Amazon's own service [118].

3.2 | New research directions in infrastructure

The many challenges resulting from population growth and urbanization offer transportation science researchers a rich set of new research directions. Notably, these challenges offer a range of new problems to researchers. These problems will require both the development of models and the solution techniques to solve them.

The design of efficient and effective public transit provides a huge opportunity for contributions from our research community. Emerging new technologies such as electric, on-demand, autonomous, and shared vehicles give rise to a host of new challenges and opportunities, both in network planning and design [119, 120] and in operational operating strategies. One important topic in this area is to better integrate travel behavior into the sophisticated transit planning models. For example, the work of Schmidt and Schöbel [121, 122] shows that taking into account the inter-dependencies between line planning and passenger routing creates computationally challenging problems. In a recent example, Gkiotsalitis and Cats [123] evaluate the effect of different COVID-19 social distancing policies on transit line frequency decisions. Another relevant topic for future research is how to design transit systems that combine scheduled public transit with on-demand mobility. Pinto et al. [115] provide a valuable starting point in this direction.

In addition, more inclusive perspectives on city planning and design give rise to new road and transit network design problems taking into account the considerations of stakeholders including pedestrians, bicyclists, personal vehicles, (shared) taxis, and public transit. Urban bicycle systems around the world have seen an increase in traffic during the recent COVID-19 lock-downs as people are afraid of using public transit. As a response, many cities, including Berlin, Bogota, and Philadelphia have started (temporally) expanding their cycling infrastructure. Designing where and how to reclaim space from cars for bicycle lanes taking into account the impact on all stakeholders provides several interesting areas for future research. Using data from shared biking systems could be beneficial here [124].

The cost-efficient and effective inspection, maintenance, and repair of road, water, electricity, and IT infrastructures are increasingly important as urbanization puts more pressure on various urban infrastructures. Moreover, more severe and frequent extreme weather events, such as heavy rainfall, high temperatures, and winter storms have a huge impact on critical infrastructure. New technology gives rise to new context and new solutions. The use of aerial imagery drones to more accurately and continuously map infrastructure conditions allows service teams to respond faster to potential issues and repair small damages before they worsen. Researchers from the university of Leeds are developing drones equipped with 3D printers to perform preventive maintenance operations [125]. Effectively exploiting these new technologies requires careful planning and optimization. As both the quality of sensing and energy consumption is often dependent on the altitude of the drone, this gives rise to challenging trade-offs [20] that cannot be modeled by existing two-dimensional vehicle routing models. Transportation scientist can help contribute to the planning problems that arise in this space. To better understand the specific operational trade-offs requires multi-disciplinary teams of operations researchers, aerospace engineers, civil engineers, and remote sensing experts.

Transportation science researchers will also need to play a role in addressing the waste issues that are beginning to plague many cities. This work will need to go beyond the design and operation of solid waste collection, recycling, and management [126, 127]. The systems need to change. For instance, reverse and closed-loop supply chains have been widely used in industry to increase the recycling and reuse of materials [128]. This asks for new collaborations between different stakeholders. For instance, Hong Kong is looking to build factories that process restaurant food waste for use as compost. Currently, Hong Kong imports most of its compost [129]. Transportation researchers will play a key role in helping to facilitate such collaborations.

Sustainable and livable cities also will require that we limit emissions. There is already a significant literature devoted to accounting for the role of CO_2 in freight logistics [130] and more recently to electric vehicle routing and its need for recharging [131], an important step in the reduction CO_2. Similarly, work on collaborative logistics [132, 133] and other schemes to reduce urban emissions [134] offer a step in the right direction. However, with the demand for last-mile delivery expected to increase by nearly 70% by 2045 in New York, and along with it congestion and emissions, research might also look to new technologies and business models. Researchers are already looking at how last-mile delivery can become more efficient through the use of autonomous vehicles [135] and parcel stations [136]. Others have found that autonomous vehicles can help improve the productivity and reduce the vehicles needed to make deliveries [137]. Transportation optimization researchers can also develop models to help policy makers better design policies to reduce the negative effects of ride-hailing and automated driving on urban congestion and air quality.

