Title

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Abstract

In this essay I reflect on the role of research – and researchers – in shaping professional thinking. It is not hard to find examples in which research has informed transportation policy and practice. But does research also influence how transportation professionals think? I start by discussing why ideas are important to the profession and what role research can play in shaping them. I then present three examples of core ideas in the transportation profession that have shifted to a lesser or greater degree, while considering the role of research, including my own, in these shifts. The concept of accessibility, as an alternative to mobility, is the first example. The induced travel phenomenon, which challenges the traditional idea of capacity expansion and points to the need for demand management, is the second example. The third example is the growing focus on the idea of connectivity. These examples illustrate a few of the ways that core ideas within the transportation profession have shifted over time and the role of different kinds of research in supporting, encouraging, and documenting those shifts. This essay is an exploration of possible connections between research and professional thinking, not a scientific study of these connections, and is intended to be a starting point for further reflection on the role of research in shaping professional thinking.

Reflections on the Role of Researchers in Shaping the Ideas that Shape Transportation

A Shift in Thinking?

In November 2023, the Metropolitan Transportation Commission, the Metropolitan Planning Organization for the San Francisco Bay Area, invited members of the public to a "virtual workshop" in which they would have the opportunity "to weigh in on tradeoffs between a future with and without freeway pricing" [1]. The proposal put forth for consideration is that in stretches of freeway with good parallel transit service, drivers would pay a fee for using the freeway, an approach called "all-lane freeway tolling." Although tolling has often been used in the U.S. as a way to pay for freeway construction and maintenance, especially on the east coast, this approach has not previously been used in California. And tolling has not yet been deployed in the U.S. with the primary purpose of managing demand.

One remarkable thing about this event is that it reflects a significant shift in thinking about the appropriate way to address congestion. For a century or more, the transportation profession has focused on capacity expansion as a response to congestion, reflecting the underlying idea that the job of transportation agencies is to provide sufficient capacity to meet the demand for driving and keep traffic moving. That MTC is now considering freeway tolls reflects a different way of thinking, an embrace of the idea that the job of transportation agencies is also to manage demand not just accommodate it. This way of thinking is also evident in the congestion pricing scheme for Manhattan that is, after decades, nearing implementation. The idea of demand management is not new, but it has never come this close, at least in the U.S., to challenging rather than supplementing the traditional way of thinking.

Another remarkable thing about the MTC event is that transportation researchers have been touting the benefits of pricing as a strategy for managing demand for decades. It is arguably accepted wisdom among researchers who study travel demand that pricing is the most effective available means of managing congestion, even if the question of how best to address its equity implications remains a matter of debate. Research on pricing as a demand management strategy goes back at least seven decades to William Vickery's 1952 proposal for congestion pricing in New York that later won him a Nobel Prize. Despite a compelling theoretical rationale and strong evidence from congestion pricing programs elsewhere in the world, the approach has so far, at least until now, remained largely an ivory-tower idea in the U.S.

These two observations suggest the premise for this essay: research will have little impact on what the transportation profession does if it does not also change how the profession thinks. The ideas that make up the traditional way of thinking in the transportation profession are the subject of my recently published book, *Shifting Gears*, from which this essay draws [2]. In the book, I focus on nine traditional ideas, and for each I identify an alternative idea that has historically found limited traction within the profession, despite strong advocates as well as credible research that supports its potential benefits (Table 1). The book draws heavily on research, including my own, as it traces the evolution of these ideas and considers their implications, but it does not focus on the role of research as a causal force in contributing to shifts in professional thinking. That question, I believe, is worthy of further reflection.

In this essay I share some of my reflections on the role of research – and researchers – in shaping professional thinking. I start by discussing why ideas are important to the profession and what role research can play in shaping them. I then present three examples of core ideas in the

transportation profession that have shifted to a lesser or greater degree, while considering the role of research, including my own, in these shifts. After these examples, I offer additional reflections on the role of research in shaping the ideas that shape transportation. This essay is an exploration of possible connections between research and professional thinking, not a scientific study of these connections: the research cited is illustrative but not exhaustive of the relevant research, and my conclusions are based on my own observations and experiences rather than systematic analysis. It is, I hope, a useful starting point for further reflection on the role of research in shaping professional thinking.

Table 1. Traditional Ideas in the Transportation Profession and Some Alternative Ideas

TRADITIONAL IDEAS	ALTERNATIVE IDEAS
Cars as **freedom**	**Mobility justice** as a guiding principle
Speed means efficiency	**Slower** is better
Maximize **mobility**	**Accessibility** matters more
Focus on **vehicles**	Focus on **people**
Add **capacity** to meet demand	Manage **demand** instead
Build a **hierarchy** of roadways	Provide **connectivity**
Separate modes and flows	Find ways to **integrate**
Control traffic flows	Allow a little **chaos**
Technology as a solution	**Human agency** may disagree

Adapted from Handy 2023

Why are ideas important?

