Exploring Equity in Transportation: a critical review and assessment of concepts, indices, and methods

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Abstract

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By definition, equity is concerned with justice. On a societal level, equity is concerned with the just distribution of resources in society. Because a wide range of theories of just distribution exist, equity considerations are multifaceted and create a normative conceptual space in which theories can be considered, argued, and applied. In the past few decades, the concept of equity has received increasing attention in the field of transportation, both within academic journals and practice-oriented books and reports. This dissertation offers a critical review and recommendations for three aspects transportation equity: concepts, indices, and methods.

Within a predominantly western, US and euro-centric context, chapter 1 uses concepts and theories from the fields of social psychology, philosophy, and economics to understand and clarify the concept of equity within the field of transportation. Chapter 2 provides a review of

cumulative impact indices that have been specified by various state and federal US agencies to quantify environmental justice and community resiliency, including a detailed analysis and comparison of equity indices created by Washington state's Department of Health (DoH) and the U.S. Department of Transportation (USDOT), respectively. Chapter 3 provides a practitioner-oriented synthesis of methods and metrics used to incorporate equity in state, regional, and corridor planning efforts.

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Acknowledgements

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Chapter 1: Exploring equity introduction

The concept of equity has received significant attention in recent years within the field of transportation. Much of the current advances in transportation equity are a by-product of environmental justice efforts. The environmental justice (EJ) movement began in marginalized communities in the US in the 1970s and by the 1980s, EJ was established as a social justice movement seeking remediation of environmental burdens that have been disproportionately located in and near socially vulnerable populations (Cutter, 1995). The EJ movement won its first major political success when EJ was elevated to a federal mandate through President Clinton's 1994 Executive Order 12898 (Cutter, 1995). Fundamentally, EJ argues that "no group of people should bear a disproportionate share of the negative environmental consequences resulting from industrial, governmental and commercial operations or policies" (EPA, 2023). The rise of widespread computing power and associated geospatial tools in the 2010s and beyond have resulted in EJ mapping tools such as CalEnviroScreen and the EPA's EJScreen (Lee, 2021).

While EJ proponents disagree on whether government entities will ever be able to fully eradicate injustices, there is widespread recognition that EJ operates on a scale that demands a government-led effort to address its many component parts (Karner et al., 2020; Lee, 2021). More recently at the federal level, the Biden-Harris administration signed EO 14008: Tackling the Climate Crisis at Home and Abroad. This includes the Justice40 Initiative which aims to direct 40% of major federal agency spending towards addressing EJ disparities. Towards this end, the White House Council on Environmental Quality (CEQ) developed the Climate and Economic Justice Screening Tool (CEJST) (White House CEQ, 2022). As a federal agency engaged in major expenditures, the US Department of Transportation (USDOT) developed the

Equitable Transportation Community (ETC) Explorer to be used for transportation-specific project assessments and in tandem with the CEJST (OST, 2023).

Within the state of Washington, EJ mandates were recently written into state law with the 2021 passage of SB 5141: the HEAL Act. The HEAL Act sets a goal for 40% of major state expenditures to be directed towards overburdened communities and vulnerable populations. It mandates that EJ analyses be performed by seven state agencies including WSDOT. Specifically, it mandates the evaluation and tracking of environmental health disparities (EHDs) with a cumulative impacts EHD map that quantifies and visualizes the concepts of overburden and vulnerability across the state. Within this context, WSDOT funded the Equity in Planning (EiP) research project; a project to identify and operationalize methods and metrics of transportation equity for state, regional, and corridor planning efforts.

However, despite a tremendous push to include equity in transportation planning and assessments, a clear understanding let alone a definitive operationalization of the concept has proven elusive. This is less a reflection of lack of academic rigor and more a reflection of the reality that equity is a complex concept that does not have a single definition or method of operationalization. To address the confusion and to provide some guidance, this dissertation presents an in-depth, interdisciplinary exploration of the concept of equity along with indicators and metrics that have been developed to operationalize these concepts. It asks the questions:

- What is equity?
- How has the concept of equity been applied in the field of transportation?
- How can the theory of intersectionality inform best practices for cumulative impact index specification?
- Are existing cumulative impact indices more likely to designate urban tracts as disadvantaged compared to rural tracts?
- How should practitioners approach existing indices?
- How can equity be incorporated in transportation planning efforts?

Chapter 2 provides a review of fundamental theories and concepts of equity and how they have been used within the field of transportation. Academic and practice-oriented works are reviewed; they present various theories of justice, either implicitly or explicitly, within the context of transportation financing, investments, and service allocations. This chapter provides the conceptual backbone, situating a subset of the many frameworks and theories of equity within the transportation space.

Chapter 3 presents the concept of cumulative impact indices and how they have been adapted to environmental justice (EJ) and, more recently, transportation equity purposes. The effect of methodological assumptions on the likelihood of urban/rural disadvantage assignments is assessed. Best practices for index development based on the theory of intersectionality are proposed as well as best practices for practitioners applying existing indices. It provides a deep dive into the specific concept and application of cumulative impact indices within transportation equity planning practice.

Finally, Chapter 4 synthesizes transportation equity planning literature to present conceptual process and frameworks. These are used to organize a detailed collection of transportation equity indicators, methods, and data sources. Recommendations including transportation equity strategies are provided. It offers an expansive overview of transportation equity planning practices, replete with detailed collections of indicators, methods, and data sources. The work presented in Chapter 2 was completed with the support of the National Science Foundation (NSF) Graduate Research Fellowship Program (GRFP) under Grant No. DGE-1762114. Chapters 3 and 4 were supported by the WSDOT Equity in Planning research project.

Taken together, this dissertation offers theoretical breadth and analytical depth to advance knowledge and application of transportation equity in research and practice.

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Chapter 2: Exploring concepts

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2.1 Introduction

This chapter provides the conceptual backbone on which the remaining chapters are built. To do this, it answers the questions:

- What is equity?
- How has the concept of equity been applied in the field of transportation?

Interest in equity within the transportation profession has exploded in the past few decades. While the delivery of equitable transportation systems has been presented as an ideal by many, few have managed to articulate what equity *is,* let alone how to functionally achieve it within a transportation setting. This conceptual confusion stems from the fact that equity is a wide-reaching concept rooted in the study of ethics and morality. In the introductory article of a special issue on Equity in Transport, Di Ciommo and Shiftan (2017) note that moral debate "is inevitable–although mostly invisible–in transport project appraisal" (p. 148). In other words, ethics have always been at play in transportation, but the explicit consideration of ethics through the lens of equity has only become mainstream within the past few decades. Moreover, it is difficult to engage in a moral debate when you do not realize there is a debate to be had, i.e. when morals in transportation remain "mostly invisible". Even with the realization that there is a debate to be had, it is difficult to engage effectively in that debate without an understanding of relevant concepts.

Accordingly, the primary goal of this paper is to provide transportation researchers and practitioners a broad, common base of understanding of the concept of equity, particularly the different types of theories that fall under the umbrella term of equity. Section 2 introduces key concepts for the paper such as how the concepts of equity, justice, and fairness relate to one another. Additionally, the distinction between positive and normative analyses within the field of economics – and how it parallels the difference between distributional effects and equity analyses – is discussed. Section 3 presents fundamental theories of equity and the key distinctions among them. The theories presented in this section are informed by – and support the analysis of – the transportation literature found in Section 4. Because the literature considered was largely generated by US- and Euro-centric authors, the theories presented in Section 3 are from predominantly western European thinkers.

It is important to note that each of the theories presented in Section 3 is the subject of entire bodies of literature spanning centuries of thought and debate. Readers familiar with the study of philosophy or welfare economics will likely command a deeper understanding of many (if not all) of these theories than what is presented in this article. The goal of Section 3 is not to capture the full depth and breadth of these theories; the goal is to present a brief explanation of core theoretical tenets and underlying assumptions to highlight differences and similarities between them.

Section 4 builds on the concepts and theories presented in Sections 2 and 3 to explore the often piecemeal and occasionally contradictory ways in which various theories of equity have been presented and used, both explicitly and implicitly, within the transportation literature. The goal of this section is to alleviate conceptual confusion by highlighting differences and contradictions in order to clarify them. It is not a comprehensive review of transportation equity literature but rather a sample of existing resources available to anyone seeking equity definitions within the transportation literature. Primary sources (journal articles) as well as derivative works (reports and books) are included in this analysis to capture the range of resources considered by academics as well as practitioners. Section 5 concludes the article with recommendations for best practices.

2.2 Key Concepts

This section introduces concepts fundamental to understanding how equity has been discussed and operationalized, both implicitly and explicitly, in transportation. Section 2.1 explains why equity is such a difficult concept to define concisely, let alone operationalize, and Section 2.2 provides clarifying terminology and associated concepts. The goal of this section is to provide readers with precise definitions of terms that are used throughout the remainder of the paper.

2.2.1 The conceptual space created by equity

While the word equity can be used with regard to monetary valuations of property, the primary dictionary definition states that equity is

> "justice according to natural law or right *specifically*: freedom from bias or favoritism" ("Equity | Definition of Equity by Merriam-Webster," 2019).

Modern transportation discussions surrounding equity mostly evoke this primary, justice-oriented definition. While this single-sentence definition may appear simple and straightforward, to understand (let alone operationalize) the concept of equity, one must first understand the concept of justice. The book *Perspectives on Social Justice: From Hume to Walzer* consider the contributions of primary western philosophers. They discuss Pareto's assessment that, because different individuals can hold different value systems and therefore competing claims of justice, this “essential contestability … renders [the concept of justice] meaningless” (Boucher & Kelly, 1998, p. 78). In response, Boucher and Kelly (1998) explain that:

> “At the highest level of abstraction, the definition of justice is uncontroversial: i.e. giving each person his due, in conformity with proper principles and procedures. Exactly what these principles and procedures should be is open to conflicting interpretations, however. ‘Empty’ rather than ‘meaningless’ would seem to be a more accurate way of describing the concept. Given that nature abhors a vacuum, it would be futile to expect people to refrain from ‘filling’ this emptiness with their subjective feelings and values (‘intuitions’)” (pp. 78-79)

By extension, equity can be viewed as an empty concept that must be filled. Put another way, when authors use the term ‘equity’, they generate a conceptual, normative space. Authors then fill this space either explicitly with clearly defined arguments or implicitly with whatever idea of justice intuitively comes to mind. Equity within the field of transportation has essentially created a normative space that many positively-trained researchers and practitioners rushed to fill, often implicitly.

2.2.2 Positive is to Normative as Distributional Effects is to Equity

The distinction between positive and normative analyses was first proposed by Robbins (1984) relative to the study of economics. Robbins (1984) distinguishes between assessments of the world as it *is* (positive) vs. the world as it *ought to be* (normative). Positive analyses provide powerful, consistent methods to understand the world around us; once a positive analysis is framed and the logic is established, the execution of that logic requires computation, not thought (Chu-Carroll, 2013, pt. IV). Proponents of positive economic analytical methods cheekily refer to this as “Mindless Economics” and argue that only positive economic analyses produce results that are objective enough to be called Economics (Caplin & Schotter, 2008, pt. I). They argue that these fixed, axiomatic interactions analyzing individual's revealed preferences of demand through monetary valuations represent objective, irrefutable, neutral truth. For example, Pareto's opinion of justice as a "meaningless" concept follows a positive line of reasoning (Boucher & Kelly, 1998, p. 78).

However, as proponents of "mindful" (normative) economics point out, both normative and positive, non-economic fields of inquiry add value and are necessary to frame positive analyses with intention (Caplin & Schotter, 2008, pt. II). Beyond problem framing, normative understandings help determine what is to be done with the knowledge produced by positive methods. As Robbins states, "[t]here is nothing in [positive] economics which relieves *us* of the obligation to choose" (Robbins, 1984, p. 152). This relationship is presented in Figure 2.1.

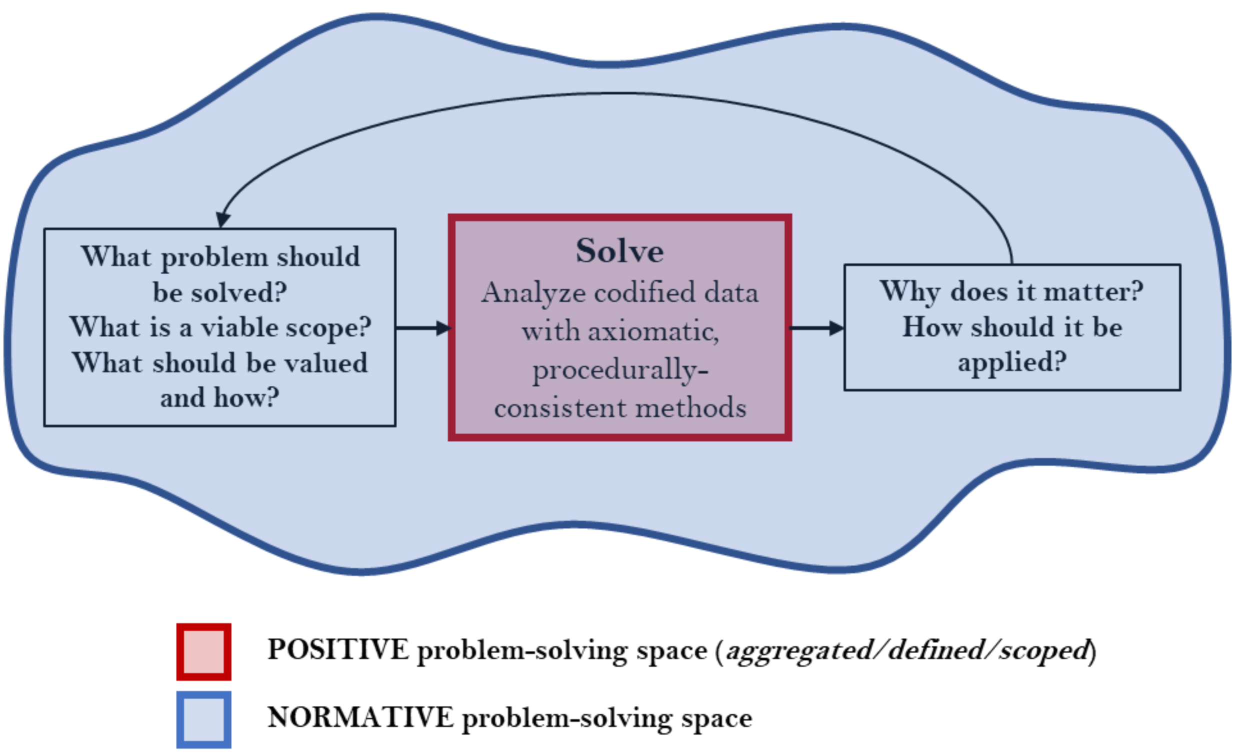

Figure 2.1. The relationship between positive and normative fields of inquiry.

The distinction between positive vs. normative analyses that Robbins first identified within the field of economics over a century ago serves as a helpful guide to understanding the confusion over the concept of equity within transportation today; rather than asking purely positive questions of revealed preference travel data, more and more transportation researchers and practitioners now also ask logical questions of stated preference data (how transportation *could* function) as well as normative questions (how transportation *ought to* function).

The use of the terms 'equity' or 'justice' suggest a normative value judgement because these concepts are inherently normative. Many authors, however, simply present how transportation *does* or *could* function, typically employing distributional effects analyses to do so. Rather than explicitly stating a normative interest, these studies imply a normative perspective within the methods used and the recommendations given. In contrast, studies that explicitly comment on how transportation *ought to* function make this normative valuation explicit. While not an exact comparison (some assessments of how transportation *is* do not necessarily employ distributional effects analyses and many distributional effects analyses consider how transportation *could be* rather than simply what *is*), this means that distributional effects are to equity as positive is to normative.

Example cases are presented in Section 4, but to provide a brief illustration of this point, consider a (theoretical) shared bicycle fleet. A positive distributional effects analysis would simply present the facts of the fleet and its utilization. For example, bikes are often concentrated in neighborhoods X, Y, and Z whose populations fit the socio-economic categories of m, n, and o. A distributional effects analysis of that fleet with an implied normative perspective might say that, if fleets were re-balanced, they could improve general accessibility of {all citizens; citizens in neighborhoods X, Y, and Z; citizens in neighborhoods U, V, and W, etc.} – depending on who the author proposed to improve accessibility for, a normative value judgement is implied. In contrast, an equity analysis would make an explicit value judgement and propose a distribution to meet that goal. For example, bikes should be rebalanced so that all citizens have equal access to them OR (though not necessarily mutually exclusively), because citizens in neighborhoods U, V, and W currently have inferior access to bikes, therefore bikes should be rebalanced to better serve citizens in neighborhoods U, V, and W.

While distributional effects analyses are a necessary component, they constitute only part of an informed, intentional equity assessment; on their own, they simply state facts but do not engage in normative thought and are therefore not equity analyses in and of themselves. Although they go beyond merely characterizing the present state, distributional effects analyses that project what *could* happen imply and obfuscate normative ideologies. In contrast, intentional equity analyses explicitly present either multiple theories of equity and compare related, positive assessments against one another, or explicitly argue for the use of a particular theory of equity and use it to propose a just distribution according to that theory. This means that a single, positive ‘answer to equity’ is not possible because the concept of equity inherently denotes a normative space for discussion. Authors interested in performing equity analyses must understand this in order to fill this normative space explicitly rather than implicitly.

A command of positive findings and normative theories from tangential fields of inquiry provide useful framing to fill this conceptual space explicitly. Positive analyses of human behavior are studied in the fields of psychology and sociology. The systematic, logical development of normative theories of resource distribution occur within the fields of philosophy and economics. These theories of justice establish logical rules to provide an adequate and fair accounting of competing claims to finite goods within society.

2.3 Filling the conceptual space of equity: theories from related fields

This section presents theories from the fields of sociology, psychology, philosophy, and economics to frame and partially define the theory of equity. This section serves three main purposes: to orient a reader unfamiliar with theories of equity; to provide the precise, concise definitions necessary to complete the assessment presented in Section 4; and to demonstrate commonalities and differences between theories. This overview is by no means comprehensive in depth or breadth, but it does present the reader with concepts relevant to the analysis of transportation literature contained in Section 4. Because the literature considered was largely generated by US- and Euro-centric authors, the theories presented are from predominantly western European thinkers.

2.3.1 Egalitarianism and equality

Similar to equity, the terms equality and egalitarianism cover a wide range of concepts and theories and are often oversimplified. "Egalitarianism is a trend of thought in political philosophy. An egalitarian favors equality of some sort: People should get the same, or be treated the same, or be treated as equals, in some respect" (Arneson, 2013). These terms are extremely broad and contested because two individuals may identify as egalitarians and argue in the name of equality but reach completely different conclusions depending on the type of equality each assumes.

To help differentiate between types of equality (and associated egalitarian thought), more precise terms exist. Aristotle identified two types of equality of treatment: numerical and proportional. Numerical equality (also known as simple equality) treats individuals as equal by "granting them the same quantity of a good per capita" (Gosepath, 2015, pt. 3.1). In contrast, proportional equality "treats all relevant persons in relation to their due" (Gosepath, 2015, pt.

2.2). Determining what someone is due is a separate exercise, but proportionality essentially accounts for the idea that some people deserve a greater share of resources, either because they are different in some way (ex: the difference in total caloric intake between an adult and a child) or because they have contributed to society in different ways (ex: the difference in income between a doctor and a sales clerk).

Formal and moral equality have also been defined. Under formal equality, if "two persons have equal status in at least one normatively relevant respect, they must be treated equally with regard to that respect" (Gosepath, 2015, pt. 2.1); putting this in terms of the doctor and sales clerk example, formal equality recognizes that it is just for sales clerks to be paid different wages relative to doctors, but demands that all doctors performing the same work be paid the same, and all sales clerks performing the same work be paid the same. Moral equality was introduced in the eighteenth century to establish the idea that all humans are created equal; up to this point, "it was assumed that human beings are unequal by nature – i.e., that there was a natural human hierarchy" (Gosepath, 2015, pt. 2.3). Moral equality is more concerned with dignity and respect than the details of resource distribution and may seem like an obvious, unspoken given to many contemporary readers. Indeed, moral equality serves as the foundation for all of the theories presented in this article.

2.3.2 Smith, libertarianism, Marx, and utilitarianism

In one application of moral and proportional equality, Adam Smith laid out the theory of supply and demand in his 1776 book *Wealth of Nations* (Fleischacker, 2020). Smith asserts that no formal evaluation of 'normatively relevant respects' is necessary to value goods or labor in society because, in a market allowed to operate freely, supply and demand will naturally interact until valuations at the equilibrium are reached. In other words, while sales clerks or doctors may perform similar roles compared to others within their group, some individual clerks or doctors may perform better than their counterparts and therefore earn higher pay. He also presents the user-fee paradigm in which he asserts that, if carriages pay for exactly the amount of roadway maintenance they generate based on their weight and distance traveled (i.e. a proportional amount), roadway funding would be inherently fair (Smith, 1789).

Informed in part by the theories of Smith, libertarianism is an ideology that has been developed by a wide range of thinkers in recent centuries. Libertarianism posits that "agents initially fully own themselves and have certain moral powers to acquire property rights in external things" (van der Vossen, 2019, pt. 1). Just, free acquisition of resources is key to libertarian theories which "conceive of distributive justice as largely (sometimes exclusively) historical in nature" and "reject theories that look merely at outcomes or end-state distributions" (van der Vossen, 2019, pt. 3). Libertarians focus on individual rights and processes and insist that "justice poses stringent limits to coercion. While people can be justifiably forced to do certain things (most obviously, to refrain from violating the rights of others) they cannot be coerced to serve the overall good of society, or even their own personal good" (van der Vossen, 2019, intro).

Because it is an ideology that has been developed by many over a long period of time, there is no single libertarian consensus regarding the exact limits of what individuals can be justifiably forced to do, with a spectrum of beliefs ranging from Left to Right (van der Vossen, 2019, pt. 4). Right-leaning libertarians have the strictest sense of individual liberty, believing that individuals, so long as they acquire resources in a just manner, have the right to use (or destroy) their property as they please and that external powers (such as a state) cannot force or coerce individuals in any way to pay for things such as military, police forces, or roadways. They believe that self-possessed individuals can, as necessary, organize and manage resources and services more effectively than what they perceive as otherwise coercive state forces.

Left-leaning libertarians believe that some level of protections for natural resources are necessary to maintain "equally valuable shares of natural resources for everyone" (van der Vossen, 2019, pt. 4). This assumes a simple equality baseline and dictates that those who "acquire more than their share (understood in terms of per capita value) owe compensation to others" (van der Vossen, 2019, pt. 4). In the name of natural resource preservation and improvement, some left-leaning libertarians also believe that "enforceable requirements to pay" can be justified for some state-like services (such as militaries, police forces, and roadways) (van der Vossen, 2019, pt. 5). Essentially, they believe that individuals can justifiably be forced to pay for public goods because "the provision of these public goods will increase the value of natural resources, making the taxed amounts a case of self-financing" (van der Vossen, 2019, pt. 5).

In contrast, utilitarianism focuses on the optimization of end-state resource distribution in whatever way maximizes the welfare of society as a whole, even if that means resources are only distributed to a few or the process of distribution infringes on the individual rights of others (Mill, 1895). For a utilitarian, moral equality means that all individuals are given equal weight in the calculation of aggregate social welfare. Taken to its extreme, this means that no individual has the right to life if the taking of that individual's life would lead to a maximized aggregate outcome.

Marxist ideologies share the libertarian interpretation of moral equality as a right to life, but the similarities largely end there. Originally published in 1875, Marx popularized the slogan "from each according to his ability, to each according to his needs" (Marx, 2008). He suggests that under individualist, capitalist systems, those in power tend to monopolize and hoard resources, and that the inevitable response to this is a popular uprising to establish state ownership and distribution of resources, beginning with a transitional, socialist state and eventually leading to a communist state. According to Marx, all individuals have an equal right to having their basic needs met, and societal resource distributions that do not accomplish this are unacceptable.

This highlights a fundamental distinction between process versus end-results equity (Tersch, 2014). Assuming equally self-possessed and free individuals engage in just resource acquisition, a Right-leaning libertarian would argue that any distribution of resources that resulted from free-market exchange would be fair. A Left-leaning libertarian would add constraints to avoid natural resource degradation and support minimalistic public resource management that bolsters this free-market exchange, however the over-arching emphasis on process remains consistent. Because a libertarian is fundamentally concerned with process, any outcome is fair so long as the rules of the game were upheld. Under this theory of justice, decreases in collective, aggregate welfare are fair and just. This is in direct conflict with a utilitarian, end-results focus under which infringing on individual rights to life, liberty, property, and contract would be deemed fair and just if they resulted in a maximized, aggregate outcome.

2.3.3 Rawls, al-Sadr, sufficientarianism, and prioritarianism

Two of the most famous justice theorists of the 20th century, Muhammad Baqir al-Sadr and John Rawls, offer some balance between these dichotomies. al-Sadr builds on an extensive history of Islamic philosophical and economic thought to present a concept of equity that falls somewhere between Smith and Marx (Khan, 2011). In his book *Iqtisaduna (Our Economy),* al-Sadr advocates for principles of dual (individual and state) ownership of resources and constrained economic freedoms (al-Sadr, 1982). These are the necessary conditions he identifies to achieve a just society, because it must develop in a way that reduces the benefit gap and ultimately eradicates poverty. This conceptualization of equity is rooted in the Islamic belief that the poverty that exists in the world is inherently unjust and must be corrected. This theory also posits that wealth monopolies among the ultra-rich are harmful to those in possession of the riches as well as the poor to whom those riches should be distributed.

Similarly, Rawls's *A Theory of Justice* put forth the concept of 'justice as fairness' (Rawls, 1971). In (very) brief, Rawls assumes rational, self-interested actors (whose true position in society is hidden by a 'veil of ignorance') seeking to maximize their individual claims to the social primary goods of income and wealth. While every individual has an equal claim to basic liberties (the principle of greatest equal liberty), "[s]ocial and economic inequalities are to satisfy two conditions: first, they are to be attached to positions and offices open to all under conditions of fair equality of opportunity (the principle of fair equality of opportunity); and second, they are to be to the greatest benefit of the least-advantaged members of society (*the difference principle*)" (Martens, 2017, p. 66). The principle of fair equality of opportunity mirrors proportional equality, because beyond equal access to opportunity (defined as positions and offices), individuals should be compensated according to the proportional importance of their position and office i.e. a doctor should make more money than a sales clerk. The difference principle, however, is the conclusion most unique to Rawls in the western philosophical canon. As a result, references to Rawlsian equity tend to refer predominantly to the difference principle.

Sufficientarianism and prioritarianism are equity theories that, beyond the basic assumption of the moral equality of humans, are not egalitarian in nature. Sufficientarianism operates on "the observation that justice requires first and foremost the avoidance of misery" and seeks to establish a threshold of insufficiency to accomplish this (Martens, 2017, p. 170). Once established, it is assumed that above the threshold, goods are best distributed through free market exchange whereas below the threshold, goods are best distributed by the state. Prioritarianism "is based on the view that benefits matter more the more worse-off the person to whom the benefits accrue" (Martens, 2017, p. 171). Functionally, prioritarianism resembles sufficientarianism, but rather than drawing a single, hard-cut threshold to designate between a zone of need vs no specific need, it assumes a continuous curve of needs vs unit value of resource distribution. Neither necessarily speaks to the structure of society but both can serve as guiding principles when working from an assumed state of injustice towards a state of justice within society. For example, prioritarianism is implied by Marx, al-Sadr, and Rawls.

Notably, sufficientarian and prioritarian theories are distinct from egalitarian theories (Arneson, 2013: Holtug, 2017). Every theory presented in this section assumes the equal value of human life (albeit in various ways) and can therefore be considered egalitarian in the broadest sense of moral equality. However, where egalitarian theories emphasize equality or balance in some way, sufficientarian and prioritarian theories focus on minimizing misery. They assume an imbalanced world and advocate for resource distributions that improve the lives of those who are already suffering from less resources (sufficientarianism) or from the standpoint of overall welfare (prioritarian); while this may move the world towards a more balanced, equal stasis, that is not the goal for a pure sufficientarian or a prioritarian.

The other theories assume a universal approach to the distribution of resources in society as a whole and are therefore not intended for disaggregate, partial application. Rawls himself stated that his theory of justice is only intended to be applied "to the basic structure of society" and "that the application of the difference principle as a single principle by itself leads to 'nonsense'" (Martens, 2017, p. 68). Moreover, these theories predominantly (if not exclusively) concern themselves with monetary resources; the difference principle is inherently designed to assess distributions of the basic goods of income and wealth. Holistic theories only retain their logical validity when applied universally; in other words, the component parts of an holistic theory such as Rawls's cannot logically be applied in isolation to any disaggregate component of society, and certainly not to a good other than income or wealth.

2.3.4 Sen and Nussbaum – the Capabilities Approach

To deal with the inability of holistic theories to deal with disaggregate components of society or with goods other than wealth, Sen's *The Idea of Justice* expanded Rawls's theory by introducing the idea of comparative states of social justice so that societies might recognize shades of justice and methods to improve justice within society rather than simply drawing lines between 'just' and 'unjust' (Sen, 1999). Rawls's theories were expanded further into the capabilities approach (Nussbaum, 2001).The capabilities approach focuses on an individual's 'capabilities' (the range of things an individual can realistically do or be) rather than on 'functionings' (what an individual has done or become)[1]. Rather than focusing on outputs to determine just deserts, the capabilities approach focuses on improving input potential in the form of functionings by improving individual's capabilities; in this way, the capabilities approach establishes the concept of freedom as justice. Nussbaum approached the concept from "Marxian/Aristotelian idea of truly human functions" (Nussbaum, 2001, p. 13) and Sen approached it from development economics. Sen's theory ultimately strives for moral equality, whereas Nussbaum recognizes that, in a world of constrained resources that is already so functionally out of balance, it is

[1]Excellent summaries of the primary theories put forth by each of these individuals as well as a number of other modern philosophers are presented and applied to the transportation sector in Martens's (2016) book *Transport Justice*

reasonable to aim for a threshold improvement rather than complete equality and is therefore sufficientarian in nature.

To aid in the process of disaggregating, Nussbaum identified a list of ten Central Human Functional Capabilities (CHFC) i.e. the concrete elements of life that all people need to lead a life befitting the dignity of a human. The CHFC serve as guidance to determine what aggregate components of society deserve additional equity consideration. Nussbaum's (2001) list of ten CHFC include the following transportation-related capabilities:

- "Bodily Integrity" defined in part as "Being able to move freely from place to place" (p. 78)
- "Affiliation" defined in part as "to engage in various forms of social interaction" (p. 79)
- "Play. Being able to laugh, to play, to enjoy recreational activities" (p. 80)
- "Control over One's Environment … B. Material" defined in part as "Being able to hold property (both land and movable goods), not just formally but in terms of real opportunity; and having property rights on an equal basis with others" (p. 80)

The combination of CHFC and the emphasis on freedom have made the theories of Sen and Nussbaum incredibly powerful and pervasive in the 21st century; modern, western, democratic theories of just development ultimately rest on the work of these two philosophers who, though they began their work in different contexts, have been collaborating for years to advance their theories (Nussbaum, 2001). For example, the United Nation's Sustainable Development Goals (UN SDGs) are based on the CHFC.

The capabilities approach does share one major similarity with the others; it is a universal theory of society. Essentially, each of these theories function on the assumption that everyone in society is constantly operating within that singular theory. However, in their book *Equity: Theory and research*, Walster et al. (1978) present and discuss equity from psychological and sociological perspectives. They find that, while equity theories such as equality and proportionality are fundamentally at odds with one another in their pure, theoretical form, they are applied interchangeably in the real world, with individuals practicing some form of equality or proportionality (or something in between) depending on the situation and their intuitions.

2.3.5 Intuitionism and the application of equity theories

The theory of intuitionism addresses this reality. Intuitionism assumes a rational actor who will draw on all relevant theories as well as their intuitions to determine what is or is not fair within a given context (Stratton-Lake, 2020). This concept of ethical pluralism is diametrically opposed to the ethical monist theories such as utilitarianism (welfare) or Marxism (need) in their pure forms. While the lack of a universal concept of justice has been deemed problematic because it can lead to conflicting value judgements and provides limited consistency, it accurately captures the way in which most people apply theories of justice.

Critical to the interplay between philosophical theories and their practical application is the concept of efficiency. Using an Edgeworth box[2], Barr (2012) explores the societal theories of libertarianism, utilitarianism, Rawls, and socialism (part of a Marxist ideology) to conclude (in part) that "all first-best socially just distributions are also Pareto efficient[3]" therefore "[e]fficiency in this case is a necessary condition for social justice" (Barr, 2012, p. 48). While each of these societal theories identify different distributions of resources as fair, to achieve any of these idealized, optimal distributions, Pareto efficiency relative to that theory of social justice must be achieved. For example, while a libertarian may view bureaucratic processes as inherently inefficient and wasteful, a Marxist would argue that the process is necessary to

[2]The Edgeworth box for this example assumes a fixed size and fixed efficiency in production and product mix i.e. it provides a framework to discuss a "first-best solution" for resource distribution (Barr, 2012, p. 46).

[3] Given multiple, potential distributions and the relative utility curves they provide individuals, a curve that intersects all of the potential *utility* curves provides a curve of *Pareto efficiency*. ***Pareto efficiency*** "incorporates two value judgements: social welfare is increased if one person is made better off and nobody worse off; and individuals are the best judges of their own welfare" (Barr, 2012, p. 46).

safeguard equitable resource distribution. That same Marxist, however, would still desire efficiency within that bureaucratic process, because inefficiency would waste resources that should otherwise be distributed to the individuals their system seeks to safeguard.

While this emphasis on Pareto efficiency provides a general, societal-level theoretical base-case, Sen argues that distributions optimized purely on utility efficiency of objective goods do not necessarily optimize the distribution of individual freedoms (Sen, 1993). This plays to the ultimate argument that optimizing based on monetary valuations of observable traits alone cannot capture the full value of social goods whose value extends beyond the readily quantifiable; in addition to transportation, primary examples of this include healthcare and education.

Transportation, healthcare, and education represent unique social goods because they relate to Nussbaum’s Central Human Functional Capabilities (CHFC). As a result, according to a capabilities approach, they can and should be treated with special care by policy makers. Both the form and function of such social goods must be considered in order to properly account for their value and determine distributions. For example, while healthcare includes and is heavily influenced by its objectively measurable form (hospitals, number and type of medical professionals, medications, etc.) and their objectively measurable outcomes (prevalence of diseases, mortality rates, etc.), the value associated with a healthy society strays into the realm of normative considerations. In other words, the function of a healthy society is ultimately derived from more than just the sum of its parts (i.e. its objectively measurable form(s)).

To measure these subjective components, *Development Microeconomics* explores sociological findings to highlight the effect of human and social in addition to physical capital on overall social welfare (Bardhan & Udry, 1999, chap. 11); while physical capital considers only objectively measurable resources (such as property and wealth), human capital accounts for tacit knowledge held by individuals and social capital considers the effect of connections and human interaction on both human and physical capital production (Coleman, 1988; Neef, 1998; Schuller, 2001). In addition to human and social capital, Lin (2000) also recognizes cultural capital, or the knowledge of social norms and broader content that can be used for personal satisfaction or to demonstrate social status. These works all find that increases in physical capital do not always correlate with increases in human, social, or cultural capital. Moreover, they find that social capital plays a key role in the development of all forms of capital and therefore on overall social welfare.

Some of the most fundamental and commonly cited theories covered in this section - libertarianism, utilitarianism, Marxism and the works of Rawls[4] - focus exclusively on the distribution of physical capital. This is problematic from a transportation standpoint because while transportation relies on and effects physical capital, it also relies on and effects human, social, and even cultural[5] capital. Moreover, these theories assume a holistic, universal application to society as a whole and break down when applied in a disaggregate manner, especially when applied without logically-argued theoretical extensions.

Similar to Walster et al.'s (1978) theory of equity based in psychology and sociology, the theory of intuitionism recognizes this reality and is particularly relevant within the context of democratic societies; democracies inherently seek multiplicity and actively oppose the application of a single, universal, social ethic. To deal with both of these issues, Sen and

[4] While al-Sadr also focuses on physical capital, he does so within the context of Islamic human, social, and cultural capital

[5] From the London Underground to Route 66 to the crosswalk symbols of East Berlin, transportation carries cultural significance in a wide variety of ways.

Nussbaum's capabilities approach provides a disaggregate theory of equitable distribution that accounts for physical, human, social, and cultural capital.

The philosophical theories of equality, libertarianism, utilitarianism, and Rawls consider equity in a theoretical society and operate outside of time and space, or a-historically. In contrast, the works of Marx, al-Sadr, and Sen and Nussbaum's capabilities approach account for the world as it is within their theories of equity. By empirical observation, all of these theorists find the base-case, existing state of the world to be inequitable and engage concepts of sufficientarianism, prioritarianism, and equality in various ways in their pursuit of remedying existing inequity in the world. However, while these theories account for historical antecedents, spatial attributes of society are not explicitly considered within the philosophical theories. Despite these limitations, all of these theories have been considered in some form within the transportation literature as demonstrated in Section 4.

Basic information about each theory and points of comparison are summarized in Tables 3.1 and 3.2. Egalitarianism and moral equality are not included as line items in these tables or in Table 4.1 because they are too general; moral equality is a fundamental theory applied in some way by all of the other theories presented. While not all of the theories presented in the tables are considered egalitarian in nature (sufficiantarianism for example), egalitarianism is an expansive ideology that accounts for all forms of equality and is therefore also omitted from the tables.

In Table 3.1 the Resource, Focus, and Base Case columns categorize underlying assumptions of the theories presented. The Resource column refers to type of resource assumed in each theory. Most theories argue in terms of the just distribution of physical capital; while utilitarianism and Pareto's theory are often expressed in terms of physical capital, they are specified more broadly in terms of the subjective concept of welfare. Concerning Focus, most of the theories presented focus on end-state distributions (ends) to determine what is just. In contrast, libertarianism and Smith's user-fee paradigm are concerned with process; so long as the rules of the game are followed, the end distribution is fair. The Capabilities Approach is also concerned with process but in the sense of opportunity; it calls for whatever level of intervention will ensure the greatest breadth (and, under Sen's version, equality) of opportunities for all. Finally, each theory assumes some Base Case. A-historical theories present a first-best, ideal, perfectly-just vision for society and are strictly normative. In contrast, contextual theories begin with the world as it already exists and are therefore both positive and normative in nature; they observe the world as it is and, based on this, propose concepts for how it ought to be. The theories that account for existing states of outcome distribution identify injustices and respond with alternatives intended to make future outcome distributions fairer.

Table 3.1 provides examples of how proponents of each theory would respond to the following prompt: in a society where bicycles serve as the primary form of transportation, what is a fair distribution of bicycles among citizens? This provides a transportation-related example to demonstrate the different ways in which different proponents of these theories approach the same question. Some are complementary, but some are diametrically opposed. All are considered equity.

Table 3.1 *A summary of theories and associated categories of underlying assumptions*

Theory	Fundamental Argument	What is ideal?	Resource	Focus	Base Case
Simple Equality	Everyone has equal humanity so deserves equal resources	Equal distribution	Physical Capital	Ends	a-historical
Formal Equality	Some reasonable distinctions between individuals exist within society (i.e. people can be categorized), but those within a given category deserve equal	Equal distribution within groups, differences justifiable between groups	Physical Capital	Ends	a-historical
Proportional Equality	Different people earn different resources – balance the equation of what is deserved and what is received	Circumstance-informed unequal distribution	Physical Capital	Ends	a-historical
Utilitarian	Resources should be distributed in whatever way maximizes aggregate welfare	Maximized aggregate benefit	Welfare	Ends	a-historical
Libertarian	Protect individual liberty and contracts – non-coerced, self-possessed individuals trading freely is fair	Individual liberty	Physical Capital	Process	a-historical[6]
Marx	Distributions "from each according to their ability to each according to their need" is just	Needs-based unequal distribution	Physical & Human Capital	Ends	Contextual
Smith (user-fee)	Individuals paying for what they use is fair	Individuals pay for their impact (cost-focused)	Physical Capital	Process	a-historical
Pareto	Distributions optimized to the point at which welfare is improved for as many individuals as possible without decreasing the welfare of any others is fair	Optimized welfare	Welfare	Ends	Contextual

[6] Left-leaning libertarianism proposes a contextualizing mechanism relative to natural resource distribution

Rawls	Unequal distributions are acceptable if they either 1) are associated with positions that deserve more resources and are accessible to all equally or 2) benefit the least advantaged	Circumstance-informed unequal distribution	Physical Capital	Ends	a-historical
al-Sadr	Poverty is inherently unjust – state and private ownership mechanisms must be used to distribute resources in a manner that eradicates poverty	Poverty eradication/suffering minimization	Physical Capital	Ends	Contextual
Capabilities Approach	If the opportunities legitimately available to individuals are maximized, distributions will be fair	Maximized opportunities for all	Human & Social Capital	Process (opportunity)	Contextual
Sufficientarian	Equality of resources is not fair, but all individuals should have basic needs met	Poverty eradication/suffering minimization	Physical Capital	Ends	Contextual
Prioritarian	Incremental improvements in welfare to those with a lower baseline welfare has greater moral value than the same incremental improvement to someone with a comparatively higher baseline	Individuals with a lower baseline welfare should be prioritized in the distribution of advantages	Welfare	Ends	Contextual
Intuitionism	There is no single theory of justice – morally-developed individuals will intuitively know the best course of action for a given situation	Morally-minded individuals following their intuition	Unspecified	Variable	Contextual

1

Table 3.2 *A theoretical transportation example: what is a fair distribution of bicycles within a bicycle-centric society?*

Theory	Bike example
Simple Equality	Give everyone a bicycle
Formal Equality	Distribute bicycles equally among relevant subsets of individuals. Ex: Give every adult an adult bicycle and every child a child bicycle/ Give every person with special needs a special needs bicycle and every able-bodied person the same standard bicycle
Proportional Equality	Give those who have trained harder or who can pay more nicer bicycles
Utilitarian	Distribute bicycles in whatever way maximizes the aggregate welfare – if measured in units of bicycles/person, in the case of three people and three bicycles, any distribution (one bike each, three bikes to one person and none to the others, etc.) yields the same result so any are ideal. Measuring in other units such as bicycle utilization in hours/day/person or Likert-scored satisfaction/person would likely yield different results.
Libertarian	Whoever can justly acquire a bicycle can have a bicycle – what constitutes just acquisition will be determined by whoever produced the bicycles and those interested in acquiring them
Marx	Those with the ability to give should give to those in need. Ex: Those who have more bicycles should give to those with less (elders who can no longer cycle should give their bike to younger adults, children growing out of their child bikes should give them to younger children, etc.)/ Those who are skilled mechanics should innovate to provide bicycles to those who are differently abled Those who are able-bodied should help the elderly (by offering rides on rickshaws) and those incapable of riding (young children in child seats)
Smith (user-fee)	Individuals pay for their use – if they wish to purchase a bicycle and have the funds to do so, they can. If there is a bicycle fleet offering rentals, individuals should pay for the incremental wear and tear their riding causes – those who ride further and on bumpier terrain should pay more, those who ride shorter distances on smooth terrain should pay less
Pareto	A similar assessment to the utilitarian distribution would be used, however a Pareto assessment is longitudinal and would account for the base case of bicycle distribution. If a base case involved no one with bicycles, the bicycles/person unit example would be constrained such that distributions in which some individuals receive multiple bicycles and some receive none would not be permissible. Similar constraints would apply to distributions measured in other units as well. However, if the base case was some individuals owned multiple bicycles and some owned none, alternate distributions would be possible only if the welfare of no one was decreased – if someone who owned multiple bicycles believed their welfare would decrease if one or more of their bicycles was redistributed, then those bicycles could not justly be redistributed
Rawls	Those who hold positions of importance within society may earn more (either in the form of more resources to buy more bicycles, buy a nicer bicycle, or in the form of more/nicer/custom bicycles given directly), and/or if unequal bicycle resources could

	benefit the least advantaged. Ex: provide a rickshaw service or custom bikes to those incapable of riding a standard bike (the elderly and the differently abled)
al-Sadr	Bicycles should be distributed using public and private means in whatever way improves the condition of the poor, ideally moving society towards poverty eradication. Ex: create a public sector program where wealthier households with extra bicycles can donate bicycles for redistribution to poorer households lacking in bicycles, requiring contributions as necessary if needs are not met by voluntary measures alone
Capabilities Approach	Distribute types of bicycles and bicycle services such that all individuals have equal cycling capabilities – this means children's bikes for children, alternative designs for those who are differently abled, and rickshaw services for those who cannot ride a bike
Sufficientarian	Distribute bikes in a way that at least meets a sufficiency threshold – perhaps that has been set at a minimum of one bicycle per household (rather than one per person), or rickshaw service for all at a level of frequency and coverage that meets the basic needs of all for basic cycle transport. So long as basic needs are met, people can own as many and as nice bicycles as they want
Prioritarian	Distribute bicycles (and/or bicycle services as welfare needs dictate) beginning with the least well-off
Intuitionism	A morally-minded person should assess the situation, consider alternatives (such as those laid out above), and take whatever course of action seems just within the context of a given situation

2.4 Equity in Transportation: how the conceptual space has been filled

This section reviews the various ways in which transportation authors have attempted to fill the conceptual space generated by equity. Within the transportation literature, various theories of equity have been discussed and applied, sometimes by name and sometimes by definition. Table 4.1 presents a collection of works within the transportation literature that have fundamentally informed the transportation equity discussion to date to demonstrate the variety of theories considered. This section is not a comprehensive review of every transportation paper that considers equity, but it does present the range of philosophical theories of equity considered implicitly and explicitly within US and Euro-centric transportation literature. Works are presented in order of publication date and are included because they have been cited extensively and/or serve as readily accessible resource guides for practitioners.