The transportation research community has only recently begun to address the equity concerns in its optimization methods. For instance, Lesmana et al. [138] seek to optimize the assignments of riders to drivers in a ride-sharing system such that drivers earnings are equitable. Analogously, Chen and Wang [139] and Nanda et al. [140] seek to balance profit with fairness to different classes of customers in ride-sharing systems. Chen et al. [141] balance service costs with equity for customers requesting same-day delivery service. All of these papers explore different measures of fairness or equity, but the identification of the best measures is an area of opportunity.

4 | NATURAL ENVIRONMENT

The third category of goals defined by Waage et al. [27] is those related to the natural environment. These include:

- Goal 2: Zero hunger: End hunger, achieve food security and improved nutrition, and promote sustainable agriculture.
- Goal 13: Climate action: Take urgent action to combat climate change and its impacts.
- Goal 14: Life below water: Conserve and sustainably use the oceans, seas, and marine resources for sustainable development.
- Goal 15: Life on land: Protect, restore, and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss.

These goals recognize that the world is facing significant challenges to its natural environment. In this section, we describe some of these challenges and then identify ways in which transportation science research can help to overcome them.

4.1 | Challenges facing the natural environment

The SDGs for the natural environment seek to mitigate issues now facing the global environment. The issues arise from changes to the environment, much of which is driven by human activity. Particularly, temperatures rose 0.85°C between 1880 and 2012 and estimates show temperatures increasingly significantly more by the end of the century [142]. Furthermore, since the Industrial Revolution, ocean acidity has increased 20% and coastal waters have been further affected by pollution and eutrophication [143]. Likewise, deforestation is accelerating with 3.3 million hectares lost between 2010 and 2015. Similarly, the loss of arable land has increased to perhaps 35 times of the historical rate, while poaching and other human actions are affecting biodiversity [144].

The effects of these environmental changes are tangible. For example, in early December of 2019, officials in the Florida Keys, a string of small islands off the southern coast of the US state of Florida, admitted that the cost to make all of its roads flood proof and keep all house accessible would be prohibitive. One 3-mile stretch of Highway 1 was projected to cost $161 million dollars to flood proof it for sea levels in 2060 [145]. The Keys are only the beginning. By 2050, one report estimates that, worldwide, 150 million people will find themselves living below high tide [146].

The rising sea levels affecting the Keys and other low lying areas are just one of the new challenges that will emerge in transportation and logistics as the result of climate change. In addition to the rising sea levels, Ng and Rodrigue [147] point to increasing Arctic temperatures, an increase in intense precipitation events, more frequent hurricanes, and heat waves as having the greatest effect on transportation. One needs to look no further than the wildfire situation in Australia in December 2019 [148] to know that these disasters are occurring more frequently and with doing greater damage due than ever before [149].

It is not only the climate that is impacting the natural environment and making it less hospitable. Consider the case of plastic debris. Because plastic is durable and slow to degrade, there are currently billions of tons of plastic waste in landfills, polluting land and marine environments across the globe. Recent studies estimate that the amount of plastic in the oceans is expected to double from 8 million metric tons in 2010 to 16 million in 2025 [150]. This ocean debris often ends up in one of the so-called ocean gyres where it is collected by the currents. One of the largest pollution centers is located in the North Pacific Ocean between California and Hawaii and is often referred to as the "Great Pacific Garbage Patch" [151].

4.2 | New research directions for the natural environment

The targets for the SDGs for the natural environment will require significant governmental cooperation [142–144]. However, transportation science researchers can play a significant tactical and operational role, a role that offers great opportunities for future research. For instance, consider the first target for Goal 13: climate action. The goal calls on us to "Strengthen resilience and adaptive capacity to climate-related hazards and natural disasters in all countries" [142]. As discussed subsequently, there is much transportation-related work needed to meet the target. The first target for Goal 14: life below water has similar implications for transportation science research. The target states, "By 2025, prevent and significantly reduce marine pollution of all kinds, in particular from land-based activities, including marine debris and nutrient pollution" [143]. Transportation science also has a role in meeting the targets for Goal 15: life on land. Particularly, the seventh target asks us to "Take urgent action to end poaching and trafficking of protected species of flora and fauna and address both demand and supply of illegal wildlife products" [144].