Decisions about the transportation system depend in large part on how the transportation profession thinks about transportation. By the "transportation profession" I mean employees of federal, state, regional, and local agencies who hold responsibility for planning, building, operating, and maintaining the surface transportation system, along with the consultants they often hire and the professional associations to which they belong. These professionals are not the only people involved in shaping the transportation system. Others play important roles, too: federal and state legislative bodies that set taxes, allocate funding, and establish broad policy; private companies with contributions ranging from road building to car manufacturing to gasoline sales to the provision of services like ride hailing and bike sharing; and private citizens who exert influence both as voters and as consumers of transportation, directly and indirectly. But the professionals are especially important because they have responsibility for the day-to-day activities necessary to provide a functioning transportation system and because they exert substantial influence over the rest of the players.

Transportation professionals bring to their work a particular way of thinking, made up of a set of core ideas. They acquire this way of thinking through their own personal experiences, their professional on-the-job experiences, and of course from the formal education they receive. Transportation professionals come from a wide spectrum of disciplinary backgrounds but two are especially common: transportation engineering, usually housed within the broader discipline of civil engineering, and transportation planning, a branch of the broader field of urban planning. These two fields instill in their graduate students different but overlapping bodies of knowledge, often sharing courses when a university offers both types of programs. They also emphasize

different approaches to decision making: engineering emphasizes a rational approach relying on cost-benefit and optimization analyses, while planning emphasizes a participatory approach with ample community input. Professional practice reflects both approaches and the underlying thinking that goes with them.

Individual professionals, with their varied knowledge and differing perspectives, make up and define the profession. It is possible to examine the thinking of individuals within the profession, as in studies by Handy, et al. [3] and Ralph and Delbosc [4]. But it is also possible to identify a dominant way of thinking in the profession, as formalized in the documents that guide the actions of individual professionals. For example, important documents influencing actions that shape the roadway system include the *Highway Capacity Manual*, the *Manual of Uniform Traffic Control Devices*, and the *Policy on Geometric Design of Highways and Streets*. Individual and collective ways of thinking are both important, and they clearly influence each other, though they are not always consonant.

The role of individual ideas can be understood with the help of the Advocacy Coalition Framework (ACF), developed by Sabatier and Jenkins-Smith [5]. This framework, which has been applied to a wide array of policy realms though rarely to transportation, highlights the beliefs that individuals bring to the policy process. A set of shared beliefs among a group of participants in the policy process is the tie that binds them and the source of their support for one policy option over another. The ACF speaks to specific policy processes, but I take the liberty here of extrapolating the framework to the transportation profession: the set of beliefs shared among transportation professionals defines the profession at its core and shapes how its members approach their work. I use the term "ideas," meaning something less closely held than beliefs, but many ideas at the core of the profession arguably rise to the level of beliefs given the degree of affirmation and acceptance the profession affords them, as in the guidance documents noted above.

Of course, not everyone within the profession thinks the same way. The ACF highlights the role of minority coalitions, that is, groups of individuals who come together around shared beliefs that differ from the shared beliefs of the majority. Although a dominant way of thinking is evident in the transportation profession, so are minority ways of thinking that also play an important role, even if they are not reflected in the documents that guide professional work. The more deeply that the majority way of thinking is embedded in such documents as well as standard practices and official policies, the harder it will be for a minority way of thinking to influence policy and practice. That doesn't mean that change is impossible, but it almost certainly won't be easy.

According to the ACF, individual beliefs span a spectrum with respect to how strongly they are held, or conversely, with respect to their susceptibility to change [6]. Deep core beliefs reflecting a person's underlying philosophy, shaped by childhood socialization, are the most resistant to change. Policy core beliefs are applications of deep core beliefs to specific policy realms, like transportation. They are also difficult to change. Secondary beliefs are narrower in scope than core beliefs and are thus more mutable, opening the door to the possibility that research can lead to a shift in thinking. But even these more mutable beliefs do not always shift in the face of direct empirical evidence of their falsity. If they do change, they may change slowly, over a decade or more. Individuals tend to hang on to their own ideas and resist opposing ideas, as various theories and ample research show.

The fact that individuals tend to hang onto their ideas helps to explain why professions also tend to hang onto their ideas. But paradigm shifts may be possible for professions. As

theorized by Kuhn [7], scientific disciplines go through "normal" phases in which work continues as it always has, but also through "revolutionary" phases involving the adoption of new ideas and practices that replace the old ones. During normal phases, the accepted ideas are rarely questioned, and anomalies are ignored or explained away. Revolution happens when the anomalies accumulate to the point of crisis and a new paradigm emerges that can solve it. This framework might apply equally well to professions, and it suggests an important role for research in bringing about change in professional thinking in transportation.