In some cases, the definitions presented within the transportation literature differ from the philosophical definitions presented in Section 3. To account for this, philosophically precise terminology is associated with each definition found in the literature. In some cases, categories defined by authors mirror philosophical terms (such as ‘egalitarianism’ or ‘Rawlsian’) but are not always defined in a philosophically precise manner. Table A.1 in the Appendix presents the studies in greater detail, documenting the exact definitions and scope of transportation application. In both tables the rows that present peer-reviewed journal articles are white, and all derivative works (namely books and reports) are gray. Both types of works are cited because both types are utilized by transportation professionals.

Table 4.1 *A summary of theories considered explicitly and implicitly in transportation literature that discusses equity.*

Theories Considered	Simple Equality	Formal Equality	Proportional Equality	Utilitarian	Libertarian	Marx	Smith	Pareto	Rawls	al-Sadr	Capabilities Approach	Sufficientarian	Prioritarian	Intuitionism
(Khisty, 1996)		X^{e}		**X**		E			**X_{dp}**	E	E	X	E	
(Litman, 2002, 2011, 2016, 2018, 2020)		H^{Ee}				V			V	V	V		V	
(Thomopoulos et al., 2009)	E			**X**					**X_{dp}**					
(van Wee, 2011)				**X**					**X^{E}**		**X^{E}**	**X**		
(TRB Special Report 303, 2011)					X	X	X_{uf}							
(Walker, 2012)		X	X				X_{uf}							
(Thomopoulos & Grant-Muller, 2013)		X^{e} H		**X**	X	E			**X_{dp}**	E	E V	X	E V	
(Fol & Gallez, 2014)	E H^{Ee}			**X**		V			**X_{dp}** V	V	V		H^{Ee}V	H^{Ee}
(Lucas et al., 2016)									**X**			**X**		
(Di Ciommo & Shiftan, 2017)				H		V				V	V		V	
(Pereira, Schwanen, & Banister, 2017)				**X**	**X**				**X^{E}**		**X**			**X**
(Bills & Walker, 2017)	Ee	X H^{e}	**X**	**X**		X V	X_{sd}	**X**	**X_{dp}** V	X V	X V	X	X V	
(Martens, 2017)				**X**					**X**		**X**	**X**	**X**	
(Stewart, 2017)		V		V										
(van Dort et al., 2019)	X^{e}	H^{e}			X	V X	X_{sd}		V X	V X	V X		V X	
(Behbahani et al., 2019)	E	H^{e} X^{e}		**X**		V			V **X**	V **X**	V X	X	V	

If a cell is blank, the author(s) do not present the corresponding theory of equity in any way.

If a cell contains a letter, the author(s) have presented the theory in some manner. The letter(s) included in the cell and their formatting provide further detail about how the author(s) present the theory. For those that contain an X, the author(s) have at least presented the theory by definition, and if **X(bold)** is used, it means the author(s) presented the theory by definition *and* by name. If the cell contains another letter, it means the authors have described the corresponding theory of equity but refer to it by a different name. In these cases, H indicates they refer to the defined theory as horizontal equity, V means they refer to the defined theory as vertical equity. An E replaces an X when the author(s) refer to the defined theory as Egalitarianism. Superscripts of E and e denote the use of the term Egalitarianism and/or equality (respectively) within the definition given by the author(s). A subscript dp denotes when author(s) only define the difference principle rather than Rawls's broader theory of just distribution. uf denotes user-fee and sd denotes supply-and-demand and are used to differentiate between Smith's theories.

Bills and Walker's (2017) work maps equity theories to positive analysis methods and serves as a useful case study of the nomenclature used in Table 4.1. In their "equity standards", they define the broadest range of theories, providing precise, explicit names for proportional equality, utilitarianism, Pareto, and Rawls (p. 65). They do not, however, provide coverage of Rawls's full theory of just distribution, instead focusing on the difference principle. Given the positive-analysis focus of the paper, this makes sense – Rawls's difference principle provides a welfare function comparable to al-Sadr and a prioritarian approach, but distinct from other approaches such as utilitarianism or Pareto.

Specifically, Bills and Walker (2017) present Rawls as "Rawls-Utilitarianism" defined as "[p]roviding the greatest level of benefits (utility) to those who are the most disadvantaged" (p. 65). Because it is defined in terms of benefits (utility) rather than physical capital, it is a departure from Rawls's difference principle; because it is presented in terms of utility, the utilitarian qualifier is precise albeit unique. Similarly, they define simple equality in terms of benefits and call it "Egalitarianism/Equality" (p. 65) – this is a departure from the core concept of simple equality which assumes physical capital and expands the realm of interpretations to include valuations such as utility. Bills and Walker (2017) also define a potential equity function that follows the principles of Smith's theory of supply and demand but do not name the theory explicitly, instead naming it "Market-based" equity (p. 65). Additionally, Bills and Walker (2017) specify "Equity Dimensions" also referred to as "Population segmentation" (p. 62). They use the definitions and names 'vertical' and 'horizontal' – the use of these dimensions within the transportation literature is discussed in Section 4.2.

Table 4.1 demonstrates a number of themes and trends within the transportation equity literature that are further explored in the subsections below. Concerning libertarian definitions, only Pereira, Schwanen, & Banister (2017) explicitly define and name libertarianism in their work, focusing on a Right-leaning version of libertarianism. Both the TRB Special Report 303 (2011) and van Dort et al. (2019) highlight public participation as a form of equity ("participatory") in and of itself. Or, more accurately, public participation provides a means by which those impacted by transportation and land use decisions can make their voices heard, presumably resulting in more equitable end results. This mirrors the Left-leaning libertarians (defined in Section 3) who hold that, when government intervention is deemed just, strong public oversight with clearly-defined rules of engagement is necessary to ensure an equitable result. Thomopoulos and Grant-Muller (2013) also present a Left-leaning, partial version of libertarianism with their environmental equity type. As with any other partial presentation of a theory (with the exception of Rawls), libertarianism is not named outright nor defined in full.

2.4.1 Egalitarianism, equality, Rawls, and al-Sadr in the transportation literature

Khisty's (1996) work provided an early attempt at applying fundamental theories of ethics to transportation alternatives analyses. In his paper, he defines six transportation-relevant theories of equity (Khisty, 1996, p. 95). He defines egalitarian policies as those that "reduce any existing social or economic inequalities" to benefit "income groups that are truly in need" (Khisty, 1996, p.96). The language used in this definition touches on a few theories; the focus on income groups in need is a concept echoed by Marx, al-Sadr, and prioritarians, therefore each of these theories is marked with an 'X' in Table 4.1. This definition, however, only captures a portion of these ideologies; it only partially captures the work of Marx because it does not explicitly factor in ability (i.e. from whom do the resources come), and only partially captures the work of al-Sadr because the focus on those in need is not explicitly placed in the context of the broader Islamic belief in poverty as an injustice. This definition is most similar to prioritarianism which, by definition, is not egalitarianism. While both are concerned with the distributions of ends, a truly egalitarian definition would call for *the eradication of* "any existing social or economic inequities" (Khisty, 1996, p.96). Instead, Khisty uses the word "reduce," which is more consistent with contextually-aware prioritarianism than a-historical egalitarianism.

This imprecise use of "egalitarianism" is mirrored by Litman (2002), Thomopoulos and Grant-Muller (2013), Fol and Gallez (2014), and Behbahani et al. (2019); Thomopoulos and Grant-Muller (2013) cite directly from Khisty (1996) to specify their "Equity principles" (p. 325). In all of these cases, Rawls is presented as an alternative to egalitarianism despite the fact that Rawls's theory of justice, taken in its full form, is inherently egalitarian. Beyond the assumption of moral equality, Rawls also assumes equal opportunity among rational, self-interested actors. Rawls's theory is unique because he reaches the difference principle as a logical conclusion to an argument based on these a-historical egalitarian assumptions. Therefore the confusion is twofold; the authors' oversimplify egalitarianism and, in their focus on Rawls's difference principle, they lose sight of Rawls's broader, egalitarian theory of justice.

The authors do, however, define egalitarian theories that are distinct from Rawls's; formal equality (Litman, 2002), simple equality (Fol & Gallez, 2014; Behbahani, 2019), and proportional equity (Walker, 2012; Bills & Walker, 2017) are all presented in theory but, with the exception of Bills and Walker (2017), not by precise name. Sometimes they are titled as 'egalitarianism' or 'equality' and sometimes the terms 'egalitarianism' or 'equality' are used within the definition as demonstrated in Table 4.1. Formal equality is assigned where authors define equity in terms of resources distributed equally for any reason of equality that is not exclusively an individual's humanity; when that is the case, simple equality is specified.

Van Wee (2011), Lucas et al. (2016), and Pereira, Schwanen, and Banister (2017) also reference "egalitarianism" in their work, however they handle it precisely. Van Wee discusses the egalitarian theories of Rawls and Sen (capabilities approach), contrasting them with utilitarianism and sufficientarianism. Lucas et al. (2016) focuses on Rawls's difference principle, also accurately contrasting it with sufficientariansim, while Pereira, Schwanen, and Banister (2017) reasonably refer to the work of Rawls as "Rawls's Egalitarianism" (p. 172).

While the majority of works reference Rawls, only van Wee (2011), Martens (2017), Pereira, Schwanen and Banister (2017), and Behbahani et al. (2019) present and consider more than the difference principle. This places the works that focus exclusively on the difference principle closer to al-Sadr than Rawls; while the logical validity of Rawls's difference principle depends on the assumption that all individuals are operating in their best interest within a universally agreed-upon social order, al-Sadr's ideals of prioritarian distribution rest on a fundamental pillar of Islamic belief which dictates that poverty is morally unjust within societies with enough resources to eradicate it.

Concerning al-Sadr, Behbahani et al. (2019) provide a uniquely insightful overview of equity theories. While they present similar imprecisions in their handling of "egalitarianism" and "equal sharing", they classify the theories of equity they present within broader, historical social movements of Ancient Europe (from Plato through the Middle Ages), Christianity, Socialism, Liberalism (Deontological and Utilitarian), and Islam. Further, they suggest equations to operationalize the equity theories they present for use in positive, distributional analyses.

2.4.2 The imprecise use of the terms 'Horizontal' and 'Vertical' equity

While categorization can be helpful to distill and present complex concepts, inconsistent attempts to categorize theories of equity along the dimensions of 'horizontal' and 'vertical' have created an additional source of confusion within the transportation literature as demonstrated in Table 4.1. In line with Musgrave and Musgrave's (1989) book *Public Finance in Theory and Practice*, these dimensions appeared in the first edition of Litman's report "Evaluating Transportation Equity" which was published online in 2002. Since then, versions of this report have been updated periodically with old versions taken down and replaced each time; the most recent edition was published June 5, 2020. While the document is updated regularly, his definitions of horizontal and vertical equity have not changed. Many (though not all) authors from Table 4.1 cite versions of Litman's report from 2002, 2011, 2016, and 2018 directly in their specification of horizontal and vertical equity.

Litman (2002) defines horizontal equity as "equal treatment of equals … also called fairness and egalitarianism" (p. 2). The imprecise qualifiers of "fairness and egalitarianism" were removed from the 2016 definition, however the broader definition presented in 2011 and onward states that the equal treatment of equals horizontal equity definition "implies that people should 'get what they pay for and pay for what they get,' unless a subsidy is specifically justified" (p. 2). This broadens the definition to include Smith's user-fee definition of equity and even opens the door to prioritarianism via an intuitionalist qualifier. With the exception of Fol and Gallez (2014), most of the authors who cite Litman (2002, 2011, 2016, 2018) focus on the formal equality definition of equal treatment of equals in their definition of horizontal equity; Fol and Gallez (2014) (citing Litman, 2011) instead specify simple equality along with prioritarianism via the same intuitionalist qualifier.

Litman (2020) defines vertical equity as requiring “that the allocation of benefits and costs favors disadvantaged people” and is broken out into two subcategories of “Vertical With-Respect-To Income And Social Class” and “Vertical With-Respect-To Need And Ability” (p. 2). The authors who define vertical equity based on a citation of Litman (2002, 2011, 2016, 2018) are consistent in this definition, with Fol and Gallez (2014) retaining the subcategorization distinction while other authors simply present a single definition of vertical equity that encompasses both subcategories (Bills & Walker, 2017; van Dort et al., 2019; Behbahani et al., 2019).

Then there are authors who do not cite any version of Litman’s work but who do define equity concepts in terms of ‘horizontal’ and ‘vertical’. Thomopoulos and Grant-Muller (2013) specify horizontal and vertical “equity types” that mirror Litman’s (2002, 2011, 2016, 2018) but are constrained by virtue of their focus on regions rather than on people; the theories of Marx, al-Sadr, and Rawls are argued exclusively in-terms of people whereas the capabilities approach and prioritarianism can be applied more broadly. Di Ciommo and Shiftan (2017) define horizontal equity as “the current, utilitarian method of transport evaluation” and they do not make specific reference to income, positions, or ability in their definition of vertical equity, instead focusing exclusively on need (p. 141). Stewart’s (2017) work only refers to vertical equity and offers a definition that resembles formal equality and utilitarianism.

2.4.3 Utilitarianism in transportation: explicit and implicit

After Rawls, utilitarianism is the second most defined *and* named theory within the transportation literature. Compared to Rawls, however, utilitarianism is more readily distilled and has been consistently defined with precision within the transportation literature. Not only that, in some cases transportation authors have built upon the underlying theory of utilitarianism. Behbahani et al. (2019) specifies a welfare function for a constrained benefit range utilitarian theory in addition to presentations of utilitarianism and al-Sadr. Van Wee's (2011) handling of utilitarianism is unique and extensive; he discusses the impact of utilitarianism on transportation decision making through Cost Benefit Analyses (CBAs).

As Thomopoulos et al. (2009) recognize, the equity theory of utilitarianism underpins the concept of CBA. Because it focuses "only on the aggregate welfare", it "often does not account for the welfare loss of certain groups or regions" (Thomopoulos et al., 2009, p. 353). Therefore, even if CBA is the existing, codified method of appraisal, that does not necessarily mean that all (or potentially any) stakeholders agree with purely utilitarian principles in transportation.

Concerns with CBA abound in the transportation equity literature; the majority of the works listed in Table 4.1 includes some discussion regarding the ethical limitations of CBA. Martens and Di Ciommo (2017), Pereira, Schwanen, and Banister (2017), and Nahmias-Biran et al. (2017) all argue that CBA is not an appropriate form of analysis for transportation due to its utilitarian roots. In his book *Transport Ethics: Ethics and the Evaluation of Transport Policies and Projects*, van Wee provides a checklist to determine when CBA is useful in policy decisions, noting that:

> "A CBA might provide a reasonable basis for decision making in cases where the winners and losers are more or less equal in their ability to pay, and when it is clear who the winners and losers are, and to what extent they win and lose. In addition, it may be

used where uncertainty about dominant consequences is limited, and where the kinds of reasons recommending different policies are widely understood." Outside of these areas, they suggest that "[a]pplying CBA for comparisons of, for example, investments in roads versus on-demand bus or taxi transport for isolated regions, can be more problematic, and at least requires a check on ethical dimensions" (van Wee, 2011, p. 48).

Essentially, inherently utilitarian CBA analyses are acceptable in transportation only if they operate within a context that has already been subjected to an initial equity assessment.

This contextual check is critical, especially when applying a-historical theories of equity. While the planning of transportation systems cannot be expected to correct for all experiences of disparities in society, transportation has created and can contribute to the perpetuation and exacerbation of disparities (Sanchez, 2018; van Dort et al., 2019; van Wee, 2011). In the second chapter of his book on transport justice, Martens (2017) provides an extensive argument to demonstrate how "traditional transportation planning … result[s] in a vicious cycle, which at best maintains existing differences in all dimensions and at worst leads to a continuous growth in inequalities in terms of travel speed, potential mobility, accessibility and revealed mobility, between persons with access to, and persons excluded from, the dominant car-road system" (p. 31). Within this context, seemingly objective tools such as CBA are more likely to actively reinforce disparities in transportation resource distribution.

2.4.4 Other ethical theories implied in transportation: discussion and new frameworks

While analyses that employ CBAs imply the ethical theory of utilitarianism, many recent works within the growing space of transportation equity literature also present implied normative theories. This occurs when author(s) present positive analyses in a way that implies an equity norm; analysis methods themselves imply norms and are often paired with policy recommendations.

For example, recent studies present positive analyses of existing distributions of benefits and burdens of new mobility services. Jin et al.'s (2018) study of New York City found that ridehailing services largely compete with transit where there is good transit coverage and complement transit where there is not, however it demonstrates fewer pickups in low-income areas and a negative correlation between pickups and minorities. Jiao and Wang (2019) also assess shared mobility services in New York and conclude that "without effective and appropriate policy and planning guidance, shared mobility may exacerbate transport equity issues" (p. 1). They base this assessment on the high concentration of ridehailing activity serving parts of the city with higher-income, less transit-dependent residents.

These studies present positive analyses of comparative ridehailing resource distribution between population groups segmented by income, transit dependence, and race. Upon finding that ridehailing provides more mobility to individuals who *already* have more mobility options (higher-income, less transit-dependent, white individuals), they suggest that inequity is a concern. The present state of transportation resource distribution is deemed inequitable in some way (i.e. lower-income, transit-dependent, minoritized individuals do not have enough), then they find that the shift with ridehailing exacerbates this base case difference in transportation resource distribution between groups. Essentially breaches of sufficientarian and capabilities approach is implied, and/or a concern under al-Sadr and prioritarian theories.

Henao et al.'s (2019) report on the distributional effects of ridehailing in the Denver, Colorado region finds that services such as Lyft, UberX, LyftLine, and UberPool have an average vehicle occupancy of 0.8 passengers and increase vehicle miles traveled (VMT) by approximately 83.5% when accounting for deadheading and mode shifts, and a gross wage average of $15.57 per hour for drivers resulting in net hourly wages between $5.72 to $10.46 per hour when accounting for expenses.

Henao et al. (2019) suggest that the VMT findings are in-line with “equity issues” identified by advocates concerned about increased congestion in cities like New York and San Francisco and cuts to transit budgets in favor of ridehailing services in mid-sized cities across the US (p. 1). Concerning the driver wage assessment, the authors state that “[e]quity – and decent wages – for millions of drivers is at the core of this topic” (p. 62). Essentially, this report presents the effects of ridehailing services and assumes readers will view them as proof of the inequity of ridehailing services; while “Equity” is stated in the title, *in*equity is implied. The language surrounding ridehailing suggests an imbalanced proper or proportional equality ideal, and the conversation regarding the driver’s wages suggests an infringement on sufficientarian justice.

Similarly, and in the interest of transparency, it is worth noting that past work by the authors of this article has similarly included implied equity norms. Hughes & MacKenzie (2016) refer to "equity of access" but do not define equity explicitly. The implied definition is one of formal equality along regional lines: it is reasonable for people to wait longer for an Uber in low-density areas, but waiting times should not depend on the income levels or racial composition of a neighborhood. The article focuses on the positive, distributive effects analyses of Uber wait times, but it implies certain equity norms in the population segmentation used in the analysis as well as in the discussion used to present results.

Shaheen et al. (2017) and Wong et al.’s (2020) studies focus on developing a new framework for the positive analysis component of equity assessments along with associated policy recommendations. Shaheen et al. (2017) present the STEPS framework which identifies five dimensions that must be considered within an equity assessment: Spatial, Temporal, Economic, Physiological, and Social. Wong et al. (2020) expands on the STEPS framework by defining 18 vulnerable groups that fall on multiple STEPS dimensions to assess shared resource opportunities for members of those vulnerable groups in the event they need to evacuate due to a natural disaster. Their paper presents extensive discussion about the barriers faced by these groups and targeted policy recommendations to increase transportation options among these groups. They essentially present a more precise, carefully-developed, and transportation-relevant alternative to the generic dimensional categories of ‘horizontal’ and ‘vertical’.

Both Shaheen et al. (2017) and Wong et al. (2020) use positive methods to define and focus attention on populations already experiencing disparities in transportation resource distributions and access. They focus on how these populations face barriers to shared mobility access and how policy might address this. Similar to the works of Henao et al. (2019), Jin et al. (2018), and Jiao and Wang (2019), these papers imply inequity based on equity assessments in line with a capabilities approach, al-Sadr, prioritarianism, or sufficientarianism.

Because the concept of accessibility is inherently concerned with the opportunities for travel rather than on travel itself, studies that measure accessibility imply a capabilities approach. Most studies are concerned with cases where citizens fall below some sufficientarian or prioritarian levels, typically presenting this with terms such as social exclusion (Church et al., 2000; Wixey, 2005; Preston & Rajé, 2007; van Wee & Geurs, 2011; Lucas, 2012; Fol and Gallez, 2014; Everuss, 2019) or transit captivity (Rutherford and Wekerle, 1988; Polzin et al., 2000; Sanchez et al., 2004; Clifton, 2004; de Vasconcellos, 2005; Golub and Martens, 2014).

2.4.5 Explicit equity: normative arguments and theories specific to transportation

In addition to providing precise presentations of ethical theories related to transportation, the works of van Wee (2011), Lucas et al. (2016), Martens (2017), and Pereira, Schwanen, and Banister (2017) offer precise presentations of ethical theories related to transportation, and normative arguments regarding how these theories *should be* applied. Pereira, Schwanen, and Banister's (2017) article was published alongside articles by Nahmias-Biran et al. (2017) and Martens and Di Ciommo (2017) in a special issue of *Transport Reviews* on Equity in Transportation. All three ultimately argue that a capabilities approach should be used in transportation planning; both Nahmias-Biran et al. (2017) and Martens and Di Ciommo (2017) use example cases where they compare this approach against the standard, utilitarian assessment method of CBA.

However, of the works listed in Table 4.1, Martens's (2017) book *Transport Justice* is unique. He draws on a variety of just society theories to propose a justice theory specific to transportation. Over the course of eight chapters of reasoned, normative argument, he defends the rather simple and intuitive thesis that "a transportation system is fair if, and only if, it provides a sufficient level of accessibility to all under most circumstances" (Martens, 2017, p. 215).

Martens's (2017) definition of transport justice is a combination of prioritarian- and sufficientarian-constrained capabilities approaches, or what he refers to as a refined prioritarianism. He notes that a just transportation system ultimately requires "real-life agents engaged in democratic deliberation … to distinguish three domains of the accessibility spectrum: a domain of clearly insufficient accessibility, a domain of clearly sufficient accessibility, and a domain of disagreement" (Martens, 2017, p. 172). Per sufficientarianism, transport falling within the domain of 'clearly insufficient' is the responsibility of the state to rectify through resource redistribution methods whereas transport in the ‘clearly sufficient’ range is subject to market-based distribution so long as they do not cause harm. While the domains of ‘clearly insufficient’ and ‘clearly sufficient’ could be recognized and codified within broader policy statements for consistent application across transport projects, the specific details of any project will likely require additional, democratic engagement to manage distributions within the ‘domain of disagreement’, because this domain is fundamentally the result of the different theories of equity applied (consciously or subconsciously) by different individuals within society.

Martens (2017) then spends the ninth chapter of his book presenting a case study of Amsterdam’s transportation system to demonstrate how his theory of transport justice can be operationalized through positive analysis methods. The tenth and final chapter of the book discusses transportation financing and fair taxation in general as well as justice considerations relative to congestion within the context of the theory of transport justice. In its entirety, Martens’s (2017) *Transport Justice* presents a normative, transportation-specific theory of justice, a positive methodology to apply it, and its implications.

In addition to Martens’s (2017) theory of transport justice, theories of mobility justice and spatial justice have also been put forth. Proponents of mobility justice and spatial justice argue that Martens’s (2017) theory of transport justice is limited by a “narrow focus on transport and urban environments and their oversight of the historical antecedents and embodied aspects of mobility systems” (Everuss, 2019, p. 3). Rather than constructing a philosophical theory of justice, Sheller’s (2018) book *Mobility Justice* presents the ways in which racial, infrastructural, migrant, and climate injustices limit the capabilities of individuals in ways not necessarily accounted for within Martens’s (2017) theory of transport justice. To address this, mobility justice “concerns overturning marginalization and disadvantage through intentional inclusion of the excluded in decision making and elimination of unfair privilege. It puts ‘oppressed’ and ’disenfranchised’ groups front and center” (Sheller, 2018, p. 28).

Transport justice and mobility justice are both fundamentally prioritarian and largely complementary theories, they differ, however, in focus. Transport justice emphasizes positive methods to identify distributional effects disparities and the relevant domains in which informed democratic engagement should occur. Instead of focusing time and energy on positive measurements of these existing distributional disparities, mobility justice advocates for immediate and prioritized engagement with known marginalized groups to inform the planning process. Mobility justice argues that, because marginalization is often a product of prejudices held in the majority against those in the minority, basic democratic engagement may reinforce rather than alleviate disparities.

Within the realm of spatial justice, non-motorized mode advocates often focus on the distribution of public right of way (ROW) by mode as an indicator of transportation network fairness. In an application of these concepts, Shi, Wu and Jin (2010) argue that Beijing should implement reforms to redistribute space away from private-vehicles and toward transit-oriented development using a combination of capabilities approach and Marxian principles. They then support their argument with a cluster analysis method to present a positive comparison of physical space allotted to private cars, taxis, and buses within a range of cities in China. They also assess public perceptions of the BRT line in Beijing to find that residents were satisfied with the service, exhibiting a form of public participation to support their argument. Shi and Zhou (2012) also present a series of distributional analyses that are paired with a clearly articulated equity assessment. Based on a review of Rawls, they argue that it is inequitable for the current transportation system to provide greater benefits to vehicle-owning individuals who take up a larger share of the public space with a larger impact on the environment, and therefore lower-income, transit-captive individuals who take up a smaller share of public space with a lower impact on the environment deserve some compensation.

There are, however, compelling arguments to demonstrate that this purely spatial assessment is inherently limited and deficient (Nello-Deakin, 2019). Nello-Deakin (2019) argues that such assessments simply pit modes against each other while ignoring the inherent properties that make each mode unique and useful under different conditions of transportation need and want. Instead, he proposes speed as a better tool to achieve transportation facilities that are fair to a range of modes and therefore user needs and interests. This method requires that a city be divided into corridors predominantly intended for faster, motorized modes, corridors for transit only, and zones with 15 mile per hour maximum speeds. Additionally, public education of rules of the road for non-motorized as well as motorized modes is required under this conceptualization of a just transportation system so that all modes might intermingle safely and efficiently. Essentially, he proposes a proper equality distribution of speed constraints on all modes in a given facility once facilities have first been separated based on considerations of the capabilities approach and prioritarianism.

Additional normative arguments relative to transportation equity exist in the overlap between the transportation and environmental justice literature (Bullard, 2003; Sanchez, Stolz and Ma, 2003; Sanchez and Wolf 2005; Beiler and Mohammed, 2016). In fact, Karner et al. (2020) create a distinction between "transportation justice" vs "transportation equity", noting that "[t]he justice framing is more common among activist groups and nongovernmental organizations… while the term equity is more commonly used by state actors" (p. 2). The authors note that these are echoed in the environmental justice literature where a similar shift in language and framing occurred in the early 1990s.

The connection between transportation and environmental justice are explored in detail relative to governance and the application of relevant sections of the Civil Rights Act. Bullard (2003) focuses on legal and policy considerations, while Sanchez and Wolf (2003) review the role of metropolitan planning organizations (MPOs) in addressing injustices. Additionally, Sanchez, Stolz and Ma (2003) present a series of positive assessments in the Los Angeles region to support the claim of inequity. Karner (2016) highlights the relationship between transportation (in)equity and environmental justice policy, exploring both disparities in distribution of emissions and resources, comparing regions in California and finding that lower-income, minority neighborhoods tend to bear the burden of higher emissions while receiving lower investments per capita.

To address these injustices, these studies present policy recommendations at a minimum. Sanchez and Wolf (2005) emphasize the importance of having the communities facing environmental injustice actively engaged and participating in processes to address those inequities. Karner & Marcanonio (2017) present a model to engage in a meaningful way with historically underserved populations as well as an argument for dedicated funding to meet those needs.

These theories and works are predicated on the assumption that the transportation good, in its present form, is inequitably distributed. The foreword of Lucas et al.'s (eds., 2019) book *Measuring Transport Equity* explicitly states that the goal of the book is not to convince readers that transportation inequities exist, it is to address the inequities that are understood to exist. Sanchez's (2018) book presents a comprehensive history of exclusionary practices within transportation and land use planning and practice in the US along with data exploring the inequities faced by individuals of lower-income, black, indigenous, and people of color (BIPOC), those with limited English proficiency (LEP), and those who are aging or otherwise limited in physical or cognitive ability. Prominent examples include the racial discrimination of redlining from the 1920s through the 50s and within the planning process of the interstate highway system (Woods, 2012; Karas, 2015).

Theories of mobility justice, spatial justice, and environmental justice explicitly seek to address historical injustices, emphasizing prioritarian participation to do so. The theory of transport justice does not begin with injustice but presents arguments and positive assessments that can be used to identify and rectify existing disparities. All four theories are transportation-specific and recommend public engagement in some form.

2.5 Conclusion

Researchers and practitioners have begun to recognize transportation as a unique societal good with properties similar to education and healthcare; like education and healthcare, transportation affects an individual's access to goods, services, and opportunities. As a result, decisions related to transportation systems embody ethical value judgements and are therefore inherently normative.

While the concept of equity has been a popular topic within transportation for decades, careful treatment of the theoretical space generated by the normative concept of equity is only a recent development. In a field dominated by positively-trained analysts, many works on transportation equity are less about the normative analysis of equity and more focused on presenting distributional effects analyses. More accurately, these works can be viewed as equity analyses in which author(s) filled the conceptual space intuitively with some implicit concept of equity.

In many cases, use of the term equity it is intended to imply that the existing state of transportation is *in*equitable. Given the evidence, such assessments are not only reasonable, but because equity is an inherently normative concept, such value judgements are required to differentiate an equity assessment from a distributional effects analysis. While equity assessments should be at least in part informed by positive information such as distributional effects analyses, they necessarily go beyond positive analysis.

Moreover, it is also important to recognize the normative value systems that positive assessment methods imply; whether one views them as equitable or not largely depends on one's normative beliefs and/or the context of the analysis in question. With this clearer understanding, perhaps misunderstandings can be circumvented or at least laid out and discussed in clearer terms. In particular, this article categorizes theories of equity based on their underlying assumptions so that researchers and practitioners might better understand how to reasonably apply these theories, or models, of equity.

Not every article employing a statistical model must present every basic statistical proof used to develop that model. Anyone employing a given model, however, should have some basic understanding of those proofs. Specifically, qualifying assumptions for potential models must be understood, explicitly stated, and adhered to for the application of a given model to yield reasonable results. While the internal logic of a given model remains valid, if the realities of a data sample stray too far from a model's underlying assumptions, the application of that model's logic to a data set that does not meet the underlying assumptions on which that model's logic is based will yield unreasonable analytical results.

The theories presented in this article are models of equity; while strict adherents to any of the models would say that their model always yields a reasonable assessment, a broader discussion of the concept of equity requires a broader lens. Each theory offers a set of sound logical arguments, but to determine whether or not it is reasonable to apply a particular theory to a particular situation, one must consider the underlying assumptions of the theory. For example, utilitarianism operates outside of historical contexts; while it offers a powerful, simple logic that is readily applicable, it is often applied without consideration for contextual realities. Specifically, in settings where historical disparities exist, utilitarian logic often exacerbates these disparities. Despite this, utilitarian ethics operationalized in Cost Benefit Analyses (CBAs) have been used extensively within the transportation profession.

Transportation is a fundamental societal service and functionally operates within the historical context of the time, place, and people. As a result, transportation researchers and professionals alike should employ healthy skepticism when employing ethical theories based on a-historical assumptions – while the argument structure of such theories may be perfectly logical in a vacuum, when contextual realities stray too far from the idealized, a-historical assumptions on which these theories are based, these logical structures may fail to provide reasonable, just solutions.

Given this, we recommend the following best practices for transportation professionals:

- Recognize that equity involves both positive analysis and normative value judgments.
- Explicitly state the normative criteria and associated assumptions used to evaluate equity. In particular, recognize the hazards and limitations of relying on a-historical theories of equity when working in such a content-dependent setting as transportation.
- Define theories and categories with precision; while it is not critical to employ the specific jargon of the philosophy literature, it is important to avoid misusing terms with established meanings. Borrowing terms but applying them to our own concepts creates

confusion and hinders effective communication and solution development. Similarly, theoretical categories should be named with as much precision as possible. For example, generic categorizations such as horizontal and vertical leave too much room for interpretation and can generate confusion; in contrast, categories based on established concepts such as types of capital, historical context, space, time, etc. are less prone to misuse and confusion.

The concept of equity is expansive. This article covered a subset of predominantly western, contemporary philosophical theories of equity. Most are specified assuming physical capital; while physical capital is a critical component of the transportation resource (i.e. you need money to pay for buses, bus stops, and their various operations costs), so is human capital (i.e. you need knowledgeable professionals to operate the system in a manner that efficiently utilizes available physical capital). Additionally, the transportation resource impacts physical, human, and social capital. Transport justice, mobility justice, and spatial justice present transportation-specific ethical theories that account for this unique, complex nature of transportation as a resource. Initial positive analysis frameworks and welfare functions have been defined and offer useful starting points, but the work to fill the space of transportation equity has just begun. Future research is needed not only to explore the practical implications of equity theories for transportation policy and design, but to further refine equity theories specific to the transportation resource.

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Chapter 3: Exploring indices

This chapter will be submitted for publication:

Lewis, E. O. C., Meunch, S., & Gordon, B. (tbd). Exploring indices: theoretical and methodological analysis of cumulative impact indices with practice-oriented recommendations. *tbd.*

3.1 Introduction

As demonstrated in Chapter 2, equity as a concept considers both the distribution of benefits as well as burdens within society. A facet of transportation equity is therefore a consideration of the distribution of negative externalities such as traffic fatalities and emissions. In the environmental and health spaces, the concept of assessing and seeking equitable remediation of environmental burdens is known as environmental justice (EJ). By the 1980s, EJ was established as a social justice movement seeking remediation of environmental burdens that have been disproportionately located in and near socially vulnerable populations (Cutter, 1995). Prior to the proliferation of computing power and data access in the 2000s, providing computational proof of disproportionate environmental burdens was a difficult task relegated almost exclusively to the academic research space. However, once the tools and data became increasingly accessible, state and federal agencies began to develop analytical tools in addition to ongoing research efforts (Lee, 2021). One such tool is the cumulative impact indicator.

Cumulative impact indicators (or indices) convert any set of variables deemed relevant measures of impact(s) of interest into a single, composite value that can be used to measure relative disadvantage over a region or between groups. Variable selection depends on the goal of a given index, but for publicly maintained indices, data must be readily available and regularly maintained (Lee, 2021). Indices follow a common set of methodological components that determine their structure: data re-scaling, weights, hierarchy, and aggregation (Nardo, 2005). For each methodological component, a decision must be made regarding which mathematical method will be applied. For example, data re-scaling could involve z-score normalization, min-max scaling, decile ranking, or any number of other methods. Once all analytical decisions are made and a single, composite score is calculated, scores can either provide a range of (dis)advantage from least to most, or a threshold value can be applied to the distribution to yield disadvantaged/not disadvantaged assignments. This chapter explores these indices through the following set of questions:

- How can the theory of intersectionality inform best practices for cumulative impact index specification?
- Are existing cumulative impact indices more likely to designate urban tracts as disadvantaged compared to rural tracts?
- How should practitioners approach existing indices?

As presented in Chapter 1, the Environmental Health Disparities (EHD) map is a Washington State Department of Health (DoH) data product that was developed as part of the HEAL Act implementation process (WSIPP, 2022). The Equitable Transportation Community (ETC) Explorer tool was developed by the U.S. Department of Transportation (USDOT) as part of Executive Order 14008 and the associated Justice40 initiative to curb climate change and address EJ issues at the federal level (OST, 2023). Both indices offer a single, composite value based on readily accessible and regularly updated spatial data used as a proxy for disadvantage. Once scores and rank-based values are calculated, both apply threshold values (60th and 80th percentile for the EHD and 65th percentile for the ETC) to ultimately designate a tract as disadvantaged or not. These designations are then used to inform prioritization decisions related to funding and programs.

Lee (2021) found that, while many states utilize the EPA's EJScreen tool, they often do it in tandem with their own state's version of CalEPA's CalEnviroScreen (Lee, 2021). The difference between the two tools lies in the variables considered and index construction. Like most states, the EHD follows the CalEnviroScreen model (WSIPP, 2022). In addition to the EPA's national-level EJScreen mapping tool, other federal agencies have followed suit with their own cumulative impact indices and tools. While some indices serve overlapping purposes and most use at least some of the same variables, they often use different data rescaling and combination methods.

Tate (2012) defined uncertainty and sensitivity as two means of assessing social vulnerability indices. Uncertainty asks how accurate is the composite indicator? Sensitivity asks what are the key factors driving uncertainty? Accuracy of cumulative impact indices can be difficult to ascertain since their purpose is to quantify concepts that buck quantification. The theory of intersectionality is used to explore this issue of accuracy from a theoretical perspective. Sensitivity, however, is more readily assessed. Frostad (2023) assessment of Washington State's EHD demonstrated its sensitivity and identified factors driving this sensitivity in general. This analysis expands on Frostad's (2023) by providing a targeted assessment of both the state-specified EHD and the federally-specified ETC relative to the concept of urban and rural areas.

This chapter begins with a review of cumulative impact indices; what they are, how they relate to the Washington State HEAL Act, their methodological assumptions, and examples from the academic literature and from practice. A set of publicly maintained indices are presented in detail for comparison and for assessment relative to the legal theory of intersectionality. The two indices of WA's EHD and the USDOT's ETC are then analyzed to identify how the methodological assumptions influence index outcomes relative to urban/rural census tract classifications. This work was supported by the Washington State Department of Transportation (WSDOT) Equity in Planning research project, thus the focus on WA's HEAL Act and associated EHD.

While the bulk of the analytical results focus on this Washington State context and the WA EHD and USDOT ETC specifically, the methodology developed is broadly applicable. All code and data used in the analysis are available at the author's github[7]. Ultimately, this analysis provides transportation practitioners with a greater understanding of the relative strengths and limitations of cumulative indices and lays out best practices for their application and specification considering insights offered by the theory of intersectionality.

3.2 A review of cumulative impact indices

This section provides a review of cumulative impact indices, beginning with how they relate to the broader concept of cumulative impact analyses defined in the HEAL Act. This is followed by a review of the methodological process used to specify a cumulative impact index and a review of indices found in the transportation equity academic literature. Finally, a critical review of cumulative impact indices specified by public entities in the US is presented. Taken by itself, this section provides insights and guidance for use in index specification and application. In the context of this chapter, it provides the necessary language and concepts used in the subsequent analysis of two specific indices: Washington State's Environmental Health Disparities (EHD) and the USDOT's Equitable Transportation Communities (ETC) Explorer.

While many still question the ability of state actors to enact systemic change, most still recognize the importance of state buy-in to achieve EJ goals (Karner et al., 2020). Specifically, the development and use of cumulative impact maps by state agencies has been lauded as a win

[7] https://github.com/elyseoc/transpoequity_indices

for the broader EJ movement (Lee, 2021). While these mapping tools have their limitations, they serve as a useful first step in quantifying and screening areas based on a composite set of considerations. For example, because EJ is primarily concerned with the intersection of socio-economic marginalization and environmental degradation (specifically relative to human health risk), EJ-focused cumulative impact indices seek to measure and identify areas where both conditions (marginalization and degradation) exist (Lee, 2021). These indices can then be visualized using maps, plots, and other data analysis methods to identify and prioritize remediation efforts where harm and associated risk is highest.

This section first presents the WA HEAL Act, highlighting the inclusion of cumulative impact analyses in Washington State law. The following subsection lays out the concept of cumulative impact indices (a subset of cumulative impact analyses), detailing the mathematic assumptions involved in index specification. Next, indices in the transportation equity academic literature are reviewed with specific attention paid to data normalization methods. Finally, a review of cumulative impact indices specified with regularly updated, large scale, publicly available data and maintained by public entities in the U.S. is presented.

3.2.1. Cumulative impact analyses are specified within the Washington State HEAL Act

WA SB 5141 passed in 2021 and requires seven state agencies (including WSDOT) to build on and implement key recommendations from the state's Environmental Justice (EJ) Task Force. Key elements include:

- Incorporating EJ in agency strategic plans
- Developing community engagement and tribal consultation frameworks
- Conducting EJ assessments for certain significant actions
- Focusing 40% of expenditures for overburdened communities and vulnerable populations
- Evaluating and tracking environmental health disparities with the Environmental Health Disparities (EHD) cumulative impacts map

The WA Department of Health (DoH) is held responsible for maintaining and updating the EHD. Additionally, the HEAL Act provides the following definitions for overburdened and vulnerable groups:

(11) "**Overburdened community**" means a geographic area where vulnerable populations face combined, multiple environmental harms and health impacts, and includes, but is not limited to, highly impacted communities as defined in RCW 19.405.020.

(14)(a) "**Vulnerable populations**" means population groups that are more likely to be at higher risk for poor health outcomes in response to environmental harms, due to:

(i) Adverse socioeconomic factors, such as unemployment, high housing and transportation costs relative to income, limited access to nutritious food and adequate health care, linguistic isolation, and other factors that negatively affect health outcomes and increase vulnerability to the effects of environmental harms; and
(ii) sensitivity factors, such as low birth weight and higher rates of hospitalization.
(b) "Vulnerable populations" includes, but is not limited to:
(i) Racial or ethnic minorities;
(ii) Low-income populations;
(iii) Populations disproportionately impacted by environmental harms; and
(iv) Populations of workers experiencing environmental harms.

(RCW 70A.02.010)

Overburdened community includes "**Highly impacted community**" means a community designated by the department of health based on cumulative impact analyses in RCW 19.405.140 or a community located in census tracts that are fully or partially on "Indian[8] country" as defined in 18 U.S.C. Sec. 1151 (RCW 19.405.020 (23)).

The legal definitions of over-burdened, highly impacted, and vulnerable communities explicitly reference tribal communities and provide the minimum guidelines for communities

[8] while the word "Indian" is used extensively in US legal documents, individuals who are not First Nations tribal members should not use the word "Indian". The one exception may occur when the word "Indian" is included in the full name of a First Nations tribe such as the Quinault Indian Nation. Even then, Quinault Indian Nation is typically referenced by its acronym (QIN) in tribal and other official documents (Quinault Indian Nation, n.d.). While First Nations, indigenous, and tribal are appropriate terms, whenever more focused analysis occurs (ex: corridor planning), it is most appropriate to refer to relevant tribes by name. There are 29 federally recognized tribes throughout the state of Washington as well as three non-federally recognized tribes (American Library Association, n.d.). Each tribe is a sovereign nation with varied cultural heritage, native lands, and treaty rights at the federal level. To navigate intergovernmental relationships with appropriate respect and in alignment with federal law, WSDOT has Tribal Liaisons on staff.

that must be considered under the HEAL Act. These definitions also, however, recognize that the given list is not exhaustive and leave space for agencies to expand on these attributes as necessary. To identify such communities, the HEAL Act recognizes cumulative impact analyses as a key method and specifies the EHD as one specific tool for maintaining and presenting such analyses in the form of a cumulative impact index and mapping interface. In other words, cumulative impact indices are a subset of cumulative impact analyses. Notably, the HEAL Act identifies three main categories that should be considered when identifying communities: burden, socio-economic vulnerability, or health vulnerability. Burden is a concept that concerns hazards related to environmental degradation such as pollution and climate change.