As is the case with well-being and infrastructure, a key to solving the challenges of the natural environment and meeting the SDG targets will be to rethink how we model the underlying optimization problems and particularly in our choice of objectives. Transportation science has long relied on cost-minimizing objectives. Researchers need to think more broadly. For example, Campbell et al. [152] show that cost-minimizing objectives can lead to large disparities in the time at which communities affected by natural disasters are served. Similarly, work on greener routing has shown that accounting for factors such as load and variable speeds leads to significantly different routing solutions than traditional time- or distance-based objectives [153, 154]. The challenge of these less traditional objectives is that they often inject randomness and nonlinearities into the optimization models. Thus, solving the challenges of the natural environment will mean not only new problems but also new methodology to overcome complexities introduced by the models.

Yet, there are considerations other than objectives. In the context of humanitarian logistics, De Vries and Van Wassenhove [155] find, "using richer objective functions may lead to more effective decisions but can also be more expensive due to software requirements, training, and data gathering." Transportation science researchers need to find the balance that best serves their stakeholders. Finding this balance means working with stakeholders to identify their requirements and develop models that can account for these.

The greatest opportunity for researchers with regard to the natural environment is likely to be the rich, new set of problems that is emerging. These new problems will emerge across the SDGs. One obvious challenge related to the natural environment and particularly climate change is the increasing number of natural disasters. Researchers have considered response preparedness [156–160], post-disaster recovery of disrupted infrastructure [161–163], the management of vehicle fleets for disaster management [164–166], the distribution of relief supplies [167–169], and search and rescue operations [170, 171].

Yet, the scale of disasters and thus the responses are changing. For example, the fires burning in Australia at the start of 2020 are larger than the 2018 California and 2019 Amazon fires combined [172]. The scale and intensity of these recent fires have lead authors to explore new technologies such as drones for both fire detection [173] and firefighting [174]. In the case of fire detection and fighting, research is needed that builds on the cited work to continue to develop methods for coordinating the fleets for greatest effectiveness. Authors are also beginning to look at forest road network design problems with fire control integrated into the planning [175], an area in which multiple objectives must be considered.

The increasing frequency and scale of the natural disasters also require new approaches to recovery. An example of an emerging opportunity is in reforestation efforts following forest fires. The company DroneSeed (droneseed.com) uses drones to first survey a burned area and then deploys another set of drones to plant new trees. The process involves the need to effectively and efficiently route the drones for both surveying and planting. The creative use of new technologies such that by DroneSeed creates new problems. It also raises important questions about in what other contexts similar methods can be used. For instance, it is well known that plants and particularly trees have a role to play in flood mitigation [176]. Could drone methods analogous to those used for reforestation be used to plant trees for flood control? How would the optimization need to change given the impact of water?

In response to rising sea levels, transportation science researchers will need to develop road network planning models that account for new and evolving flood risks. It will also be important to develop models that help planners understand how to adapt existing infrastructure for the higher water levels. There will also be a need for adaptive or even risk-mitigating route guidance for navigating the existing networks. In places like the Keys, there will need to be research to help planners understand how to coordinate the movement of people and goods when access is frequently cut off.

While rising sea levels will flood some roads, the United States Environmental Protection Agency (EPA) points to a different challenge in places like Alaska. In Alaska, many areas rely on winter ice roads for the movement of freight. The EPA highlights that, with global warming, these ice roads will become less reliable [177]. These roads are unlikely to be replaced and an altogether new logistics system will need to be designed to meet the needs of communities previously served by the ice roads.

Communities will also need novel solutions to other challenges introduced by climate change. Consider the case of cities like Cape Town, South Africa, that has recently been battling severe drought conditions. One proposed solution to the ongoing challenge is to harvest icebergs in Antarctica and transport them to Cape Town [178]. Ice harvesting of this kind will require precise iceberg monitoring. Albert and Imsland [179] propose a method for path-planning for a drone to monitor icebergs. However, to reliably provide cities with water from icebergs will require controlling fleets of drone that respond to dynamic information. This work is yet to be done.

Researchers might also consider how to remove plastic from the oceans. For example, Netherlands-based non-profit The Ocean Cleanup is seeking ways to remove plastic from oceans and waterways [180]. The group needs to optimize placement of its passive collection units and monitors the units using telemetry. These concepts are familiar in the transportation literature, but Ocean Cleanup has applied them to solving a great challenge in the natural environment.