How does research shape ideas?

The purpose of research, as I tell my undergraduates when they question why they are required to take a research methods course, is to understand how the world works. When we understand how the world works, we have the power to make things better, I say, to improve conditions for humanity and for the natural world of which humanity is an integral part. This universal proposition certainly applies to the enterprise of transportation research, which is driven by an overt problem-solving mission. The Transportation Research Board (TRB), for example, according to its website, "mobilizes expertise, experience, and knowledge to anticipate and solve complex transportation-related challenges" [8].

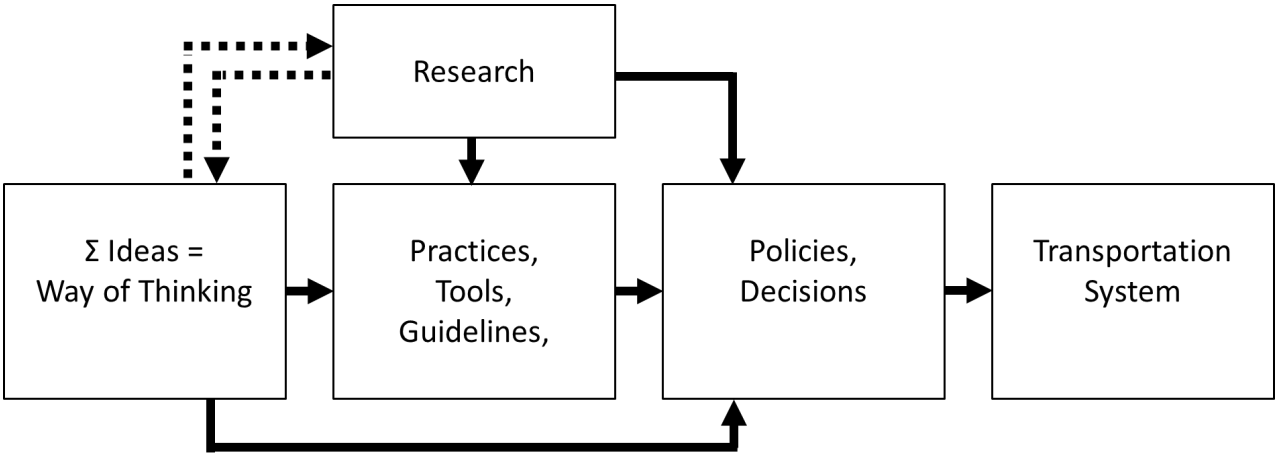
For research to contribute to the solving of those complex challenges, it must focus on those challenges and it must get into the hands of transportation professionals. Considerable effort directed at ensuring both outcomes, neither of which is a given. As stated in its *2022-2027 Strategic Plan*, "TRB is committed to advancing the state of the practice through sound research, sharing of information on cutting-edge innovation, and rigorous analysis of current policy issues" [9]. Programs like the National Cooperative Research Program (NCHRP) and the Transit Cooperative Research Program (TCRP) are designed to fund research that directly addresses questions of importance to practice and are intended to bring research to bear on critical aspects of practice, to ensure that professional practice reflects the best understanding that research has produced.

The transportation research enterprise comprises many types of research. Basic research builds knowledge of how the transportation system works, piece by piece and as a whole. Applied research uses the knowledge gained from basic research to help agencies, industries, others find solutions to specific problems. Research contributes to the development and deployment of new technologies. Evaluation studies assess whether policies, practices, and technologies perform as expected and identify strengths and weakness that can inform future efforts. Historical research generates insights into the evolution of the transportation system and its impacts. Scenario-testing studies examine how the transportation could work in the future under differing conditions, for example, with the adoption of new technologies. Much of my recent work I characterize as translational, in that we are synthesizing a body of research and then helping agencies, industries, others make use of that synthesis by translating research findings into plain English and sometimes transforming them into decision-support tools. Theoretical and conceptual work is important for framing all of these efforts.

It is not hard to find examples in which research shaped and informed transportation policy and practice. Just how important research is to the transportation policy process is hard to say, as this process has too rarely been the subject of study, as argued by Marsden and Reardon [10]. Research may have a direct influence on the development and adoption of policies as well as decisions about transportation investments and facility design by informing the responsible

individuals (Figure 1). It also shapes the transportation system through its influence on various practices, tools, and guidelines that shape those policies and decisions. But does it also influence the ideas at the core of the profession – does it influence the dominant way of thinking within the profession? And if so, how?