3.2.2. Cumulative impact indices are a specific type of cumulative impact analysis.

Cumulative impact analyses quantitatively assess the socio-technical impacts experienced by a community relative to other communities. Socio-technical impacts aim to estimate negative externalities of society and the technologies we rely on and can include a wide range of considerations: from poverty to health conditions to infrastructure to pollution concentrations. Cumulative impact indices combine multiple burdens and vulnerabilities and express them in a single, composite value. This article focuses on cumulative impact indices expressed in map form with index values aggregated over geographic areas. In the US, indices are specified relative to United States Census Bureau (USCB) areal designations. These are deliminated by the USCB data product of TIGER/Line files and range from Blocks (smallest) to Block groups, Tracts, Counties, State, and Nation (largest). Cumulative impact indices are most often specified at the census Tract level, but some use Block groups, Counties, or a combination.

The goal of these maps is to highlight areas that are comparatively more disadvantaged. Comparisons can be made at various spatial scales, such as a comparison of each census tract to every other census tract in a state (Min et al., 2019; UW-DEOHS, 2019), each city block within a metro area (Carrier et al., 2016), or in the case of numerous indices specified by US federal agencies, each census area relative to every other census area in a state OR relative to every other census area in the nation (OEJECR, 2023; OST, 2023; Zuzak et al., 2023). This quantification of relative disadvantage can then be used to prioritize fund allocation, such as the HEAL Act's 40% spending allocation goal.

3.2.3. A series of methodological choices are required to specify a cumulative impact index.

Figure 3.1 presents the series of methodological choices involved in the calculation of a cumulative impact indicator such as an EJ index. The gray, right hand side items specify the process stage while items to the left of the dashed line specify the alternatives considered in this analysis. These are further classified as either deductive or universal. Deductive methods are based on researcher/practitioner choices whereas universal methods are universal mathematical methods. While the selection of a given universal mathematical method is a deductive choice, the method itself is not deductive.

To specify cumulative impact index, relevant indicators of impact must be selected. A wide range of variables can (and have) been identified as relevant based on various scientific assessments of the relationship between socio-technical systems and human health and well-being. Generally, these variables fall into the three main categories defined in the HEAL Act: burden (or hazard), socio-economic vulnerability, or health vulnerability. Ideally data sources and variables are selected based on completeness and minimal errors. It should be recognized, however, that large-scale, full coverage (i.e. state-wide and nation-wide) data typically involves a tradeoff in detail and precision. For example, the United States Census Bureau (USCB) provides annually-updated population data based on the American Community Survey (ACS) in addition to decennial census products. While the decennial census serves as a detailed benchmark, the resources required make this only viable every ten years. ACS data products utilize these benchmarks to define sample populations for annual surveys and to generate full-coverage estimates. All ACS data includes margin of error estimates corresponding to value estimates. Many other state- and nation-wide data sources do not have the resources to set equivalent benchmarks and therefore cannot provide error estimates.

Once indicators have been selected, the data need to be re-scaled so variable values have similar magnitudes relative to one another. For example, poverty levels expressed in units of percent of an areas population cannot be compared to directly to $\mu g/m^3$ of particulate matter (PM) concentrations. Figure 3.1 presents the three data re-scaling techniques considered in this analysis: decile ranking, z-score normalization, and min-max scaling. These methods were selected based on their use in the academic literature and in practice and are discussed in detail in subsequent sections.

Next, the index structure must be specified. This process can be broken out into three main elements: weights, hierarchy, and aggregation. Taken together, these three analytical choices result in the mathematical formula used to combine all variables into a single, composite index value. Weights refer to values assigned to either magnify or reduce the relative importance of a variable or set of variables within an index. Variables can be left unweighted and assumed to be of equal relevance, or weighting can be assigned based on theoretical rationale. Hierarchical index structures involve two key components: 1) the categorization of variables, and 2) the data rescaling of the sum of the variables by category. Examples include taking the average of variables in each assigned category (Min et al., 2019; UW-DEOHS, 2019) or taking the percentile rank of the sum of variables in each assigned category (OST, 2023). While non-hierarchical indices may select and present variables in terms of categories, non-hierarchical indices do not apply a categorical aggregation step.

Finally, aggregation refers to the broad mathematical methods of variable combination: addition (simple sum) or multiplication (multiplicative). Of the indices presented in this article, these are the two methods used to yield a single, composite indicator value. The multiplicative method is based on the established risk-scoring model (Brody et al., 2012):

$$Threat * Vulnerability = Risk$$

This model was popularized in the EJ space through tools such as the EPA's EJScreen and California state's CalEnviroScreen (Min et al., 2019; Lee, 2021). The CalEnviroScreen example informed the HEAL Act definitions and the specification of the EHD; threats (or hazards) are comprised of environmental burdens such as concentrations of pollutants and proximity to pollution-producing sites, and vulnerabilities include health sensitivities and socio-economic factors (Min et al., 2019; UW-DEOHS, 2019).

All this data processing yields a single composite index score. While any data re-scaling technique could be applied to transform the score into a rank at the classification stage, percentile ranking is the only method highlighted and applied in this article. The purpose of the classification stage is to transform the raw index score into a value range that is more readily understood for final comparative purposes. Percentiles are therefore ideal and are the most used categorization method (see Table 3.4). In many cases, thresholds are then assigned to designate areas as disadvantaged. Thresholds vary by purpose and examples are detailed in Table 3.5. Figure 3.1 provides examples of threshold values used for WA's EHD and the USDOT's ETC. Notably, the USDOT's ETC 65th percentile threshold value recommendation was determined via a sensitivity analysis (OST, 2023). Still, the application of singular thresholds to assign a binary disadvantaged/not disadvantaged always runs the risk of arbitrarily excluding disadvantaged communities that rank just below the threshold value.

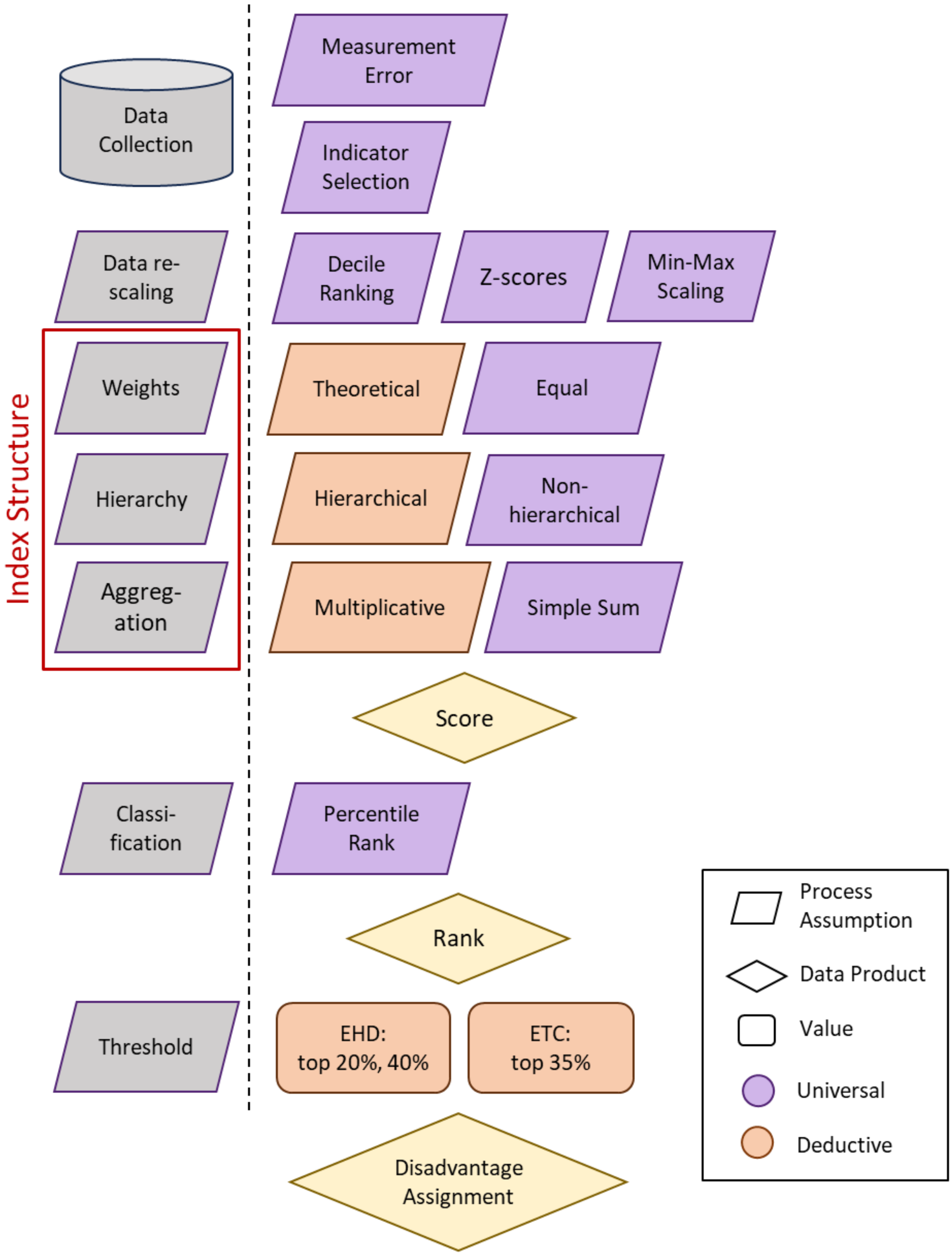


Figure 3.1. The series of methodological decisions involved in the calculation of a composite indicator.

3.2.4. Indices in the transportation equity academic literature tend to utilize z-score normalization for variable re-scaling.

A number of cumulative impact indices have been developed within the transportation equity academic literature at various spatial scales and inclusive of various indicators. Spatial scales range from city blocks (Carrier et al., 2016) to census block groups (Anderson et al., 2017), traffic analysis zones (TAZs) (Sider et al., 2015), and municipalities (Beiler & Mohammed, 2016). Indices have also been specified for non-US analyses such as for census areas in Australia (Currie, 2010) and cities in China (Yang et al., 2018). Beiler and Mohammed (2016) specify their Transportation Justice Threshold Index (TJTI) with the express purpose of applying EJ principles with a transportation focus. Others also focus on concepts of social or spatial equity in terms of relative disadvantage, but without an explicit emphasis on justice. Additionally, a clear reporting of data re-scaling method is absent from some articles, but as Table 3.1 demonstrates, the preferred method among these examples is z-score normalization.

Table 3.1. Data rescaling alternative attributes and example use cases in the academic literature.

Method	Transformation Type	Ability to preserve original distribution		Examples from Transportation Equity Literature
Min-Max	Linear	Varies	Sensitive to outliers which can cause a compression of mid-distribution values	(Currie, 2010)
z-score	Standard normal distribution	Consistently high	Shifts distribution around a mean of 0	(Anderson et al., 2017; Sider et al., 2015; Carrier et al., 2016)
Decile	Uniform distribution	Poor	Insensitive to outliers - binning can create high variation between similar values, causing an arbitrary expansion of otherwise condensed distributions	

Relative to one another, decile scaling is the least sensitive to outliers, z-score is sensitive but will still retain the original shape of the distribution, and min-max scaling is the most sensitive of the three. The compression of a distribution causes differences to be reduced, resulting in values that are distinct and relatively far from one another in the original distribution being treated as closer to equal within a min-max scaled version of a distribution that has outliers. Conversely, decile scaling applies a uniform distribution that can arbitrarily stretch out a distribution, resulting in values that are relatively close to one another in the original distribution being separated and treated as significantly different within the decile-binned transformation. This will occur to some degree regardless of outliers. While Z-score normalization shifts a distribution to have a mean of 0, the relative distance between values is retained. It is likely for this reason that it is the preferred data re-scaling method used within the academic literature reviewed.

3.2.5. Cumulative impact indices have existed for public use for nearly a decade, but many have been developed in the last few years.

Lee (2021) found that, while many states utilize the EPA's EJScreen tool, they often do it in tandem with their own state's version of CalEPA's CalEnviroScreen. The difference between the two tools lies in the variables considered and index construction. Similar to most states, the EHD follows the CalEnviroScreen model (WSIPP, 2022). In addition to the EPA's national-level EJScreen mapping tool, other federal agencies have followed suit with their own cumulative impacts EJ indices and tools. While some indices serve overlapping purposes and most use at least some of the same variables, they each use different data rescaling and combination methods. They all work to identify disadvantaged areas based on EJ principles. These federal indices and Washington's EHD are outlined in Table 3.2.

Table 3.2. Summary of existing indices related to environmental justice (EJ) initiatives.

Developed & Maintained by	Name(s)	Purpose	Citation
Center for Disease Control, Agency for Toxic Substances and Disease Registry (CDC/ATSDR)	Social Vulnerability Index (SVI)	EJ Disaster risk assessment and management	(Flanagan et al., 2011; GRASP, 2022)
CDC/ATSDR	Environmental Justice Index (EJI)	EJ disadvantage screening	(McKenzie et al., 2022)
White House Council of Environmental Equity (CEQ)	Climate & Economic Justice Screening Tool (CEJST)	Climate & Economic disadvantage screening	(White House CEQ, 2022)
Environmental Protection Agency (EPA)	Environmental Justice Screening Tool (EJScreen)	EJ disadvantage screening	(OEJECR, 2023)
Federal Emergency Management Agency (FEMA)	National Risk Index (NRI)	EJ Disaster risk assessment and management	(Zuzak et al., 2023)
United States Department of Transportation (USDOT)	Equitable Transportation Community (ETC) Explorer	Transportation, Climate & Economic disadvantage screening	(OST, 2023)
Washington Department of Health (WA-DOH)	Environmental Health Disparities (EHD) Map	EJ disadvantage screening	(Min et al., 2019; UW-DEOHS, 2019)
University of Wisconsin Center for Health Disparities Research (CHDR)	Singh's Area Deprivation Index (ADI)	Community disadvantage indicator for regression analyses	(Singh, 2003; Kind et al., 2014)

3.2.5.a. EJ indicators and analyses explicitly account for historical harms such as racial discrimination.

Tables 3.3 and 3.4 provide further details and classification distinctions for each index identified in Table 3.2. Two main themes emerge at the national level: screening areas for various forms of disadvantage or identifying areas with heightened disaster risk. All indices include at least one variable related to transportation, but only the CEQ's CEJST and the

USDOT's ETC explicitly include transportation as its own category. They also, however, exclude race and ethnicity.

While some indices (such as the CEQ's CEJST and the USDOT's ETC) attempt to remain agnostic to the historical practices that led to present distributions of populations and degradation, EJ indices explicitly recognize and attempt to operationalize variables related to the harms that served as antecedents to current risk. Specifically, the government sanctioned and (in many cases) mandated policies of racial segregation that continued late into the 20th century and continue to be reinforced by modern day tax and resource distribution structures (Rothstein, 2017). EPA's EJScreen's primary set of indicators uses a race-inclusive Demographic Index (DI) but offers the Supplemental Demographic Index (SDI) as a non-racial alternative.

Beyond attempts to remain ahistorically, racially agnostic, indicators such as EJScreen's SDI indicator set and Singh's ADI omit race for analytical reasons. In the case of these two indices, the analysts who developed them did so with the intention of providing future analysts with metrics that could be used in race-based causal and correlative analyses (OEJECR, 2023; Singh, 2003). This highlights an important distinction regarding the intentions and associated limitations of many cumulative impact indices (see Section 3.2.4.c).

3.2.5.b. While most indices do not apply weights explicitly, categorical hierarchies result in implicit weights.

Table 3.5 builds on the three other index-specific tables (3.2-4) by providing details about the categories used to group variables within each index. Additionally, the number of index variables per categorical group is presented along with breakdowns of how much each variable contributes to the composite index score. One purpose of this table is to present the different categories included in each index and how themes and language used to define those themes vary and intermingle between indices. The second is to illustrate the implicit weighting that occurs as a methodological by-product of categorical hierarchies. This implicit weighting is presented as what percent of the total index score comes from each variable in the given index category. Percentages are calculated for an existing condition which, for most indices, means a hierarchical structure, along with a simple sum alternative for the sake of comparison.

Notably, the USDOT's ETC includes two subcomponent indicators (transportation access and future extreme weather risk) that are the composite of six and four indicators, respectively. Because these indicators experience an additional round of aggregation and re-scaling, they are recognized separately because their values contribute uniquely compared to the other variables (2 each) in their categories of Transportation Insecurity and Hazard Vulnerability, respectively.

Table 3.3. Overarching agency index details.

Agency, Index	Total Variables	Transportation Included?	Race/Ethnicity Included?	First Release	Current Release	Current TIGER Lines	Current Data Source Dates
CDC/ATSDR, SVI	16	1	Yes	2014	6th	2020	2016 - 2020
CDC/ATSDR, EJI	36	4	**Yes**	2022	1st	2010	2014 - 2021
CEQ, CEJST	31	2[a]	No	2022	v.1.0	2010	2014 - 2022
EPA, EJScreen	2 (DI[1]) or 5 (SDI[1]) + 12	1	DI[1] - Yes, SDI[1] - No	2015	v.2.2	2020	2017 - 2021
FEMA, NRI	85	2	Yes	2023	v.1.19.0	2020	2015 - 2021
USDOT, ETC	48	8	No	2023	1st	2020	2016 – 2022
WA DoH, EHD	19	1	Yes	2019	v.2.0	2010	2014 – 2021
UWisc, Singh's ADI	17	1	No	2014	3rd	2020	2016 - 2020

[a] The CEQ's CEJST includes Diesel particulate matter (µg/m3) a third measure of transportation burden, but this is not consistent with other indices which treat Diesel PM2.5 as the broad measure of industrial emissions that it functionally measures.

[1] (DI) and (SDI) refer to the Demographic Index and Supplemental Demographic Index, respectively. The DI is the default composite sociodemographic indicator multiplied against each Environmental Indicator presented in the EJScreen with the SDI offered as an addition/alternative composite sociodemographic indicator for the same purpose.

The total number of variables considered in each index varies widely, as do the dates of source data back-ending existing, published versions of each index. While each index is a composite of publicly maintained, regularly updated source data, a wide range of data sources are included in each index, and each of those data sources are updated on different schedules. This means the data included in any single index will almost always include data from at least a five-year date range. The number and inclusion criteria for variables in each index varies by analysis intent and is discussed in greater detail below. It's also worth noting that, while some indices have been around for nearly a decade, most are in their infancy. Much like software, early versions of complex tools inevitably contain bugs and errors that require time and engagement to identify and address.

Table 3.4. Methodological details for the agency indices considered.

Agency, Index	Data Re-scaling[1]	Hierarchy	Aggregation	Spatial Scale	Outcomes reported in online application			
					Binary Disadvantage	Single Composite	Component Composites	Variable
CDC/ATSDR, SVI	percentile rank, percentile rank	Yes	Additive	Tract	-	X	X	X
CDC/ATSDR, EJI	percentile rank, average	Yes	Additive	Tract	-	X	X	X
CEQ, CEJST	percentile rank	N/A	Thresholds + Logic[2]	BG & Tract	X	-	X	X
EPA, EJScreen	percentile rank, percentile rank	Yes	Multiplicative	BG & Tract	x[3]	-	X	X
FEMA, NRI	percentile rank, percentile rank	Yes	Multiplicative	Tract	-	X	X	partial
USDOT, ETC	min-max scaling, percentile rank	Yes	Additive	Tract	X	X	X	X
WA DoH, EHD	deciles, average	Yes	Multiplicative	Tract	-	X	X	X
UWisc, Singh's ADI	unclear	No	Additive	BG	-	X	-	-

[1] For Hierarchical indices, the data re-scaling method for base variables is listed first, followed by categorical data re-scaling.

[2] The CEQ's CEJST offers a unique methodology that applies thresholds (ex: 90th percentile) to each variable considered within a category and identifies an area as disadvantaged if ANY individual variable is classified as disadvantaged AND if the associated socio-economic variable also meets the disadvantage classification. While no singular, composite indicator is developed, this disaggregate, logic-based methodology allows for more focused, variable-specific analysis of disadvantage.

[3] The EPA's EJScreen doesn't provide a visual disadvantage/not layer, but they do provide a recommended threshold of disadvantage of 80% (i.e. 80^{th} percentile or top 20% of the distribution).

Table 3.5. Comparative breakdown of agency indices by categories, thresholds, variable counts and weights applied and implicit (1/2)

Agency, Index	Categories Defined	Threshold(s)	# Variables	Weighting	% of score from each variable	
					existing[1]	simple sum
CDC/ATSDR, SVI	Housing and Transportation	none specified	5	-	~5%	6.3%
	Household Composition and Disability		5		~5%	
	Socioeconomic Status		5		~5%	
	Racial & Ethnic Minority Status		1		~25%	
CDC/ATSDR, EJI	Environmental Burden	none specified	17	-	2%	2.8%
	Health Vulnerability		5		6.7%	
	Social Vulnerability		14		2.4%	
CEQ, CEJST	Climate change	90th	5	-	N/A	
	Energy	90th	2			
	Legacy pollution	90th	5			
	Water and wastewater	90th	2			
	Housing	90th	5			
	Transportation	90th	3			
	Health	90th	4			
	Workforce development	90th	4			
	Socioeconomic burden	65th OR <10%	1 OR 1			
EPA, EJScreen	Environmental Indicators	80th but variable	12	-	~50%	N/A
	Demographic Index (DI) OR Supplemental Demographic Index (SDI)		2 (DI) OR 5 (SDI)		~25% (DI) OR ~10% (SDI)	

Table 3.5. Continued (2/2)

Agency, Index	Categories Defined	Threshold(s)	# Variables	Weighting	% of score from each variable existing[1]	% of score from each variable simple sum
FEMA, NRI	Expected Annual Loss	Centiles: 5 very high, 4 high	18	-	1.9%	1.2%
	Social Vulnerability		16		Varies[2]	
	Community Resilience		51			
USDOT, ETC	Environmental Burden	65th	16	-	~1%	1.8%
	Hazard Vulnerability		(4) + 2[a]	-	~(1.4%), 6%	
	Transportation Insecurity		(6) + 2[a]	2	~(2.8%), 12%	3.6%
	Health Vulnerability		5	-	~3.3%	1.8%
	Social Vulnerability		13	-	~1.3%	
WA DoH, EHD	Fossil Fuel Pollution Exposure	Deciles: 9-10 highest need, 7-10 expanded consideration	5	-	5.7%	6.1%
	Other Toxic Exposures		5	0.5	2.9%	3.0%
	Sensitive Populations		2	-	14.3%	6.1%
	Socioeconomic Factors		7	-	4.1%	
UWisc, Singh's ADI	N/A	N/A	17	Varies[3]		5.9%

[1] For the indices that use percentile ranking (rather than averaging) to establish category-based hierarchies, the estimated existing percent of score derived from each variable represents the average value with the ~ symbol used to denote variation.

[2] The Expected Annual Loss is the only sub-index developed by FEMA for use in the NRI, therefore a simple breakdown of hierarchical/non-hierarchical is not possible. The Social Vulnerability component of the NRI is simply the CDC/ATSDR, SVI. The Community Resilience component was developed by (Cutter et al, 2014) and is comprised of six "resilience categories": social, housing/infrastructural, community capital, economic, institutional, and environmental (p. 70).

[3] The 17 variables were identified using factor analysis (FA) and uses the rotated factor scores to weight variables (Singh, 2003).

[a] The USDOT's ETC includes sub-categorized variables that are the min-maxed sum of 4 future climate risk and 6 transportation access variables, respectively, added to the other min-maxed variables (2 each) of the Hazard and Transportation categories.

The percent of the overall score derived from each variable included in the index under the existing index calculation structure, $P_{existing}$, can be calculate using Equations 3.1 through 3.3, where n_v is the number of variables per category, w_i is the weight applied to the category, and n_c is the number of categories.

$$P_{existing} = 1/f(n_v)/f(n_c) \tag{3.1}$$

$$where$$

$$f(n_v) = \sum_{i=1}^{n_c} n_{vi} * w_i \tag{3.2}$$

$$f(n_c) = \sum_{i=1}^{n_c} w_i \tag{3.3}$$

In contrast, the simple sum formulation assumes no categorical hierarchy. Under this assumption, the functional number of categories, $f(n_c)$, goes to one, therefore the percent of the overall score derived from each variable included in the index, $P_{simple\ sum}$, can be simplified as Equation 3.4.

$$P_{simple\ sum} = 1/f(n_v) \tag{3.4}$$

For indices that apply a hierarchy by taking the average of the variables in each category (CDC/ATSDR's EJI and WA's EHD), the values for existing percentage presented in Table 3.5 are exact. However, for indices that apply a hierarchy by taking the percentile rank of the sum of the variables in each category (CDC/ATSDR's SVI, EPA's EJScreen, and USDOT's ETC), the values for existing percentages will vary with the magnitude of each variables value. The values presented in Table 3.5 do, however, provide an estimate of the contribution of each variable on average to the overall index score under hierarchical percentile ranking conditions.

Table 3.5 illustrates the inverse relationship between the number of variables and the functional contribution of any given variable to the overall score of a composite index. Essentially, with each variable added, the individual contribution of any given variable is reduced. Applying hierarchies through categorization and either averaging or percentile ranking can serve as a mediator that amplifies some variables. The most extreme example of this in Table 3.5 is the CDC/ATSDR's SVI treatment of the race and ethnicity. Because the CDC/ATSDR's SVI places its singular race and ethnicity variable in a category distinct from other socioeconomic variables categorized under "Socioeconomic Status", the mathematical hierarchy of the index yields, on average, an implicit 5-times weighting of Race and Ethnicity compared to the other 15 variables included in the index.

Across indices, health vulnerability variables tend to carry higher implicit weights compared to other socioeconomic variables used to estimate vulnerability. This is a product of the lack of health data compared to the plethora of socioeconomic population data available via the USCB. WA's EHD includes fewer socioeconomic variables (7) compared to other indices, however the specification of only two (2) health vulnerability variables in their own "Sensitive Populations" category results in those variables carrying nearly a third of the total EHD score. Essentially this inverse relationship means that the more variables a cumulative index or a hierarchical category within an index contains, the less relative weight each of those variables contributes to the final index score.

3.2.5.c. Cumulative impact indices developed for disadvantage screening serve a different purpose and should follow different methodological processes compared to composite indicators intended for regression analyses.

Singh's ADI was developed two decades ago, is a regularly utilized index within health research, and provides a less-common example (in the U.S.) of a publicly maintained index that utilizes the dimension reduction method of factor analysis (Kind et al., 2014; Singh, 2003).

Factor analysis and other dimension reduction methods offer powerful means of managing covariate correlation; therefore, Singh's ADI provides a single value that captures non-health outcomes for use in regression analyses seeking to understand correlations between spatial-based disadvantage and health outcomes. Race is left out of Singh's ADI so that it can be included as a separate, distinct variable in such analyses to define and identify the contribution of race to health outcomes more explicitly and clearly.

EJScreen's SDI indicator set is specified for similar reasons; EJScreen focuses on the intersection of single measures of environmental degradation (ozone concentration OR wastewater discharge etc.) multiplied by an index of demographic variables (DI or SDI). Therefore, while each outcome variable is inherently composite, they only include three to seven total variables. Covariation can be readily handled by not using the variables included in the composite EJScreen indicator as separate variables within, for example, a subsequent regression analysis. Like Singh's ADI, using EJScreen's environmental degradation times SDI variable set allows an analyst to consider race as a distinct variable.

When selecting variables for inclusion in a composite index that will be used within a subsequent regression analysis, covariation of the indicators within the composite index as well as with other variables considered in the subsequent regression must be accounted for and managed. For example, Singh's ADI manages covariation within the indicator with factor analysis, and a subsequent analyst would be responsible for ensuring that the variables included in the ADI are not included in other parts of the regression specification. Most cumulative impact indices, however, are not specified for this purpose.

While other cumulative impact indices listed in Tables 3.2-5 can (and have) been used in regression analyses, this is not the intended function of most of them (Rufat et al., 2020;

Flanagan et al., 2020). The goal of cumulative impact indices (such as WA's EHD or the USDOT's ETC) is to assess relative cumulative risks over a given area. For example, WA's EHD assesses relative disadvantage within the state of Washington and the USDOT's ETC presents assessments by state as well as nationally. As a result, variable selection and correlation management can and should follow different processes and guidelines.

Each variable must be selected based on its ability to serve as a proxy measure for barriers to or outright harm of human health and wellbeing, either inherently (ex: toxic waste releases) or based on societal, structurally inflicted harms (ex: racial identity). Relative to the theory of intersectionality, the presence of each of these barrier variables places individuals at a uniquely multidimensional distance from an ideal state/opportunity for health and wellbeing. Taking each variable as a potential barrier (either in the form of vulnerability or burden) and the value of each variable as the magnitude of that potential variable, correcting for general intercorrelations in the data set through dimension reduction is less important than focusing on which combination of variables provides the most diverse and complete assessment of vulnerabilities and risks. Specifically, the theory of Intersectionality offers guiding principles for specifying and appreciating the inherent limitations of quantitative cumulative impacts analyses such as these indices.

3.2.5.d. Prior analysis of Washington State's EHD found high variation in score results depending on the methodological choices made in index specification.

Frostad's (2023) analysis of the construction of the current EHD found high levels of scoring variation between potential composite index scoring methods. He generated a multi-dimensional sampling space that included seven distinct methodological decision stages used in composite indicator development and sampled quasi-randomly using Sobel sequencing to test index construction permutations. His analysis included many of the alternatives presented in

Figure 3.1, however his assessment of aggregation methods focused on variations in ways to calculate a mean (arithmetic vs. geometric) and the use of Principle Component Analysis (PCA). He also considered additional weighting alternatives such as PCA loadings and inverse correlation weights. He found that census tract rankings could deviate by over one hundred points and that these deviations were not uniform across the ranking distribution. Specifically, tracts originally classified as mid to low impact were found to be most sensitive to index construction methods while the top 10% of tract estimates were the most consistently ranked.

He demonstrates how the current construction of the EHD, though unweighted, includes implicit weighting bias based on data re-scaling through deciles and deductive hierarchical data combinations. He includes a case study comparing a more affluent urban tract to a rural tract with higher rates of vulnerable populations, exemplifying the way mathematical decisions impact each tract's score at each level of calculation. Ultimately, his work suggests that the current EHD tends to highlight more urban areas regardless of population vulnerability. This is a concerning finding given that the EHD has widespread buy-in from various state actors and is currently held as the primary vetting method for state-wide project funding prioritization.

3.3 Cumulative impact indices through the lens of Intersectionality

The goal of cumulative impact indices is to quantify the multiplicative nature of burden and vulnerability so that it might be addressed. The theory of intersectionality originates in Black feminist ideology and seeks to bring light to the ways in which individuals who hold multiple, marginalized identities face unique, cumulative burdens (Carbado et al., 2013). Therefore, in addition to the mathematical considerations presented in Section 3.2, this section offers a broader theoretical perspective. Specifically, this section addresses the question: How can the theory of intersectionality inform best practices for cumulative impact index specification? This section offers insights both for consideration in index specification and, more broadly, a discussion on which components of intersectionality can and cannot be adequately captured using quantitative methods.

Intersectionality emphasizes distance from power and how individuals who hold multiple marginalized identities are positioned at a uniquely multi-dimensional distance from power. The theory of intersectionality was developed for use in case law and associated research as a qualitative theory with no intention of quantitative application. Since its initial introduction, however, quantitative researchers have sought to operationalize intersectionality. As a result, a wide variety of statistical methods have been applied, varying by data type, research question, and field of study with most work occurring in the health sciences (Bauer et al., 2021; Guan et al., 2021; Wang, 2022).

In addition to a multitude of potential, valid quantitative methods, there are multiple expressions of intersectional theory identified by researchers in the decades since its original introduction (Guan et al., 2021). Table 3.6 details these sub-theories along with the guidance they offer relative to mathematical decisions at various stages of cumulative index development. Of four sub-theories identified, the theories of simultaneity and multiple jeopardy offer insights that can inform cumulative impact mathematical decisions. The other two theories, intersectional multiplicativity and invisibility, cumulative impact analyses at the scale of census areal unit analysis do not offer the requisite level of disaggregate detail to perform a reliable analysis.

Table 3.6. Theories of Intersectionality and associated index constructs

Sub-theory	Description[1]	Associated Index Decision	Associated Index Guidance
Intersectional multiplicativity	"axes of inequality (example: sexism and racism) interact to create unique social positions which cannot be explained as a sum of their parts"	N/A	

Intersectional invisibility	"social oppression experienced by easily recognized "prototypical" members of marginal groups differ from less visible "marginal" members" and that oppression can be context-specific		
Simultaneity	"all social positions exist together, and that axes of inequality should not be ranked (i.e., giving more importance or value to one axis over another)."	Weights	Do not weight identity variables
Multiple jeopardy	"describes the extra disadvantages or oppressions experienced by individuals with multiple marginalized social positions"	Data Collection: Indicator Selection	Represent as many marginalized positions as possible

[1] All quotes taken from Guan et al. (2021) p. 2

3.3.1 The Intersectionality sub-theories of intersectional multiplicativity and intersectional invisibility require analytical methods beyond the scope of composite cumulative impact indices.

Instead, these sub-theories offer insights into the limitations of cumulative impact indices. Intersectional multiplicativity highlights the complexity and vast variety of experiences that can occur and that would functionally require more detailed data sources and statistical analyses to approach a viable approximation. Examples might include studies working with data that includes individual-level observations of identity and outcomes of interest that employ latent class analyses to generate composite profiles that can then be compared to outcomes (CITE).

Intersectional invisibility recognizes the reality that whatever is not measured is not considered. Data may not exist either due to aggregation or coverage requirements (i.e. cumulative impact index data limitations), or because the concept in question is too complex to be captured with quantitative methods. For example, quantifying differences between multiple intersecting identities (i.e. race, ethnicity, gender, sexuality, age, disability, immigration status, English language proficiency, educational attainment, and more) requires enough observations from individuals at every unique intersection to explore statistically significant relationships between groups. If differences between groups are expected to be relatively small, the sample size necessary to perform analyses with any statistical power becomes exponentially larger with each new class of identity introduced. Add to that analysis any dimensions of context (i.e. time of day, week, year, life and location of home, work, and other activities by type, etc.) and it becomes rapidly apparent that quantitative data collection efforts that attempt to capture the highly dimensionally complex reality of identity-based experiences is bound to render invisible some identities and their experiences.

Because cumulative impact maps are large-scale, aggregate assessments of standardized data related to environmental injustice and social disadvantage, they will consistently fail to account for identities rendered invisible by their unique nature and position at the periphery of other, more common identities. However, even in instances where data exists in high quantity and high resolution (such as Big Data sets created and sold by major service providers such as Google, Facebook, Amazon, etc.), the most widely used statistical techniques focus comparisons at distributional means (Bills & Walker, 2017). Analyses that exclusively focus on mean values fail to account for experiences at either end of a distribution. In other words, even given massive data sets capturing multiple identities and their behaviors at varying points in time, analyses at the means still render invisible the experiences of those that don't fit the average within each unique intersection of identities.

While some methods have been developed to capture more of the nuance of distributions (Bills & Walker, 2017; Aemmer & MacKenzie, 2022), the methods are only as useful as the available data. Even in these massive data sets that are seemingly comprehensive (and extremely expensive to procure), they still omit individuals with limited access to the internet such as the unhoused, lower-income, or the elderly. When Big Data is used indiscriminately, marginalized individuals remain invisible and risk having their experiences further obfuscated while the identities present in the data set have their experiences and trends illuminated and reinforced. Addressing intersectional invisibility concerns requires targeted methods that aim to explicitly illuminate and address the experiences of these marginal-marginalized identities. Qualitative methods such as semi-structured interviews, targeted surveys, and hybrid qualitative/quantitative community mapping approaches within the context of small-scale, localized initiatives are necessary.

3.3.2 The methodological implications of viable sub-theories of Intersectionality on cumulative impact indices: simultaneity and multiple jeopardy.

While not every type of intersectionality can be operationalized by a cumulative impact index, and while these indices contain variables that measure more than just identity attributes, the lens of intersectionality offers important methodological insights into how variables measuring identity attributes should be selected and weighted.

The simultaneity sub-theory offers a clear guiding principle: do not weight identity variables. As Table 3.5 shows, weighting is not a common trend within publicly developed and maintained indices. The application of weights is often viewed as paternalistic and, if applied to a non-normal distribution, risk having unintended down weighting effects across distributions. (Decancq & Lugo, 2013). The only cases of explicit weight applications are applied to non-identity variables: WA’s EHD and the USDOT’s ETC. In the case of WA’s EHD, the 0.5 weight is applied to proximity-based environmental burden category because the effect of these variables on human health is less clearly established (Min et al., 2019; UW-DEOHS, 2019). These variables are down-weighted so that the variables with a clearer relationship to human health will hold more relative weight. For the USDOT’s ETC, the decision to double the Transportation Insecurity category was the product of community engagement and stakeholder feedback (OTC, 2023). However, as Table 3.5 demonstrates, the number of variables selected within hierarchical data structures results in implicit value weights that can result in certain variables carrying many times more of the final index score compared to other variables.

Identity variables tend to be categorized together in a single socioeconomic vulnerability-focused category, meaning that even with implicit weights imposed by categorical hierarchies, these identity variables are still treated as equal relative to one another. An exception to this is the CDC/ATSDR's SVI. The SVI's hierarchical structure places variable, percentile rank-driven implicit weights on the variables included in the index. However, rather than grouping race and ethnicity with the other socioeconomic variables, it holds race and ethnic minority status in its own category separate from other socioeconomic variables, an average implicit weight of 5-times is applied. The SVI applies this designation with the intention of highlighting the racial component of disadvantage in the US – a distinctly valid approach given the nation's ongoing history of racial segregation and associated race-based disadvantage (Rothstein, 2017). It does not, however, provide a viable measure of the intersectional relationship between race/ethnicity and other socioeconomic identity factors under the intersectional theory of simultaneity. Additionally, measures of disability fall under varying index categories and typically held separate from other socioeconomic factors. Given that disability can serve as a form of self-identification (Forber-Pratt et al., 2017), treating variables associated with disability as identity variables would require a restructuring of index categories to better approximate simultaneity.

Multiple jeopardy offers guidance regarding variable selection. Ideally, an index will include as many variables as possible to estimate the many ways in which individuals face multiple disadvantages (i.e., jeopardies). The variables selected offer proxies for the varied, multiple axes of burden and vulnerability, and the values for each variable provide a means of assessing relative (dis)advantage. Variables should be selected for the variation in socioeconomic constructs they represent. This is a distinct divergence from the statistical assumptions and edicts related to more common analytical methods such as regressions. In regressions, variable inclusion and treatment is guided by assumptions related to the covariance of independent variables. It's in the name: *independent* variables should be independent of one another i.e., should not co-vary. If covariance exists amongst independent variables, proper procedures require analysts to manage this covariance by either removing variables or mediating the covariance using some other form of statistical intervention.

The goal of a cumulative impact index is not to determine the relationship between a given variable and the cumulative impact score, it is to offer a single, composite value of measures that have already been established as having a relationship with human health and well-being. Cumulative impact index scores and ranks are therefore not dependent variables in the same sense as a regression analysis and the variables combined to generate the index should not be treated as independent variables of a regression analysis. Each variable in a cumulative impact index serves as a proxy for a different form of disadvantage, with the value of each variable serving as an estimate of relative disadvantage compared to the broader population. Rather than relying on data structure to determine variable selection and management, multiple jeopardy instructs analysts to select variables based on the variety of factors that have been found to have a negative impact on human health and well-being. Under this model, covariation between the selected variables is not a bad thing to be mitigated, but a phenomenon that the cumulative impact index helps visualize.

Still, aggregation of multiple, varied data will always involve some level of imprecision and inaccuracy, especially for a tool such as a cumulative impact index which offers a proxy value for complex concepts that buck quantification. As highlighted in Section 3.3.1, it is always important to recognize the limitations of quantitative methods to avoid treating outcomes as definitive arbiters of reality when they simply do not have the power to capture nuance. However, cumulative impact indices can – and have (Lee, 2021) – served as useful tools to quantify and address social justice issues. These tools are best used, however, when their limitations are understood and accounted for.

3.4 Analyzing indices: Washington State's EHD and the USDOT's ETC

The subsequent sections provide a detailed analysis of two indices specified by US government agencies for the purpose of screening areas for funding priority: Washington State's Environmental Health Disparities (EHD) Map and the USDOT's Equitable Transportation Communities (ETC) Explorer. These indices were selected from the broader list of publicly developed and maintained cumulative impact indices presented in Section 3.2 for their relevance to WSDOT's equity in transportation planning efforts. These two indices are analyzed to answer the question: Are existing cumulative impact indices more likely to designate urban tracts as disadvantaged compared to rural tracts? While this analysis only provides an answer for these two indices, the methods are broadly applicable and draw on the fundamental mathematical principles presented in Section 3.2.

The EHD was developed by the Washington State Department of Health (DoH) based on the example of CalEnviroScreen developed by the State of California's Department of Ecology (DoE) (Min et al., 2019; UW-DEOHS, 2019). Its ongoing maintenance and utilization are a legal requirement in the state of Washington under the HEAL Act. The ETC was developed by the United States Department of Transportation (USDOT) as part of the Biden-Harris Administration's Executive Order (EO) 14008: Tackling the Climate Crisis at Home and

Abroad. Specifically, the Justice40 initiative was established under EO14008. Both the HEAL Act and the Justice40 initiative set a goal of 40% of expenditure allocation be directed toward relatively disadvantaged communities.

Both indices are specified using readily available, regularly maintained, census tract-level data sources. Details about both indices are highlighted in gray in Tables 3.2-5. Additional details are provided in Appendix A.3.

3.4.1 Data

For the EHD, a compilation of underlying variable data was accessed via the github repository[9] developed by Frostad (2023) as well as the current version 2.0 EHD tract scores access via the Washington State Geospatial Open Data Portal (WGODP)[10]. The state-level (rather than nation-wide) version of the ETC data was accessed via the USDOT's Justice40 ETC Explorer information page[11]. Notably, the current version of the EHD is calculated with data aggregated to 2010 decennial census tract TIGER/Lines (n=1458 tracts) while the ETC is calculated with data aggregated to 2020 decennial census tract TIGER/Lines (n=1773 tracts). The R package *sf* was used to access 2010 and 2020 census tract TIGER/Lines and the WGODP was used to access WSDOT's 2023 version of Highway Urban and Urbanized Areas shapefile[12]. The ETC data download included a variable of total population for each census tract based on ACS 2016-2020 estimates. Population data for the EHD's 2010 census tract TIGER/Lines was accessed via the Washington Tracking Network (WTN) database[13]. The WTN is maintained by the WA DoH and provides a centralized source of population-level health data. The 2019

[9] https://github.com/jfrostad/ehd_mapsense/tree/main/code
[10] https://geo.wa.gov/datasets/WADOH::environmental-health-disparities-overall-ranking-current-version/about
[11] https://www.transportation.gov/priorities/equity/justice40/etc-explorer
[12] https://geo.wa.gov/datasets/WSDOT::wsdot-highway-urban-and-urbanized-areas/explore?location=47.131866%2C-120.274655%2C7.83
[13] https://fortress.wa.gov/doh/wtn/WTNPortal/#!q0=660

population estimates used in this analysis were developed by the Washington State Office of Financial Management (OFM).