While many transportation-related challenges of the natural environment need mitigation solutions, there is also the role that transportation can play in conservation to slow the degradation of the environment. For example, Wich [181] highlights the role that drones can play in wildlife surveying as well as monitoring poaching and illegal logging. While conceptually appealing, there is still work to be done in effectively operationalizing these ideas. Importantly, new route-planning models will need to incorporate not only interdiction concepts but also the specifics of drone flight.

Transportation science researchers also have a role to play in helping advance new agriculture techniques. These practices are important for combating land degradation and nutrient runoff. New problems in drone routing can play a role in sustainable food production. As recent work in the literature demonstrates, a first step in sustainable food production is optimizing agricultural supply chains [182–184]. This requires marrying new technologies to new methods.

For example, companies like John Deere are emphasizing “precision agriculture” in their sales pitches [185]. Precision agriculture combines large amounts of data with preparation, planting, and harvest decision making. The goal is to increase yields while reducing waste by placing seeds, fertilizers, and pesticides in the right amounts in the right places in the fields. Gathering the necessary data requires sensor networks and more recently drone observation. The placement of the sensors and routes of the drones is still an area of open research. For example, while research has looked at surveying by a single drone, the work on surveying by drone fleets is limited [186]. There is also limited research that makes use of collected data, particularly in real time.

Perhaps more controversially, climate change is also opening up opportunities for commerce where none previously existed. McKinnon and Kreie [187] note that the Arctic route from Yokohama to Rotterdam is 39% shorter than the route through the Suez Canal. Yet, ship routing from Asia to such a port will, at least in the near future, need to account for sea ice. Most notably,

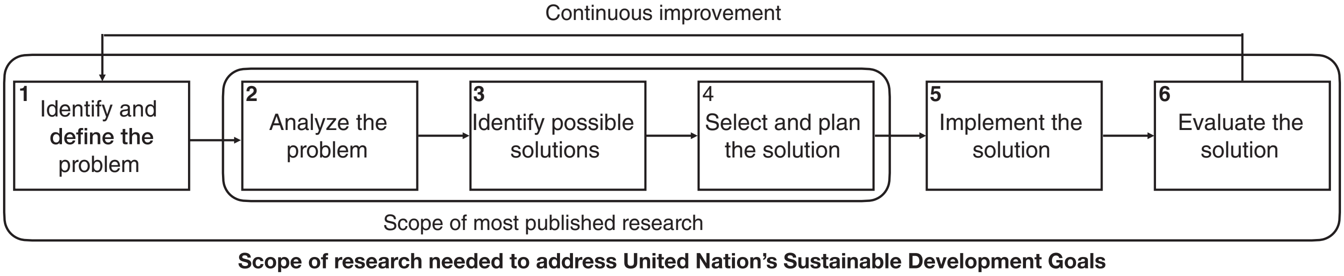

FIGURE 1 Problem solving process

taking advantage of melting polar ice will also require new infrastructure. For example, the town of Kirkenes, Norway, is seeking to develop a deep-water port that will support shipping from Asia. This port will need new rail lines that connect with Europe [188].

As it ruins agriculture in some regions, climate change is also bringing opportunities in others. For example, England is increasingly finding itself capable of producing high quality wines [189]. These producers need to develop new logistics networks to bring increasing yields to market while also being mindful of their impact on climate.

It is no secret that climate change and the degradation of the land and sea are perhaps the greatest challenges facing humans in the coming decades. Solving these challenges will require the work of many people with diverse skill sets. Transportation science researchers have a key role to play in helping to slow climate change and environmental degradation as well as in helping to mitigate the effects. To be successful, transportation researchers will need to rethink traditional ways of modeling, particularly objectives, and also boldly explore new problems.

5 | RESEARCHING FOR IMPACT

To address the challenges identified in the previous sections, we believe that transportation science researchers must step back and rethink how they engage in research. Much of the published research by the transportation science community focuses on existing models of—what are perceived to be—well-understood problems (e.g., an arc-based formulation of the capacitated vehicle routing problem). These papers often document research that seeks faster exact solution approaches for those models. For some problems, and the "right" models for those problems, this is indeed important. However, these papers rarely document assessments of whether solutions to those models affected positive change. Such assessments are not seen as critical for publication in many journals. Thus, the question of whether the model was indeed the right one is rarely addressed. For other problems, and this is also the case in other disciplines within the broader field of operations management, the path of least resistance for publications focuses on stylized models without an empirical foundation [190, 191]. Such research will not address the challenges identified above in a meaningful way.