Figure 1. Conceptual Model of the Role of Ideas and Research



A scan of the program for the TRB Annual Meeting suggests that the ideas that have traditionally dominated the profession have a strong influence over research questions. Conversely, if research focuses on existing policies and practices, with the aim of improving them, it may help to perpetuate the dominant way of thinking that underlies them. In this way, the bi-directional relationship between research and ideas potentially creates a self-perpetuating cycle that reinforces the status quo. But as Kuhn's framework suggests, that cycle breaks when research identifies enough problems with existing practices that they trigger a reconsideration of core ideas and eventually a paradigm shift in the profession. In this way, even research inspired by the dominant way of thinking can contribute to a change in that thinking.

Research may also contribute to a shift in core ideas by addressing questions that challenge the dominant way of thinking. Research is done by researchers, after all, who bring their own beliefs to their work, just as professionals bring their own beliefs to their work. The questions that researchers choose to address are informed not just by the needs of agencies but also by their own beliefs about the transportation system and the policies and practices that shape it. Researchers may be less steeped in the dominant way of thinking in the profession, given some remove from professional activities. Researchers may also have a built-in incentive to challenge status-quo thinking, as suggested by the work of Tal and Cohen-Blankshtain [11]; incentives may include the generation of "buzz" for their work and increasing the potential for rewards such as citation rates, media attention, and academic tenure. The growing interest in community-engaged research, in which members of the communities impacted by the research participate in its formation and execution from the start, is leading to a shift in research questions as well as methods. By asking different questions, researchers can potentially contribute to a shift of thinking in the profession.

The distinction between "researchers" and "professionals" is quite blurry, and this creates another potential pathway for research to influence professional thinking. As reflected in the diversity of presenters at the TRB Annual Meeting, transportation research is carried out not just

by academics, my focus in this essay, but also people at agencies, consulting firms, private companies, non-governmental organizations, community-based organizations, and other places. To further cloud the distinctions, many academic researchers also at times engage in practice or have previously had professional experience. The overlap between who is a researcher and who is a practitioner – when practitioners do research and when researchers engage in practice – creates another pathway for research to influence professional thinking.

Researchers, especially university-based researchers, often have another pathway to influence professional thinking through teaching. Because the goal is to for students to enter the workforce after completing their degrees, the content of courses reflects the demands of potential employers for certain knowledge and skillsets. Accreditation processes ensure that programs deliver the "right" content by the standards of the profession. For this reason, programs tend to reinforce dominant ways of thinking. But how instructors deliver that content matters, too. The ideas that instructors convey to students will inevitably reflect their own beliefs, which are shaped in part by their involvement in research. An instructor's beliefs may influence how critically they present standard practices and prevailing policies and whether they encourage students to think critically about them as well. Directly or indirectly, an instructor's beliefs are bound to have some influence the beliefs of their students, who will bring those beliefs to their work as professionals.

Through all these pathways, change in professional thinking is possible and perhaps inevitable, at least over the long term. Through the accumulation of knowledge over time as well as the natural though gradual turnover of transportation professionals – and the faculty who train them – professional thinking is shifting. The following examples illustrate some of the ways that research is contributing to this shift but also highlight the limits of its influence.

Example 1: Accessibility

The transportation profession has long focused on the goal of maximizing mobility, defined as the ease of movement, and its corollary, the goal of minimizing congestion. Level of service, measured according to procedures outlined in the Highway Capacity Manual and widely used as a performance metric for the roadway system, reflects the long-standing focus on mobility maximization and congestion minimization.

The competing idea is that accessibility – not mobility – is what really matters. This idea goes back to at least the 1950s, when Lewis Mumford, the urban historian, published a series of essays in *The New Yorker* that articulated the idea of accessibility though he did not use that term. In a 1955 essay, he explained, "Transportation . . . is a means and not an end," adding, "I blush to utter a truism now so frequently ignored" [12]. In a 1958 essay, he argued that "The purpose of transportation is to bring people or goods to places where they are needed" [13]. He also made the point that focusing on accessibility minimizes rather than expands the demand for travel: the goal is "to concentrate the greatest variety of goods and people within a limited area, in order to widen the possibility of choice without making it necessary to travel."

Many academics in the fields of urban planning and geography also believed in and wrote about the concept of accessibility in the following decades. Webber brought the term "accessibility" firmly into the planning lexicon in the 1960s: "The unique commodity that the city offers to location seekers is accessibility. . . The history of city growth, in essence, is the story of man's eager search for ease of human interaction" [14]. In the 1970s researchers promoted the concept of accessibility as a way to measure the performance of metropolitan areas

and called for agreed-upon definitions and measures of accessibility. One paper offered a simple but powerful way to use accessibility to employment and services as a social indicator for cities or regions, an indicator of "the quality of urban living" [15]. That idea is echoed in more recent work using the concept of accessibility as a way to think about social inclusion and social justice [16]. A 1980s paper proposed a more complex framework motivated by the idea of accessibility as "an aspect of the freedom of action of individuals" [17]. These authors were optimistic about a shift toward an accessibility-oriented approach to transportation planning.