All variables included in the EHD have a positive association with the concept of disadvantage. In other words, as the value of any given variable increases, the level of disadvantage increases. While this is also true for the majority of variables included in the ETC, it is not true for all of them. The ETC includes the variables of "Frequency of Transit Services per Sq Mi" and "Jobs within a 45-min Drive" – for these two variables, a higher value means greater advantage and therefore lower relative magnitude of disadvantage. In the original calculation of the ETC, they take the inverse of each variable in an effort to make these variables representative of relative disadvantage (OST, 2023). However, while taking the inverse of the values calculates the mathematical opposite of each value, it does not change the overall distribution of the values. Therefore, in my re-calculation of the index, instead of taking the inverse of each value, I reverse the distribution of these variables using equation 3.5. Where v_{rev} is the reversed distribution value, v_{max} is the maximum value of the original distribution, v_{min} the minimum value, and v is the value in the original distribution.

$$v_{rev} = v_{max} - v + v_{min} \tag{3.5}$$

Index score iterations were calculated from these base variable values as detailed in the subsequent section. All data developed in this process along with the code used can be found at the lead author's github page[14].

[14] https://github.com/elyseoc/transpoequity_indices

3.5 Methods: testing urban/rural correlations in the EHD and ETC indices.

Two methods were used to test for urban/rural correlations in the EHD and ETC indices; each variable used in both indices was tested for correlation to tract population density, and odds ratios of disadvantage classification by urban/rural tract status were tested for multiple iterations of each index. Population density was calculated for the respective TIGER/Line tract areas (2010 for EHD and 2020 for ETC) and respective population estimates (see Section 3.4). A binary urban/rural indicator was coded for the respective TIGER/Line tract areas based on the percent each area overlapped with WSDOT's Highway Urban and Urbanized Areas; if 50% or more of a tracts area is classified as a Highway Urban and Urbanized Area, it was classified as Urban, else Rural.

3.5.1 Testing variables for population density correlations

Each variable's correlation to population density was tested using both Pearson and Spearman tests to ensure the robustness of conclusions. Both tests are used to assess the correlation between two continuous variables, with the Pearson test assuming and measuring the linear relationship between variables. In contrast, the Spearman test does not assume a linear relationship and instead measures the monotonic relationship i.e. whether the variables tend to increase or decrease together. Three conditions had to be met for a variable's Pearson correlation coefficient to be reported as likely correlated to population density:

1. the Pearson correlation 95% confidence interval does not cross zero (0), AND
2. the sign (+ or -) of the Pearson correlation coefficient (r) and the Spearman Rank correlation coefficient (ρ) must be the same, AND
3. the p-value calculated for r and ρ must be of the same magnitude (<0.001 ~ ***, <0.01 ~ **, <0.05 ~ *, <0. 1 ~ -)

Variables that did not meet these conditions were treated as non-correlated and assigned values of zero (0) for r and upper and lower confidence intervals to clearly distinguish them from likely correlated variables in results reporting.

3.5.2 Testing variable re-scaling and index structures for existing indices (EHD and ETC)

Figures 3.2 and 3.3 lay out the alternative mathematical choices used to specify alternative versions of the EHD and ETC. These alternatives are then compared against the current versions of each. Details about the current version of each index can be found in Tables 3.2-5. Weighting for each index is discussed in Section 3.3.2 and was held constant within iterations. Categorical hierarchies were established using percentile ranking for all iterations, and non-hierarchical multiplicative structures mean categorical scores were multiplied together without the intermediary, hierarchical step of percentile ranking. For the EHD, two thresholds are considered; a more strict 9's and 10's or top 20% of tracts and a more lenient 7's-10's or top 40% of tracts. The latter is more comparable to the sensitivity-tested ETC 65th percentile threshold.

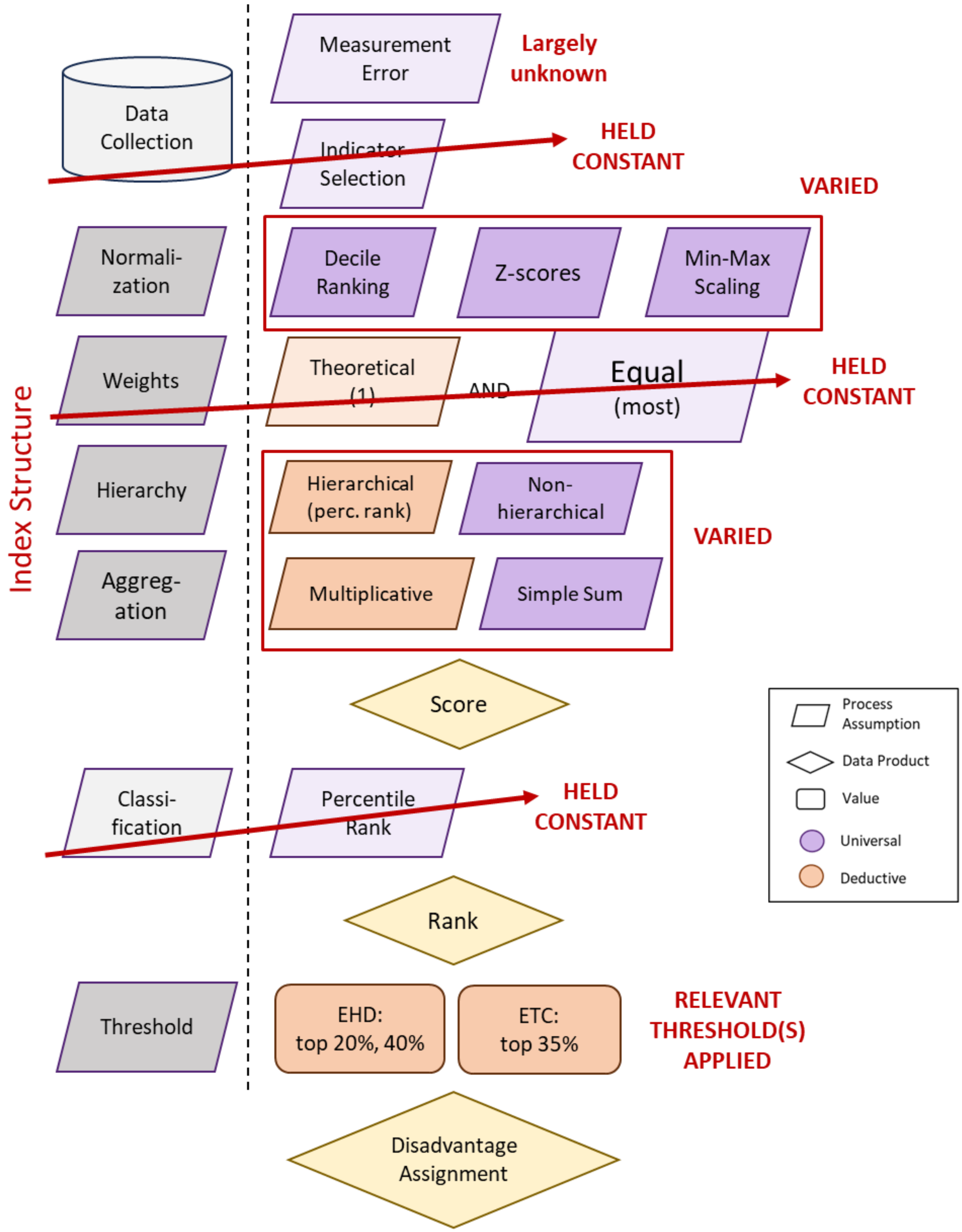
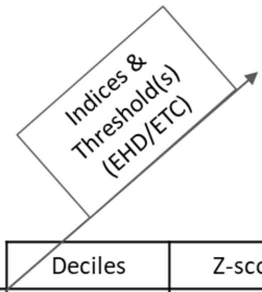


Figure 3.2. Representation of the mathematical choices held constant and varied in index alternative iterations.



(3x4 iterations + 1 current verson) * 3 indices+thresh = **39 total iterations**

	Deciles	Z-scores	Min-Max
Hierarchical, Multiplicative	1	5	9
Hierarchical, Simple Sum	2	6	10
Non-hierarchical, Multiplicative	3	7	11
Non-hierarchical, Simple Sum	4	8	12

Index	Threshold
EHD	9s & 10s (top 20%)
	7s-10s (top 40%)
ETC	65^{th} percentile (top 35%)

Figure 3.3. Iterative breakdown of alternative index versions estimated and tested for urban/rural correlations.

3.6 Results

This section details the results of the two methods used to test the urban/rural correlations of variables and tract disadvantage assignments by methodological iterations.

3.6.1 Variable re-scaling method selection has greater impact on urban/rural disadvantage likelihood than individual variable correlations.

Figures 3.4-6 present the results of the variable and index iteration urban/rural tests. Figure 3.4 presents the Pearson correlation coefficients and 95% confidence intervals for each variable considered in both the EHD and the ETC. Variable types were differentiated by HEAL Act concepts of burden, health vulnerability, and socioeconomic vulnerability. These concepts in turn relate to the risk model concepts of threat/hazard (burden) and vulnerability (health and socioeconomic). Variable names were harmonized such that variables measuring the same concept in both indices appear on the same line of the forest plot in Figure 3.4 (a). Variation in correlation estimates between indices occur for three potential reasons: difference in source data, difference in estimation method, or difference between years. Details about each variable relative to each index can be found in Appendix A.3.

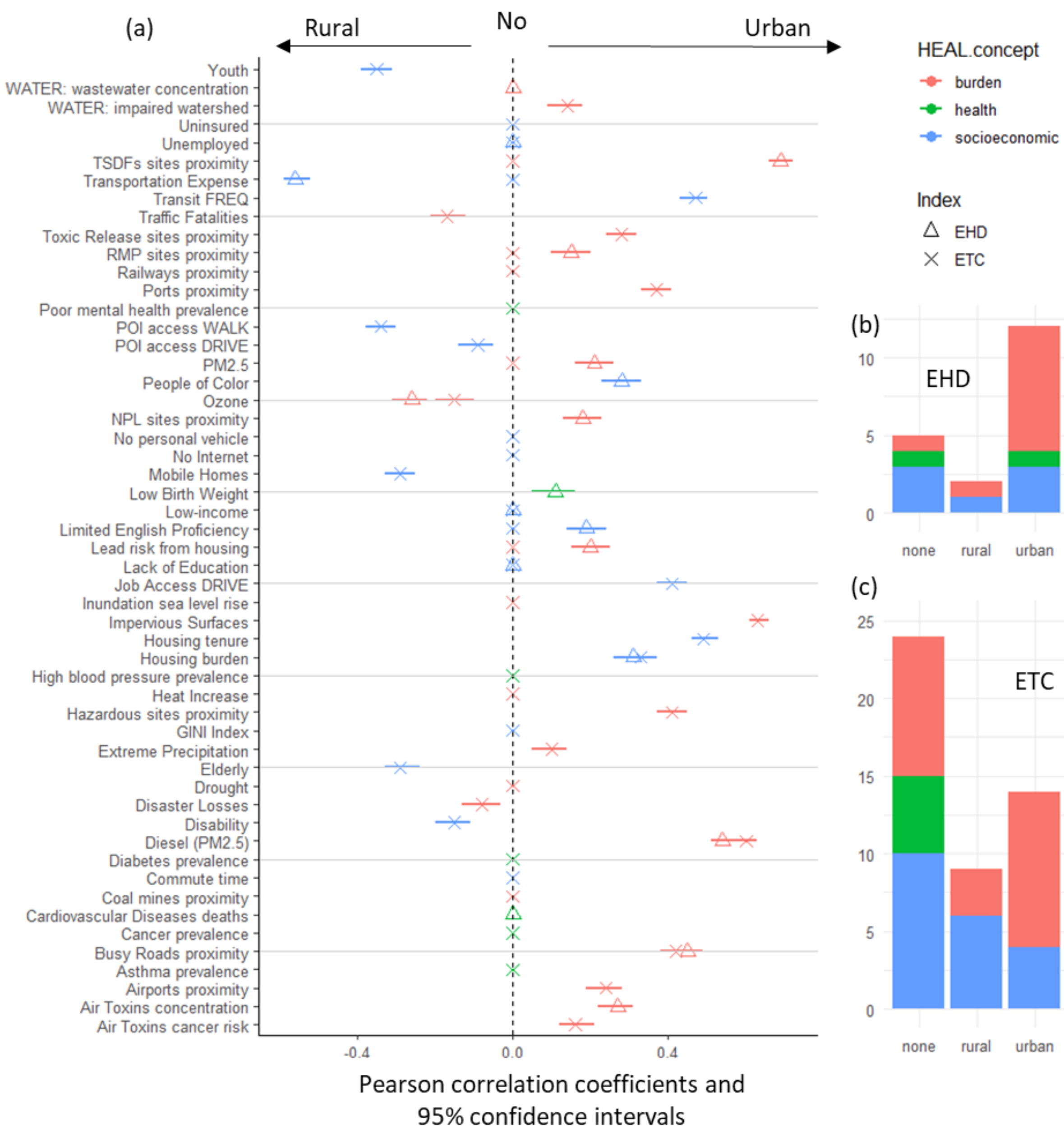


Figure 3.4. Each variable's estimated correlation to census tract population density by HEAL Act concept type (a) reported by Pearson correlation coefficient and 95% confidence interval by index (b) counts of variables in the EHD (n=19) by correlation type (c) counts of variables in the ETC (n=48) by correlation.

The first and second types of variance (difference in source data and difference in estimation method) tend to go hand-in-hand. For example, in both the EHD and ETC, the transportation expense variable estimates transportation expenditures per household as a percentage of household expenditures. However, because this is a value that cannot be calculated from individual responses to household surveys (at least not the household surveys administered nationally by the USCB), it must be estimated using aggregate data from a variety of sources. The EHD uses the estimates developed and published by the Center for Neighborhood Technology (CNT) within their Housing and Transportation (H+T) Affordability Index[15] while the ETC includes an in-house calculation. The CNT H+T I variable is calculated using a set of gravity models for jobs that account for and areas mix of job types, household characteristics, and peak transit service to estimate auto ownership, use and transit use which is then used to estimate a USD annualized average expenditure as a percentage of regional moderate household income. In contrast, the ETC uses rougher approximations based on value of time estimates by trip purpose to estimate a USD annualized average expenditure as a percentage of average household income.

Similarly, while both indices include measures of toxic site (TSDF, RMP, and NPL) proximity, the source data and estimation methods are again quite different. Both ultimately rely on EPA data sources, however the EHD utilizes data directly from the EPA's EJScreen which relies on more complex proximity models for each type of site. In contrast, the ETC utilizes toxic site location data, applies a buffer area of 1-mile around each, and calculates the percentage of the tract area covered by the buffer areas. In the case of air pollutant concentrations, differences between the indices are most likely the result of different data sources, with the EHD relying on

[15] https://htaindex.cnt.org/about/

Washington State Department of Ecology (DoE) 2014-2017 AIRPACT estimates and the ETC using data directly downloaded from estimates published to the EPA’s 2022 version of EJScreen. Like other EJScreen estimates, these values were derived from other EPA models and sources.

The third source of variance (difference between years) is demonstrated by variables such as Limited English Proficiency and Lead risk from housing are identical in both indices apart from the data vintage. The EHD relies on data from the 2015-2019 ACS estimates that are aggregated over 2010 census tract areas (n=1458) and the ETC uses 2016-2020 ACS estimates that are aggregated over 2020 census tract areas (n=1773). The larger number of tracts in the 2020 TIGER/Lines reflects population growth and the division of individual, larger tracts generated based on the 2010 decennial census into multiple, smaller tracts based on the 2020 decennial census.

Figures 3.4 (b) and (c) present the count of variables for each index by HEAL Act concept and urban/rural correlation. The total number of variables in the ETC (n=48) is over 2.5-times greater than the number included in the EHD (n=19). Both indices contain more variables with an urban correlation, and the majority of these urban-correlated variables are measures of environmental degradation burden. In the ETC, most variables have no correlation to population density, however the variables that do have consistently higher correlation estimates as compared to EHD variables (see Figure 3.4 (a)). The EHD, however, contains 3.5 more urban-correlated variables relative to rural, with the EHD (i.e. the EPA’s EJScreen) TSDFs (treatment, storage, and disposal facilities) sites proximity estimate having the highest urban-oriented correlation coefficient of all variables considered. These variables combined using different mathematical choices lead to estimated indices that are all more likely to assign disadvantage status to urban tracts as compared to rural tracts as shown in Figures 3.5 and 3.6.

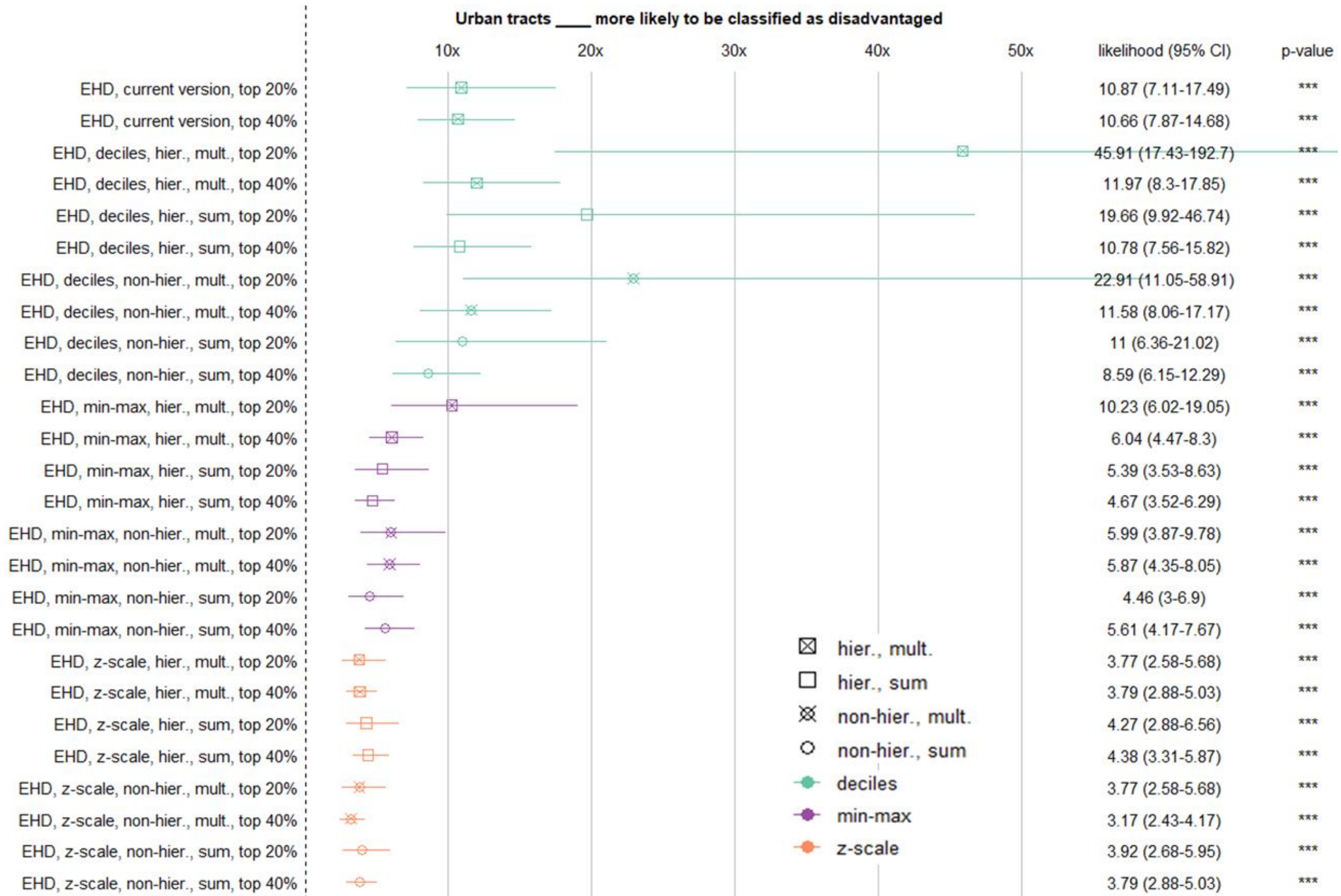


Figure 3.5. Likelihood of urban tracts to be classified as disadvantaged relative to a rural tract baseline (0) by iteration of EHD calculation and threshold values (top 20% or deciles 9 & 10; top 40% or deciles 7-10).

Figure 3.6. Likelihood of urban tracts to be classified as disadvantaged relative to a rural tract baseline (0) by iteration of ETC calculation and threshold value (65th percentile).

For the EHD, the increased likelihood of urban disadvantage assignment tends to be exacerbated by the multiplicative structure when a stricter inclusion threshold is applied. When a more lenient threshold is applied, the multiplicative effect becomes significantly less pronounced. This is not the case for the ETC, where the multiplicative structure consistently yields a higher likelihood of urban disadvantage assignment. This is most likely a function of the larger number of variables considered in the ETC; more variables means larger potential sums in each category and larger potential multiplicative products. Additionally, given that variables measuring environmental burden tend to be correlated with population density, multiplying the sum of these variable values will naturally lead to an increase in urban disadvantage assignment.

Of the data re-scaling methods tested on the variables included in the original indices, z-score normalization consistently reduces the likelihood of urban tracts being classified as disadvantaged over rural tracts. In contrast, decile and min-max rescaling methods tend to be more volatile. Of the three options, z-score normalization offers the best method to retain the distribution and statistical properties of the original data. It therefore makes sense that this method offers the most consistent estimates.

3.6.1.a. Variation between the published index values and those calculated.

In the case of the EHD, variation between the published version and my calculated versions were expected for two reasons. First, the EHD applies an averages-based hierarchical structure (see Appendix A.3). Additionally, the EHD estimation follows a more robust decile ranking methodology that better accounts for the base variable distributions (UW-DEOHS, 2019). While a uniform distribution is still applied, data missingness and similar values are handled more explicitly. The combination of multiple layers of averaging and more robust decile ranking offer a likely explanation for the variation in the likelihood results when comparing the current version of the EHD to the similar, calculated iterations of deciles, hierarchical, multiplicative.

In addition to the correction applied to the variables of "Frequency of Transit Services per Sq Mi" and "Jobs within a 45-min Drive", there is a discrepancy between the assignment of disadvantage (and associated final score percent rankings of tracts) in the ETC data download vs. the data back-ending the ETC explorer online[16] vs. my calculated version (min-max, hierarchical, simple sum) which should match the values in at least one of the published versions

[16] https://experience.arcgis.com/experience/0920984aa80a4362b8778d779b090723/page/ETC-Explorer---State-Results/

according to their published methodology (see Appendix A.3). My version, however, matches neither published version. Two explanations for the discrepancies are likely:

1. additional data processing/more detailed handling of each variable went into the published scores/ranks/disadvantage assignments that were not included in published documentation, and/or
2. some data hygiene QA/QC steps have been missed.

Explanation 1 addresses the discrepancy between my calculation and both published outcomes and explanation 2 addresses the discrepancy between the two versions currently published. As of this draft, the author has reached out to the USDOT's posted email associated with the ETC to hopefully resolve these discrepancies. Regardless of discrepancies, the comparisons of the twelve other iterations completed by the author still serve the function of comparing the effects of methodological choices on index disadvantage assignments.

3.6.2 Tract scores and disadvantage status are consistent for most urban tracts but are more varied for rural tracts.

Figures 3.7 and 3.8 present the range of index ranks over the 13 index iterations considered for each index. Figures 3.9-11 present the iteration outcomes in terms of number of times a tract is classified as disadvantaged by index and threshold (EHD top 20% and 40%, ETC 65^{th} percentile). While direct comparisons between index results cannot be made for all tracts given that the ETC is specified using 2020 census tracts (n=1773) and the EHD is specified for the 2010 tracts (n=1458), many comparative insights exist. The ETC scores exhibit wider variation in minimum and maximum values compared to the EHD. In both indices, the most consistent scores (with ranges <20%) occur, unsurprisingly, in rural tracts. Similarly, the tracts that are always classified as disadvantaged in all 13 iterations and at all thresholds are almost exclusively urban tracts.

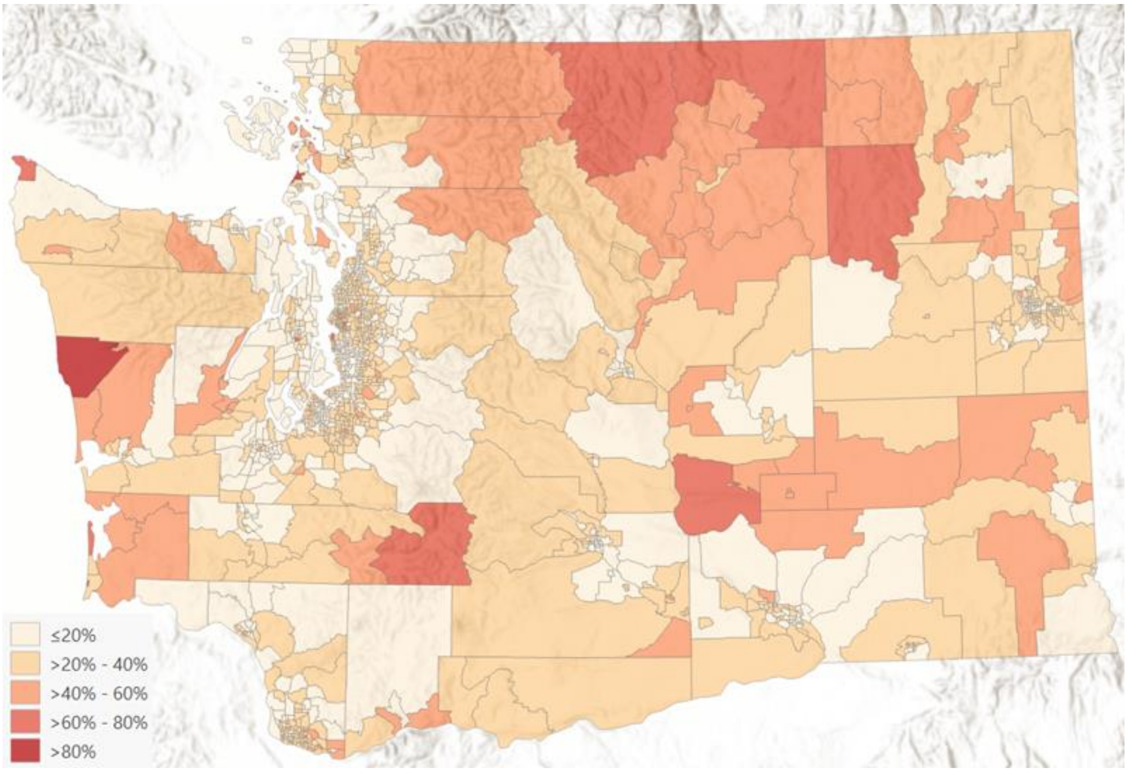


Figure 3.7. Range of EHD index values by tract calculated over the 13 iterations.

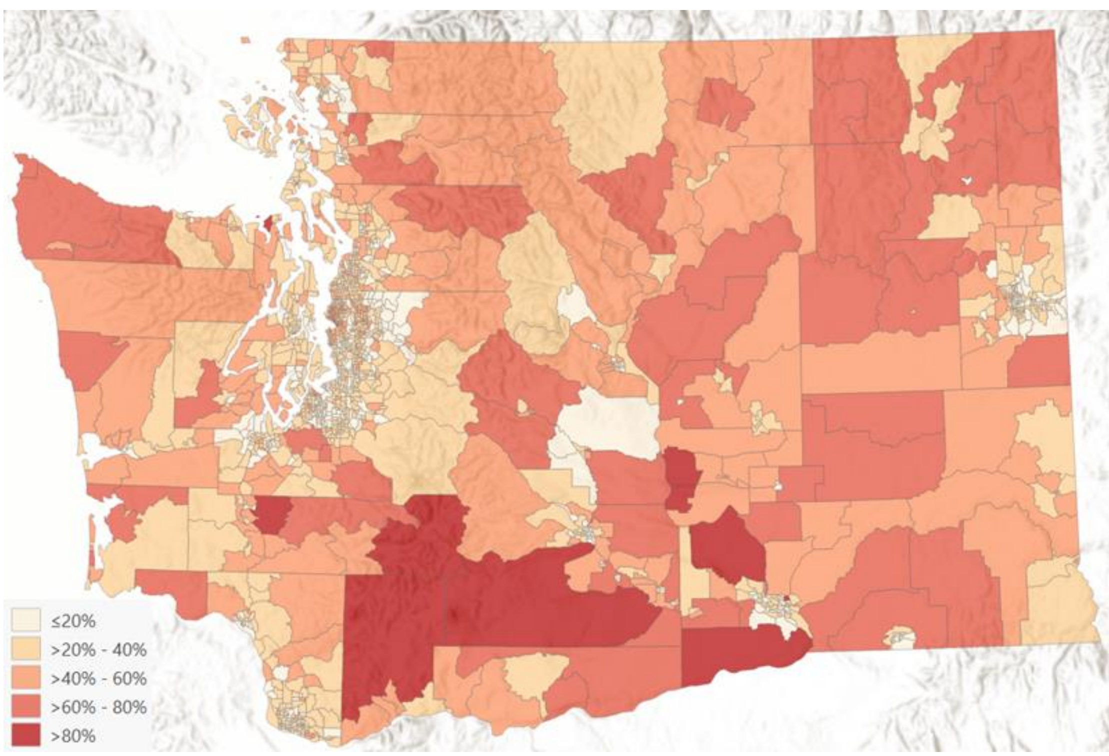


Figure 3.8. Range of ETC index values by tract calculated over the 13 iterations.

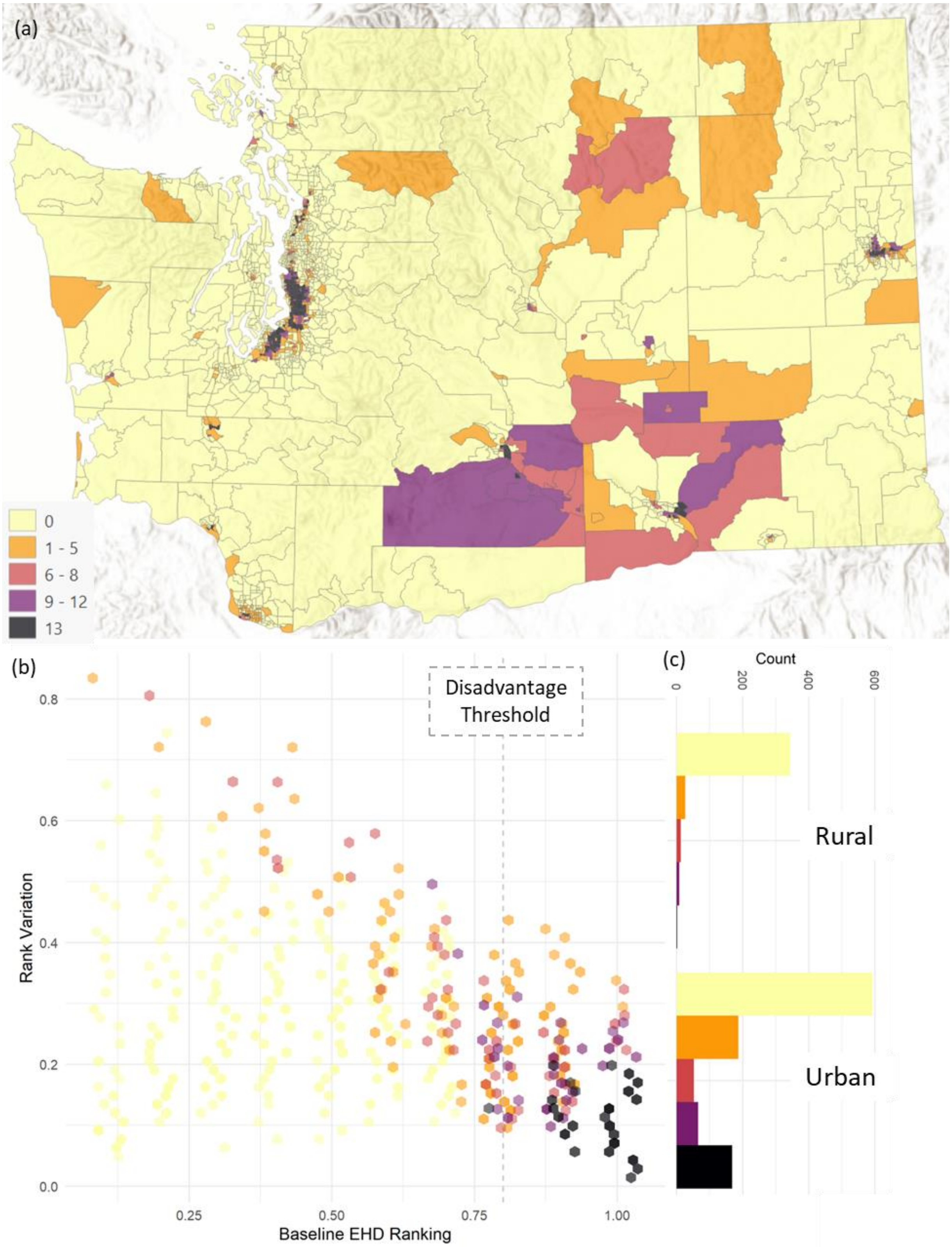


Figure 3.9. Number of times in the 13 index iterations a tract is classified as disadvantaged by the top 20% threshold (a) mapped (b) plotted as point fill within a plot of current v.2.0 EHD ranking vs. range of rank variation over all 13 iterations (c) by urban/rural tract type.

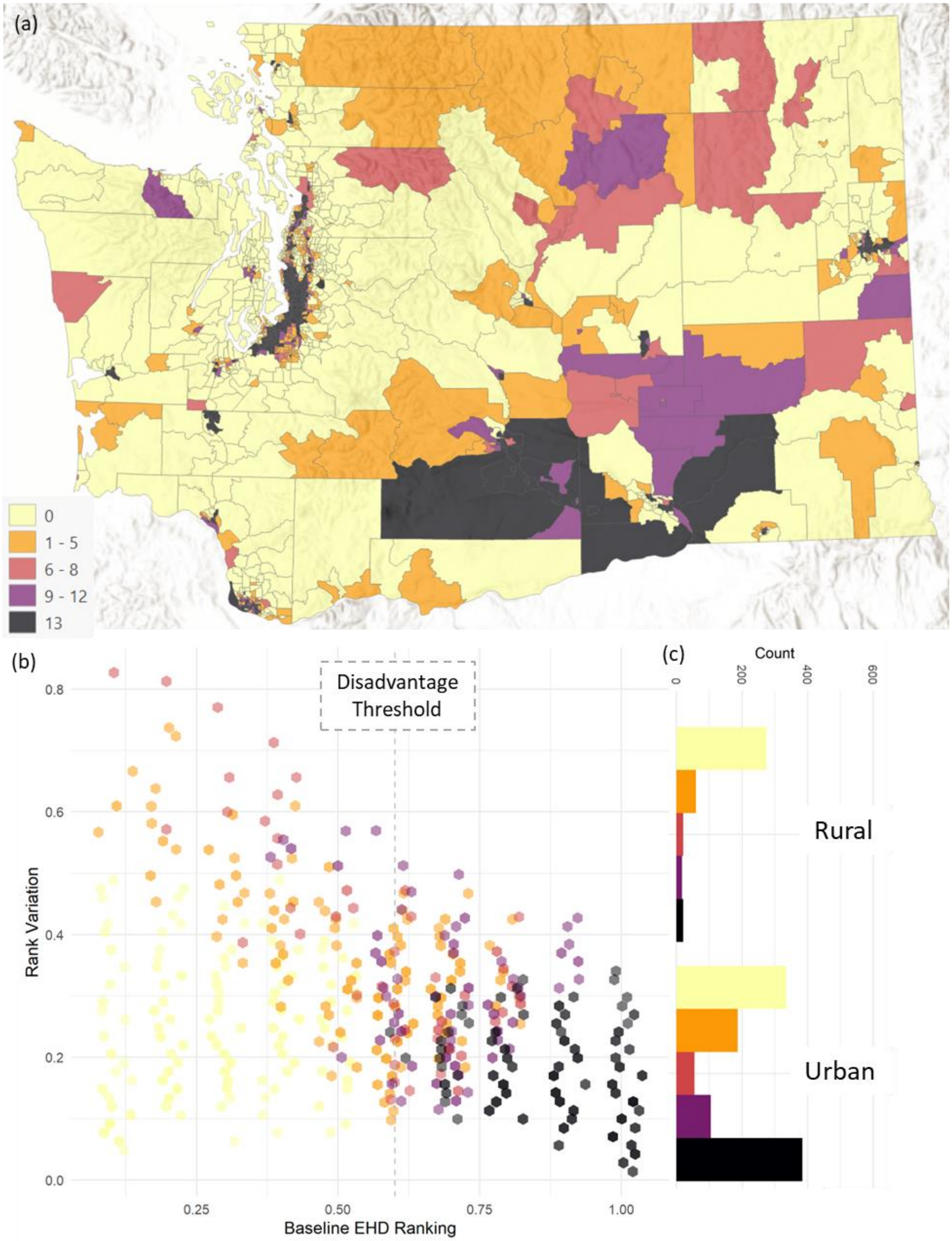


Figure 3.10. Number of times in the 13 index iterations a tract is classified as disadvantaged by the top 40% threshold (a) mapped (b) plotted as point fill within a plot of current v.2.0 EHD ranking vs. range of rank variation over all 13 iterations (c) by urban/rural tract type.

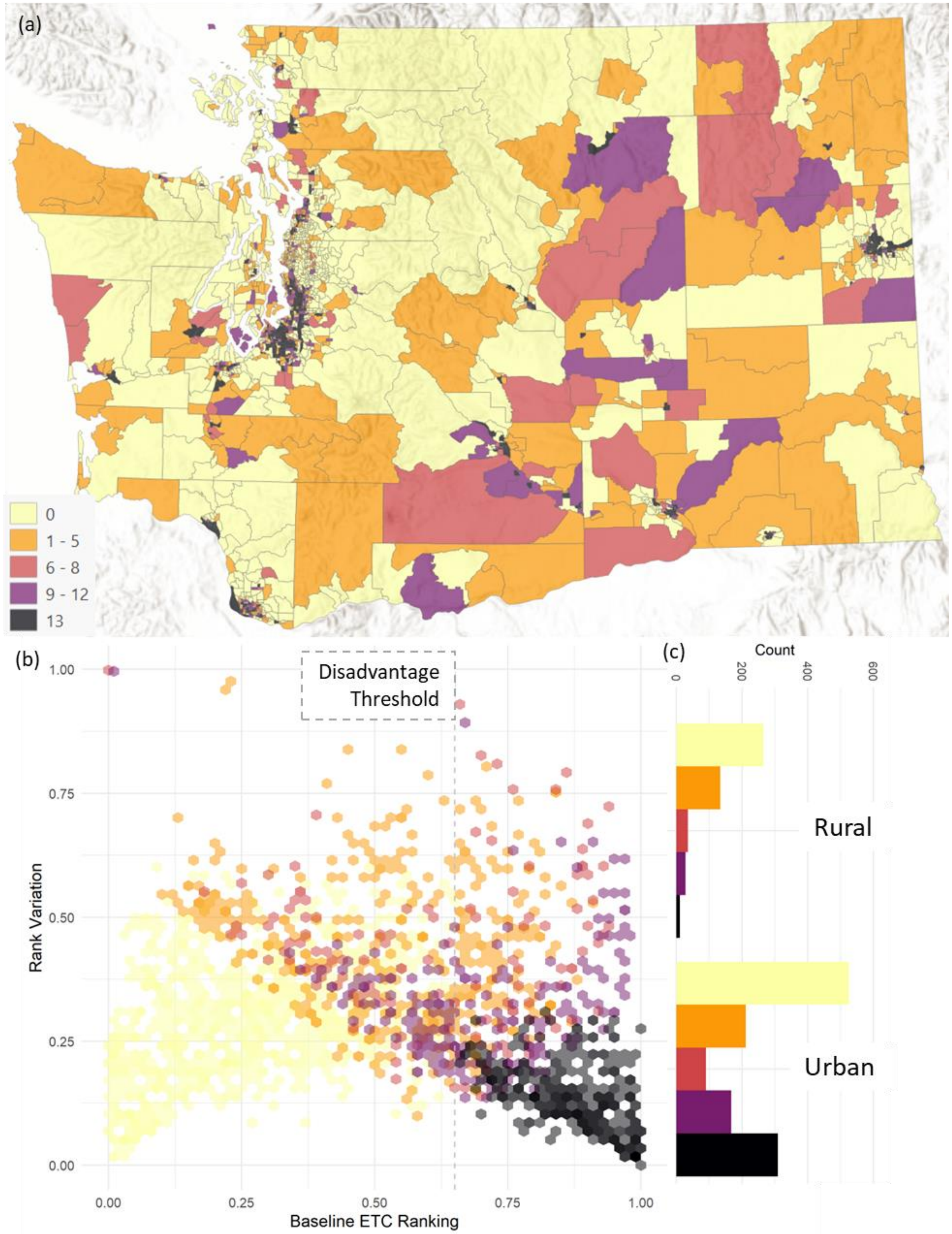


Figure 3.11. Number of times in the 13 index iterations a tract is classified as disadvantaged by the 65th percentile threshold (a) mapped (b) plotted as point fill in a plot of the data download v.1.0 ETC ranking vs. range of rank variation over all 13 iterations (c) by urban/rural tract type.

Comparing the number of disadvantage classifications between the two indices yields a wide variety of results, with many tracts deemed never disadvantaged by one index classified as disadvantaged in many iterations of the other index and vice versa. That said, both indices include most tracts that are consistently classified as disadvantaged with limited variation between iterations. In the case of the EHD, applying the stricter threshold value of top 20% (i.e. deciles 9 & 10) yields almost exclusively urban tracts classified as disadvantaged. Even when the more lenient threshold of 40% is applied, Figure 3.10 (c) shows that the vast majority of consistently disadvantaged tracts are urban. The ETC offers a similar trend, though at the 65^{th} percentile threshold there are more rural tracts that are classified as disadvantaged in at least one but less than half of the iterations calculated.

3.6.3 Disadvantage classifications vary widely between indices, but z-scored iterations seem to offer more clarity.

Figures 3.12 and 3.13 present the 2020 census tracts in terms of whether they were classified as disadvantaged by either of the indices, both indices, or neither under any iteration of mathematical choices and under only the iterations that were based on z-scale normalized variables. Table 3.7 presents the percentage of tracts that are classified as not disadvantaged (i.e. consistently ruled out of disadvantaged status) but types of iterations considered and tract type. Z-score normalized iterations were chosen for comparison because z-score normalization retains the original statistical properties of each variable. Because the magnitude as well as relative positionality of differences is an important consideration in evaluating cumulative impacts. Additionally, because the z-score normalized iterations yielded the most precise results, this subset of iterations is presented as a potentially more accurate representation of tract disadvantage relative to the other iterations based on min-max and decile data re-scaling.

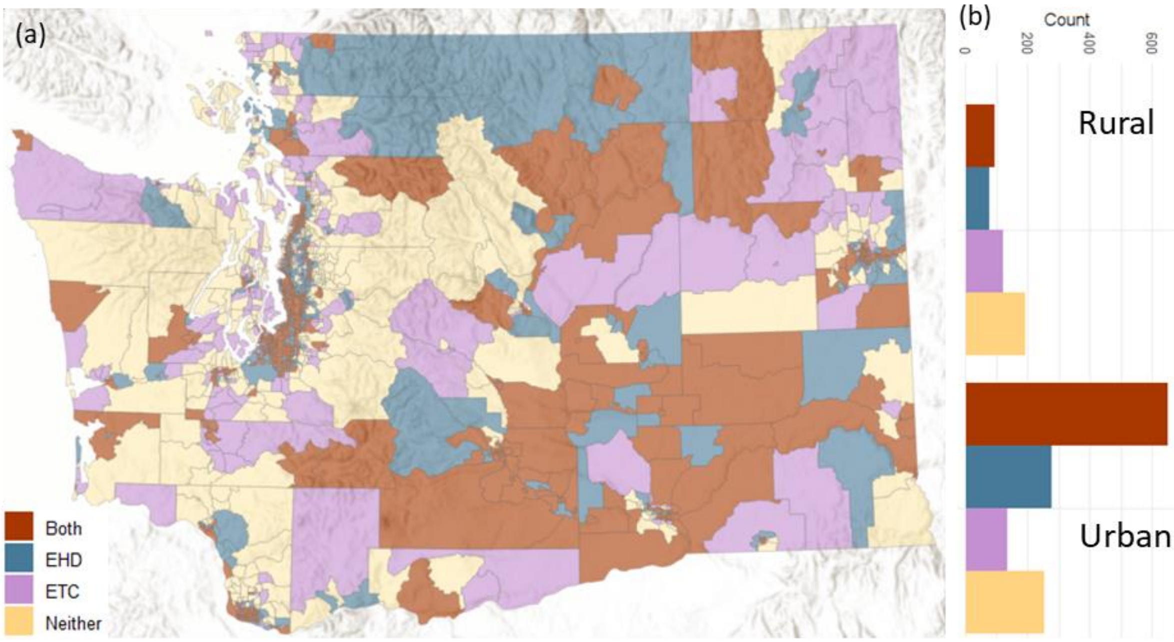


Figure 3.12. Tracts classified as disadvantaged given any of the 13 iterations at the top 40% threshold for EHD and 65th percentile threshold for ETC by inclusion type (a) mapped (b) by tract type.