We view addressing these challenges as problem solving. Many descriptions of the problem solving process have been proposed in the operations (or operations-related) literature, including Plan-Do-Check-Act [192] and Define-Measure-Analyze-Improve-Control from Six Sigma [193]. Figure 1 illustrates one such description [194] and in particular which steps in that process are typically addressed in transportation science research. While addressing these steps is important, doing so does not solve the problem. We call on the transportation science research community to expand the scope of its research efforts in order to address the challenges identified above.

Focusing on the first step in Figure 1, addressing these challenges in an impactful way will require researchers to focus less on problems already neatly presented in journals and more on problems as they appear in the field. We suggest transportation science researchers adopt a Lean-type philosophy wherein they "go to Gemba" [195] to regularly engage with practitioners. That said, a theme common to many of the proposed directions is that they are based on problems that involve multiple stakeholder groups. In addition, the preferences of some stakeholder groups are not naturally quantifiable. To address these global challenges, researchers will need to engage with each of the stakeholder groups in problem identification and model development.

Effectively engaging with stakeholder groups to identify the problems that need to be solved necessitates having empathy for their position and perspective. As many of the challenges identified above affect the globe, stakeholder groups may come from different areas of the world and be composed of individuals with diverse backgrounds. Thus, identifying the appropriate problems to model may be best done by a diverse community of researchers with varied training and varied lived experiences.

It is unlikely that the problems identified to address the challenges above can be solved through optimization alone. Instead, their solutions may require educational outreach and training, transportation infrastructure development, and urban planning, and engagement across multiple disciplines. Of course, work is already being done in these fields to address these challenges.

However, few papers published in the top transportation science journals are the product of teams consisting of individuals from these different disciplines. In addition to considering diversity when constructing research teams, addressing these grand challenges will require a commitment to multi-disciplinary research.

Transportation science researchers typically address steps two through four in Figure 1 through model development and data collection (Step 2) and solution method development and execution (Steps 3 and 4). However, researchers will also need to design and execute model development processes that regularly engage with stakeholders, with model refinements based on stakeholder input. Project management methodologies like Agile [196] from the software development industry can serve as blueprints for these processes. Even with a multi-disciplinary team composed of researchers from diverse backgrounds, disciplines, and perspectives, it is still important to step back and reflect on how optimization-based research relates to implementation (Step 5). Specifically, such research must provide decision-makers with models that they can solve to derive actions that have a positive impact.

Whether a decision-maker can derive actions from a solution to an optimization model often depends on whether they can understand what the solution suggests. Decision-makers and stakeholders in many of the contexts discussed in this article will be nontechnical. Thus, it is critical that researchers develop mechanisms for effectively communicating to a broad audience, both with respect to background and technical ability, what a model solution is prescribing. This is another step in the process where a diverse research team is critical. Data/information visualization, a topic that is under-represented in the transportation science literature, can play a key role here.

Relatedly, whether a decision-maker adopts actions associated with an optimization-model solution is often due to their perception of, and confidence in, that model and its solutions actually addressing the problem they want solved. Often, implementing the solution to an optimization model involve significant financial and organizational investment as well as risk. Decision-makers are often wary of undertaking such an investment based solely on the recommendations of a “black box.” Thus, for research to make an impact it must focus on optimization-based methods that are “interpretable.” An interpretable method could be one that, while it may not find the “optimal” solution to the model, behaves in a way that a non-technical individual can understand the intuition behind its solution. Alternatively, an interpretable method could produce both a solution and an explanation of the “logic” that lies at the heart of why that solution is optimal. To address these global challenges, researchers will have to think beyond algorithms for deriving optimal solutions to communicating the logic behind those solutions to decision-makers and stakeholders. From the perspective of addressing the challenges identified above, a solution is not “optimal” if it does not lead to positive change.