The transportation profession has shown increasing interest in the idea of accessibility, even if it has not fully grasped its meaning and implications. In recent decades, many transportation agencies have made accessibility a goal of their plans but often in conjunction with mobility as a goal, without clearly defining or distinguishing between the concepts. The two concepts are in fact related: good mobility contributes to good accessibility, and policies to increase mobility will generally increase accessibility by making it easier to reach destinations. But good mobility is neither a sufficient nor a necessary condition for good accessibility, and prioritizing mobility (e.g., by building freeways) often produces secondary effects that negate any initial increases in accessibility (e.g., by encouraging more driving that increases traffic). The synergies and tensions between the ideas of accessibility and mobility are rarely spelled out in plans.

Researchers have helped to clarify the relationship between accessibility and mobility. Levine et al. pointed out the important difference between speed-based accessibility, dependent on speed of travel because destinations are relatively far, and proximity-based accessibility, dependent on close proximity to destinations in which case travel speeds are less important [18]. Their analysis shows that good proximity generally overcomes the problem of low speeds. Mondschein and Taylor similarly found that accessibility was higher in areas with "agglomerations of activity," where proximity to activities is high but where speeds are low because congestion is high [19]. As these places offer "congestion-adaptive travel choices" such as walking and transit that are not affected by congestion. These studies and others demonstrate that good mobility by car is not necessary for providing a high level of accessibility.

Researchers have also contributed to the development of accessibility measures, essential to the adoption in practice of accessibility as a performance metric for the transportation system. Notable university-based efforts to develop practical accessibility measures include (but are not limited to) the Accessibility Observatory at the University of Minnesota [20], the State Smart Transportation Initiative (SSTI) at the University of Wisconsin [21], and projects at the University of Toronto, UCLA, and the University of Texas at Austin. In 2018 the National Cooperative Highway Research Program, funded by state departments of transportation, initiated a project to provide guidance to state DOTs as well as MPOs and other agencies on their options for measuring accessibility for different purposes [22]. With the advent of commercially available packages that provide data and algorithms for producing accessibility measures, researchers continue to play a role in adapting these measures for the specific needs of agencies. Our UC Davis team, in partnership with SSTI, is currently working with the California Air Resources Board and Caltrans to develop accessibility measures to support planning efforts throughout the state.

Researchers have also examined the use of accessibility measures in practice, identifying many barriers to their adoption. Boisjoly and El-Geneidy surveyed 343 transportation professionals from around the world and found that the main barriers to the use of accessibility measures in practice were a lack of knowledge and data [23]. While 99 percent of respondents

were familiar with the concept of accessibility, only 55 percent used accessibility measures. Sadiq and Taylor found that the theory and measurement of accessibility had advanced more than had the use of accessibility measures in practice [24]. Continued efforts on the part of researchers to develop accessibility measures that are easy to use and easy to communicate should help to increase their adoption in practice.

The idea of accessibility has made significant inroads into professional thinking, with researchers playing an important role in the process. But this change is not exactly a *shift* in thinking: although professional thinking increasingly embraces accessibility, it has not let go of the idea of mobility as a primary objective. Another way that researchers are shifting the profession towards the idea of accessibility is by demonstrating the limits of the mobility-focused approach to solving the congestion problem, as discussed in the next example.

Example 2: Induced Travel

A mobility-focused approach to transportation, one that aims to minimize congestion, is closely associated with the idea that the job of the transportation professional is to provide enough roadway capacity to meet demand. This idea is evident in the "predict and provide" approach to highway planning that emerged in the 1950s and remains the dominant mode of planning, even as the idea of accessibility gains credence as an alternative approach – and in the face of a growing body of research documents the increase in vehicle travel that inevitably follows an expansion in highway capacity. The "induced travel" phenomenon lies at the crux of a possible shift from the idea of capacity expansion to the idea of demand management as the appropriate way to address congestion.

Some transportation professionals recognized the induced travel phenomenon as early as the 1920s, as documented by Ladd [25]. As car ownership increased over the decade, some transportation professionals proposed road widenings as a way to reduce congestion. But others argued that such projects did little to alleviate congestion because they simply attracted more driving. A Los Angeles official, for example, observed that "a newly opened . . . or widened street immediately becomes glutted by the access of cars that hitherto have reposed more in their garages than they have utilized the streets." In the 1950s, Mumford, in addition to promoting the concept of accessibility, argued that highway building was adding to rather than solving the congestion problem: "Most of the fancy cures that the experts have offered for New York's congestion are based on the innocent notion that the problem can be solved by increasing the capacity of the existing traffic routes… Like the tailor's remedy for obesity—letting out the seams of the trousers and loosening the belt—this does nothing to curb the greedy appetites that have caused the fat to accumulate" [12]. As he noted, the public as well as the professionals did not understand the phenomenon: "People, it seems, find it hard to believe that the cure for congestion is not more facilities for congestion." Research by Thigpen et al. shows that even today, most people do not understand induced travel [26].