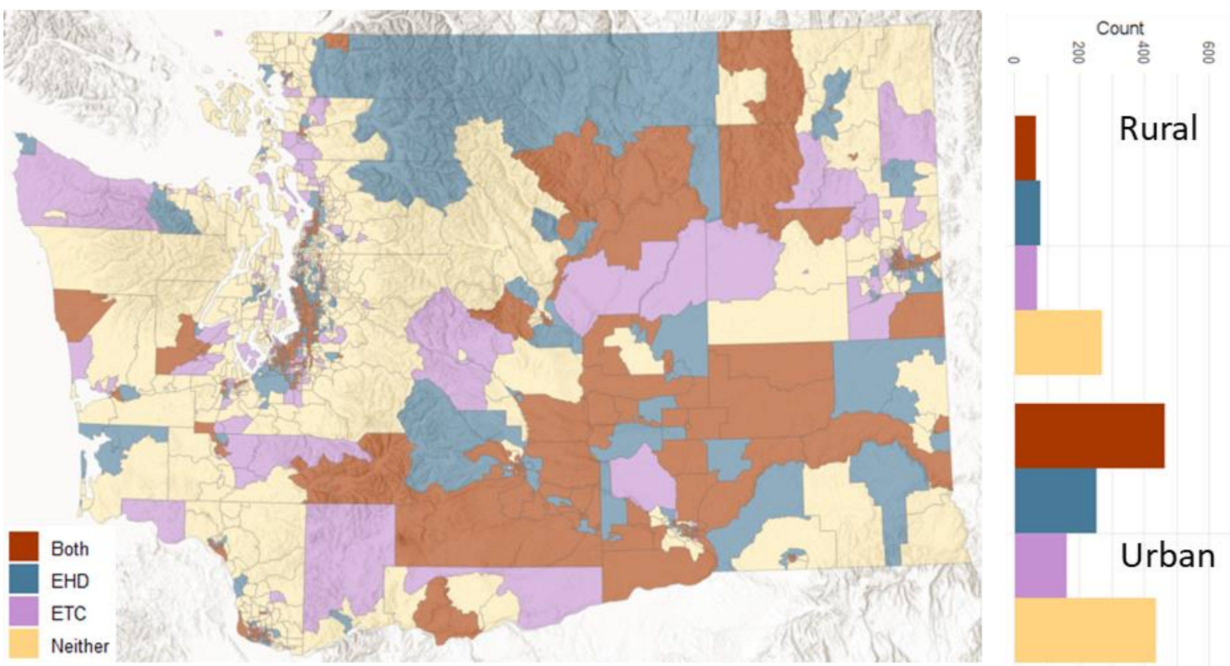


Figure 3.13. Tracts classified as disadvantaged given only the z-score iterations at the top 40% threshold for EHD and 65th percentile threshold for ETC by inclusion type (a) mapped (b) by tract type.

Table 3.7. Percent of tracts classified consistently as not disadvantaged by data re-scaling method and tract type.

Tract type	All	Rural	Urban	Urban/Rural Exclusion Ratio
All iterations	25%	40%	19%	2.1
Z-score only	39%	56%	33%	1.7

3.7 Discussion & Recommendations

Taken as a whole, the analysis provided in this chapter offers many insights into the specification and use of cumulative impact indices. Tate (2012) defined uncertainty and sensitivity as two means of assessing social vulnerability indices. Uncertainty asks how accurate is the composite indicator? Sensitivity asks what are the key factors driving uncertainty? This article focuses less on the assessment of accuracy and more on the aspect of sensitivity. Specifically, sensitivity to identify urban versus rural tracts as disadvantaged. While disadvantaged status is of course sensitive to the threshold assignment decision, this article highlights key considerations at each stage of the index development process. The key methodological considerations of cumulative impact index specification were laid out by the Organization for Economic Cooperation and Development (OECD: Nardo, 2005) and visualized in Frostad's (2023) analysis of the EHD. To explore these components in a practice-oriented manner, two cumulative impact indices specified by and for state and federal funding allocation vetting purposes were selected for analysis: WA's Environmental Health Disparities (EHD) map and the USDOT's Equitable Transportation Communities (ETC) Explorer.

First, indicators from both indices were assessed based on their correlation to population density. Most of the indicators of environmental degradation are correlated with densely populated areas. There are also a wide variety of potential measures, sometimes with comparable measures yielding significantly different results. Additionally, measures of some phenomena, such as water pollution, have proven difficult to measure and report reliably at scale (OEJECR, 2023). Both the EHD and ETC each contain only a single indicator for water degradation, and Frostad (2023) found that the indicator used in the EHD (wastewater concentration) contains mostly NULL values. It is likely that other instances of degradation and harm unique to rural settings are also being rendered invisible by the combination of abundant data for more populous areas and limited data in more rural areas.

Prior studies agree that the aggregation formula is typically the most impactful decision in cumulative index estimation (Frostad, 2023; Tate, 2012; Saisana & Saltelli, 2010). Relative to the concept of urban/rural likelihood of disadvantage assignment, the aggregation alternatives considered (multiplicative and simple sum) were less impactful relative to data re-scaling techniques. Both aggregation and data re-scaling techniques were identified based on the methods currently in use by public agencies to develop the cumulative indices. While more statistically advanced aggregation methods exist such as Principal Component Analysis (PCA) and Latent Class Analysis (LCA), these methods were not considered in this analysis. While PCA has been used in the variable selection and categorical assignment process, it is not used as a final aggregation method due, at least in part, to its statistical complexity (OST, 2023; Cutter et al., 2014). At present, practice-oriented tools are most useful when their structure can be clearly and readily explained to the general public. Additionally, while methods such as PCA may reduce a data set by managing covariation, in Section 3.3.2, I argue that the type of management they offer is not adequately aligned with the purpose of cumulative impact indices, particularly under the intersectional theory of multiple jeopardy.

Ultimately, because these concepts – intersectionality, cumulative impacts, composite disadvantage – are multifaceted and complex in a way that bucks quantification, a wide range of quantitative methods have been utilized with no clear consensus on which is ideal (Bauer et al., 2021; Guan et al., 2021). There is no ideal method that can produce a perfectly accurate benchmark from which other methods might be compared. Arguably the use of more complex statistical methods runs the risk of producing measures that offer a false sense of accuracy and precision. Instead, a suite of methods applied by conscientious analysts is recommended. The following subsections detail recommendations for two types of practitioners: those who are tasked with applying cumulative indices as published and those tasked with developing new (or revised) indices.

3.7.1 Recommendations for practitioners applying EXISTING cumulative indices.

Cumulative impact indices offer a useful first step in the process of assessing disadvantage and associated resource allocation. For the areas that are consistently classified as not disadvantaged, it is likely fair to assume that there are areas in greater need. For areas that are consistently classified as disadvantaged, it is likely fair to assume that these areas should be treated as top priority locations. It is the areas in-between the far ends of the distribution where cumulative impact indices become most sensitive and deserve the highest scrutiny. Or, more specifically, decisions regarding an area’s status of relative disadvantage deserve more careful consideration in the form of additional analytical steps.

Presumably the more consistently a tract is classified as disadvantaged, the more likely the disadvantage classification reflects a disadvantaged reality. At this level of data aggregation, it is not, however, possible to definitively determine whether the more variable tracts (i.e., those that are sometimes classified as disadvantaged but sometimes not) are indeed more or less disadvantaged than other variable tracts. Classifying these tracts as definitively not disadvantaged based on a single index or even a single version of the possible ways an index could be calculated runs a distinct risk of screening out disadvantaged areas with a just claim to fund allocation. Screening such areas based on a single method would be disingenuous to the broader effort of equitable consideration when many assignments could be based more on methodological artefacts than an accurate representation of disadvantage.

This limitation is recognized in the materials used to document and present every index identified in this article. The EPA's EJScreen documentation clearly states that the tool should not be used as the sole arbiter of EJ status for areas or communities (OEJECR, 2023). The WA EHD is similarly presented as a first step in an EJ screening process and not a definitive end-all-be-all scoring system (UW-DEOHS, 2019; WSIPP, 2022). This can be difficult to reconcile with the reality that tools such as WA's EHD have been developed with considerable public engagement and have received buy-in across state actors, boards, and citizen groups (UW-DEOHS, 2019). However, the use of multiple tools to screen areas based on cumulative impacts has precedent. The USDOT's ETC is explicitly intended for use in conjunction with the CEQ's CEJST (OST, 2023) and Lee's (2021) finding that EJ assessments tend to be completed with a combination of EPA's EJScreen and a state's version of CalEnviroScreen. In the state of Washinton, this is the EHD (WSIPP, 2022).

Figure 3.14 presents a decision tree to guide practitioners on how to utilize the existing indices identified in this article. Because different indices include and present different types, sources, and aggregations of data all relevant to the overarching concept of cumulative disadvantage, different situations may call for different processes and considerations. This decision tree, however, is intended for transportation professionals, particularly in the state of Washington. This Washington-specific state-level step could be replaced by a given state's version of the EHD (such as California's CalEnviroScreen). Alternatively, analyses at the federal level may skip the state portion and begin with the USDOT's ETC.

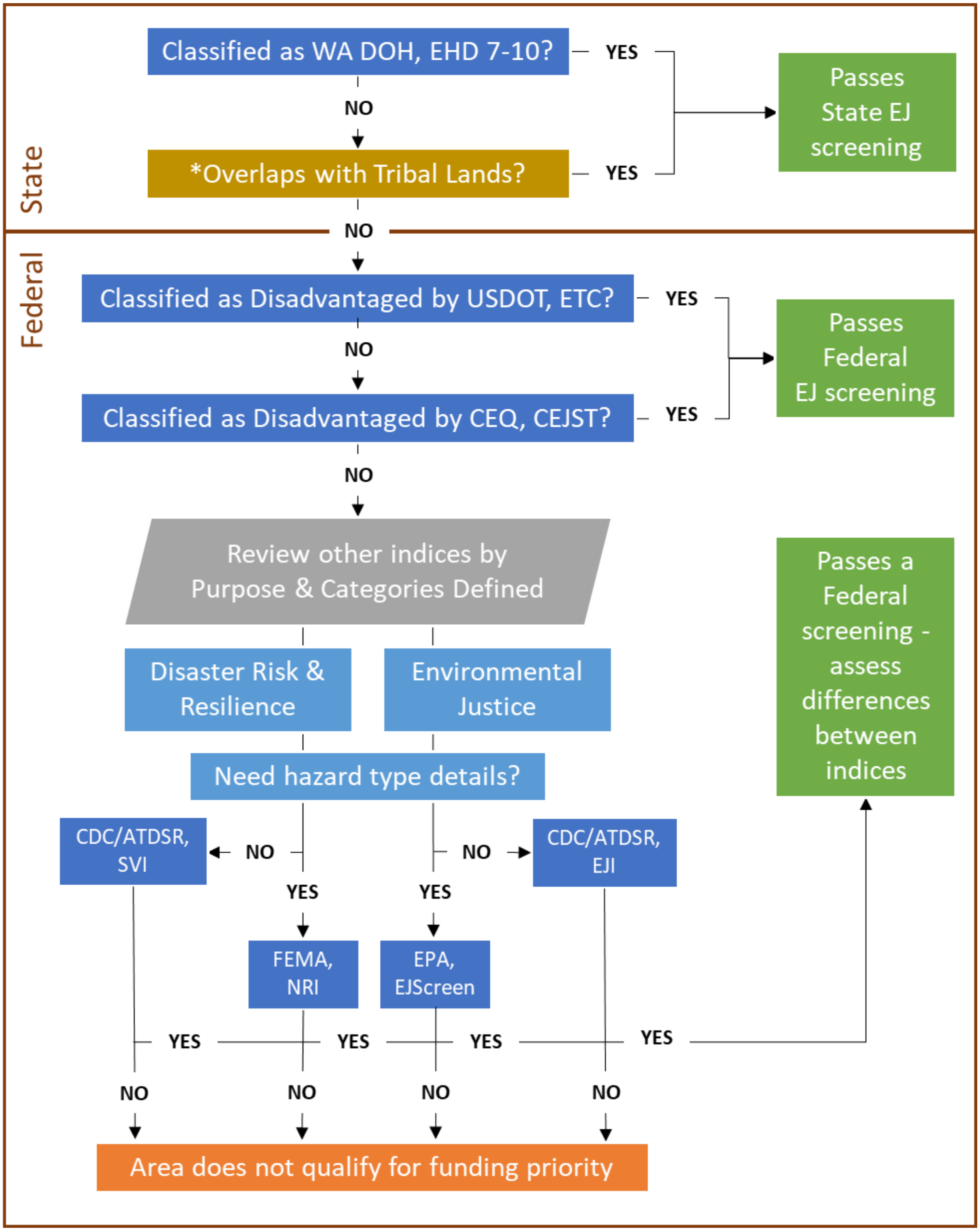


Figure 3.14. Recommended process of cumulative impact index application to determine if an area qualifies for equity-oriented funding priority. *seek local guidance regarding Tribal land designations and appropriate applications relative to unrelated census TIGER/Lines

It is also important to recognize that cumulative impact indices such as these present data aggregated over large geographic areas. The attributes are therefore representative of the given geographic area and not of the individual experiences of members of the population residing within them. Specifically, population-oriented data represents the home locations of individuals but does not necessarily represent the places they go for work, school, health, or recreation. If justice initiatives are developed to address past harms and/or present needs of specific populations (such as racial and ethnic minorities or people with disabilities), those initiatives must involve additional measures beyond a cumulative impact index based on USCB areas and data aggregations. Rowangould et al. (2016) offer alternative geospatial methods to locate disadvantaged communities including standard aggregation over tracts, density-weighted estimations, and self-report methods and found that intervention location recommendations varied by method. They did find, however, that the density-weighted estimations and self-report methods yielded similar results while the standard aggregation method differed.

Practitioners are advised to err on the side of inclusion, at least at this level of aggregation. Then look to more disaggregate, localized data sources and analyses to make more informed funding determinations. Additionally, given that urban areas will more likely be identified as disadvantaged, efforts to distribute funding equally to urban and rural areas will require an additional, conditional step such as setting quotas by tract type.

3.7.2 Recommendations for analysts specifying NEW cumulative indices.

Beyond assessing the urban/rural correlations and assignment likelihoods of variables and indices, respectively, this article also identifies guiding principles for cumulative impact index development according to theories of intersectionality. Multiple sub-theories of intersectionality exist, some of which lend themselves to application in a cumulative impact index format. Other sub-theories provide insight into the limitations of quantitative methods; limitations which should remain front-of-mind. The directly applicable sub-theories offer guidance regarding weighting and variable inclusion.

Taken together, the intersectionality sub-theories of simultaneity and multiple jeopardy provide insights into the process needed to identify a final set of variables for inclusion in an index. Multiple jeopardy encourages analysts to seek out as many variables as possible to offer proxy measures of the various ways in which individuals face relative disadvantage in society. Simultaneity suggests that all socioeconomic positions be treated as equally important in the analysis. While a simple edict, this functionally means a careful consideration of variable categorization and index structure to avoid (or at least minimize) implicit weights that may unintentionally up- or down-grade the weight of variables. Analysts should therefore be less concerned about correlations between variables and more considerate of the relative weight each variable will functionally contribute to the final index score. Given the inverse relationship between the number of variables included and the functional weight of each variable on the final score, this means a balance must be struck between including many variables that capture a variety of vulnerabilities (i.e. a variety of forms of jeopardy) and including so many variables that the relative contribution of each is so small as to be negligible.

It is also important to remember that, when specifying a cumulative impacts index, covariation is not necessarily a problem that requires statistical remediation. While an ideal index would offer a set of variables that measure a variety of forms of vulnerability and burden, covariation should not be used as an exclusion criterion. A core tenet of the theory of intersectionality is the unique experience of individuals with multiple, disadvantaged identities. While income and race are highly correlated in the US, this does not mean that one variable alone can capture the experience of an individual who holds both low-income and minoritized identities. Racial and ethnic minority status has, and continues to be, a major contributing factor in the health and well-being of individuals in the US (Rothstein, 2017). Rather than being concerned about the potential of covarying variables such as these to double-count the same phenomena, analysts should include variables that represent distinct socioeconomic phenomena. A person's skin color or ethnic background is utterly distinct from the concept of income. Considering both together does not double-count the same phenomena, it highlights the multiple jeopardy faced by individuals who hold these identities and helps highlight the harmful reality of a history of racialized policies that led to the covariation we see in the data. Variables should therefore be selected and managed such that higher values equate to higher relative disadvantage.

3.8 Concluding Remarks

As the statistician George Box famously stated, "All models are wrong, but some are useful" (1976). As the sub-theories of intersectionality highlight, quantitative measures will never be able to capture the full, nuanced reality of identity and associated disadvantage. Carefully specified and applied measures can, however, offer a useful aid in efforts to remediate identity-based social harms. This is especially true for cumulative impact indices. Because they are specified using data at large scales, aggregated over large geographic areas, then subject to a series of mathematical decisions, cumulative impact indices are prone to wide margins of potential estimate outcomes: they are highly sensitive. Intersectionality is a component piece of the EJ concept of relative social disadvantage: a highly multifaceted and complex concept with no singular, definitive baseline value available for testing and comparison: there is no quantitative method to test accuracy.

Given this, a few key takeaways and some associated questions emerge:

- Nearly half of the environmental degradation (burden) variables considered are correlated with urban populations, and both indices had more urban correlated variables than rural.

Of the 37 environmental degradation (burden) variables considered between both indices, 18 (49%) exhibit significant correlation with populous areas. The ETC exhibited a slightly more balanced collection of burden variables, with 10 of 22 (45%) being urban correlated. The EHD, however, was significantly more skewed with 8 of 10 (80%) burden variables exhibiting urban correlation. In both indices, burden variables had the most extreme urban correlations of any variables considered and were significantly more numerous than rural correlated burden variables (10 to 3 for the ETC and 8 to 1 for the EHD). This begs the question: why? Are urban areas more environmentally degraded? Or do we simply have more data in urban areas? Answers to these questions would provide critical insights into the accuracy of these indices. Notably, data related to water degradation, or lack thereof, is concerning. The lack of observations present in the water degradation variable used in the EHD is particularly concerning; is a variable that seems to measure a phenomenon but lacks the data to truly do so worth inclusion? Or does this merely offer a false sense of precision?

- Sometimes comparable measures yield significantly different correlation results.

Of the three reasons for variation identified – difference in source data, difference in estimation method, or difference between years – difference between years is the least concerning reason for variation. Since the EHD relied on 2010 census tracts and the ETC used 2020 tracts, it should come as no surprise that data varied in vintage and spatial aggregation exhibits differences in urban/rural correlations. Additionally, these variations were consistently small in magnitude. In contrast, high variation between variables that offered proxies for similar concepts but based on different source data and estimations methods raises some concerns. The most notable example of this occurs in the transportation expense variable; the ETC version of this variable exhibits no correlation while the EHD version exhibits a rural correlation with the highest magnitude of any of the variables assessed. While this variation is explained by the significant differences in data and methods used by the different sources, it raises the question: which one is best? Or perhaps its not a question of choice – perhaps both variables offer insights into different types of transportation cost. Should both be included in a single index?

- While the methodological process is established, each stage involves analytical decisions that result in a range of viable outcomes.

Identifying an area as disadvantaged using a cumulative impact indicator requires a series of analytical choices, from identifying variables to data re-scaling to choosing a mathematical structure to combine metrics to assigning thresholds of disadvantage. Each stage presents a range of equally valid analytical choices. Different sets of choices, however, combine to yield a wide range of viable outcomes. This imprecision is an understandable outcome of combining an array of population and areal data sources, each with varied levels of accuracy and precision, at a coarse level of aggregation. Errors and omissions should be the expectation under these circumstances. These can be mitigated, particularly at the data re-scaling phase. Rather than utilizing methods that overly constrain the re-scaled distribution with uniformity (deciles, centiles, or percentiles) or with a linear transformation (min-max scaling), applying a methodology the retains as many of the characteristics of the original distribution as possible (z-score normalization) is recommended. While this still cannot guarantee the accuracy of the measurements, z-score normalization at least generates values that more accurately reflect the original variable distributions. Taken together, does this mean these indices are too imprecise to be of use? I would argue no, in large part because:

- Indices are most stable at the extremes while results near the middle of the distribution tend to be more sensitive.

Due to the resources of time, effort, and money necessary to build and maintain the data needed to specify a cumulative impact index, certain concepts will be missed or will be included at a resolution that is too coarse to make definitive judgements. This is especially true when attempting to differentiate levels of disadvantage near the middle of distributions. Instead, these indices work best at the ends of the distributions – at identifying tracts that are almost certainly disadvantaged, and those that almost certainly are not. It is in this capacity – identifying extremes – that cumulative impact indicators work best. Ideally these extremes would be established through a comparison of multiple iterations of possible calculation methods as demonstrated in this chapter. Regardless, analysts should be advised to always err on the side of caution and inclusion at the low levels of resolution these indices provide. Cross-referencing with other indices and more localized data and analyses is strongly recommended. If areas are identified as disadvantaged by one or more method, there is most likely a valid reason for this assessment. If they are not identified as disadvantaged by multiple sources, there are likely other areas that deserve higher priority for disadvantage-focused funds.

Combining population-level variables realistically cannot capture the multi-dimensional nature and unique experience at the various intersections of given identities and their associated relative disadvantage. As a result, cumulative impact indices offer a proxy value for a complex concept that bucks quantification. Rather than letting these imprecisions dissuade analysts from using these indices, it is instead important to recognize the limitations to ensure these tools are used with appropriate caution. Because they will always inherently fall short, it is critical for indices to be specified with careful reasoning and to be interpreted with a clear appreciation of their limitations.

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Chapter 4: Exploring methods

4.1 Introduction

This report was commissioned as part of the Washington Department of Transportation (WSDOT)'s Equity in Planning (EiP) project. This version of the report presents knowledge drawn from the transportation equity academic literature which will be combined with knowledge drawn from practice-oriented literature, community engagement, geospatial (GIS) analysis, and a survey of planning professionals. The project aims to comply with Washington State SB 5141: the HEAL Act. The HEAL Act sets a goal for 40% of major state expenditures to be directed towards overburdened communities and vulnerable populations. It mandates that EJ analyses be performed by seven state agencies including WSDOT. The goal of the project is to identify leading indicators of transportation equity that can be incorporated in WSDOT's planning process for long-range, regional, and corridor planning initiatives. In short, it seeks to answer the question:

- How can equity be incorporated in transportation planning efforts?

The concept of leading indicators comes from the discipline of construction safety with the Occupational Safety and Health Administration (OSHA) defining leading indicators as "proactive and preventive measures that can shed light about the effectiveness of safety and health activities and reveal potential problems in a safety and health program" (US Department of Labor, n.d.). Within academic literature, the concept of leading indicators remains focused on occupational hazards such as construction safety (Alhammadi, 2022). To apply the concept to a transportation equity context, this base definition can be restated as:

> "proactive and preventative measures that may indicate the potential equity impacts of transportation plans. This includes revealing potential inequities so that they may be

> addressed early and at every level possible in the transportation system planning process."

This chapter is broken into four main sections number two through five: (2) Components of Transportation Equity, (3) Identification of Components, (4) Limitations, and (5) Recommendations. Section 4.2 provides a working definition for leading and lagging indicators of transportation equity within this context of a transportation equity process. Section 4.3 contains most of the content presented in this report because it breaks down and presents detailed examples of each component of transportation equity defined in Section 4.2. The first subsection of Section 4.3 presents equity standards found in the transportation literature that the authors deem most relevant to the EiP project. This is followed by subsection 4.3.2 which presents the concept of communities of concern as defined by the Washington State HEAL Act as well as definitions found in the transportation equity literature. Subsection 4.3.3 presents the main categories of units of analysis used in transportation equity assessments and explains the benefits and potential pitfalls associated with each type.

Subsection 4.3.4 summarizes the various types of measures (indicators) of transportation equity collected from a review of over 100 scholarly articles drawn from a search for transportation planning equity indicators. The beginning of this subsection provides a detailed explanation of how the indicators were organized by type, with the detailed lists of indicators broken out by Accessibility, Mobility and Economy, Land Use, Environment Health and Safety, and Qualitative and Engagement. Subsection 4.3.4.1 is the most extensive of the five because it presents the concept of transportation accessibility, indicators, as well as associated threshold commonly found in the literature. Each table of indicators includes columns detailing those indicators' potential utility as leading indicators of transportation equity.

The final subsection (4.3.5) details methods of analysis that can be used to operationalize and assess the indicators presented in subsection 3.4. Section 4 identifies and details limitations in the current transportation equity literature. Based on the information presented in Sections 4.2 through 4, Section 4.5 presents recommendations including transportation equity strategies.

4.1.1. Literature review methodology: snowballing technique

The literature review methodology follows the snowballing technique (Wohlin, 2014). Google scholar searches for “transportation planning equity”, “leading indicators of transportation equity” and “transportation equity planning guidance material” were used to identify an initial subset of texts. Based on a review of abstracts, key texts were identified and used to identify additional, more recent texts that cited them. A total of n=110 articles were reviewed. The study focuses on work from the academic literature and largely excludes secondary sources.

4.2. Components of Transportation Equity

Because transportation equity is a multifaceted concept inherently tied to social norms and population dynamics, working towards transportation equity requires a recursive process – no single step or indicator (or even set of indicators) alone can guarantee transportation equity. This section presents a working definition for leading and lagging indicators of transportation equity within this context of a transportation equity process.

4.2.1. Leading & Lagging Indicators

Leading indicators of transportation equity can take a few forms; benefits and opportunities, burdens and barriers, and subjective experiences and perceptions. Benefits and burdens are things that can be directly measured, such as the number of buses in operation or emissions generated by a bus. Opportunities and barriers can also be measured, but they typically require analyses of direct measures. For example, access (or lack thereof) to regional jobs is measured based on an analysis of values such as travel times, residential locations, and employment centers.

These components of the transportation system can be quantified using observed values and are therefore classified as **objective measures**. In contrast, **subjective measures** are based on individual experience and perceptions; they cannot be objectively observed, they can only be self-reported. For example, many attributes of transit service can be objectively measured, but whether riders are satisfied with the service can only be collected through rider survey responses. *Figure 4.0.1* presents the types of indicators (measures), how they relate to each other, and how they combine to inform the development of leading indicators of transportation equity.

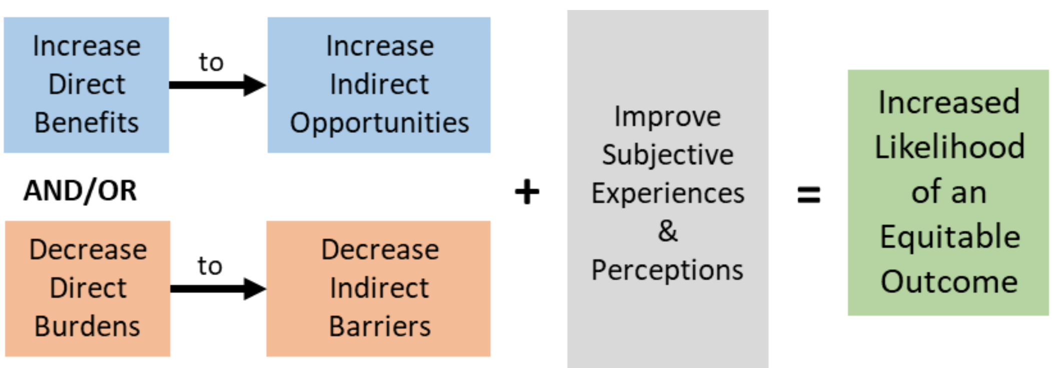

Figure 4.0.1. The different types of transportation indicators and how they combine to create leading indicators of transportation equity.

Outcomes that are projected to provide some increase in direct benefit must also provide an appreciable, meaningful increase in associated indirect opportunities. For example, adding bicycles and stations to a bike sharing service can be viewed as a direct benefit; the exact number of vehicles (bicycles) and facilities (stations) can be measured. However, if these direct benefits are not added with the broader cycling network in mind (ex: protected bike lanes) or the origins and destinations most useful to users (ex: housing, employment centers, recreation areas, etc.), then the added, direct benefits may not have any appreciable, meaningful increase in the indirect opportunity of accessibility. And if an increase in direct opportunities is not achieved, an improvement in subjective experiences and perceptions (ex: people believing the bike sharing service meets their needs or enjoying using the service) will likely not occur either.

To be a leading indicator of transportation equity, projected outcomes should not only yield positive results based on objective measures, but should also yield positive, subjective results. While it is possible for some people to perceive and feel bad or upset about a change that objectively improves their lives, most often people's perceived frustrations provide insight into elements not well measured or potentially overlooked entirely by objective measures (Curl, 2018). For example, objective measures such as satisfaction have been proven to be stable indicators of subjective experience, particularly when aggregated over a population (Di Ciommo et al., 2019). It is therefore critical to not only account for objectively observed measures of the transportation system and associated outcomes, but also the subjective experiences and perceptions of those who use and are impacted by the system.

As a result, a measure of a direct benefit alone does not meet the criteria for a leading indicator of transportation equity – direct measures must always consider the broader context of their indirect impacts and associated subjective experiences and perceptions. Leading indicators can also be understood by their counterpart, lagging indicators. Whereas leading indicators aim to address equity issues before they arise, lagging indicators simply measure the situation as-is. For example, a leading indicator of equitable transportation safety is the coverage of streetlights and general lighting at transit stops. This is a leading indicator because well-lit areas are known to reduce the experience of crime, both perceived and actual (Uteng et al., 2019).

In other words, this measure of an object is known to decrease direct burdens (crimes), associated indirect barriers (perceived danger preventing a trip), as well as improved subjective experiences (less fear and stress in transit) and perceptions (belief that transit is dangerous). A lagging indicator may be reported crimes and survey responses of perceived safety. While the lagging indicators can help highlight and quantify a problem, the leading indicator can be used during the planning stage to help alleviate the burden altogether.

4.2.2. The Transportation Equity Planning Cycle

Most metrics have the potential to be both leading and lagging – the difference depends on the point at which it is applied in an equitable planning process. Berg and Newmark's (2020) work on exploring equity in pedestrian master plans breaks down the equity process into phases of acknowledgement, accountability, and application. The HEAL Act has already created the policy environment of acknowledgement, and their accountability and application components have been integrated with the processes defined by Guo et al. (2020), Martens et al. (2019), and Davis and Pilkington (2019) to create *Figure 4.0.2*.

The cyclical format is used to highlight the recursive nature of transportation equity efforts and the different phases are highlighted to clarify at what point an indicator may be leading vs. lagging.

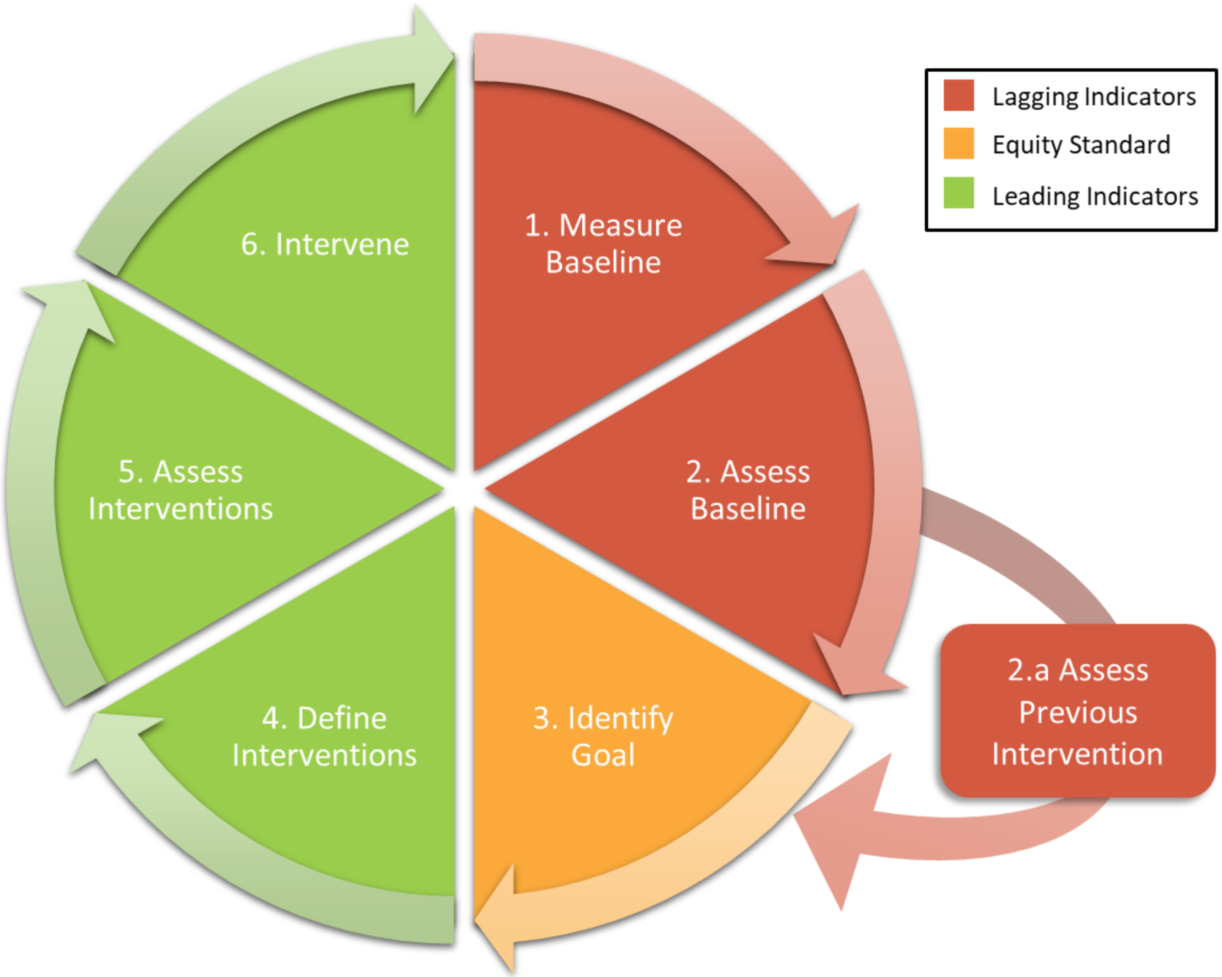

Figure 4.0.2. The relationship between leading and lagging indicators in the Transportation Equity Planning Cycle.

Table 4.0.1 provides further details related to each step in the transportation equity planning cycle and is again a synthetic product of the reviewed literature. Each process step has a set of associated questions to guide planners at that stage as well as a rough estimate of an ideal knowledge split between community and transport professionals. This is intended to highlight and differentiate the roles of community and professional within a transportation equity process. To achieve transportation equity, impacted communities must be centered (Boisjoly & Yengoh, 2017; Griffin & Jiao, 2019; Stewart & Zegras, 2022). When community identified concerns and professional interventions are closely aligned, an equitable outcome is more likely to occur (Sanchez and Brenman, 2008).

Table 4.0.1. Transportation equity cycle guiding questions and ideal knowledge split.

Process Step		Associated Questions	Ideal Knowledge Split	
			Community Identified	Professional Analyses
1	Measure Baseline	What should be considered?	Half	Half
		How should it be measured? (data & methods)	-	Full
		Where? For Whom?	Half	Half
2	Assess Baseline	How equitable is the status quo?	Majority	Partial
2.a	Assess Previous Intervention	Has the status quo changed?	Half	Half
		In what way? By what amount?		
		Was the change meaningful?	Majority	Partial
3	Identify Goal	What reality would be more equitable?	Half	Half
		What would constitute a meaningful change towards this equitable reality?		
		By what amount? By when?		
4	Define Interventions	What changes might help move towards equity?	Partial	Majority
5	Assess Interventions	What is the potential equity impact?	Feedback	Majority
		What resources are necessary to achieve results?	-	Full
		How long will it take to see results?	-	Full
6	Intervene	Actualize intervention(s) that have the highest equity potential	-	Full

After any given intervention, a new baseline is established – it is important to compare the new, post-intervention baseline to the original baseline to assess the impact of the intervention. Rather than assessing the potential of an intervention, this assessment uses lagging indicators to determine the effectiveness of a previous intervention. Specifically, the degree and meaningfulness of the change is key. While transportation professionals can objectively measure the amount of change that occurred using observational, objective measures, meaningfulness is an inherently subjective measure. The impacted communities are therefore the best judge of the degree to which a change was meaningful. This assessment can then inform a renewed resolve towards the existing equity goal or help reshape it.

It is critical that interventions address disparities identified in the early stages of the process, and involving communities in the process early and often not only promotes accountability but ensures that community members will be key players in identifying where and for whom interventions are necessary (Berg & Newmark, 2020). It is then the responsibility of transportation professionals to execute this vision, balancing competing interests and constraints. Karner and Marcantonio (2018) emphasize the importance of fund allocation, not only to support the engagement process, but also to ensure that the engagement process will be made meaningful through intervention. They discuss how to identify and "tailor" metrics to address the identified problem and recommend using metrics on an annual basis to measure progress as it unfolds over time (p. 119).

Concerning metric (or indicator) identification, *Figure 4.0.3* was developed by some of the leading academics in the transportation equity and accessibility field as part of the National Cooperative Highway Research Program (NCHRP) (Karner et al., 2022). It outlines the steps required to select appropriate measures for a transportation accessibility analysis. While the researchers specify this process for accessibility measurement purposes, it can be applied to other types of measures as well. Example indicators by type along with further details related to subtypes and their potential use cases as leading and lagging indicators is provided in Section 3.4.

Figure 4.0.3. Steps for accessibility measurement and application. Copied from Karner et al. (2022, p. 22)

4.3. Elements Needed to Identify Leading Indicators of Transportation Equity

The concept of leading and lagging indicators and the transportation equity planning cycle defined in the previous section provides a framework for the necessary components of transportation equity and how they relate to each other. This section details the component parts of the process, including detailed lists of transportation equity indicators. These indicators are organized along multiple dimensions and presented in terms of their utility as leading and lagging indicators.

4.3.1. Equity Standards

As the Transportation Equity Planning Cycle demonstrates, a key component of transportation equity work is setting a goal (Step 3). To inform this goal-setting effort, theories of equity have been established that can guide transportation professionals. This section relates extensively to Chapter 2 which provides extensive background and should be treated as a reference guide for theories presented in this section.

Equity standards refer to the different theories of equity that might be applied to a given situation. Theories of equity are a product of philosophical ideas related to how resources should be distributed within society; they are inherently concerned with justice and are therefore inherently normative (Chapter 2: Lewis et al., 2021). In contrast to **positive knowledge** which is concerned with observing and measuring the world *as it is*, **normative knowledge** is concerned with how the world *should be*. Because of the subjective nature of normative ideals, it is critical that impacted communities be consulted early and often (as highlighted in Table 4.0.1) to ensure interventions reflect their needs and expectations.

Leading indicators hold normative import whereas lagging indicators simply offer positive measures of existing or past phenomena. For example, lagging indicators related to safety simply measure the state of (un)safe conditions – they offer information about what is without passing any normative judgement. In contrast, leading indicators operationalize a normative goal. Leading indicators related to individual efficiency operate on the normative ideal that transportation *should* prioritize the use of personal vehicles.

Several equity standards have been applied in transportation literature either implicitly or explicitly (Lewis et al., 2021). When equity standards and associated goals are not defined explicitly, planner and researcher biases are instead applied as implicit equity standards and goals. This implicit, unintentional application of the concept of equity has led to confusion within the transportation literature and can lead to incoherent and contradictory assumptions, methods, and results (Lewis et al., 2021). Martens and Golub (2021) provide an explicit connection between equity standards and US policy as presented in Table 4.0.2.

4.3.1.a. Pareto, Proportional, and Restorative Equalization

Table 4.0.2. The Ladder of Justice Standards relative to US Policy guidelines. Copied from Martens and Golub (2021, p. 432)

Standard	Definition	Relevant planning guidance
Restorative equalization	Traditionally marginalized communities receive substantially more benefits than the majority population with the aim to correct past wrongs over time.	Civil Rights Act was meant to address past discrimination. DOT Title VI regulation (49 CFR Part 21) explicitly condones affirmative action where past discrimination left inequalities in the present.
Proportional equity	All communities receive a level of benefits that is roughly in line with the average improvement across the entire population.	Avoid disparate impacts and "disproportionately high and adverse" effects (EJ Order) plus broader acceptance of "equality" as general principle of fairness.
Pareto-plus	All communities receive at least some positive and nontrivial benefits.	Prohibition of "exclusion from" or "denial of benefits" (Title VI, EJ Order).
Pareto	No community is made worse off while benefits can accrue to one or a limited number of communities.	None (though embodies a basic principle of "do no harm").
Legal	No community is overtly discriminated against.	A core tenet of civil rights law (Title VI, etc.).

Note: DOT = US Department of Transportation; EJ Order = "Federal Actions to Address Environmental Justice in Minority Populations and Low-Income Populations."

While the Pareto standard (also known as Pareto-optimal solutions) holds a pragmatic appeal, Martens et al. (2019) warn against this as a stand-alone equity approach. They note that, while the worse off may receive some benefit, constraints often lead to relatively small improvements. Not only might the change be so small as to be practically insignificant, it may actually increase disparities – those who already have more may receive more. As a result, they recommend against Pareto-optimal solutions when meaningful efforts to reduce disparities are the goal.

In the state of Washington, the **HEAL Act** provides an example of a restorative equalization standard based on a proportional equity evaluation; because the environmental justice body of knowledge has established that some communities face disproportionately high environmental burdens (i.e., are overburdened), the HEAL Act has mandated restorative equalization equity efforts among state agencies.

The equity standard of equalization is most often found in the transportation literature and concerns two different types of equity efforts: a move toward equality or a reduction in existing disparities (Martens et al., 2019). The latter is based on the understanding that equality is not reasonably possible but recognizes that the existing state is clearly unfair and should be improved. However, without further specification of timeline and degree of change (goal), equalization efforts will fail to achieve meaningful change. Rather than addressing disparities and improving conditions for overburdened communities, such efforts can instead tokenize these communities while maintaining the status quo with minor, ultimately insignificant changes.

If it is accepted that perfect equality cannot be reasonably achieved, the equity standards of basic need, sufficiency, prioritarian, and maximum gap can provide useful guidance and operationalizations in pursuit of a restorative equity goal. Table 4.0.3 defines and provides examples of these equity standards from the literature and policy.

Table 4.0.3. Equity standards and associated transportation examples that align with restorative equity.

Standard	Description	Examples
Basic Need	different individuals and groups have different needs – resources should be allocated according to needs	Martens et al. (2019) highlight how vulnerable populations for disease receive additional protections from pollutants, or provisions of transport for those with inability to have private transport (cannot afford, disability, no license)
Sufficiency	sets a minimum necessary benefit threshold to judge the distribution of benefits and to prioritize those below the threshold	researchers tend to agree that a minimum level of accessibility to some key destinations should be ensured, and that this threshold should be defined to allow individuals to meet their basic needs and participate in society (Lucas et al., 2016)
		Golub and Martens (2014) propose thresholds of “access poverty” - % of population who experience an accessibility ratio (transit access/car access) of 0.25 and 0.34
	sets a maximum allowable burden threshold to judge the distribution of benefits and to prioritize those above the threshold	legal thresholds regarding maximum allowable exposure to pollutants

Prioritarian	benefits (or burdens) matter more the worse off a person is (i.e. marginal value is higher) and therefore those worse off should be prioritized	"individuals inevitably have unequal opportunities in a society, given internal and external constraints, therefore individuals more likely to have limited opportunities due to financial, cultural, physical, situational (e.g., lack of access to information), or cognitive constraints should be provided with higher levels of accessibility" (Boisjoly & El-Geneidy, 2021, p. 228)
		Murray and Davis (2001) focus on expanding public transit provisions to socio-economic groups most likely to need public transit
		Anderson et al. (2017) identify & focus analysis where disadvantaged groups are located in placement of multimodal facility recommendation analysis
Maximum Gap	defines a maximum range of fair outcomes – accepts inequality so long as they remain within range	Martens et al. (2019) notes that disparities may be the result of choices (ex: purchasing a house in suburbs with lower access for lower cost and more sq ft) – this theory allows for choice but aims to limit potential harm for those without the resources to make such a choice by assigning allowable range values

4.3.1.b. Basic Need & the Capabilities Approach (CA)

While basic need offers a straightforward concept that has been applied in various sectors, Martens et al. (2019) caution that, to execute a basic needs assessment properly, detailed information about individuals/groups is required. Similarly, the Capabilities Approach (CA) is presented in many transportation equity articles and is the equity standard that informed the United Nation's Sustainable Development Goals (SDGs) (Pereira et al., 2017; Nahmias-Biran & Shiftan, 2020; Lewis et al., 2021). The CA distinguishes between opportunities and functionings; opportunities are all the things a person reasonably *could* do, and functionings are what someone *does* do. Functionings are a product of opportunities and personal preference (choice), but one can only do what one has the legitimate opportunity to do. This opportunity set is based on many constraints, from the built environment to personal ability, and is concerned with all aspects necessary for a person to lead a fulfilling life.