Considering Step 6, optimization models are typically rough approximations of operations, and stakeholders cannot always envision all the practical impacts of implementing decisions based on a model solution. Actually implementing a solution in order to evaluate its effectiveness may be too costly or time-consuming. An alternative method is to instead complement an optimization model with a much more detailed simulation model of operations. Such a simulation model will provide a more accurate estimate of the impact of decisions derived from model solutions on different performance measures. Yet, much of the research published by the transportation science community is done by groups of individuals from the same functional silo within operations research, with optimization-focused researchers focusing on optimization-based research and simulation-focused researchers focusing on simulation-based research. To address these global challenges, operations researchers with different focuses and skill sets will have to collaborate to ensure that their research has a real impact.

Lastly, Figure 1 highlights that problem solving is a process of continuous improvement. It is unlikely that the first attempts by transportation science researchers at addressing the challenges described in the previous sections will fully meet the needs of each stakeholder group. Instead researchers must be prepared to repeatedly execute a process like the one in Figure 1 in a manner similar to *kaizen* [195]. As with model development, software development methodologies such as Agile may be helpful here.

6 | CONCLUDING PERSPECTIVES

This paper has proposed multiple research directions related to global issues for transportation optimization-based researchers. Section 2 identified the need for optimization-based approaches that take into account specific context of the developing world and equitably recognize the presence of large numbers of objectives, many of which are “fuzzy” due to the nature of human preferences. Section 3 argued that many of fundamental challenges of rapid urbanization are associated with the planning and design of transportation systems. We identify several new areas of research in relation to novel technological developments in this space. Section 4 highlighted the many challenges resulting from climate change and other human impacts on the natural environment. These challenges will require solutions to a large number of new transportation problems, problems that will require new thinking about models and particularly objectives and new solution methods to solve them. In Section 5, we suggested that researchers broaden their vision beyond the work necessary for publication in top journals to include the actions necessary to make a lasting impact on society and the planet.

While the goal of this paper was not to propose specific optimization models for transportation researchers to solve, there are three themes that run through much of the research that addresses these grand challenges in an impactful way. They are:

1. Multiobjective transportation optimization models: A recurring theme of the challenges discussed in this paper is that they impact multiple stakeholder groups, and in different ways. Multiobjective optimization has received greater attention in the general optimization community recently. We anticipate a similar trend in the transportation science community, both in research that addresses these grand challenges and in general.
2. Integration of stakeholder behavior in transportation optimization models: Many of the challenges discussed in this paper will require designing transportation-based systems whose effectiveness depends in part on the behaviors of individuals from different stakeholder groups. Representing traveler behavior in the design of public transportation networks and/or systems with discrete choice-type models is well studied. We anticipate similar types of representation in the models developed to address the challenges discussed above.
3. Strategic and stochastic transportation optimization models. Many of the challenges discussed above may be best addressed through long-term investments of large amounts of capital and time. The transportation science community has of course studied strategic-type models (e.g., facility location). However, it is fair to say that much of its attention has focused on tactical (e.g., network design) and operational (e.g., vehicle routing) models. Measuring the impact of long-term investments often requires models that consider long planning horizons, which in turn necessitate recognizing uncertainty. Stochastic optimization models have received increasing attention by the transportation science community in recent years and we expect that to continue in the context of models developed to address the challenges discussed above.

An example of the class of optimization model we anticipate researchers will develop and solve to address these challenges might be a bi-level optimization model wherein the first level represents strategic decisions involving long-term investments, potentially in infrastructure. The second level consists of multiple optimization problems that represent the actions of individuals from different stakeholder groups. However, decisions regarding investments (e.g., the first level decisions) are made and committed to long in advance of individual behaviors. Thus, there is uncertainty regarding what those behaviors will be when investment decisions are made. Lastly, the effectiveness of investment decisions depends on how their impact on different stakeholder groups. Yet, these different stakeholder groups may interact with and assess the results of those investment decisions in different ways. Thus, models in this class will be multiobjective.

Ultimately, we believe that the transportation science research community has the experience and skill to develop solutions that address the global challenges discussed in this article. However, doing so will likely require researchers to adopt a different mind-set. It is common for researchers to be evaluated based upon their productivity level with respect to published articles. While research projects that address these challenges will likely yield articles in top journals, they will also take more time than research projects whose sole outcomes are journal articles. However, by addressing these grand challenges, the transportation science research community can improve global quality of life as well as inspire the next generation of scientists to do so as well.

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