Downs's 1962 paper on "The Law of Peak-Hour Expressway Congestion" brought the concept of induced travel into professional thinking [27]. Based on his observation that "recent experience on expressways in large US cities suggests that traffic congestion is here forever," he formulated his well-known "law" that "peak-hour traffic congestion rises to meet maximum capacity." As he explained, highway expansions lead drivers to adjust their travel, such as shifting departure times, routes, modes, and/or destinations. Downs continued to write about traffic congestion for four more decades, publishing *Stuck in Traffic* in 1992 [28] and *Still Stuck*

in Traffic in 2005 [29]. Although Downs is widely cited on this topic, the federal Bureau of Public Roads had acknowledged induced travel in its 1950 annual report: "It is definitely known that a new route generates a certain amount of travel that did not occur before the improvement was placed in service, but the relative amount of increase has been unknown" [30]. *Traffic Engineering*, a classic textbook from 1955, also explained the phenomenon: "Induced traffic appears on almost every new traffic facility, especially in urban areas and under conditions where the facility creates a new accessibility between areas. This factor calls for extreme care in estimating traffic volumes" [31]. In other words, the induced travel effect was well known within the profession before Downs, but as policies throughout this period would suggest, largely ignored.

The magnitude of the effect, more than the existence of the effect, is at the heart of current debates within the profession. The debates center around the environmental review process for highway widening projects and are arguably most heated in California. In response to Senate Bill 743, signed into law in 2013, the California Department of Transportation (Caltrans) revised its guidelines for assessing the environmental impacts of proposed highway expansion projects under the California Environmental Quality Act (CEQA). Rather than quantifying the effects of the project on level-of-service, a measure of congestion, environmental assessments must now quantify the effects on vehicle miles of travel (VMT), a measure more directly tied to environmental impacts such as greenhouse gas emissions. This quantification is important in assessing the environmental impacts of projects but also the project's benefits in terms of potential reductions in congestion, often the primary rationale for the project. To accurately assess both environmental impacts and congestion reduction benefits, an accurate estimate of induced VMT is essential. Under CEQA, the induced travel estimates are of even greater significance than for the environmental review process under the National Environmental Policy Act (NEPA): the induced VMT of a highway project must be mitigated, meaning that VMT must be reduced elsewhere in the system (though projects can move forward without full mitigation if Caltrans declares "overriding considerations"). The higher the estimate of induced VMT, the higher the costs of mitigation.

Adding to the challenge is the fact that many travel demand forecasting models used in regional transportation planning do not provide accurate estimates of induced travel [32]. Our UC Davis team found that some environmental impact assessments for highway projects in California prior to the new policy ignored induced travel altogether [33]. A team of experts from academia and consulting firms assembled for a Caltrans-funded project agreed that the models typically omit feedback loops that are important for accurately estimating induced VMT, including the impact of changes in travel times on destination choice, trip frequency, and, over the longer term, land use patterns [32]. The more sophisticated models, developed with the help of researchers, do a better job of capturing the induced travel effect. But many of the advancements in travel behavior modeling made by researchers have not yet been implemented in travel demand forecasting models used in practice.

A growing body of empirical research on the induced travel phenomenon provides the basis for another approach to estimation. Conducted by researchers from transportation, economics, and other fields, these studies show a strong positive association between highway capacity and VMT. They consistently report elasticities close to 1, meaning that a 1 percent increase in highway capacity is associated with a 1 percent increase in VMT after a period of five years or so [34, 35]. This elasticity, representing an average effect, can be used to produce a back-of-the envelope estimate of induced VMT for a given highway expansion. Our UC Davis

team developed the California Induced Travel Calculator, an online tool based on the elasticities from the empirical research that anyone can used to estimate induced VMT in urban areas of California[36]. After an expert review of our tool, Caltrans approved the use in the environmental review process [37]. This approach was then used in a Colorado calculator [38] and a national calculator [39]. Because the California calculator generally produces higher estimates than travel demand forecasting models, its use has been questioned by state, regional, and local officials who support highway widening projects. In this way the empirical research is playing a large role in the discourse over induced travel though it does not yet seem to have shifted the majority view within the profession beyond "skeptical acceptance."