Lira (2019) presents a methodological approach to quantify and compare capabilities and functionings and argues that the nuance provided by CA offers key insights into how users experience the transportation system. It required, however, a 60+ question representative survey. Nahmias-Biran and Shiftan (2020) present a method that utilizes activity-based models to evaluate the equity of transportation project alternatives. Again, this requires significant data collection efforts to power this person-based method (for more information on person-based measures, see Section 3.3.a). As a result, data and privacy constraints may limit the widescale operationalization of both CA and basic needs standards.

4.3.1.c. Sufficiency & Prioritarian

The equity standard of sufficiency provides a method that relies on widely available data and generalized goals. Maximum allowable thresholds of pollutants are common in environmental regulations, by minimum allowable thresholds are less common as a framework for discussing transportation benefits. Golub and Martens (2014) operationalize this standard with their concept of an access poverty line (see .

Table 4.0.8). While setting a specific threshold could prove to be a difficult, political exercise, analysts can present possible threshold measures to provide useful, data-driven talking points.

The use of thresholds, however, has a significant drawback; they divide individuals and groups in black-and-white terms of haves and have-nots. Consider Golub and Martens (2014) example thresholds; if the threshold of 0.25 were selected, someone with an accessibility ratio of 0.26 would be classified as access rich and given the same consideration as someone with a ratio of 0.8. Martens et al. (2014) present prioritarianism as a remedy to the rigid nature of sufficiency thresholds - instead of a fixed threshold, those lower in the distribution are prioritized.

While the other three equity standards focus analytical attention on those worse-off (ex: lower on the distribution of benefits), the maximum gap standard is concerned not only with the worse-off, but also with how disparate the worse-off's experience is from the best off. Many authors discuss methods to minimize this gap; Bajada et al. (2016) suggest adding bus-only lanes "where the time and cost savings to the bus operators and passengers exceed the equivalent delays to other road traffic" (p. 78). Guo et al. (2020) recommend interventions that offer a balance of minimizing the gap within and between groups while maximizing average benefits, particularly when working to balance conflicting goals and constraints.

Guo et al. (2020) provide an excellent example of how to combine equity standards. Left as the only goal, the utilitarian ideal of maximizing average benefits is susceptible to the same pitfalls as Pareto optimization. Additionally, focusing on average benefits alone can negate serious and concerning effects at the extremes – this is why additional, gap-focused constraints are important to consider when setting equity goals. It is important to remember, however, that minimizing the gap and setting clear bounds on a maximum gap are distinct exercises; the latter requires more political will and is more robust.

Prioritarianism aligns most closely with the current iteration and recommended use of the Washington State Department of Health's Environmental Health Disparities (EHD) map[17]. The scoring system of the map highlights areas where burdens are highest so that those regions and individuals can be prioritized in planning efforts. However, without clear goals that hold agencies accountable to meaningful change for those prioritized, prioritarianism can fail to

[17]For more information on the EHD, see Chapter 3

deliver equitable outcomes. Because all the equity standards presented in Table 4.0.3 align with restorative equalization, any of them can fall prey to the same pitfalls. Specifically, if targets related to basic need, sufficiency, or maximum gap are too small and/or limited, they will also fall short.

Each equity standard does not necessarily need to be applied independently – conceptual overlap exists and can be harnessed to improve outcomes. Because the reality of planning includes constraints and competing interests, creative problem solving is necessary to find balance. Where conflicts occur between groups (ex: interventions that might improve outcomes for some but cause a reduction for others), clearly defined equity standards can serve as a solid guide. However, where conflicts occur between categories (ex: accessibility vs. economy vs. environment), professional judgement informed by policy and community engagement must be used to weigh and choose the best course of action.

4.3.2. Communities of Concern

Communities of concern is a concept that consistently arises in the transportation equity literature because identifying these communities allows analysts to measure and compare transportation outcomes between groups. For example, Bills and Walker (2017) present their equity analysis methodology in terms of a target group vs. a comparison group, the target group being a group facing some form of transportation equity burden. To identify which communities should be prioritized for transportation planning initiatives, first the relevant socio-economic attributes must be identified. The HEAL Act provides guidance for agencies in the state of Washington by defining communities of concern that must be considered by agency. They do not, however, claim this to be the full and complete list of communities that should be considered. The following sections present the HEAL Act definitions followed by communities of concern identified in the transportation equity literature, why, and how they relate to the HEAL Act.

4.3.2.a. As defined by the HEAL Act

The HEAL Act provides definitions for overburdened and vulnerable groups and is quoted in full in Chapter 3 Section 3.2.1. 64 of the transportation equity articles reviewed included lists of relevant socio-economic variables, some simply as lists (ex: review and community engagement articles) and others as quantified components of analysis. Table 4.0.4 presents socio-economic variables found in the transportation equity literature and how they relate to HEAL Act definitions. Of the 110 articles reviewed, 64 provided community of concern classifications.

4.3.2.b. As defined by the Transportation Equity Literature

Table 4.0.4. Communities of Concern identified in the transportation equity literature, rationale, and their relationship to the HEAL Act.

Variable	Communities of Concern	Measures	Transportation concern	Reason for concern	Frequency of use in Lit. (n=64)	Defined in HEAL Act
Age	children, young people	<5yo, <18yo, <19yo	exposure to high levels of ambient noise	significant deficits in cognition, memory, and executive functions	39%	"other factors"
	children, the elderly	<5yo, >= 60, 64, 65, 70yo (varies)	exposure to high levels of air pollutants	at higher risk for morbidities		
			experiences of traffic collisions	disproportionately high		
			limited access to private vehicle, spatially diverse activities, reliance on transit	increased experience of social isolation		
			difficulties navigating hostile traffic environments	restricted ability to travel		
	the elderly	>= 60, 64, 65, 70yo (varies)	concerns & feelings regarding traffic safety			
Ability	people who are physically or mentally	census or other survey responses %	experiences of traffic collisions	at increased risk of traffic injuries and fatalities	22%	"other factors"

	impaired (disabled)	for permanent disabilities	inaccessible design of street environment and public transport vehicles	severely restricted ability to travel		
			lack of information necessary to identify traversable routes			
			negative attitudes of drivers and passengers alighting transit vehicles			
			limited access to private vehicle, spatially diverse activities, reliance on transit	increased experience of social isolation		
			tend to be dependent on more-expensive modes	transportation costs tend to make up a disproportionately high cost of living		
			more likely to travel during off-peak periods	disproportionately large amounts of time spent in transit		
Gender & Sexuality	women	census or other survey responses %	more likely to serve as caregivers and travel during off-peak periods	disproportionately large amounts of time spent waiting for low-frequency transit	19%	"other factors"
	women & LGBTQ+		experiences of sexual harassment while traveling	disproportionately high		
			concerns & feelings regarding traffic safety	restricted ability to travel		

Race & Ethnicity	people of color (Black, Hispanic non-white, American Indian or Alaskan native, Asian or Pacific Islander, multiracial)	>= 50% or >70% PoC (by area or elementary school enrollments)	higher exposure to heavily trafficked roadways	increased risk of negative health and safety externalities	31%	yes
			exposure to high levels of air pollutants	disproportionately high		
			experiences of traffic collisions	disproportionately high		
			limited access to private vehicle, spatially diverse activities, reliance on transit	increased experience of social isolation		
Language	% of people who speak another language at home and who speak English "less than very well"	census or school recorded %	tend to have more difficulty navigating transportation system	increased experience of social isolation	5%	yes
			see Race & Ethnicity concerns			
Income	people with low-income	<= poverty line or a regional-specific value related to median and/or quantiles	higher exposure to heavily trafficked roadways	increased risk of negative health and safety externalities	66%	yes
			limited access to private vehicle, spatially diverse activities, reliance on transit	increased experience of social isolation		
			affordability of available modes	transportation costs tend to make up a		

				disproportionately high cost of living		
			experiences of benefits of shared mobility	disproportionately low		
Credit	people who are unbanked	census or other survey responses %	access to payment methods for trips	likely to experience lower levels of access	2%	no
Employment Status	people who are students or unemployed		reliance on transit services in remote locations and during off-peak operating hours	disproportionately large amounts of time spent in transit that can affect ability to earn or retain employment	16%	yes
Job Type	people who work low-paying/deemed "low-skill" jobs	census by industry sector (LODEs data) %			9%	"workers experiencing environmental harms"
Educational Attainment	people with high school as highest level	census or other survey responses %	experiences of traffic collisions	at increased risk of traffic injuries and fatalities	6%	no
			experiences of benefits of shared mobility	disproportionately low		
Cost of Living	people facing high housing and transportation costs relative to income	census or other survey responses % OR % rent-burdened households (>= 30%	affordability of transportation & housing	potential for displacement due to rising housing costs in high-growth areas	11%	yes

		income spent on rent)				
Household Composition & Marital Status	varies (single parent, divorced households)	varies	varies	varies	14%	no

The longest list of transportation concerns is associated with the variable of ability and people who are physically or mentally disabled. It is important to note that experiences of disability can be permanent or temporary; while much of the literature is concerned with identifying individuals with permanent disabilities, this undervalues the breadth of experience captured by this variable. Immigration status was mentioned in one paper reviewed, but the relevant concern (linguistic isolation) is more precisely covered by a measure of language use in the household. Variables related to household composition and marital status, while being included in 14% of the 64 articles, the details and specifications varied widely. Like immigration status, this suggests that the variation found in these social attributes may simply duplicate elements more precisely measured and more directly associated with transportation outcomes. For example, a single parent household is more likely to only have one earner supporting one or more children. This earner may be classified as low-income, or they may not – the variable for income is more directly related to transportation outcomes and is directly measured. In studies of transportation behavior, however, a single parent may combine trips and broadly exhibit different travel patterns relative to other types of households. Different types of analyses and considerations will call for different communities to be included and centered.

Social exclusion is defined as a "constraints-based process which causes individuals or groups not to participate in the normal activities of the society in which they are residents and has important spatial manifestations. (Preston & Raje, 2007). Although employment is an important component of social inclusion, the concept of social exclusion encompasses a wider set of attributes such as participation in cultural and leisure activities, political engagement, and social networks (Currie & Delbosc, 2010)." (Boisjoly & El-Geneidy, 2021, p. 226).

It is also important to recognize that the lived experience of individuals within any given socio-economic category can vary tremendously. For example, while elderly individuals tend to experience lower rates of accessibility, this will vary dramatically depending on the ability (physical and mental), race, ethnicity, English proficiency, income, transportation resources, and residential location of any given elderly individual. If the goal is to capture the diverse breadth of transportation experience and associated equity, focusing on any one socio-economic variable or category will not provide the depth of information necessary to accomplish this.

The theory of intersectionality originates in Black feminist ideology and seeks to bring light to the ways in which individuals who hold multiple, marginalized identities face unique, cumulative burdens (Carbado et al., 2013). Kimberlé Crenshaw introduced the concept of intersectionality to identify the ways that the intersection of marginalized identities leads to a compounding experience of marginalization (Carbado et al., 2013). Her work used case law to demonstrate that Black women, when considered by just their racial identity (Black), or by just their gender identity (woman), were not perceived as facing statistically significant burdens – companies hired racially proportionate numbers of Black workers or offered equal pay to women. However, when considering the intersection of their racial and gender identities, Black women did, indeed, face both disproportionately low job offers and wages.

Sider et al. (2015) recommend and develop a context-specific composite variable of socio demographics need they refer to as a Social Deprivation Index (SDI). The SDI considers unemployment rate, immigration rate, % of income spent on rent, and median income for all Traffic Analysis Zones in the Montreal Metropolitan Area. A full list of composite indicators is included in Section 4.3.4.1 – the Accessibility indicators subsection.

4.3.3. Units of Analysis: benefits and potential pitfalls

One of the primary debates in current transportation equity discourse is the question of units: do you perform an equity analysis at the individual level or at the communal/spatial level? The two analysis types vary tremendously in data requirements, computational complexity, and in the accuracy and precision of results. Each type has its benefits and pitfalls that must be understood and either compared against available resources or used to guide necessary funding allocation to acquire or develop the resources necessary. This section outlines the difference between the two types of measures and presents common spatial units of analysis.

4.3.3.a. Person vs. Place

Place-based measures account for an attribute or phenomenon relative to its location in space. For example, air pollutants can be measured by their concentration in a census block group. In contrast, person-based measures account for attributes specific to individuals. For example, satisfaction with a transportation facility would have to be measured on a person-by-person basis.

An associated concept within the transportation equity literature is the distinction between horizontal and vertical equity. These terms, however, are imprecise and have led to conceptual confusion (Ch. 2: Lewis et al., 2021). Most commonly, these terms are used to differentiate between analyses that consider distributions of benefits and burdens by spatial units or by socio-economic attributes, respectively. For example, an analysis that measured the distribution of a bike share fleet by neighborhood (or by census block or tract or any spatial unit of analysis) would be classified as horizontal equity whereas an analysis that considered bike share user registrations and trip characteristics by race (or gender or income or any socio-economic variable of interest) would be classified as vertical equity. Additionally, socio-economic variables can be expressed in terms of spatial units (ex: % race by category by census tract). In this report, these concepts will be broken out and named precisely; units measure spatial (place) or individual (person) characteristics, and equity analyses can pertain to spatial and/or socio-economic equity considerations.

Siddiq and Taylor (2021) find that, of 54 accessibility tools analyzed, the vast majority (36) were place-based, nine (9) were person-based, and nine (9) offered a combination of place- and person-based approaches. Only five (5) tools were packaged and readily available for use in planning applications – of these five, all are useful for planning (rather than project) efforts and all were place-based only. This corresponds to the tendency towards more simplistic, lower-data and analytical effort measures.

Such simplified measures, however, are subject to a few issues. First, overly simple methods risk fake precision; **fake precision** (or overprecision or spurious precision) occurs when detailed values are used to represent calculations and data that are not very precise to begin with. These detailed values can give the appearance of precision and cause overconfidence in results that may misrepresent the reality and ultimately lead to skewed equity analyses (Fransen & Farber, 2019). For example, any software-based calculations – whether in excel, R, Python, or even a simple calculator app – will produce a result with as many decimal places as it has space to print. For example, if a planner used observed travel times between two locations to calculate an average travel time, they may get a result of 23.7932 minutes. To avoid fake precision, the reported value should be reported as roughly 25 minutes. Essentially, to avoid fake precision, analytical outputs should be no more precise than the data used to generate them.

Another source of concern is the potential of ecological fallacy. **Ecological fallacy** occurs when all individuals living in the same area are assumed to have the same attributes and experiences. For example, a rural census tract could include a high percentage of older individuals. As Table 4.0.4 shows, older individuals face an array of transportation risks such as limited access to private vehicles. It would be an ecological fallacy, however, to assume that every person aged 60 years and older does not have access to a private vehicle.

Fransen and Farber (2019) recognize that person-based measures require "a collection of elaborate" data sets of individual travel behaviors, detailed data related to the transport network, and computationally complex models, they still argue that the "benefits outweigh the costs" and that person-based measures are "vital in counteracting the phenomenon of transport poverty and social exclusion" (p 68). Miller (2018) also argues in favor of person-based utility measures while acknowledging that current tools will need significant refinement before becoming widely operational. Fransen and Farber (2019) also note, however, that person-based measures present a composite score of place- and person-based contributions that are difficult to disentangle and isolate. Levine et al. (2019), argue that person-based measures will never be viable for longer-range planning efforts because they require too many assumptions of the attributes of future residents which can also risk fake precision.

A recent NCHRP report presents a comprehensive list of accessibility measure types as detailed in Table 4.0.7 and *Figure 4.0.5* (Karner et al., 2022). Another practice-focused report focuses on the accessibility measures they deem most applicable in a planning context: place-based (or spatial) measures (Sundquist et al., 2021). They argue that spatial measures offer the most readily available application of accessibility for planning purposes and provide a solid foundation on which additional accessibility concepts such as considerations of time, cost, and competition can build. Regardless of the method chosen, it is critical to remember that objective measures such as these always risk misrepresenting the lived experiences of the traveling public, and especially those that fall into the category of communities of concern. It is therefore imperative for agencies to always assume community engagement as a given, required analysis cost and select additional units of analysis and analytical methods accordingly.

4.3.3.b. Spatial Units

The two main types of geospatial information system (GIS) analysis are vector and raster analysis. Raster analysis is based on values assigned to pixels of areal or satellite photographs. Vector analysis relies on shapefiles that can either contain points, lines, or polygons. While rasters, points and lines all have potential applications in transportation GIS analyses, this section focuses on polygons, or areal spatial units of analysis (shortened to spatial units in this document). These vector, polygonal, spatial units of analysis are used to measure and describe attributes distributed over an area.

Figure 4.0.4 presents the hierarchy of spatial units of analysis by number of people represented and associated levels of detail and aggregation. Arrows denote how each unit relates to others, as does color; green is used for spatial units generated by or that align with US Census Bureau (USCB) units. For example, contiguous census block groups create a census tract, contiguous census tracts create counties. PUMAs are Public Use Microdata Areas and correspond to Public Use Microdata Sample (PUMS) data sets generated by the USCB for each calendar year. The PUMS data set provides a representative sample of long-form American Community Survey (ACS) responses over areas that encompass multiple census tracts to provide detailed data while maintaining the privacy of respondents. Similar to counties, they are comprised of tracts, but they do not necessarily align with county boundaries. The red lines highlight person-based units and how PUMAs can be used to disaggregate aggregate spatial data using a method called population synthesis (Bills, 2022).

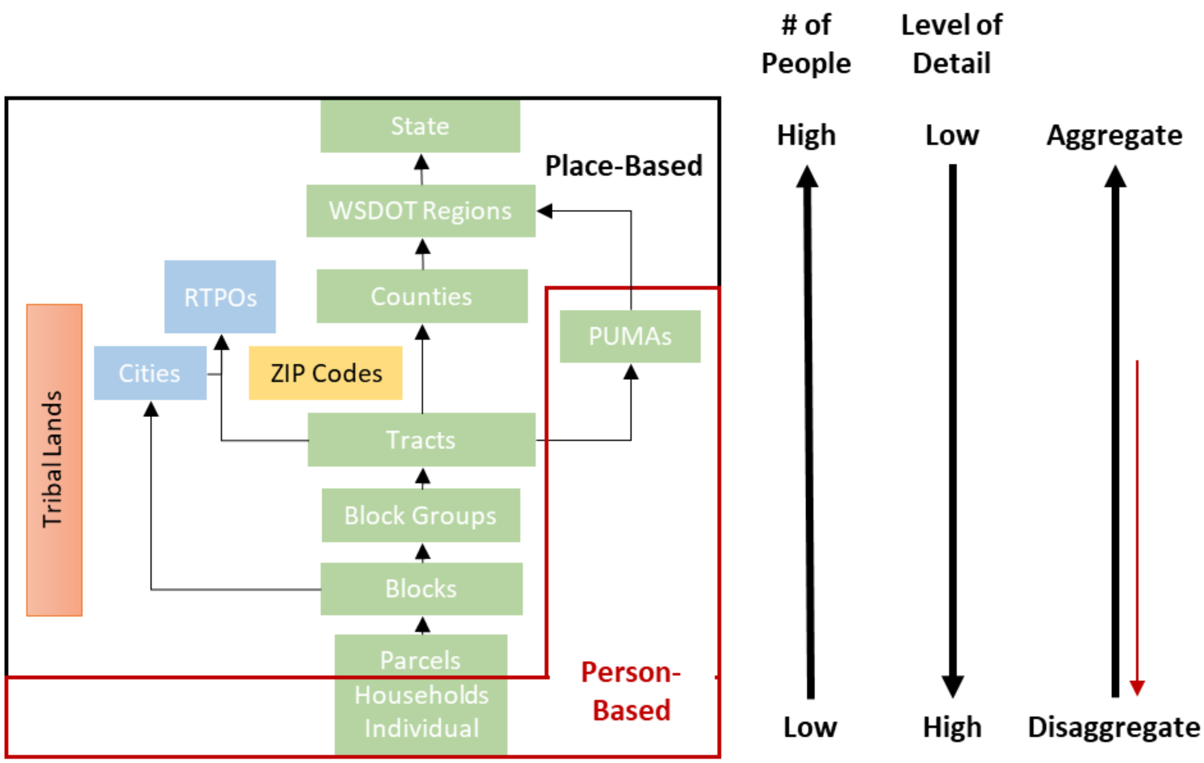

Figure 4.0.4. Levels of data aggregation and associated spatial units of analysis.

Non-USCB spatial unit types include Tribal lands, cities, regional transportation planning organizations (RTPOs) and postal Zone Improvement Plan (ZIP) codes. Tribal lands and ZIP codes are the product of federal negotiations and postal service operations (respectively) and do not relate to USCB boundaries. Cities are comprised of census blocks, but their boundaries may overlap with rather than contain larger-scale USCB boundaries. RTPOs contain city boundaries, but (at least in the state of Washington) correspond to broader USCB tracts for the areas surrounding city limits.

The selection of the appropriate spatial unit(s) of analysis often depends on the data available. Still, appropriate spatial scale is important to consider. The **modifiable areal unit problem (MAUP)** is a phenomena similar to the ecological fallacy; findings at more aggregate levels (i.e. large areas with less detail) may not reflect the reality at a more disaggregate level (i.e. small areas with more detail). In the case of environmental justice analyses, smaller spatial scales tend to reveal greater environmental disparities and burdens as compared to analyses at higher scales (ex: areas surrounding roadways vs. aggregated over census tracts) (Mohai et al., 2009). Transportation equity researchers, however, have found that, depending on the spatial unit of analysis, the outcome of an equity analysis could flip from a positive to a negative outcome (van Wee & de Jong, 2023).

Generally, analyses that begin with more disaggregate data (i.e. values presented relative to a smaller spatial scale) tend to yield better results because they allow for more precise measurements that do not risk ecological fallacy and so long as samples are representative of larger areas of interest, the risk of MAUP is also low. However, when dealing with rural areas, a new issue arises. Because rural areas are so sparsely populated, using smaller spatial scales can skew results because there are not enough observations of all variables of interest in a given area (Karner, 2016). For example, cases of asthma in low-income children in a rural area may be difficult to measure at a small spatial scale because some areas may not contain enough or even any children who are low-income to complete the analysis. This can lead to extreme values suggesting either no air quality issue for low-income children or an extreme issue because there is one child with comorbidities that skews results to the higher extreme. It is therefore important to carefully assess not only what data is available, but its quantity and quality – while some data may exist, it may not be sufficient to answer a detailed question.

The Environmental Health Disparities (EHD) tool presents data at the census tract level for this reason. However, while their use of tract-level data protects against fake precision, extreme misrepresentation, or missing data, it only provides data at a highly aggregate, limited detail scale. The creators of the tool recognize this limitation and emphasize the importance of using the EHD as a first step in identifying areas and communities of concern; to avoid ecological fallacies, they encourage agency staff to remain critical and utilize other methods such as community engagement to inform action.

4.3.4. Indicators

Over 100 scholarly articles pertaining to transportation equity planning indicators were reviewed to inform the summary tables presented in this section. These included several literature review articles and a community engagement article in which the authors identified organizational structures to summarize different types of transportation equity metrics as presented in Table 4.0.5. These categorizations informed the structure of this report.

Table 4.0.5. Metric classifications by review article.

Citation	Dimensions	Description
van Wee & Mouter (2021)	• Accessibility • Safety • the Environment	Review of transportation equity evaluation methods in academic literature
Heyer et al. (2020)	• Accessibility/Mobility • Health (traffic-related air pollution exposure) • Distribution of transit funds • Potential for Displacement (housing and transportation affordability)	Review of transportation equity metrics used by MPOs in Regional Transportation Plans
Guo et al. (2020)	• Accessibility • Traffic emissions • Safety outcomes	Review of transportation equity metrics in academic literature
Lucas & Martens (Eds.) (2019)	Benefits: • Accessibility Burdens: • Pollution, • Safety, • Health • Social Outcomes (negative)	Section organization of book on Measuring Transport Equity
Martens et al. (2019)	• Resources • Opportunities/Risks • Outcomes	Focal Variable of transportation equity measures given a review

	• Well-being	of transportation equity evaluation methods
Boisjoly and Yengoh (2017)	• Transportation infrastructure and services • Impacts (burdens) • Places • Groups	Community engagement to identify transportation issues important to community members:
Bajada et al. (2016)	• Meso (physical & online infrastructure) • Micro (ability to move easily in system)	Public transport infrastructure equity analysis

For this report, indicators were recorded and classified by characteristics such as what is measured, transportation components considered, and inferred analysis type. These classifications, their categories and definitions are provided in Table 0.6.

Table 0.6. Metric type classifications used to structure indicator organization.

Classification	Category	Accounts for..
What is measured	Access	how people access destinations and services
	Mobility	how people and goods move through the transport system
	Environment	how transport externalities interact with environmental considerations
	Health	how transport externalities interact with human health
	Safety	how transport externalities interact with human safety (collisions)
	Economy	how transportation interacts with economic considerations
Transport Components	Fleet	vehicles in the transport system
	Facility	transportation facilities used by individuals and vehicles
	Service	transportation services
	Land Use	various land uses that interact with transportation components
	Finance	funding of transportation components
	Policy	guiding requirements and expectations, legal or otherwise
	Engagement	community and stakeholder interactions
Inferred Analysis	Summary	values that provide an overview, aggregate data point
	Place-based	values derived from geospatial analysis (GIS)
	Person-based	values derived from individual-level, highly disaggregate data

The tables further summarizing the indicators by sub-category are broken out by the categories of what is measured. Over 40% classified as accessibility, and just under 40% of indicators classified as mobility. Because measures of mobility are needed to specify the spatial component of accessibility, many articles include both types of indicators. From there, nearly 10% consider the environment, 15% consider health, 10% consider safety, and nearly 35% consider economy. Economic indicators are often combined with mobility and/or accessibility indicators, whereas indicators related to environment, health, and safety tend to arise in separate articles. The exception is articles that base their findings on stakeholder interviews (Lowe, 2014; Boisjoly & Yengoh, 2017; Karner & Marcantonio, 2018; Boisjoly & El-Geneidy, 2021) or that provide a review of other research articles (see Table 4.0.5).

Though accessibility as a concept has existed in the transportation lexicon since the mid-20th century (Hansen, 1959), accessibility measures are still in their infancy and diverse in nature. They are therefore given their own Accessibility subsection. Because accessibility indicators are specified using some combination of mobility, economy, and land use indicators, these sub-subsections follow the Accessibility subsection. While economic indicators can be found in most of the indicator subsections, the majority of the overlap occurs with mobility indicators, thus the combined subsection of Mobility and Economy.

These are followed by a subsection for Environment, Health and Safety as well as a subsection summarizing indicators of Qualitative and Engagement measurement. Environment measures in the transportation equity literature are almost exclusively concerned with human health impacts, making these two categories a natural combination. Safety is another indicator that can be found interspersed throughout the other subsections, but collision-specific measures are included in the Environment, Health and Safety subsection. Finally, qualitative measures cover all other categories and are often associated with measures of engagement efforts, thus the combination of these categories from separate classifications.

The transport component categories are used as subcategories within relevant tables. For example, the Mobility and Economy table (Table 4.0.11) is comprised predominantly of fleet-based and facility-based subcategories used to organize the indicators summarized. The other transport component categories are similarly utilized throughout the other tables. The inferred analysis categories are not broken out in the tables, but it is interesting to note that of the 380 indicators 28% are summary, 55% place-based, 18% person-based. This aligns with the place vs. person units of analysis findings.

4.3.4.a. Accessibility

Accessibility measures are considered critical to transportation equity analyses and therefore make up nearly half of the transportation equity literature. As a result, accessibility is a critical indicator type with many applications as a leading indicator of transportation equity. Section 4.3.4.a.i defines the concept of accessibility, metric types and organizational frameworks developed to help structure the concept, and data requirements to specify the different types of measures. This is followed by a detailed list of accessibility indicators by type and their utility as leading and lagging indicators of transportation equity. The final three sub-subsections provide details concerning types of thresholds commonly used in accessibility metric specifications: spatial, temporal, and speed.

4.3.4.a.i. Defining the concept of accessibility, metric types, and data requirements

Hansen's (1959) seminal article on the relationship between transportation and land use defined accessibility as "the spatial distribution of activities about a point, adjusted for the ability and the desire of people … to overcome spatial separation" (p. 73).

While simply stated, the concept of accessibility has proven difficult to operationalize due to its multi-faceted nature. Until recently, the computational power required to analyze the relationship between users, time, the transportation system, and land uses at scale did not exist. While the necessary computing power does exist now, readily applicable tools are still a work in progress. To meet a reasonable level of conceptual completeness, an accessibility analysis tool "should account for many of the most important factors thought to affect accessibility, be able to depict accessibility at both the individual and spatially aggregated levels, draw on widely available data, and be relatively easy to use and intuitive to understand" (Siddiq & Taylor, 2021, p. 505). Currently no such tool exists.

As a result, there are many different types of accessibility measures that have been proposed and even fewer in-use by agencies and practitioners. Table 4.0.7 presents review articles dealing with transportation equity and the categories they have used to organize the concept and associated measures of accessibility. In addition to the academic literature review, practice-oriented reports were also consulted for this section. The dimensions identified in the recent NCHRP report by Karner et al. (2022) were used as the primary organizational structure for the accessibility indicators presented in this report. While the focus of this report is summary and place-based measures, Karner et al.'s (2022) category of "Trip Characteristics" provides a section for temporal constraints and beyond. Additionally, *Figure 4.0.5* from Karner et al. (2022) provides a breakdown of level of difficulty related to data and analysis for each of these categories of indicators.

Table 4.0.7. Accessibility measure classifications by review article.

Citation	Categories	Description
Karner et al. (2022)	• Proximity • Access to opportunities • Competitive	NCHRP Report on accessibility measures in practice

	• Trip Characteristics • Potential Path Areas • Logsums • Conceptual • Qualitative • Other	
Siddiq and Taylor (2021).	Place-based: • Cumulative Opportunities • Gravity Based Person-based: • Utility-based • Constraints-based	Critical review of accessibility measures
Guo et al. (2020)	Coverage-based • service zone Reachability-based • cumulative opportunities, • negative exponential, etc.	Review of transportation equity metrics in academic literature
Fransen and Farber (2019)	Place-based: • Spatial restrictions Person-based: • Temporal restrictions • Individual restrictions	Argument and case demonstration for use on person rather than place-based accessibility measures
Curl (2018)	• Time • Cost • Frequency • Quality • Comfort	Study of perceptions of accessibility and the disconnect between objective and subjective assessments
Caspi et al. (2012)	• Spatial • Availability • Affordability • Acceptability • Accommodation	Conceptual components of accessibility from a disabilities perspective
Lucas (2012)	• Individual • Land-use • Transportation • Temporal • Cognitive	Five conceptual components of Accessibility (building off of Geurs and van Wee (2004))

Lotfi and Koohsari (2009)	infrastructure-based (mobility) activity-based: • macro: potential-accessibility • micro: time-space utility-based (economic)	Comparative analysis of objective vs. subjective assessments of accessibility

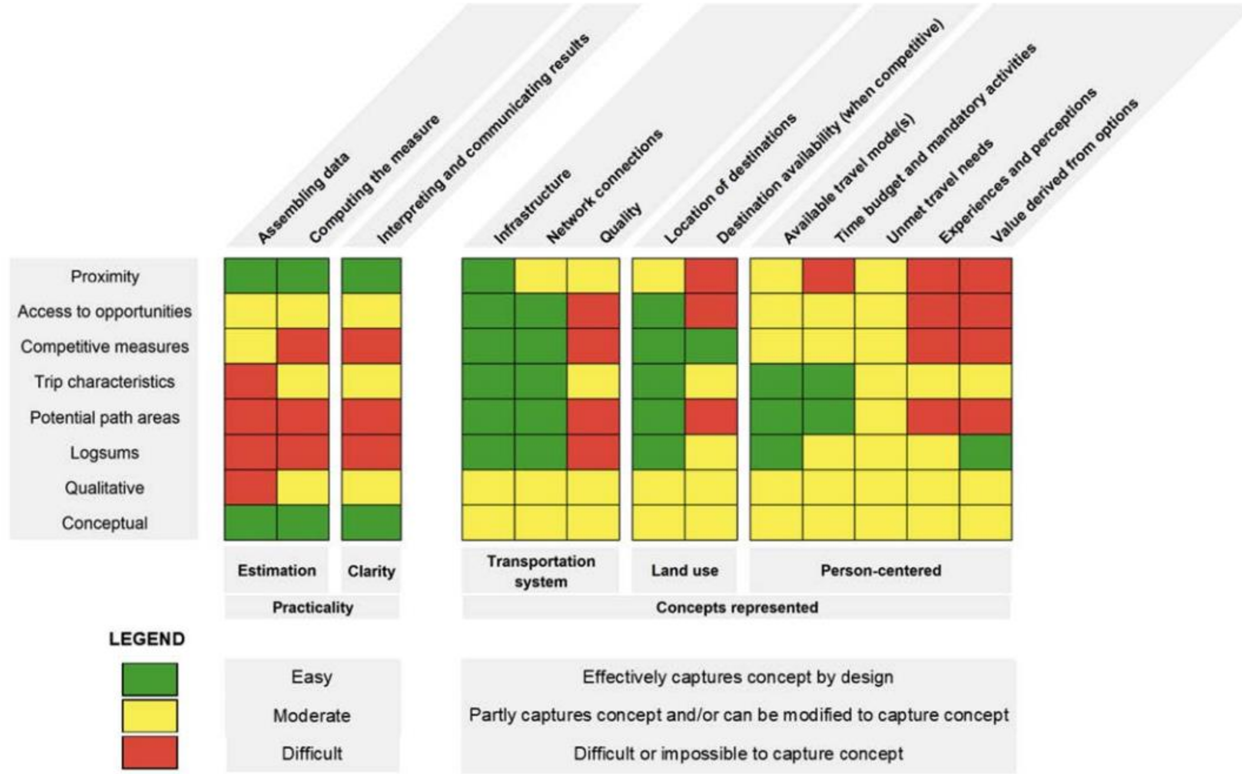

Figure 12. Practical and conceptual summary of eight accessibility measures.

Figure 4.0.5. Summary of eight accessibility measures by level of difficulty. Copied from (Karner et al., 2022, p. 28).

4.3.4.a.ii. Detailed list of accessibility measures and their relationship to leading and lagging indicators

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Table 4.0.8 summarizes the accessibility indicators identified in this literature review. The “Type” classifications draw primarily from Karner et al. (2022) with “Components” for each type drawing from structures from other review articles presented in Table 4.0.7, and specifically from Siddiq and Taylor (2021). The “Variations” column lists out the indicators relevant to that type and component – different variations are all listed here. The “Mode Relevance” column identifies which modes, if any, are specifically covered by that subset of indicators. Finally, the

"Leading when…" and "Lagging when…" columns identify the leading and lagging use cases for the given indicators.

The leading and lagging use case columns align with the definition of leading and lagging indicators presented at the beginning of this report. The use of the word "meaningful" follows the expectations set in Section 4.2.2; essentially, leading indicators of equity must prove that a proposed intervention has the potential to move the needle towards an established equity goal by an appreciable amount in a timely manner. The projected outcomes of an intervention must meet these conditions to be considered meaningful.

Table 4.0.8. Accessibility measures and their potential as leading and lagging indicators of transportation equity.

Type	Components	Variations	Mode Relevance	Leading when..	Lagging when...
Proximity (coverage, service area, buffer)	distance threshold	Euclidean	any	projected increase in benefit areas and/or decrease in burden areas	measured
		network (by mode)			
		network (by type)			
	temporal threshold	based on assumed modal speed by mode type along a network			
	spatial statistics	clusters			
		kernel density			
		standard deviational ellipse			
Access to opportunities (points of interest, key destinations, peripheral destinations)	fixed temporal threshold	# of available destinations by type (cumulative access)	any	projected, meaningful increase	measured
		isochrone of accessible area			
	variable threshold	# of available destinations by type (gravity function, decay function)	any		
Trip Characteristics	safety	see other tables where safety is presented			
	temporal	in-vehicle/out-of-vehicle components[1]	any	projected, meaningful decrease	measured
		average trip time for required trips			

		congestion			
		trip time variation by time of day, week, and season			
		experienced			
	cost	road-pricing schemes (ex: tolls)	private motorized	considered as components of affordability	
		parking			
		purchase price			
		insurance			
		maintenance			
		cost of fuel/energy			
		fare structure	service-based		
	affordability	transport costs as % of national median income	all	projected to be meaningfully more affordable	
		cost relative to household income			
		% household income spent on transport			
		payment plans			
		discounts or subsidies[2]			
	service	hours of operation	service-based	projected meaningful improvement	
		peak/off-peak[3] frequency			
		reliability			
		transfers			
		counts of available vehicles/access points			
		accessibility accommodations[4]			
		perceived			
	booking & payment	level of digitalization	service-based	projected to be measingfully accessible & accurate	
		off-line options			
		banking requirements			
		pre-paid options			

		perceived ease (user experience)			
	reliable[5] traveler information	distance	any		
		routing alternatives			
		expected travel time			
		grade differential	private modes		
		facility type (ex: separations & restrictions)			
		pavement type			
		allowable speeds			
		parking locations			
		costs (ex: tolls, parking)			
		presence of stairs or steps	non-motorized		
		service locations	service-based (fixed-route[6])		
		wayfinding			
		service routes			
		service type	service-based (general)		
		service area			
		service timing			
		vehicle types			
		real-time vehicle locations			
		crowding			
		service cost			
		terms of agreement	service-based (on-demand/ shared[7])		
Models & Microsimulations[8]	spatial components	derived activity area	any	projected, meaningful increase	measured
		tour-based accessibility			
		tour-level trip classifications			
		tour frequency			
	outcome measures	consumer benefits	any		
		consumer surplus			

		(dis)utility			
		logsum measures			
		value of time			
Composite (other)	Facility	walkability index	walk	used to inform meaningful, accessibility-focused interventions	measured
		bikeability index	cycling		
		index of network vulnerability and resilience	motorized		
		index of transportation connectivity	varies		
		multi-criteria index for mobility hub site selection	service-based		
	Service	new service viability index	service-based		
		public transport access			
		public transport need index			
		connecting power of a transit station			
		mode provision and vulnerability			
	Land use	index of land use intensity	N/A	used to inform meaningful, resilience-focused interventions	
		index of resiliency			
		comparative environmental risk index (CERI)			
		index of future growth potential			
		economic potential accessibility index			
	Justice	subgroup index of inequality	N/A	used to inform meaningful, accessibility-focused interventions	
		index of disadvantaged populations			
		socially relevant accessibility impacts	varies		
		bike equity index	cycling		
		transportation justice threshold index framework (TJTIF)	varies		

		Equitably Designed Network optimization			
		public transport need indicator (PTNI)	transit		
	Behavior	low automobility index	motorized		
		activity-weighted accessibility	any		
		social demand index			
	Engagement	enthusiasm index	any	used to inform engagement methods	
		dialogue quality index			

[1] in/out of vehicle time varies by mode: walk [access, egress], wait, transfer, park. Wait time can also be used as a proxy measure for supply of demand-responsive ridehail services when actual supply data is not available as is often the case with major service providers such as Uber and Lyft (Guo et al., 2020)

[2] discounts and subsidies could be based on frequency of transit use or socio-dem characteristics. Ghasemlou et al. (2021) present transit pass categories of normal, student, elderly, person w/ disabilities, and limited use

[3] recognizing that off-peak may look different for midday, nights, Saturdays, and Sundays and that service quality characteristics impact access potential

[4] see facilities & fleets for more details on accommodations

[5] reliable refers to accuracy, precision, and consistency of data coverage and access

[6] fixed-route: traditional transit

[7] on-demand/shared: bikeshare, carshare, ridehail, CAV

[8] because they often are concerned with modeling potential scenarios, they often report in changes - average change in

Both proximity and access to opportunities measures are place-based indicators and are the most common form of accessibility measures found in the literature. A wide range of trip characteristics can be measured and used to improve on these core place-based measures as recommended in the SSTI report (Sundquist et al., 2021). The concept of affordability is particularly important as a measure of access; it is comprised of trip cost characteristics, but affordability measures account for more contextual information such as income and subsidies. Some affordability measures specified in the literature focused on transportation costs needed to reach basic, mandatory activities such as school and work. Some refer to this as commute burden or required trip burden. These analyses operate from a sufficiency lens and focus on the economic component of social life.

It is important to remember, however, that many more types of trips (ex: grocery, healthcare, recreation) are necessary to live a fulfilling life and that analyses that focus exclusively on accessibility from an economic lens tend to overlook the experience of broad social groups such as the young, the elderly, individuals with disabilities, and caretakers. This is where not only type of destination (discussed further in Section 4.3.4.c) but also time of day become critical accessibility considerations. Periera (2019) refers to the potential to lose important insights and reach non-generalizable conclusions based on time of day variation as the **Modifiable Temporal Unit Problem (MTUP)**, and compares it to the Modifiable Areal Unit Problem (MAUP) discussed in Section 4.3.3.b.

The affordability of private modes can be difficult to quantify because private modes come with purchase cost, insurance, and maintenance in addition to cost of fuel. Cost of fuel, however, is the most obvious cost - while it's possible to combine all costs to calculate a cost-per-trip for private vehicle use, it is not an intuitive way to present this information as users rarely think in these terms. An exception to this, of course, is lower-income individuals. Those with tighter budgets are more sensitive to all aspects of transportation costs and, as a result, private vehicle ownership can be a greater source of economic stress and burden than benefit (Martens et al., 2019).

4.3.4.a.iii. Spatial Thresholds (proximity/coverage)

Spatial thresholds are integral to proximity measures which are concerned with spatial coverage of transportation opportunities and barriers. Example distances and thresholds by type are presented in Table 4.0.9. Threshold distances are most often measured as Euclidean, or as-the-crow-flies, distances, and are always measured this way when considering exposure. For example, to estimate the area most likely to experience air pollution from a highway capacity expansion project, a spatial threshold of 1,000-ft might be used to create a halo (or buffer) area around the centerline of the proposed project corridor.

Table 4.0.9. Common distance thresholds used to calculate transport service areas.

Type	Components	Variations	Use-case
Facilities	Non-motorized Access	400-m (0.25-mi)	general access, transit stop, bus stop
		0.5-mi	metro, Amtrak, ferry, intercity bus
	Investment	2-km, 3-mi	motorized transport facility proximity
	Exposure	150-m, 1000-ft	more/less conservative estimates of exposure to motorized facility externalities
Land Use	Required	1-mi, 2-km	access to jobs and schools
	Necessary	1-km, 2-km, 4-km, 5-km	access to healthcare, food, social services, recreation

Alternatively, spatial thresholds can define an area based on network distance. For example, to estimate the service area around a transit stop, a buffer can be generated either using a Euclidean distance of 400-m to generate a circular area with a radius of 400-m, or a network distance could be used to generate a buffer that better reflects the user experience. Network-based thresholds can be further specified by only considering pedestrian or bicycle-friendly infrastructure. Bolten & Caspi's (2021) work details additional network components that must be considered to accommodate individuals with varying levels of ability. The tool, AccessMap, operationalizes this with a data structure and routing algorithm.

Once a buffer area is established, GIS analysis tools can be used to measure access or exposure in terms of % population, % homes, % area, or ratio of area. Essentially the thresholds can be used to calculate areas which can then calculate values for comparison. While they offer a relatively quick and simple estimate of proximity or coverage, it is important to remember that these estimates do not account for many factors. For example, thresholds of 0.25-mi for bus stops and 0.5-mi for longer-distance transit services estimates the reality that most individuals will accept a longer first mile/last mile access distance for longer-distance transit trips, these values do not hold true for every potential user.

Concerning exposure to negative externalities, the relationship between pollutants emitted along a corridor and actual exposure concentrations vary tremendously by weather patterns as well as by patterns in human behavior. As a result, there is no universal, causal proximity distance for estimating exposures (Guo et al., 2020). As with any threshold, they have the benefit and drawback of drawing a definitive break within the data. While this is conceptually and analytically simpler compared to other methods, this break can eliminate important complexity in the data and effectively obscure and/or misrepresent complex realities.

4.3.4.a.iv. Temporal Thresholds

Temporal thresholds are most used in access to opportunity accessibility measures but have broad application potential. Table 4.0.10 presents thresholds commonly found in the literature and why. In some cases, multiple thresholds are considered and compared such as Karner and London (2014) who analyzed access to jobs by type [blue-collar, healthcare, education, and retail] at temporal thresholds of 15, 30, and 45 minutes. They then compared accessibility by car to accessibility by transit at each threshold to highlight the disparity in accessibility between those with access to a private vehicle and those who are transit-captive.

Table 4.0.10. Common travel time thresholds used to calculate accessibility.

Thresholds	Associated consideration
10 min	Very short trip, preferred trip time range for non-motorized trips
15min, 20min	Short trip for motorized modes, longer trip for non-motorized but still viable
30min, 45min	Medium trip for motorized modes, too long for non-motorized – typical time thresholds considered for commute trip accessibility
60min, 90min, 120min	Considered for transit trips and depending on context (ex: large metro areas)

A common policy application of temporal thresholds are the 15- or 20-minute city initiatives (Cappasso Da Silva et al., 2019; Mackness et al., 2021; Moreno et al., 2021; Millonig et al., 2022; Khavarian-Garmsir et al., 2023). These initiatives try to operationalize a sufficiency equity standard that all urban residents should be able to meet all of their needs within a 20-minute travel time. Cities from Paris to Portland have made this a development goal.

4.3.4.a.v. Speed Thresholds

Unlike spatial and temporal thresholds, discussions of speed threshold tend to focus on safety and mode mix rather than possible accessible destinations. Rather than focusing on spatial allocation of facilities by mode, Nello-Deakin (2019) suggests that a more appropriate measure of transportation equity would be reached by offering an equitable mix of speed zones for multi modal travel. For example, offering an adequate network of low-speed zones focused on pedestrian and cyclist mobility as well as higher-speed facilities focused on motorized vehicle movement. The goal of safety would be achieved by keeping the modes as separated as possible.

While appropriate speed thresholds would vary by mode or mode mix, leading indicators of 20mph zones maintained through traffic calming measures have been found to reduce lagging indicators collisions, deaths, and injuries. Traffic calming measures offer a design-based alternative to enforcement; rather than attempting to prevent speeding through external punitive measures, the road itself is designed to only allow comfortable travel at low speeds. A more recent study even found no evidence of casualty migration to nearby roads without interventions; however, this study was not able to account for potential confounders such as other road safety initiatives such as traffic cameras (Davis & Pilkington, 2019). They also note that sign-only enforced low-speed zones have a smaller effect on collision reduction. In other words, low-speed zones are safer and more effective when enforced with traffic calming measures and potentially with other measures such as speed cameras.

4.3.4.b. Mobility & Economy

While economic indicators can be found in most of the subsections, most of the overlap occurs with mobility indicators, thus the combination of the two indicators in this section. Mobility indicators are important measures of direct transportation system benefits and burdens and are common within current transportation analysis practice. They are useful measures of observable, objective aspects of the transportation system and are necessary first steps to calculating higher-order measures such as accessibility. As a result, most mobility and economic metrics do not serve as leading indicators of transportation equity by themselves, but they offer important insights within the broader equity analysis process.

Currently, academic literature regarding longitudinal measures of large-scale economic impacts comes from China (Li et al., 2018; Yang et al., 2018; Zhou et al., 2018; Sun & Zacharias, 2020; Zhang & Zhao, 2021), whereas US-based literature focuses on economic impacts from the perspective of agencies in investment cost (Karner & Golub, 2019; Heyer et al., 2020), the perspective of workers in spatial access to jobs (Golub & Martens, 2014; Karner & London, 2014; Anderson et al., 2017; Martens et al., 2019; Dixit & Sivakumar, 2020; Chen & Li, 2021), or the perspective of individuals in utility-based measures (Bills & Walker, 2017; Nahmias-Biran & Shiftan, 2020). Utility-based measures originate in economic literature and can serve multiple purposes. For example, in the Accessibility table of indicators (.

Table 4.0.8), they fall under the “Models and Microsimulations” indicator type.

Table 4.0.11 summarizes the indicators of transportation equity that measure components of mobility and economy. They are divided into types of supply (facility-based and fleet-based), demand (behavior), and measures that are a function of both supply and demand.

Table 4.0.11. Mobility and Economy measures and their potential as leading and lagging indicators of transportation equity.

Type	Components	Variations	Mode Relevance	Leading when..	Lagging when...
Facility-based	capital investments	total funds allocated by program	any	allocation aligned with equity goals	measured
		projects by type/mode[1]			
		capacity per facility			
		road density by type	motorized		
		intersection density			
	safety	pavement quality	non-motorized	meaningfully integrated in life cycle expectations	
		protected/separated ROW			
		zebra crossings			
		traffic calming speed bumps			
		chicanes			
		lighting			
		resilience			
	operations	funds for O&M by facility type	any		
		regularity of maintenance by facility type			
	connectivity	% with two or more types of connecting modes	any		
		# of possible paths/routes			
		efficiency of intermodal interchanges			
	regulations	ADA compliance	non-motorized	end users integral players	measured by associated lagging
		pedestrian priority			

		private vehicle use restrictions	motorized	in regulation choice	indicators (outcomes)
		speed limits[2]			
		HOV/HOT lanes			
		bus priority lanes			
		parking restrictions			
		parking pricing			
		requirements for developers to fund necessary remedial roadworks at time of development	varies		
Fleet-based	safety	vehicle ratings by vehicle or average for all vehicles per household	motorized	projected, meaningful increase	measured
		level of automation[3]			
	vehicles	total private vehicle ownership	motorized	projected outcomes align with equity goals	
		average # of vehicles per household			
		% households with 0 vehicles			
		% households with fewer vehicles than adults			
		market penetration by sales, by type, by emissions, by efficiency, by operational needs, by relation to roadway types			
	operations	bikes rebalanced[4] by time period	Service-based		
		# transit lines in operation by time of day and week			
		frequency of service by time of day and week			
		reliability of service by time of day and week			
	regulations	safety rating requirements	motorized*	established with end user safety held paramount	measured by associated lagging indicators (outcomes)
		automation-related			
		emissions-related			
		ADA compliance	varies		
		capacity requirements			
		roadway-type requirements			
	mode share	miles by type per time period	any		measured

Demand (behavior)		% split		projected outcomes align with equity goals	
		vehicle occupancy rates			
		primary mode of transport			
	miles traveled	person miles[5]	any		
		vehicle miles	motorized		
		congested vehicle miles			
	trips	by type by time period	any		
		total distance by time period			
		vehicle drop-offs	service-based		
		boardings			
		alightings			
		riders by type[6] by timeframe			
	activities	by type by time period[7]	any		
		use of local & small businesses			
	temporal	value of time	any		
		idle time[8]			
	regulations	laws	any	established with end user safety held paramount*	measured by associated lagging indicators (outcomes)
		licensing	motorized		
		posted restrictions			
		average daily distance BUDGET by [mode] based on equivalent CO_2 and emission reduction goals			
Combined	travel[9] cost[10]	distance and/or time/duration	any	projected outcomes align with equity goals	measured
		value-weighted travel times			
	facility use[10]	user volume	any		
		utilization of capacity			
		level of service			
		marginal cost			
		travel impedance parameter	motorized		
		vehicle volume			
		flow of traffic			
		traffic levels by type[11]			
		traffic density per area			

[1] measured as lane miles, % lane miles, % area, cost, % cost, average cost – note that the funding source as well as allocation of funds are of interest from an equity perspective
[2] see discussion about speed thresholds in Section 4.3.4.a.v
[3] safety considerations vary by automation levels of different types of vehicles and their integration in the overall fleet (fleet mix)
[4] mean # bikes rebalanced can be used as a proxy measure for demand when actual data is not available as is often the case with private service providers (Guo et al., 2020)
[5] weekly walking for transport vs. leisure purposes hold different equity implications, particularly between income groups with different access to transport services and safe facilities (Iroz-Elardo et al., 2020)
[6] type of card/account holder
[7] could be referred to as frequency of going to a given destination of interest/activity
[8] mean inverse idle time in spatial unit per day to estimate demand for shared use vehicles when actual demand data is not available
[9] journey is a synonym for travel or trip
[10] by segment, network link, O/D pair, between spatial units, generalized over a spatial unit
[11] ex: % of truck traffic per current annual average daily traffic rate (Beiler & Mohammed, 2016)

Connectivity is a key mobility concept that has a strong influence on accessibility. It involves assessing transportation facility investments not only as individual projects, but as components of an interconnected network. Connectivity can be achieved through intentionally locating things like bus hubs, pedestrian bridges, or any type of transportation facility that improves the flow of people through the broader system. The more connected a system, the higher the regional accessibility.

Fleet regulations could theoretically include non-motorized fleets (bicycles, skateboards, etc.) but most frequently refers to what powers (gasoline, diesel, electric, etc.) and who controls (non- vs. autonomous vehicles and by level of automation) a motorized vehicle. Relevant non-motorized regulations can include weight capacity while motorized can included person capacity (and associated weight assumptions) or regulations by roadway type such as narrower and/or winding streets requiring smaller vehicles to navigate them safely.

Laws and restrictions related to mobility behavior range from speed limits to stop signs, lights, turn restrictions, etc. and can also include restrictions related to walking (ex: no jaywalking) or where bicycles or e-vehicles (bikes, scooters, etc.) may or may not operate. Many of these restrictions are long-standing, but wider-reaching enforcement of new restrictions would require significant end-user engagement and buy-in to function equitably. For example, restricting private vehicle access to promote healthier, safer non-motorized environments (Bajada et al., 2016) or an even more ambitious mobility budget regulation scheme; Millonig et al. (2022) propose a mobility budget which would restrict individual mobility based on emissions goals.

While measures of mobility and associated economic indicators do not address transportation equity considerations directly, they are necessary components of the transportation equity analysis process. They can be used to specify place-based accessibility measures or statistical models to estimate person-based accessibility in the form of marginal costs by facility, mode, or activity location, among others.

4.3.4.c. Land Use & Displacement

Land use and transportation components are inextricably linked – land use impact transportation behaviors and experiences and vice versa. Because measures of accessibility are concerned with the transportation externality of opportunity, land use measures are key elements of accessibility measures which, in turn, are key indicators of transportation equity. Land use measures detail origin and destination types and densities and offer means of measuring economic development and displacement precarity. Table 4.0.12 details the indicators related to land use found in the transportation equity planning literature.

Table 4.0.12. Land Use measures and their potential as leading and lagging indicators of transportation equity.

Type	Components	Variations	Leading when..	Lagging when...
Land Use	origins: residential	population density	used to inform meaningful, accessibility-focused interventions	measured
		residential density (# of dwellings per area by type)		
		adverse housing structure (lead likelihood, reinforcement)		
		peripheral location		
		segregation		
	destinations: economic	destination density		
		employment density		
		total jobs by type[1]		
		employment by sector		
		multi-type employment mix[2]		
		employment mixture entropy		
		proportion of population accounting for secondary and tertiary industries		
	destinations: other	education: schools by level		
		health: hospitals, clinics, pediatricians, general practice doctors, dentists, pharmacies		
		healthy food: greengrocers, butchers, bakers, supermarket, farmer's markets		
		social needs: bookshops, general shopping, social service offices, banks, post offices, libraries, voting locations		
		recreation: parks, beaches, greenways, open space, recreation facilities		
	categories	urban, suburban/peri-urban, rural[3]		
		neighborhood		
		car-oriented, active transport-oriented[4]		
		mixed land use		
		urban sprawl		
		priority development areas		

		high-growth areas		
	environmental factors	FEMA 100yr floodplain	used to inform meaningful, resilience-focused interventions	
		annual flood risk zone		
		sea level rise risk		
		tsunami inundation zone		
		wildfire risk		
		earthquake risk		
		liquefaction susceptibility		
Economic Development	jobs	employment growth (new jobs by sector)	projected outcomes align with equity goals	measured
		unemployment rate		
		% difference in people employed between census years		
	broader	GDP per capita by area		
		% GDP comprised of secondary and tertiary industries in area		
		proportion of local fiscal expenditure on education and science		
		total sales of consumer goods per capita		
		investment in fixed assets per total GDP		
Displacement	factors[5]	households	projected outcomes align with equity goals	measured
		multifamily housing options		
		new homes		
		activities		
		jobs by type		
		population characteristics		
	precarity	% people with a median monthly housing costs for occupied housing units below the regional average	projected, meaningful decrease	
		% income spent on transportation and housing		
		% discretionary income spent on transportation		
	regulations	zoning		

		affordable housing: public housing projects, rent stabilization	end users' integral players in regulation choice	measured by associated lagging indicators (outcomes)
		anti-displacement policies		

1 job types by sector [service, retail, manufacturing, healthcare, education, finance, etc.] or by wage

2 Iroz-Elardo et al. (2020) utilize a 5-tier employment mix to capture multiple categories in a single, composite value

3 types of rural = Declining rural (population, enviro hazard, economic losses), chronic poverty rural Eisenberg (2020)

4 well-designed, safe, and clean

5 amount measured in #, % difference, % change - change in location of, amount of, cost of all measured relative to proportion of regional population density

Beyond categorical differences between urban and rural settings, Eisenberg (2020) further differentiates between four different types of rural Americas and focuses their analysis on the two main categories: chronically poor rural America and declining resource-dependent rural America. They note that the former category tends to be comprised of racial minorities whereas the latter is comprised of predominantly white Americans. Both groups tend to face environmental harm, however residents of the latter category have historically enjoyed economic benefits in exchange for environmental and health degradation. They specifically discuss the experience of rural communities in the Pacific Northwest living in communities formerly sustained by the timber industry but currently in decline due to reductions in harvesting on public lands.

4.3.4.d. Environment, Health & Safety

Within the transportation equity literature, indicators concerning the environment are almost exclusively tied to impacts on humans, making these two categories a natural combination. Safety is another indicator that can be found interspersed throughout the other subsections, but collision-specific measures are included here. While these three categories combined make up only a third (or less, given the overlap in content) of the transportation equity literature reviewed, the definitions of communities of concern within the HEAL Act (overburdened, vulnerable, and tribes) focus heavily on the externalities covered in this section. As a result, these indicators are important factors when considering leading indicators of transportation equity.

Table 4.0.13 details the various types of indicators related to the environment, health, and safety. While many measures relate to environmental impacts, only metrics that directly measure environmental conditions are included in this section. For example, number of bicycles owned or number of SOV trips have associated potential (bicycles) or direct (SOV trips) emission values that in turn have lower or higher environmental impacts. These are not considered in this section but instead can be found in the Mobility and Economy indicators Section 4.3.4.2.

Table 4.0.13. Environment, Health and Safety measures and their potential as leading and lagging indicators of transportation equity.

Type	Components	Variations	Mode Relevance	Leading when...	Lagging when...
Air & Noise	emissions[1]	by mode, by facility, by congestion levels	motorized	projected, meaningful[2] decrease	measured
		area-based emission inventories modelled concentration			
		dispersion modelling			
	exposure	proximity to facility by type	motorized		
		measured concentration			
		land use regression (LUR)			
		by individual travel behavior (travel demand modeled - TDM)			
	efficiency	by mode	motorized	projected, meaningful increase	

	regulations	low-emission zones[3]	motorized	established with knowledge and buy-in from impacted communities	measured by associated lagging indicators (outcomes)
		zero-emission vehicle projects[3]			
		proximity of busy traffic corridors to sensitive facilities[4]			
Temperature	land use	spatial coverage of well-maintained greenery[5]	N/A: facilities and land use	meaningfully integrated in life cycle expectations	measured
		land cover near facility			
	individual	experience of thermal comfort	any + facilities and land use	projected	
Outcomes	life	expectancy	any	associated interventions utilized to reduce projected risk exposure	measured
		# years lost			
		deaths, morbidity, mortality			
	injuries[6]	by severity, by collision type, by mode, by facility, by actual travel behavior	any		
	broader health outcomes	incidence by area by type	any		
		% increase in likelihood			
		by type and prevalence of prescriptions			
	costs	treating injuries	any		
		lost days of work			
		prescription costs			
	satisfaction	health	any		
		environmental quality			
		safety			

[1] equivalent CO2 (thousands of tons), or other pollutants such as NOx/SOx/COx/PMx, dB(A) for noise

[2] highly-used and presently high-emitting modes

[3] measured in # & location, selected by highly polluted areas/locations of overburdened populations and/or high diesel air pollution areas (given a prioritarian, restorative equality equity lens)

[4] Locations where vulnerable populations are more likely to be such as hospitals, schools, elder care facilities - also pertains to noise

[5] well-maintained greenery effects aesthetic & safety experience as well as thermal outcomes
[6] measured in # & location, % (ex: % collisions that are fatal per year), crashes per 100,000 per area

Equivalent CO2 is the most common measure of pollutants for climate purposes, the full list of regulated air pollutants found in traffic emissions includes CO, NOx, benzene, PM including fine particles (PM2.5) and elemental carbon (EC), all of which have been linked to adverse health effects. CO, NO2, PM2.5 routinely-monitored pollutants throughout the US BUT “monitoring networks are very sparse and generally inadequate for intra-urban equity analyses (Guo et al., 2020, p. 5). NO2 has been found to be influenced by traffic counts and is less-commonly found in the atmosphere compared to other air pollutants (Guo et al., 2020). Therefore, where reliable measures of NO2 do exist, these provide the best proxy estimate of the presence and severity of transportation-specific emissions. For more details, Guo et. al (2020) provide an excellent discussion of trade-offs between types of pollutant measures and estimates.

Concerning human health, impacts include exacerbated asthma, potential childhood asthma development, impaired lung function, other respiratory ailments, cardiovascular disorders associated with mortality and morbidity (Guo et al., 2020). Additionally, exposure to high levels of ambient noise pollution has been linked to significant deficits in cognition, memory, and executive functions for children and young people (Martens et al., 2019). A notable exception to this can be found in Millonig et al.’s (2022) article that explores the concept of fair mobility budgets. Budgets would be set based on accessibility level considerations and emissions with the goal of reducing total emissions.

Studies concerning broader health outcomes can consider positive, negative or both, but the literature mostly focuses on negative health outcomes (burdens) related to transportation. Studies of active transport modes, however, have found tremendous health benefits for individuals and for society, accounting for positive impacts to mortality, morbidity, quality-of-life indices as well as controlling for negative externalities of increased exposure to pollutants and traffic risks (Martens et al., 2019).

4.3.4.e. Qualitative & Engagement

Qualitative measures of transportation equity cover the full spectrum of indicator types. While some measures of engagement found in the literature are objective measures (ex: number of community meetings), many are subjective in nature. As a result, both qualitative and engagement indicators are included in this section. Because these measures focus on the self-reported, lived experience of community members, they are indispensable tools of transportation equity. However, because qualitative measures tend to focus on past experiences, they are most often expressed as lagging indicators. These are critical to understanding how meaningful an intervention was (or wasn't) and therefore play a crucial role in the cycle of transportation equity. In contrast, indicators of engagement are almost exclusively leading indicators of equity, so long as these indicators demonstrate meaningful engagement and lead to associated interventions. When community identified concerns and professional interventions are closely aligned, an equitable outcome is more likely to occur (Sanchez and Brenman, 2008; Karner & Marcantonio, 2018).

Transportation experiences that are self-reported, or perceived are synonymous with qualitative measures. Karner et al. (2022) included qualitative as a category of accessibility measures. Since this report considers transportation equity indicators more broadly, qualitative accessibility indicators are instead placed in this section as shown in

Table 4.0.14.

Table 4.0.14. Qualitative & Engagement measures and their potential as leading and lagging indicators of transportation equity.

Type	Components	Variations	Mode Relevance	Leading when..	Lagging when...
Qualitative (self-reported, perceived)	accessibility	of trip by characteristics	varies	associated interventions utilized to increase likelihood of positive outcome	measured
		to a private vehicle			
		available opportunities			
		capabilities, functionings			
		barriers, opportunity inaccessibility			
		difficult routes by mode and user type			
		perceive driving alone as only modal option			
	satisfaction	with transport experience	varies		
		accessibility in the local area			
		experiences with trip characteristics			
		with participation in out-of-home activities			
		with ownership of a vehicle by type			
	impact of[1]	facilities by type	any		
		vehicles by type			
		interactive planning tools			
	impact on	self, skills, ability to work, comfort, stress, safety, vulnerability, convenience	any		
		region, mode users by type, norms, efficacy, control, aesthetic experience			
	attitude toward	project, agency, engagement process	any		
	guidance	# and clarity of equity goals	any		
		materials and trainings			
		performance measures for accountability			
Engagement	representation	vote share of each MPO member from a given jurisdiction relative to total	any	representation reflects constituency	measured

		number of votes for all jurisdictions			
		socio-dem summary statistics within geographical area of participation by public engagement method			
		population share of a member jurisdiction relative to total population of MPO			
		representation ratio - vote share/population share			
	events	# of citizen forums	any	meaningful amount and type provided to engage communities	
		# and type of public engagement events			
		# of focus groups w/ combination of experts & citizens			
		# transportation equity planning-specific meetings w/ diverse community representatives			
		# of consultation meetings open to citizens and community groups by location			
	resources	# of community orgs working specifically on transportation issues	any		
		presence of skilled facilitator to engage stakeholders with transportation-related social issues			
		resources provided to community groups to meaningfully participate			
		representative survey responses			
		actively maintained informational website			
	interaction	use of information website	any		
		use of platform for citizen comment on transportation issues[2]			
		# of persons involved in engagement method			

		# of survey respondents by identity and location			
		average # of planning tool device interactions per user by [touching, pointing at] screen			

[1] can be impact of any type of intervention - most commonly refers to projects, but can apply to programs, services, etc. concept of traffic-related stress applicable to fleets and facilities includes AVs and potential ability (or inability) to work while in-vehicle

[2] separate considerations for interactions during vs. outside of an event setting

In contrast to the indicators presented in the tables in the above sections, qualitative indicators cannot be readily observed. Qualitative indicators are most often collected in the form of survey responses to questions that use a Likert scale to record an individual's experience. For example, a survey could include a question about transit service satisfaction on a (Likert) scale from 1 to 5, satisfied to unsatisfied. Use of a Likert scale provides respondents an opportunity to rate the intensity of feeling.

The qualitative experience of accessibility is of particular interest within the transportation equity literature. Curl (2018) notes that "where perceived accessibility differs from objective measures the reasons need to be understood, otherwise basing policy decisions on objective measures are likely to perpetuate inequalities and exclusion from activities by ignoring the reasons why some people do not or cannot access destinations, despite having an 'acceptable' level of access according to objective measures" (p. 1150).

Lotfi and Koohsari (2009) find that subjective (qualitative) assessments of accessibility often do not correspond to objective (quantitative) assessments, even when multiple objective, quantitative measures are considered. Notably, trip characteristics are experienced differently depending on the experience of choice in selecting a mode (Reardon et al., 2019; Nahmias-Biran and Shiftan, 2020). For example, the experience of walking or riding a bus will typically be more enjoyable for individuals who chose to walk or ride, whereas those who have no choice (i.e. are transit-captive) typically experience less satisfaction and more negative affect related to their travel. One's ability to participate in the decisions that ultimately impact their daily lives also tends to lead to greater overall satisfaction (Banister, 2008)

Uteng et al. (2019) present multiple methods for engaging with urban women to identify and address experienced and perceived safety issues in their daily trips. To measure the complex relationship between objective and qualitative transportation experiences, Reardon et al. (2019) present the daily reconstruction method (DRM) which involves a daily activity diary and survey to gain an understanding of how and to what degree an individual's subjective well-being is impacted by their daily activities. Additionally, semi-structured interviews were conducted with respondents to place their survey responses in the broader context of their lives. Table 4.0.15 presents the dimensions of subjective well-being included in their survey.

Table 4.0.15 Affective dimensions by category, measured on a Likert scale from 0 ("not at all") to 6 ("very much"). Copied from Reardon et al. (2019, p. 210).

Categories	Affective Dimensions Considered
Experiences	Happy, Relaxed, Frustrated, Sad, Anxious, Impatient, Engaged, Focused, Competent
Eudemonia	Worthwhile and meaningful, Benefitted someone else, Helped achieve goals
Evaluation	Day satisfaction, Life satisfaction

Di Ciommo et. al (2019) use a similar yet simplified approach – rather than collecting detailed diaries and multiple affective states, they focus on travel time and satisfaction to classify trips as shown in Table 4.0.16.

Table 4.0.16. Categories of comparative travel time and level of satisfaction. Copied from Di Ciommo et. al (2019, p. 267).

Travel time threshold	Level of satisfaction	
	Satisfied	Unsatisfied
Below threshold (faster trip)	1	2
Above threshold (slower trip)	3	4

In a review of transportation equity literature, van Wee and Mouter (2021) find that the vast majority of studies employ a metric of accessibility. They note, however, that "it is not clear whether this is caused by a researcher's preference to study this topic (supply driven research) or because potential users of (in)equality studies value this information (demand driven research)" (p. 121). Stewart and Zegras (2022) provide some insight into this question by studying how citizens respond to different framings of transport project benefits. Using an interactive tool representing the effect of a hypothetical transit improvement project, they test stakeholders' response to benefits presented in terms of accessibility vs. travel time. They found that use of an accessibility framing "encouraged discussing the wider land-use system" and "seemed to mitigate skepticism and car users' predispositions against upgrading bus service" (p. 646). Broadly, they found that use of an accessibility framing led to improved attitudes about the project and engagement process. Essentially the use of accessibility as a means of presenting potential intervention outcomes will likely lead to an improved engagement experience.

4.3.5. Methods & Data

Once relevant indicators have been identified for a given planning process, one or more methods of analysis must be employed to inform action (leading) or measure results (lagging). For example, if an assessment of environmental externalities and health concerns is being performed and a combination of values of NO2 emissions and proximity to high-capacity facilities have been selected as indicators, these values must then be analyzed using an equity-relevant method.

Similar to the Indicators Section 4.3.4, this section details the categories of analytical methods identified in review articles which helped inform the structure of analytical methods presented. Table 4.0.17 presents the categories identified in review articles of transportation equity analyses.

Table 4.0.17. Analysis method classifications by review article.

Citation	Categories	Description
Boisjoly and El-Geneidy (2021)	Measure of inequality (Gini) Gap Analysis (composite indices of provision and vulnerability)	Critical review of public transport equity outcomes

	Difference Between groups (descriptive stats, correlation tests)	
Guo et al. (2020)	mismatch analysis statistical approaches inequality indicator-based approaches.	Critical review of transportation equity measures

Guo et. al (2020) define a mismatch analysis as essentially bivariate mapping, noting that it serves to present macro information in an intuitive manner. Indeed, mismatch analyses can offer a presentation of how (dis)proportionate transportation system externalities are. Guo et. al (2020) note, however, that the products of mismatch analyses are cumbersome to analyze and do not readily offer quantitative information on equity performance. They recommend that they instead be presented in tandem with a provision and need index. All the types identified by both articles aim to measure whether or not transportation conditions are proportionally distributed, either spatially or between socio-demographic groups. Table 4.0.18 accounts for the structures presented in Table 4.0.17 and expands on them.

Specifically, Table 4.3.17 presents methods of analysis by type, focus, and variations, similar to the tables in previous sections. This table, however, focuses on use-cases as well as software available, proprietary and open-source, that can be used to actualize the analyses detailed.

Table 4.0.18. Methods of analysis, use-cases, and software to realize analyses

Type	Focus	Variations	Use-case	Software	
				Proprietary	Open-Source
Measures	Cross-sectional Comparison	absolute value by comparison group, % of total, ratio, share, ratio of 95th/5th quantile, Cost Benefit Analysis (CBA), Aggregate Density curve comparison	Comparing between groups, modes, alternatives, or outcomes	Excel, Matlab, Minitab, SAS, SPSS, Stata	Python, R/RStudio
	Longitudinal Change	absolute change, % change, change in %	Measuring impact of intervention or general change over time		
Statistical Methods	Distributional Descriptors	quantiles [5th, median, 95th], mean, min, max, standard deviation (std), mean log deviation, relative mean deviation, coefficient of variation, density curves	Describing potential values and variation	Excel, Matlab, Minitab, SAS, SPSS, Stata	Python, R/RStudio
	Significance Tests	analysis of variance (ANOVA), bivariate correlation analysis, odds ratio, Fisher exact test, Kendall's tau, Wilcoxon signed-rank test, Mann-Whitney U test	Determining the statistical significance between comparison group values	Matlab, Minitab, SAS, SPSS, Stata	
	Models	OLS regression, spatial autoregression, Poisson, negative binomial, latent variable, structural equation modeling (SEM), activity-based model, travel demand model, Land use regression (LUR), dispersion modelling	Identifying complex relationships between relevant variables to better understand phenomena and/or to estimate potential outcomes		
Indices	Established Inequality Indices	Gini coefficient (also: Gini index, Lorenz curve), Atkinson Index, Theil Index	Comparing relative range of differences within distributions and between groups[1]	Excel, Matlab, Minitab, SAS, SPSS, Stata	Python, R/RStudio
	Composite Indices	See Accessibility table			
Geospatial	Areal Analysis (Euclidean)	points of interest, census area assessments (blocks, block groups, tracts, counties, etc.), service/catchment area (buffer analysis), clusters, kernel density, standard deviational ellipse	Assessment of phenomena over a geospatial area	ArcGIS Pro, ArcGIS Online	QGIS, Python, R/RStudio[3]
	Raster Analysis	% paved area, vegetation/pavement mix, heat island effect	Land cover assessments for environmental considerations[2]		

	Network Analysis	# of available destinations by type, isochrone of accessible area from a point	Accessibility assessments	ArcGIS Pro - Network Analyst[4], ArcGIS Online - World Traffic Service[4], CUBE Access, Conveyal	

[1] limitation of Gini is that it cannot compare between groups - that is utility of Atkinson and Theil indices

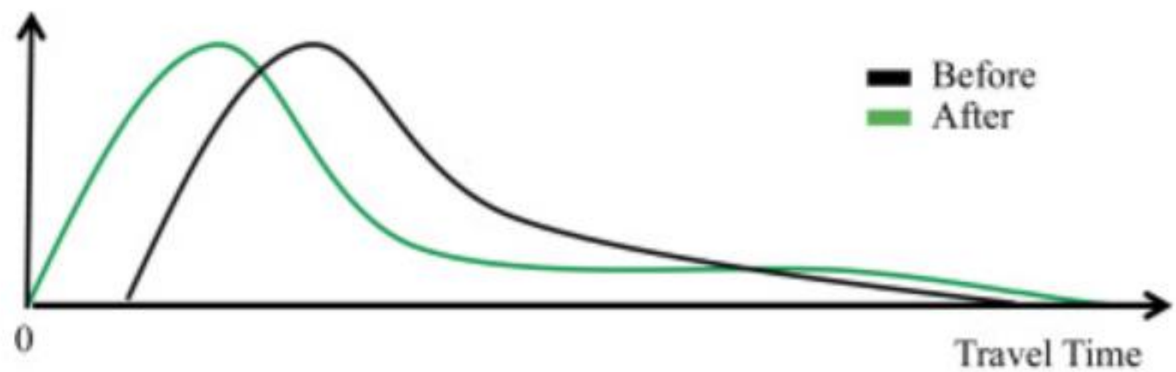
[2] heat island effect, vegetation/ pavement mix, etc.

[3] all three softwares have open-source add-ons and packages for analysis; R packages include *sf* for basic geospatial analysis and *r5R* for network analysis - *r5R* utilizes the Conveyal JavaScript-based network algorithm and includes options for GTFS-based transit networks and bicycle level of stress network attributes - network data is typically pulled from Open Street Map (OSM) using API scraping scripts/packages for open-source analyses

[4] network analyst extension costs extra, World Traffic Service requires an organizational subscription

Percentages are often used to make cross-sectional (i.e. point-in-time) comparisons between groups. Comparisons of percentages relative to average or median values are also common. For example, % of truck traffic per current annual average daily traffic rate (Beiler & Mohammed, 2016), or household transportation costs as a percentage of national median income (Anderson et al., 2017).

Fransen and Farber (2019) average accessibility across all socio-economic groups considered as the regional benchmark against which each group is compared. Bills and Walker (2017) argue for analyses should look beyond comparisons of average values because average values “may mask important individual level outcomes” (p. 63). They instead encourage analysts to plot and compare the distributions of outcomes for the socio-economic “target” and “comparison” groups defined within a study (p. 66). These are visualized in *Figure 4.0.6*. Many researchers have accounted for this by employing other descriptive statistics of population outcome distributions.



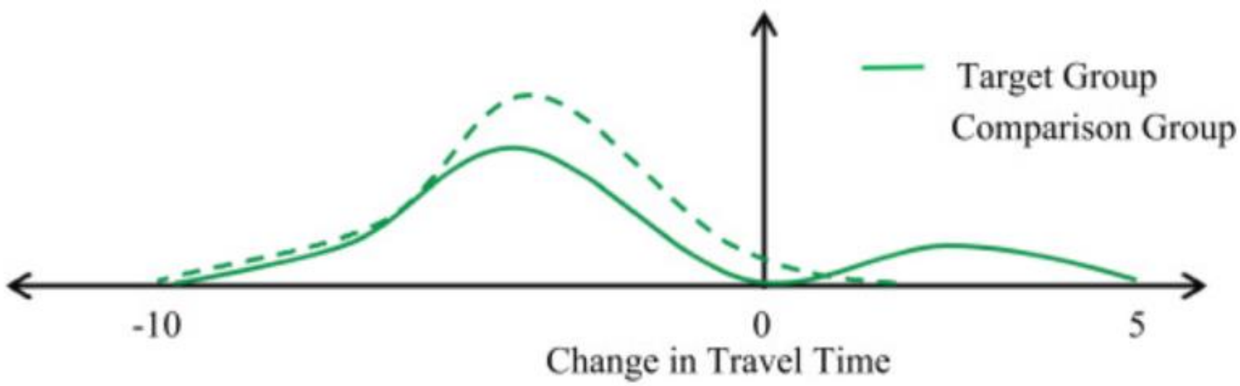


Figure 4.0.6. Hypothetical analysis curves for an aggregate density comparison (above) and for individual difference density (below). Copied from Bills and Walker (2017).

Concerning composite indices, van Wee and Mouter (2021) find that the Gini Index is the most frequently employed. Again, they note that it is unclear if policy makers prefer this means of analysis or if it is simply a researcher preference. In this review of over 100 transportation equity articles, nearly a third of the articles included a composite index of the authors' creation.

Table 4.3.18 details some sources of data that can be used to perform transportation equity analyses along. The goal is to provide examples of some of the primary, regularly maintained data sources rather than to attempt to offer a comprehensive list. A non-public agency data sources are included for comparison, but many additional open-source and proprietary data sources exist. For each source presented, example data sets available via that source are described. Again, this is not meant as a comprehensive list of data sets available from each source, but rather a starting point to understand where data can be accessed and a sample of what data exist to operationalize the methods and indicators listed above. The annotation used in the Geospatial and Network columns are detailed below the table. These columns are used to denote how the given data sets can be utilized in geospatial analysis, with special additional categorization for data sets that can be used for network analysis, respectively. All the data presented can be analyzed in tabular form using software such as Excel, R, or Python.

Table 4.0.18. Some sources of transportation equity analysis data and example data sets by type

Source		Data			
Name	**Type**	**Example Sets**	**Description**	**Geospatial**	**Network**
USCB	Public - Federal	TIGER/Lines	census-derived areal units of civic organization & analysis	v	
		Decennial	aggregated, complete US national census collected every 10 years	a	
		ACS	aggregated, sampled surveys based on decennial census, collected annually	a	
		PUMs	detailed ACS responses anonymized and sampled over census areas (PUMAs) of 100K people	a	
		LODEs/LEHD	jobs, work trips, and work-related population data	a	
USDOT/ BTS-NTAD	Public - Federal	HPMS	Highway Performance Monitoring System maintained by FHWA	v	
		FAF5	Freight Analysis Framework maintained by FHWA	a	
		FARS	traffic fatality data set maintained by NHTSA	v	
		all federal facilities	all data re: transportation facilities collected by federal agencies (FHWA, FAA, FRA, etc.)	v	*
		National Transit Map Routes & Stops	geospatial data product composite of all GTFS feeds nationally	v	X
		ACS-based data products	transportation-specific geospatial data products derived from ACS data such as household size by vehicles available, travel time to work, etc.	v	
		National Transportation Noise Map	Volpe data product	r	
		Alternative Fueling Stations	NREL-maintained data set updated daily	v	
WTN	Public - Washington State DoH	Climate & Health, Community, Environment, Exposure, Health	Single source of data sets aggregated to WA and relevant to cumulative impact analyses	v	
WA Geospatial Open Data	Public - Washington State	Natural Hazards, Boundaries, Economy, Geology, Environment,	single source of data sets collected and maintained by WA agencies + ACS and	X	*

		Agriculture, Education, Imagery, Health, Water, Transportation, EHD	other geospatial data products		
MPOs, RTPOs	Public - within state	HHTS	Household Travel Surveys and other localized data are collected, maintained, and made available by these entities	a	
Counties, Cities, DOTs	Public - within state	varies	various localized data are collected, maintained, and made available by these entities	a	
Transit authorities	Public - within region	GTFS	Generalized Transit Feed Specification is the standardized data format for transit schedule data - many software packages and applications have been developed to analyze and operationalize GTFS data	a	X
		rider card data	data generated by rider card taps while using transit system	a	
		AVL	Automated Vehicle Location data collected from vehicles with GPS	a	
		APC	Automated Passenger Counter data collected from vehicles with counters set up for vehicle boardings and alightings	a	
		other operations	various other data collected and maintained by transit authorities	a	
Open Street Map (OSM)	Open-source	points, lines, and areas of interest	wide range of tags available to search and scrape features of the natural and built environment (29 primary categories and over 70 sub-categories)	v	X
AccessMap	Open-source, public university maintained	accessmap	detailed non-motorized network attributes with a standardized data framework and collection methodology to power network routing that can be queried by mobility (dis)ability - only available in cities/localities where data has been collected	v	X

Google API	Proprietary	points, lines, and areas of interest	extensive geospatial and metadata Big Data repository and API engine - expensive	X	X
Esri	Proprietary	points, lines, and areas of interest	extensive geospatial and metadata repository specifically designed for the Esri product suite (ArcMap, ArcGIS Pro, ArcGIS Online)	X	X

a Data is available in tabular (CSV, TXT) formats with identifiers necessary to visualize in a geospatial format (ex: lat/lon coordinates, TIGER/Line identifiers)

r Data is available in raster format only – rasters are pixelated geospatial data typically conveyed in JPEG, PNG, or GIF file formats.

v Data is available in vector format only – vectors are either points, lines, or polygons (areas) typically conveyed in SHP file format.

X In the Geospatial column, this means all possible geospatial formats are available, in the Network column, this means the data is built to routable network specifications

* This means data could potentially be used for networking purposes, but may not have been developed with network routing in mind and so may require additional cleaning and management to meet network functionality

NOTE: GDB (geodatabase) file structures can contain vector, raster, and tabular data
Acronyms not specified in the table can be found in Appendix A.4

4.4. Limitations of the Academic Literature

This section highlights the limitations of the academic transportation equity literature.

4.4.1. Localized Studies and Knowledge

Many examples of transportation equity case studies focus on locations outside of the US (Murray & Davis, 2001; Solomon & Titheridge, 2007; Arsenio et al., 2016; Bajada et al., 2016; Lucas et al., 2016; Boisjoly & Yengoh, 2017; Aparicio, 2018; Aivinhenyo & Zuidgeest, 2019; Carrasco & Lucas, 2019; Curl, 2019; Jaramillo et al., 2019; Kim & Wang, 2019; Lira, 2019; Antipova et al., 2020; Vecchio et al., 2020; Qi et al., 2020). A significant portion present Chinese case studies (Zhou et al., 2018; Xiongbin, 2019; Zhao & Zhang, 2019; Sun & Zacharias, 2020; Wang et al., 2022) some of which focus on high-speed rail project analyses (Yang et al., 2018; Li et al., 2018; Fan et al., 2019). Zhang and Zhao (2021) provide an excellent review, comparing and contrasting the literature on transportation equity in China with western-based methods and framings. While the end-user (citizen) insights derived from these non-US works are not directly applicable to a US case, they do provide useful frameworks and fresh ideas. For example, the UK's social exclusion report (Solomon & Titheridge, 2007) led to the creation of extensive data collection and analysis methods driving a robust application of accessibility concepts through the UK (Dixit & Sivakumar, 2020). In the US, many studies focus on the Bay Area of California (Castiglione et al., 2006; Bills et al., 2012; Karner & Niemeier, 2013; Golub & Martens, 2014; Bills & Walker, 2017; Karner & Marcantonio, 2018; Heyer et al., 2020; Bills, 2022).

US state-level planning studies tend to only exist in the form of non-academic reports (Creger et al., 2018; Fan et al., 2019; Williams et al., 2021) which develop useful frameworks, but are not subjected to the same level of academic rigor as a journal article. An exception to this comes from Wang et al. (2022) who analyze perceived accessibility in South Carolina using structural equation modeling (SEM) which is rigorous, but difficult to achieve in a state agency planning context.

4.4.2. Urban, motorized focus

The majority of US-focused studies are reviews of MPO plans and projects funded (Grengs et al., 2013; Lowe, 2014; Luna, 2015; Manaugh et al., 2015; Lubitow et al., 2019; Karner & Golub, 2019; Heyer et al., 2020; Lempert et al., 2020; Boisjoly & El-Geneidy, 2021; Krapp et al., 2021; Martens & Golub, 2021). There are comparatively few studies that focus on rural, US contexts (Karner & London, 2014; Beiler & Mohammed, 2016; Karner, 2016). Fransen and Farber's (2019) analysis of the Wasatch Front region of Utah provides an interesting comparison not only of place- vs. person-based measures, but also accounts for urban and rural areas. Their solution to rural analysis is extensive, individual-level data collection.

While some articles focus on non-motorized modes in US contexts such as analyses of micromobility such as escooters and bikeshare fleets (Johnston et al., 2020; Chen & Li, 2021) or on active modes in general (Lee et al., 2017; Wu et al., 2019; Griffin & Jiao, 2019; Berg & Newmark, 2020; Iroz-Elardo, 2020), the vast majority of analyses focus on motorized modes.

4.4.3. Infancy of Tools

Siddiq and Taylor (2021) find that, of 54 accessibility tools analyzed, only five (5) tools were packaged and readily available for use in planning applications – of these five, all are useful for planning (rather than project) efforts. Planners interviewed for the article noted that, while there's significant desire to incorporate accessibility into planning efforts, the lack of tools poses a significant deterrent. The concern related to more complex measures was also presented, namely that complex tools tend to operate as "black boxes", are difficult to operationalize, and produce results that are more difficult to interpret and explain which leaves them more uncertain and easier to contest.

4.4.4. Data

Because transportation equity is such a wide-ranging topic that is most accurately and precisely assessed at the individual-level of data (dis)aggregation, data is a major limitation. Fransen and Farber (2019) provide a compelling argument in favor of data investments to power person-based analyses and the UK's data investments have proven fruitful (Dixit & Sivakumar, 2020), quality data collection, maintenance, and analysis would require a concerted staff and financial effort.