Many professionals who fully accept the induced travel phenomenon nevertheless continue to support highway widening projects. They give a variety of interconnected rationales, as documented in a recent dissertation by Lee [40]. One rationale is that the public wants highway widenings (and will vote for local-option sales tax measures to pay for them), suggesting that how professionals think is tied to how the public thinks. If so, the traditional way of thinking within the profession may continue to dominate unless the public shifts its thinking as well. Researchers are playing a role on that point, too, by sharing their expertise with the media and developing their own public-facing content. As Thigpen et al. [26] show, efforts like this can make a difference.

Example 3: Connectivity

In contrast to the two previous examples, professional ideas about the layout of street networks have shifted around over time. Starting in the nineteenth century and through the first half of the twentieth, most US cities and towns were laid out along rectilinear grids. Cities adopted grids because they were an efficient and orderly way to lay out a city: they simplified surveying, maximized the number of houses facing a street, minimized disputes over legal boundaries, and allowed for standardization of lot sizes [41]. With the rise in car ownership in the US in the 1920s, transportation professionals observed that grids encouraged through traffic in residential areas, much to the detriment of residents. By the end of the decade, planners sought to design communities to accommodate the car but also to protect neighborhoods from them. Radburn, NJ, for example, was intended to be a "town for the motor age," a way to live with the car or "in spite of it" [42]. The plan put houses on cul-de-sacs, linked cul-de-sacs through a system of grade-separated off-street paths, and channeled car traffic to the arterials that bounded the community.

The concept of a roadway hierarchy emerged from such plans. As defined by the transportation profession, the roadway hierarchy and its attendant classification scheme differentiate roadway types by the degree to which they serve mobility or access functions. At one end of the hierarchy are cul-de-sacs, providing access to the houses and other land uses located there. At the other end of the hierarchy are freeways, providing the highest level of car mobility with no direct access to abutting land uses. In between are collectors and arterials of various sizes. The natural outcome of the hierarchy is a series of "superblocks" bounded by high-traffic arterials, within which through traffic is minimized. The efforts of the Federal Housing Administration (FHA) to standardize residential development in the 1930s with the goal of stabilizing the mortgage market led to the widespread adoption of the hierarchy and superblock concepts across the U.S. [43]. The concepts were subsequently included in professional guidance, such as the Institute of Transportation Engineer's *Recommended Practice for*

Residential Street Design published in 1965 [44] and in similar form in 1984 and 1990 updates. A "loops and lollipops" layout became the norm by the end of the century [45]. Research helped to support this approach, including Appleyard's famous study of the negative impacts of traffic levels on residential streets in *Livable Streets* [46].

But just as some in the profession came to revile the grid in the early years of the twentieth century, many came to revile the superblock approach with its loops and lollipops by the later years of the century. Researchers documented a number of problems created by grids: concentrating traffic on the arterials, thereby fueling the cycle of capacity expansion; providing limited entrances into and out of the neighborhood, which can be problematic and even fatal in the face of natural disasters like fast-moving wildfires; reducing the efficiency of public services like trash collection and lengthening response times for emergency services; and discouraging walking and bicycling by increasing travel distances [47]. In the 1990s, the Congress for the New Urbanism (CNU) and other professional organizations pushed for a return to the rectilinear grid.

At the core of this debate is the concept of connectivity. Connectivity can be defined as the degree of interconnectedness of a network. It influences the directness and multiplicity of routes through a network and, in conjunction with land use patterns, determines the travel distance between origins and destinations. The concept can be measured in a variety of ways. A basic method is to count the number of intersections in a given area, a square mile for example, to determine the density of intersections. Using this approach, Southworth and Owens showed that the number of intersections in a square mile dropped by more than two-thirds from a typical grid network from 1900 to a "lollipops on a stick" network from the 1980s [45]. Jacobs used a similar approach to compare the street networks of cities around the world to dramatic effect in *Great Streets* [48]. Researchers studying the effect of neighborhood design on travel behavior have found that intersection density is strongly associated with walking and transit use [49].

The concept of connectivity gained traction among professionals over a similar time frame. Recognizing the downsides of superblock-style development, a number of US cities adopted connectivity ordinances in the 1990s. These ordinances amended long-standing subdivision ordinances encouraging a superblock approach to require street networks with a higher level of connectivity. Some cities encouraged connectivity by setting maximum block lengths, while others set standards based on a node-to-link ratio. Some cities required pedestrian connections at more frequent intervals than street connections, while some outlawed cul-de-sacs. Colleagues and I documented the different approaches taken by these cities and published a Planning Advisory Service report to share this research with the professional community [47]. Boeing provides evidence of this shift in thinking back towards the grid: street networks in US neighborhoods built after 2000 have a higher level of "griddedness" than those built in the preceding half century, though still less griddedness than neighborhoods built before 1940 [50].

Cul-de-sacs have been an interesting point of contention within the larger debate. The FHA encouraged cul-de-sacs in the 1930s as "the most attractive street layout for family dwellings" [43]. But the resurgence of interest in rectilinear grids also brought a backlash against cul-de-sacs within the planning community. Newspaper articles about an anti-cul-de-sac sentiment among professionals led some researchers to push back against a wholesale dismissal of cul-de-sacs, arguing that a cul-de-sac-rich network with a high level of pedestrian and bicycle connectivity could even help to promote active modes over driving [51]. A colleague and I documented the higher level of connectivity for pedestrians and bicyclists than for cars in Davis, CA [52], in part explaining its success in having the highest bike mode share in the U.S. With

other colleagues I published a study showing that children play outdoors more frequently when they live on a cul-de-sac, an important finding for the public health profession in its efforts to increase physical activity among children [53]. The anti-cul-de-sac movement seems to have abated since then, though probably not because of this research .

The quality of connections also matters, especially for pedestrians and bicyclists who are exposed to the elements and vulnerable to car traffic. Following the installation of the first bike lane in the U.S. in Davis in 1967, the profession devoted much attention to the design of bike lanes and other bicycle facilities but with less consideration for the quality of the network that these facilities together comprised. That changed following the development by Furth et al. of the concept of a "low-stress network" [54]. In this approach, individual streets are assessed as to their stress level for bicyclists based on the amount and speed of car traffic as well as the quality of the bicycle facility. The stress levels are then mapped to enable an analysis of gaps in the network of low-stress streets. The bicycle network in San Jose, they found, has many "islands" – areas of low-stress streets separated by high-stress streets that necessitate potentially dangerous crossings. Many cities by now have defined low-stress networks and are using the concept to prioritize investments so as to improve connectivity for bicyclists as well as pedestrians.

Although the idea of a roadway hierarchy remains central to transportation policy and practice, the idea of connectivity has grown in prominence within professional thinking. Research has contributed to this change by developing ways to understand and measure connectivity and by demonstrating the many different ways that connectivity is important to the ability of the transportation system to meet human needs.

Additional Reflections

These examples illustrate a few of the ways that core ideas within the transportation profession have shifted over time. They also illustrate the role of different kinds of research in supporting, encouraging, and documenting those shifts. Research on its own may have limited power to shift professional thinking, but many different types of research contribute to the process in various ways. The one clear pattern that emerges from these examples is that research is a part of the story of the evolution of professional thinking. Research on the role of research in the policy process could help to illuminate its influence and importance.

The possibility that research influences not just policy and practice but also the dominant way of thinking within the transportation profession is both an opportunity for researchers and a significant responsibility. Research is never completely objective. Researchers can direct their work toward supporting the status quo, toward challenging the status quo, or somewhere in between. Research can help transportation can stay stuck in what Lyons and Davidson call a "regime-compliant" pathway to policy, in which traditional ways of thinking shape policy, or it can help shift the profession to a "regime-testing" pathway in which those ideas are questioned [55]. Research has an especially important role to play in the latter, for example, by evaluating current approaches and developing new ones. Programs that train researchers to think more deeply about the questions toward which they choose to direct their energy may be shifting the research enterprise toward more of a regime-testing pathway.

That researchers have their own beliefs raises the question of their role as advocates in the transportation policy realm. Arguably, all researchers are also advocates, implicitly if not explicitly. They are almost certainly advocates for research and for a role for research in informing policy and practice. Whether they are *seen* as advocates with respect to policy itself

may depend on what questions they are asking. In my experience, when researchers ask questions consistent with the dominant way of thinking in the field, they are not generally seen as advocates. When researchers ask questions that challenge the dominant way of thinking, they often are, as researchers who study bicycling as a mode of transportation well know. Researchers who actively advocate for changes in policy or practice, whether at local, regional, state, or national levels, risk being labeled "not objective." In reality, no researcher – and no professional – is entirely "objective," whether they are supporting or challenging the status quo.

A paradigm shift in the transportation profession becomes more likely by the day as the limits of the traditional way of thinking about transportation become harder to ignore. Those limits are increasingly evident in worsening congestion, deteriorating pavement, increasing fatalities, fiscal crises for transit agencies, skyrocketing costs of car ownership, and many other vexing problems. The climate crisis demands immediate action to both mitigate the contribution of transportation to the crisis and prepare the system for the impacts of ever worsening climate-related events. How we choose to address these problems depends on whether, in what way, and to what degree the transportation profession shifts its thinking. Research can help to ensure that professional thinking shifts in the most helpful ways.

Author Contribution Statement and Conflict of Interest

The author confirms sole responsibility for the following: study conception and design, data collection, analysis and interpretation of results, and manuscript preparation. The author does not have any conflicts of interest to declare.

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