4.5. Recommendations

Transportation equity is a multifaceted concept and therefore requires a multi-facetted and multi-disciplinary approach. Incorporating equity into the WSDOT planning process will require a shift in analysis tools and methods, both for technical analyses as well as subjective engagement and analysis methods. Many of these tools and skillsets exist outside the traditional realm of the planning and engineering professions. It is therefore imperative that the agency invest in people to ensure the necessary skills are available at scale, likely through some combination of continued education initiatives and new staff.

4.5.1. Context and Accountability are key to equitable outcomes.

Transportation plans and interventions do not exist in a vacuum, they exist within the context of communities, land, and history. Community engagement is a critical component to establishing accountability and developing a rich sense of context, but it is important for planners to develop some contextual knowledge of their own. This self-education is not meant to supplant community voices, but to ensure that communities do not bear the sole responsibility for educating planners. Developing a sense of context for an area can range from scrolling through google maps to familiarize oneself with an area to exploring cumulative impact indices (see Chapter 3), to a full Environmental Impact Statement (EIS). Taking any amount of time to learn about an area and the people who live there will allow planners to approach their work from the perspective of the end user and increase their likelihood of proposing equitable solutions.

Efforts to self-educate and familiarize themselves with and area and the people who live there also sets planners up for more successful community engagement efforts. This is like reading course materials prior to attending a lecture; is it possible to learn from the lecture regardless? Probably. Would you take in more information and perhaps even be ready to apply more of the lecture material if you prepare before attending? Almost certainly. But unlike a single course, this work involves higher stakes and greater responsibilities. Transportation planners are civil servants whose clients are the traveling public. Engaging with the public should therefore be treated more as a performance review than a passive lecture. A performance review requires preparation and collaboration for a successful outcome. It is also a sign of respect and accountability to arrive prepared. WSDOT includes Tribal Liaisons, Title VI experts, GIS staff, and Planning and Data Academy seminars to provide knowledge and support to aid in this process of context development.

Community engagement is not just a source of knowledge to inform the planning process, community engagement is a collaborative, iterative process. As Section 4.2 illustrates, community engagement in the early stages of a planning process are critical for knowledge and context building, but it must also continue into later stages to revise and maintain alignment with overarching needs and goals. It is this regular and ongoing conversation that holds planners accountable and provides citizens with full participation in the decisions that impact their lives.

4.5.2. Meaningful interventions must consider Alignment, Timeliness, and Magnitude.

The concept of meaningfulness is reiterated throughout the above sections because it is a critical element of equitable work. For an intervention to be equitable, it must be meaningful. Meaningful can account for many things, but relative to equity, key elements can be summarized by the concepts of alignment, timeliness, magnitude.

Alignment considers how well a given intervention aligns with established equity standards and goals. Such standards are defined by civic engagement and become the responsibility of transportation planners to enact. In the state of Washington, the HEAL Act provides a mandate towards restorative equalization in alignment with the broader environmental justice (EJ) movement. This means that meaningful transportation equity interventions in the state of Washington must align with the restorative equalization equity standard. A restorative equalization equity standard operates on the assumption that the existing distribution is unjust and that efforts must be made to reduce disparities. Functionally, this means focusing efforts on (i.e. prioritizing) overburdened and vulnerable communities (i.e. communities of concern). Alignment suggests not only prioritizing interventions towards communities of concern, but ensuring interventions align with community identified concerns and goals.

Timeliness and magnitude are highlighted by Martens et al (2019) when they note that equity-oriented interventions that do little to appreciably reduce disparities and/or that will not or cannot be delivered in a reasonable timeframe may offer “no more than tokenism, while largely maintaining the status quo” (p. 33). Transportation planners are tasked with defining actionable visions over varying timeframes. Timeliness and magnitude urge long-range planners to be bold and shorter-range planners to be exacting, pushing forward interventions that appreciably reduce disparities and improve health and well-being as soon as possible.

The inherently subjective nature of meaningfulness makes impacted communities the best judge of whether or not, and to what degree, a transportation intervention in meaningful. Transportation professionals can, however, use the concepts of alignment, timeliness, and magnitude to guide their efforts.

4.5.3. Equity Strategies Tables

Tables 4.5.1 and 4.5.2 offer example interventions by equity indicator category and communities of concern. Table 4.5.1 presents examples of interventions that, when applied with appropriate context, will most likely lead to an equitable outcome. These interventions are divided into eight groups detailed below the table and are related to the broad categories of indicators presented in Section 4.3.4. The interventions presented cover a range of detail and complexity; for example, improving access (as defined in category #1) can occur in many forms and requires an accessibility analysis to estimate project outcomes. In contrast, category #3 lays out more defined interventions such as safe intersections and traffic calming measures.

Table 4.5.2 provides detail regarding context by relating interventions to communities of concern. While interventions such as any of the access improvements presented in example intervention set #1 would benefit any community, assignments in Table 4.5.2 focus on interventions explicitly related to known burdens faced by each community. These assignments are based on findings presented in Section 4.3.2. Because community engagement is a critical component of any leading indicator of transportation equity, locations, organizations, and groups are presented to highlight engagement opportunities. Taken together, Tables 4.5.1 and 4.5.2 offer an example set of leading indicators of transportation equity; when the interventions in Table 4.5.1 are with and for associated communities of concern, equitable outcomes will most likely occur.

Table 4.5.1. Examples of leading indicators of transportation equity interventions by equity concept

		Example Interventions	Concepts Addressed			
			Accessibility	Mobility & Economy	Land Use & Displacement	Environment, Health & Safety
1	a	improved access to required activities (school, work)	X	X	X	
1	b	improved access to care destinations (health, day, elder, disability)	X		X	X
1	c	improved access to healthy, affordable food	X		X	
1	d	improved access to other basic needs (recreation, banking, postal, voting)	X		X	
2	a	a variety of transportation options	X	X		
2	b	low-stress transportation options	X	X		X
2	c	time-efficient, off-peak transportation options	X	X		
2	d	affordable transportation options	X	X		
2	e	facility wayfinding designed to meet a wide range of user needs	X			
2	f	facilities, fleets, and services designed for varying physical & cognitive limitations	X	X		
3	a	good-quality, well-maintained, well-connected non-motorized facilities	X	X		X
3	b	separated non-motorized facilities	X	X		X
3	c	safe intersection crossing measures				X
3	d	traffic calming measures (physical & monitor-based)				X
4	a	community re-connection projects (bridges & interstate caps)	X	X	X	X
4	b	noise wall construction near sensitive facilities				X
5	a	a variety of forms of information about transportation options	X			
5	b	access & communication support services	X			
6	a	well-lit and monitored facilities	X			X

	b	well-kept greenery in/around facilities				X
	c	safe reporting processes	X			X
	a	various payment plans & methods offered	X	X		
7	b	discounts & subsidies	X	X		
	a	policies to encourage diffuse, wide distribution of goods & services (20-min city)	X			
	b	affordable housing & anti-displacement policies in conjunction with transport projects		X	X	
	c	policies to prevent siting of hazardous facilities near sensitive populations				X
	d	emission reduction policies & programs				X
8	e	considering operator labor needs (living wage, affordability, dignified working conditions) within program funding and administration efforts		X		X

Intervention types are grouped numerically by the following categories:

1. key components of accessibility
2. key transportation system components
3. safety & flow considerations
4. community-oriented
5. information access
6. sexual assault mitigation
7. affordability
8. policy & programmatic

Table 4.5.2. Example transportation equity leading indicator interventions and engagement by communities of concern.

Community of Concern	Relevant Interventions	Engagement Opportunities
the Young	1[a,b], 2[b,f], 3, 4[b], 7[b], 8[c,d]	schools, after-school programs, youth groups
students	1, 2[a,c,d], 3, 5[b], 7[a,b], 8[a,b,d]	higher education institutions
the Elderly	1, 2, 3, 4[b], 5, 7, 8[a,b,c,d]	senior centers, community centers, elder care facilities
people who are disabled		disability advocacy groups, disability community groups, disability support & education centers, care facilities
caregivers		care facilities (health, day, elder), schools, support groups
women	6	women's advocacy groups, community centers
LGBTQ+		LGBTQ+ advocacy groups
limited English proficiency	1, 2[e], 5	ESL schools & support services
people of color	1, 2[a,c,d], 3, 4[a], 8	racial & ethnicity-based/oriented advocacy groups, community centers
people with low-income	1, 2[a,c,d], 3, 4[a], 7, 8	advocacy groups, social workers, support organizations, posted fliers (at libraries, community centers, rental properties, public housing, transit stops)
renters	8[b]	
people facing high housing costs relative to income		
people facing high transportation costs relative to income	2[d], 7, 8[a]	
people without access to a private vehicle	2[a,c], 3[a], 8[a]	
people who are unbanked	7[a]	
people who are unemployed	1[a], 2[c,d], 7	
people without access to the internet	5[a], 7[a]	
people who are unhoused	5[a], 7, 8[b]	

While identifying relevant communities of concern must align with HEAL Act definitions, the communities identified in the HEAL Act should serve as the baseline. Additional, transportation-specific attributes should also be considered. The vulnerable communities highlighted in the transportation equity literature but not mentioned explicitly in the HEAL Act are children, young people, the elderly, women and queer individuals, and individuals with disabilities. It is also important to understand that Tribal Nations require unique consideration because they are sovereign nations. Tribal relations must first and foremost recognize Tribal councils as governing bodies of sovereign nations rather than community boards or organizations. Consulting with and working through Tribal Liaisons (such as WSDOT's Tribal Liaison Office) is critical to ensuring respectful and meaningful engagement with Tribes.

Designs that improve accessibility for individuals who are disabled improve travel conditions not only for individuals who are permanently disabled, but also for those who have experienced a temporary disabling or in some way limiting events and experiences. For example, an individual who is otherwise able-bodied could break their leg and experience limited mobility due to crutches. Or even more common, individuals with babies, small children, or traveling with bulky objects such as groceries also need accommodations similar to those needed by individuals with disabilities.

Broadly, ensuring that people have reasonable, reliable transportation choices is critical to delivering an equitable transportation system. This means investing in modes beyond private vehicles in ways that provide meaningful improvement to accessibility. To accomplish this, investments of time and resources will need to be allocated to establishing analysis and associated data collection and management structures. An immediate jump to person-based analysis methods may not be viable, but as data collection and accessibility analysis tools continue to advance, the cost barrier will ideally decrease. While some of the more elaborate qualitative methods may not be viable for large-scale planning efforts, incorporating questions related to satisfaction such as Di Ciommo et. al (2019) may provide key, subjective accessibility insights.

Beyond regional accessibility analyses, Guo et al. (2020) emphasize good quality, well-maintained, well-connected non-motorized infrastructure as critical to transportation equity. This would require the separation of modal facilities if not entirely, then at least by speed (Nello-Deakin, 2019). Where modes mix or when low-speed enforcement is critical (such as near sensitive facilities), physical traffic calming methods as well as regulatory measures such as cameras and speed level readouts are known to improve safety outcomes. Incorporating streetlights and greenery in corridor designs will not only aid in safety improvement but environmental heat island reductions as well.

It is especially important to prioritize non-motorized infrastructure improvements in areas with low-income communities of color because they tend to have worse existing infrastructure and therefore face the worst safety outcomes. Analysis of crash data in addition to socio-economic data can be used to focus these interventions. Efforts to reconnect communities divided by the interstate system are especially important, either in the form of bridges or full highway caps. It is also critical to account for housing policies and housing security when considering transportation system improvements in communities of concern. If these interventions do not go hand-in-hand, these investments may prove more harmful than helpful by driving up housing costs and displacing the communities they were intended to serve.

While policy interventions such as affordable housing considerations may fall outside of the historical scope of transportation planning activities, the displacement of marginalized communities is inextricably linked to the many ways transportation systems have been used to reinforce and exacerbate a history of government-enforced segregation that permeates to this day (Rothstein, 2017). Transportation professionals have always played a role in this process, whether they realized it or not. If we are to achieve the restorative equalization goals laid out in the HEAL Act and Title VI, a broader awareness and professional consideration for the relationship between transportation, housing, and opportunity must be incorporated into transportation planning practice.

4.5.4. Equity Standards

Restorative equalization and proportionality are most aligned with the HEAL Act, and prioritarianism aligns most closely with the current iteration and recommended use of the Washington State Department of Health (DOH)'s Environmental Health Disparities (EHD) map. Sufficiency is an additional, useful standard, especially when setting equity goals. While rigid sufficiency thresholds should not be held as a goal in-and-of themselves, defining thresholds of sufficiency and assessing the transportation system relative to those thresholds provides all stakeholders with tangible values and talking points to work from. Regardless of the equity standard employed, however, practitioners must engage community members and set robust goals based on their needs and concerns. Concerning community engagement, or the communities where technology presents an additional equity concern, established community relationships and engagement will be key to ensuring historically marginalized populations are appropriately represented in the data and considered in analyses. To engage these populations, equitable compensation for their time is critical. The Washington State Office of Equity provides guidelines for community compensation.

4.5.5. Accessibility Guidance

As Section 4.3.4.a demonstrates, the concept of accessibility, while over a half century old, is still in its infancy from an application standpoint. While a simple concept in theory, its multi-dimensional nature paired with computational limitations have made it difficult to operationalize. Computational power now exists, however complete, readily useable tools are still in development (Siddiq & Taylor, 2021). As a result, while many agencies have implemented some form of accessibility analysis in their workflows, the exact form and function remain highly varied (Karner et al., 2022).

Section 4.3.4.a of this report presents yet another overview of accessibility by offering summary information from the current state of transportation equity literature. It builds on the structure of prior work but presents a summary of measures relative to the concept of leading indicators. For further guidance relative to practical, agency-focused accessibility methods, we strongly recommend a close read of both practice-oriented reports cited in this report: the SSTI report and the NCHRP report (Sundquist et al., 2021; Karner et al., 2022).

The SSTI report offers an easy-to-read walk through of accessibility calculation and reporting basics, necessary data, existing methods and tools, and example analyses (Sundquist et al., 2021). The NCHRP report is organized in three concise chapters followed by seven appendices that present example metrics organized by agency as well as accessibility practices by state DOT, case studies of existing practices and a use-case for the report, a comprehensive summary of software and data resources, and worksheets to step a planner through the processes laid out in the report. Both reports serve as excellent resources for planners seeking guidance in accessibility implementation.

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Chapter 5: Conclusion

This dissertation presents a wide-ranging and detailed overview of transportation equity. It is wide ranging because the shear expansiveness of the space created by the concept of equity requires it. To accomplish this, the following questions were answered:

Question	Answer
What is equity?	Inherently normative
How has the concept of equity been applied in the field of transportation?	Often implicitly and imprecisely
How can the theory of intersectionality inform best practices for cumulative impact index specification?	By highlighting quantitative limitations and guiding methodological choices
Are existing cumulative impact indices more likely to designate urban tracts as disadvantaged compared to rural tracts?	Yes (the EHD and ETC)
How should practitioners approach existing indices?	Understand limitations and cross-reference with other indices and localized analyses
How can equity be incorporated in transportation planning efforts?	Through a process framework and detailed components

Chapter 2 addresses the first two questions by identifying a wide array of potentially applicable theories of equity and an even wider array of theory use in transportation literature. While explicit normative reviews as well as arguments have been presented, implicit applications and imprecise definitions of equity theories have largely obfuscated and over-simplified this multifaceted topic. Chapter 2 helps disentangle and frame out the space for further work to fill in and add detail to the space equity creates.

Chapter 3 addressed the questions highlighted in gray. It starts with a critical review of cumulative impact indices, their underlying assumptions, and their use in practice. A breakdown of the analytical process illustrates the many methodological assumptions necessary to specify a composite index. The subsequent analysis of existing indices demonstrates the significant and substantial impacts these analytical assumptions can have on disadvantage assignment outcomes. This includes a disconnect between data rescaling methods used in the literature (z-score) versus those used in practice (min-max scaling and percentile ranking). Modern EJ mandates offer a first step in remediating government sanctioned and mandated segregation that permeated legal and housing codes late into the 20^{th} century. The ongoing repercussions of this segregation necessitate racial consideration in U.S. equity practice. Ultimately, theories of intersectionality offer insights into how cumulative impact indices should be specified and, more importantly, into the inherent limitations of quantitative methods including but not limited to cumulative impact indices. Transportation practitioners are left with the recommendation to err on the side of inclusion at the course resolution of equity screening that these indices offer.

Chapter 4 details the varied means by which equity can be incorporated in the transportation planning process. Specifically, a cyclical process is derived from an expansive literature review. It highlights the nature of transportation equity in practice: it is a circular, iterative process. There is no single, linear path to identifying communities of concern, designing a solution, and moving forward. It is iterative and regressive. Within this process, a wide range of analyses and interventions can be considered depending on the contextual details at hand. Chapter 4 presents a detailed overview of types of people facing disproportionate transportation burdens, metrics to assess both transportation burdens and benefits, and analytical methods and data sources to measure and address these issues.

To apply some limits to the analysis to ensure its utility for US transportation practitioners, theories of equity presented come from a predominantly western, US-centric lens and the indices and methods are all presented in the context of U.S. federal Washington State environmental justice (EJ) legal mandates. This does not mean, however, that US practitioners would not benefit from insights provided by non-western theories of equity and justice, or that non-US practitioners stand nothing to gain from the critical and analytical insights presented. Indeed, both present avenues for growth, not just for US practitioners but for transportation in general. The methodology presented in Chapter 3 is applicable to any cumulative impact index, including those developed by nearly half of US states (WSIPP, 2022). The critical review and categorization of federally developed and maintained indices along with the user flowchart presented at the end of the chapter have practical applications for practitioners and researchers alike. This flowchart is developed specifically for Washington State practitioners, but the overarching guidance to err on the side of inclusion at low spatial resolution stands for any and all practitioners using cumulative impact indices to determine funding priorities. The methodological and theoretical cumulative impact index critical review, the detailed tables of indicators, and the transportation equity planning cycle offer the most broadly applicable contributions.

Taken together, this dissertation offers a rich and varied overview of a rich and varied topic. It:

- identifies and clarifies points of theoretical confusion using common language from interdisciplinary fields.
- provides detailed recommendations for cumulative impact index specification based on the theory of intersectionality and correlation analysis findings along with guidance for practitioners using existing indices.
- developed a practice-oriented process framework and component details to bring transportation equity analysis from academic literature and into planning practice.

Plenty of work remains in this rapidly growing space; this work offers structure and guidance with depth and breadth to help advance transportation research and practice with justice at the core and equity as the goal.

Appendix

A.1. U.S. Legal mandate language regarding environmental justice

The HEAL Act provides the following definitions for overburdened and vulnerable groups:

(11) "**Overburdened community**" means a geographic area where vulnerable populations face combined, multiple environmental harms and health impacts, and includes, but is not limited to, highly impacted communities as defined in RCW 19.405.020.

(14)(a) "**Vulnerable populations**" means population groups that are more likely to be at higher risk for poor health outcomes in response to environmental harms, due to:

(i) Adverse socioeconomic factors, such as unemployment, high housing and transportation costs relative to income, limited access to nutritious food and adequate health care, linguistic isolation, and other factors that negatively affect health outcomes and increase vulnerability to the effects of environmental harms; and

(ii) sensitivity factors, such as low birth weight and higher rates of hospitalization.

(b) "Vulnerable populations" includes, but is not limited to:

(i) Racial or ethnic minorities;

(ii) Low-income populations;

(iii) Populations disproportionately impacted by environmental harms; and

(iv) Populations of workers experiencing environmental harms.

(RCW 70A.02.010)

Overburdened community includes "**Highly impacted community**" means a community designated by the department of health based on cumulative impact analyses in RCW 19.405.140 or a community located in census tracts that are fully or partially on "Indian country" as defined in 18 U.S.C. Sec. 1151 (RCW 19.405.020 (23)).

FROM Cabello, M., Hyland, M., & Marantz, N. (2023). From State of the Practice to State of the Art: Improving Equity Analysis in Regional Transportation Plans. Available at SSRN 4384696. P. 8

"In 2012, the Federal Transit Administration (FTA) published a circular with specific guidance on how recipients of federal funds can meet Title VI requirements (Federal Transit Administration 2012). This is the latest of several guidance documents produced across decades by US DOT modal agencies related to Title VI and Environmental Justice-related Executive Orders (Eos) — see Williams and Golub (2017) for a detailed overview of these guidance documents. According to the 2012 FTA circular, MPOs are required 297 to submit the following:

1. Documentation of public engagement and participation.
2. A demographic profile of the region, including the region's share of ethnic/racial minority 300 populations.
3. A description of the procedures by which the mobility needs of minority populations are identified 302 and considered within the planning process.
4. Maps that overlay the location of transportation investments and areas where protected populations are concentrated, as well as charts that quantify how these investments are distributed.

5. An analysis of disparate impacts on the basis of race, color, or national origin. If disparate impacts are found, the MPO must determine whether there is a substantial legitimate justification for the policy that resulted in the disparate impacts, and if there are alternatives that could be employed that would have a less discriminatory impact.

While Title VI compliance is mandatory, MPOs appear, from their RTP documentation, to have considerable flexibility in how they approach their equity analyses."

Federal Transit Administration: Title VI Requirements and Guidelines for Federal Transit Administration Recipients. Federal Transit Administration. https://www.transit.dot.gov/sites/fta.dot.gov/files/docs/FTA_Title_VI_FINAL.pdf (2012). Accessed 8 May 2022

Williams, K.M., Golub, A.: Evaluating the distributional effects of regional transportation plans and projects: final report. (2017)

FROM Barajas, J. M., Braun, L. M., Merck, A., Dean, B., Esling, P., & Persaud, H. (2022). The State of Practice in Community Impact Assessment (No. FHWA-ICT-22-011). Illinois Center for Transportation. Pp. 6-10

FHWA CIA Quick Reference

In 2018, FHWA released an update to the original CIA Quick Reference guide published in 1996. The CIA Quick Reference (2018, p. 8) defines community impact assessment as:

An iterative process to evaluate the effects of a transportation action on a community and its quality of life. The assessment process is an integral part of transportation planning and project development that shapes the outcome of transportation decisions. It involves understanding the needs of communities and documenting the existing and anticipated social environment of a community with and without the proposed action. The information gleaned from this iterative process can inform decisions concerning transportation planning, project alternatives, design, and implementation. The assessment should include all items of importance to people, such as mobility, safety, employment effects, relocation, isolation, and other community issues.

The guide explains that CIAs are integral to the entire transportation decision-making process to:

- Foster quality of life and support sustainable, livable communities

- Ensure policies and investments are in line with community concerns and values
- Reduce project delays and the risk of litigation • Coordinate among land use, economic, and transportation plans and goals
- Achieve nondiscrimination

CIA serves a number of key roles in guiding the consideration of transportation impacts within the long-range planning process, the project development process, and in project implementation. While the FHWA guide focuses on describing how to conduct an assessment during project development, it emphasizes that “effective assessment begins in the long-range planning process before project decisions are made” (2018, p. 18).

CIAs are both iterative and scalable. The guide explains that there is not a one-size-fits-all approach and that analysts must be prepared to anticipate future steps and revisit prior steps. Moreover, the findings of a CIA are not merely something produced at the end of the assessment but are valuable for decision making throughout the planning and project development process. The guide is organized into ten sections, which are based on the following components of the assessment process: engage the public, develop community vision and goals, define need and action, identify community characteristics, analyze impacts, identify solutions, document findings, implement and monitor, and sources of information. …

Effective engagement involves reaching people, providing information, and gathering input. According to the CIA Quick Reference, strategies include:

- Scheduling meetings or activities that are convenient to the public, with considerations for people with nontraditional work schedules
- Reaching out to the public rather than having them come to you
- Virtual meetings
- Recognizing and addressing potential barriers to low literacy
- Recognizing and avoiding technical jargon
- Partnering with locals to serve as liaisons
- Using visualization techniques, photographs, or videos

- Conducting surveys, interviews, and focus groups
- Using interactive polling and mapping”

A.2. Detailed table of philosophical theories of equity and associated citations from transportation literature

Table A.1 *Underlying philosophical theories of equity as considered in fundamental transportation literature related to equity.*

Citation	Social Justice Theories Considered	Spatial Considerations
(Khisty, 1996, pp. 95–96)	"Theories of Justice" "Equal shares" which "distributes benefits equally (or as equally as possible) among relevant socio-economic groups" i.e. **formal equality**, or **Utilitarianism**, or "maximizing the average net benefit with a minimum floor benefit of [X] units" i.e. **partial al-Sadr/sufficientarian**or "maximizing the average net benefit with a benefit range constraint of [X] units" **partial al-Sadr**), or Egalitarianism in the sense of a "regulative procedure … to reduce any existing social or economic inequalities" to benefit "income groups that are truly in need" i.e. **partial Marx/ partial al-Sadr/capabilities approach/prioritarian**, or Rawlsian i.e. **Rawls's difference principle**	Yes - the theories are applied to an example city with example regions of analysis and example bus routes
(Litman 2002, p. 3)	"Horizontal" defined as "equal treatment of equals" and "also called fairness and egalitarianism" i.e. **formal equality**, or "Vertical With-Respect-To Income And Social Class" i.e. **Rawls's difference principle/partial al-Sadr/prioritarian**, or "Vertical With-Respect-To Need And Ability" i.e. **Marx /partial al-Sadr/capabilities approach/prioritarian**	Yes – "Location" noted as a category of equity analysis
(Thomopoulos et al., 2009, p. 352)	"Three fundamental theories can beconsidered to summarise the main equity theories that exist(Young, 1994). Whilst this may be an oversimplification, it offers an overview of the core principles applied in practice:" Egalitarian: "where everyone has equal rights or benefits for a particular service or scheme" i.e. **simple equality**, or **Utilitarian**, or	

	Rawlsian "where the aim is to retain the existing status quo between those better- and worse-off, alongside an attempt to improve the situation of those worse-off as much as possible, after everyone has secured one's fundamental rights." i.e. **Rawls's difference principle**	
(van Wee, 2011, pp. 26-32, 83)	Income classes (social) considering the following transportation-relevant theories: **Utilitarianism**, or **Egalitarianism**: **Rawls**, or Sen (**capabilities approach**), or **Sufficientarianism**	Yes – notes that if assessments are not divided along social lines, they can be considered along Regions (spatial)
(TRB Special Report 303[18], 2011, p. 41, 44)	"Type of Equity" "Benefits received" i.e. benefits-focused **Smith's user-fee paradigm** "Ability to pay" i.e. **partial Marx** "Return to source" i.e. **Smith's user-fee paradigm** "Costs imposed" i.e. **Smith's user-fee paradigm** "Process (or participation)" i.e. **partial libertarian**	Yes – within "Criteria for Grouping Individuals"
(Walker, 2012)	"Equity" appears three times in discussions: Comparing competing claims to transit service, he defines an "Equity Goal: Service shall be allocated proportional to population" i.e. he defines equity in terms of **proportional equality**, noting that this will "draw complaints from all sides" despite being 'fair' (p. 128). In the discussion for a "Coverage Goal" he notes "concerns about equity ("we pay taxes too, so we deserve service even if we don't use it much")" which considers **formal equality** – under the equal status of tax-paying citizen, a citizen might demand equal service (p. 118). Finally, he proposes a fare system with a "very smart card" that could calculate the exact cost of your trip based on the "cost of each increment of the trip, divided by the	Not in relation to equity

[18] Full citation is "National Research Council (U.S.). Transportation Research Board. Committee on Equity Implications of Evolving Transportation Finance Mechanisms" but has been shortened to "TRB Special Report 303" for in-text citations

	number of people who used that increment" i.e. **Smith's user-fee paradigm**, claiming that "[t]his system, and only this system, could be called "equitable"" (p. 143)	
(Thomopoulos & Grant-Muller, 2013, pp. 325–326)	Same as Khisty, but numbered and presented in a different order as "Equity principles": P1 – **utilitarian**, or P2 – equality i.e. **formal equality**, or P3 – Rawlsian i.e. **Rawls's difference principle**, or P4 – Egalitarian i.e. **partial Marx/partial al-Sadr/capabilities approach/prioritarian**, or P5 – minimum floor i.e. **partial al-Sadr/sufficientarian**, or P6 – maximum range i.e. **partial al-Sadr** Additionally, "Equity types" are established: T1 – horizontal: "the same benefit to all regions with similar socio-economic characteristics," i.e. **formal equality**, and T2 – vertical: "benefits more the least advantaged regions instead of the most advantaged ones," i.e. **capabilities approach/prioritarian**, and T3 – environmental: focuses on "environmental protection, through direct or compensatory actions and policies," i.e. **Left-leaning libertarian**, and T4 – regional/spatial: "benefits more the remote regions instead of those centrally located," i.e. **capabilities approach/prioritarian**, and T5 – accessibility: "improves accessibility for all regions impacted" i.e. **formal equality-constrained capabilities approach**	All principles and types are defined with regard to regions (similar to the way in which Khitsy (1996) operationalized his definitions)
(Fol & Gallez, 2014, pp. 70–71)	Summarizes (Thomopoulos et al., 2009) which considers the following theories as transportation relevant: "Egalitarian: everyone has equal rights or benefits for a particular service or scheme" i.e. **simple equality**, or **Utilitarian**, or Rawlsian i.e. **Rawls's difference principle** Summarizes (Litman, 2011) which considers:	Thomopoulous et al. (2009) presented in terms of regional access, Litman (2011) in terms of individual access

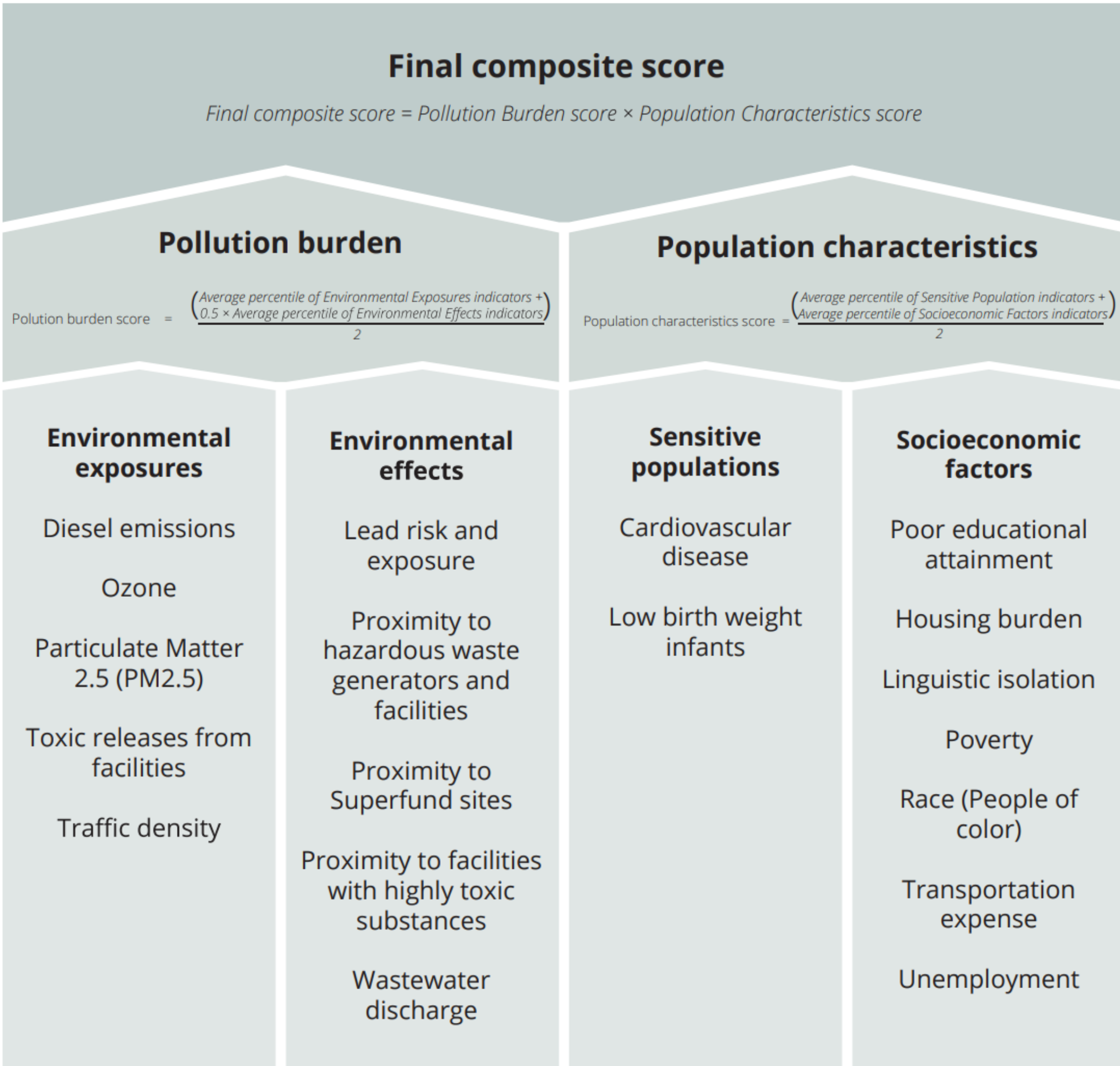
	“Horizontal equity: requires that public resources be allocated equally to each individual or group unless a targeted subsidy is specifically justified” and classifies this as “egalitarian” i.e. **simple equality** unless **prioritarianism** is justified so **partial intuitionism**, or “Vertical” equity with respect to income/social class i.e. **Rawls’s difference principle**/ **partial al-Sadr/prioritarian** or “Vertical” with respect to need and ability i.e. **Marx/partial al-Sadr/capabilities approach/prioritarian**	
(Lucas et al., 2016)	Divides into: Egalitarian (focused on **Rawls’s difference principle**), or **Sufficientarianism**	Yes – considered in light of five different components of accessibility, including human
(Di Ciommo & Shiftan, 2017 pp. 141, 146)	“horizontal equity here (i.e. each individual is considered with the same weight)” classified as “the current, utilitarian method of transport evaluation” i.e. **utilitarian**, or “Vertical” equity or “social equity” defined as “a new appraisal framework based on “needs”” i.e. **partial Marx/partial al-Sadr/capabilities approach/prioritarian**	Yes – discusses “Place of residence (inaccessible areas/socio-economically deprived areas)” as a variable in need of attention
(Pereira, Schwanen, & Banister, 2017, p. 172)	Defines and discusses these “key theories of justice” relevant to transportation equity: **Utilitarianism** **Libertarianism** **Intuitionism** “**Rawls**’s Egalitarianism” **Capabilities approach**	Yes – discusses how concept of accessibility operationalizes spatial component of *capabilities*
(Bills & Walker, 2017, pp. 65, 62-63)	“Equity standards” are defined as: “Basic Needs” i.e. **sufficientarian**, or Equality/Egalitarian “Providing an equal level of benefits among all groups of interest. Note that given the different levels of need and value that individuals place on these	Yes – included within the “Horizontal Equity Dimension” though with the note that “in some

	benefits, equality of benefits may be achieved without the actual amount of benefits being equal" i.e. **simple equality of benefits**, or "Market-based … 'You get what you pay for'" i.e. **Smith's supply-and-demand**, or "Maximum Average Net Benefit" defined as "Maximizing the average benefit, using a certain amount as a constraint, to ensure that certain groups of interest (the most neglected groups) receive a certain minimum amount of benefit" i.e. **partial al-Sadr/sufficientarian**, or **Pareto**, or Proportionality i.e. **proportional equality**, or "Restorative Justice" or "remediating the existing disproportionality of transportation benefits" i.e. **Marx/ al-Sadr/capabilities approach/prioritarian**, or **Utilitarianism**, or "Rawls-Utilitarianism" defined as "Providing the greatest level of benefits (utility) to those who are the most disadvantaged" i.e. **Rawls's difference principle** "Equity Dimensions" also referred to as "Population segmentation" defined citing Litman (2002) as: "Horizontal equity, which may include spatial and generational equity, refers to the distribution of impacts (costs and benefits) across groups that are considered to be equal in ability and need" also giving travel mode and time-of-day as examples i.e. **formal equality** and "Vertical equity refers to the distribution of transportation impacts among sub-populations that differ in ability and need, such as different social and income classes, age groups, and disabled or special needs groups" and later noting gender as well i.e. **Marx/partial al-Sadr/Rawls's difference principle/capabilities approach /prioritarian**	cases spatial and generational equity are seen as separate dimensions"
(Martens, 2017, pp. 170–173)	Multiple explored (including extensive discussion of Rawls and the capabilities approach), but transportation examples are given for the following: **utilitarianism** (there is no moral value for marginal increases in access – it is constant), or	Yes – focuses extensively on accessibility as a spatio-human measure that

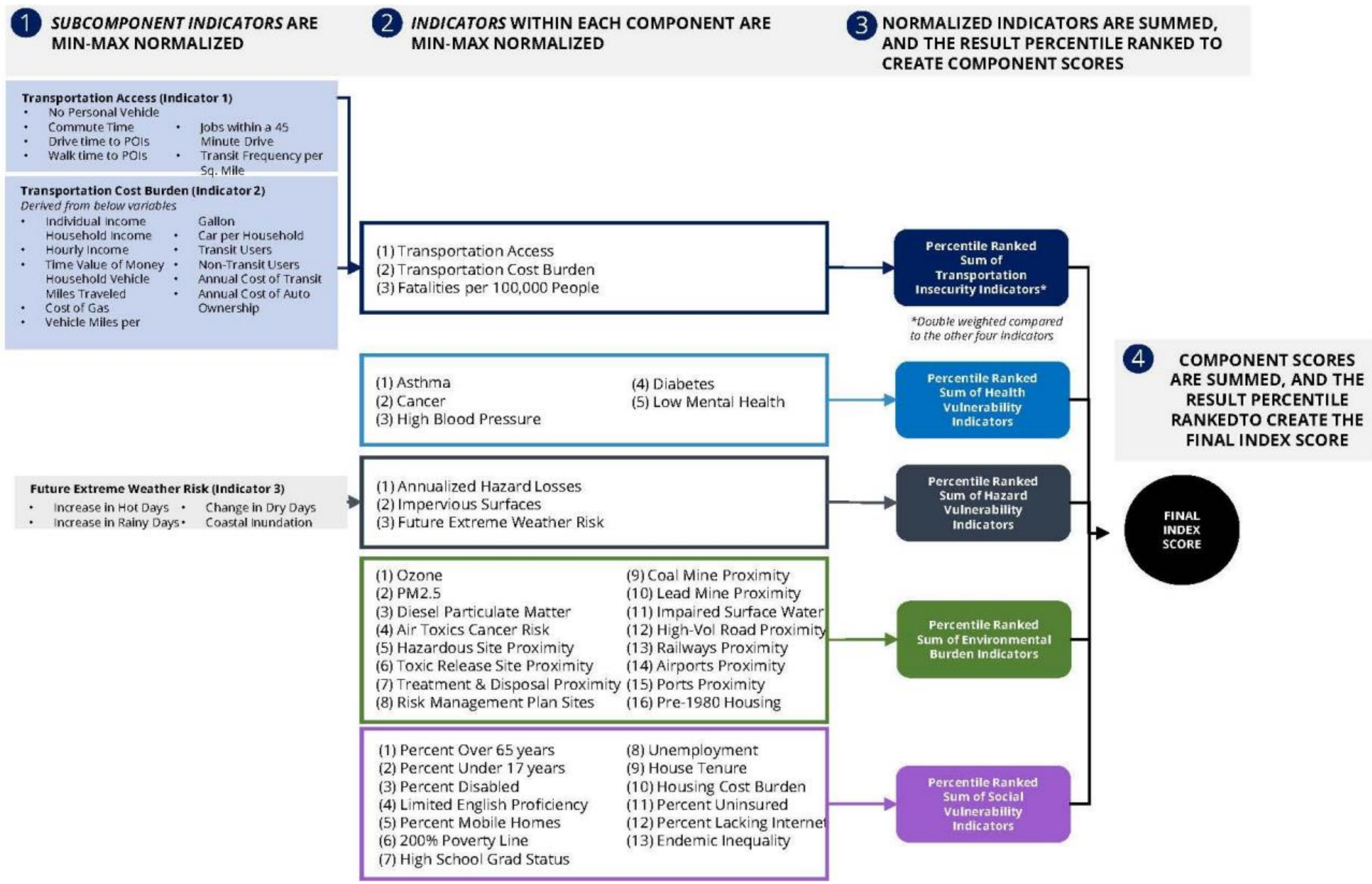
	sufficientarianism (establish a fixed cut-off point for sufficient vs. insufficient access), or **prioritarianism** (places needs/burdens on a continuous spectrum), or "**refined prioritarianism**" (considers three different curves of moral access distribution for the three domains of insufficient, disagreement, and sufficient)	operationalizes the capabilities approach
(Stewart, 2017, p. 244)	Broadly referred to as "Vertical" equity, but just assumes a-spatial application of "fairness" principles with hints of the limits of theories that consider only **formal equality** and **utilitarianism**	Yes – called "Horizontal" equity and explored with regard to cordon pricing
(van Dort et al., 2019, p. 3, 21)	Summarizes Litman (2018) which presents the same distinctions for "Horizontal" and "Vertical" as Litman (2002) – see row for Bills and Walker (2017) Additionally: "Substantive equality" is defined the same as **simple equality** "Compensatory equity considers how much and in what direction a given social structure, decision, or policy affects those overall outcomes (Taylor, 1970) with the intent of providing resources to all commensurate with individual need" i.e. **partial Marx/partial al-Sadr/Rawls's difference principle/capabilities approach/prioritarian** Per Talen (1998): "distribution of specific resources commensurate with local demand for them" i.e. **Smith supply-and-demand** "willingness to pay [assuming this] corresponds to how strongly [a given resource] is needed or desired" i.e. **partial libertarian** "Equity perspectives" "Compensatory Equity" i.e. **partial Marx/partial al-Sadr/Rawls's difference principle/capabilities approach/prioritarian** "Geographic Equity" defined as "a mix of horizontal and vertical spatial equity perspectives" i.e. **formal equality/Marx/partial al-Sadr/Rawls's difference principle/capabilities approach /prioritarian**	Yes – "Geographic Equity"

	"Procedural Equity" i.e. **partial libertarian**	
(Behbahani et al., 2019, pp. 171-172, 178-179)	"Horizontal" and "Vertical" used to define "two main categories of equity" citing the 2016 version of Litman (2002) and summarizing the category concept in the same way as Bills and Walker (2017) and van Dort et al. (2019) – see row for Bills and Walker (2017) Equity "theories" or "approaches": **Utilitarianism** "**Rawls**'s theory of Justice" Egalitarianism or "all human beings are equal, so we should, as soon as possible, reach a point where they can be treated equally" and so must "eliminate any accumulated historical inequality" i.e. **simple equality** (on the basis of moral equality) "Equal Sharing" meaning "to divide the added benefits (net benefits) in the society [through] equal distribution among groups" i.e. **formal equality** "Narrowing the Gap in Final Benefits" meaning bounded maximization of total net benefits i.e. **range-constrained** version of **utilitarianism/partial al-Sadr** "Limiting the variance in added benefits" meaning "maximization of total net benefits of the society, the constraint that the increase in the profits of the poor is now lower than a certain minimum level" i.e. **sufficientarian-constrained** version of **utilitarianism/partial al-Sadr** **al-Sadr**	Yes – operationalizes theories in terms of accessibility and development of comparative regions

A.3. Additional content related to Chapter 3



EHD specification



ETC specification

A.4. Acronyms and detailed tables of indicators and communities of concern from Chapter 4

A.4.1. Acronyms

Acronym	Full Text	Note
ACS	American Community Survey	All data from ACS 2015-2019 5-year data release - 2019 when possible to specify
ADI	Area Deprivation Index	developed in Singh (2004) and now maintained/disseminated via UWisc
AQS	Air Quality System	EPA's combined monitoring and modeled data
ATSDR	Agency for Toxic Substances and Disease Registry	
BCA	Benefit Cost Analysis	guidance provided by USDOT for US citizens' value of time by trip purpose and transit trip component
BIA	Bureau of Indian Affairs	housed in the DOI
BRIC	Baseline Resilience Indicators for Communities	
BTS	Bureau of Transportation Statistics	part of the USDOT
CDC	Center for Disease Control	
CEJST	Climate & Economic Justice Screening Tool	developed & maintained by the CEQ
CEQ	Council of Environmental Equity	Housed within the Executive Office of the President, created in 1969 as part of NEPA
CES	Consumer Expenditure Survey	annual data set re: fixed auto costs
CHAS	Comprehensive Housing Affordability Strategy	
CHDR	Center for Health Disparities Research	housed at the University of Wisconsin - maintains the ADI
COOP	Cooperative Observer Program	network of weather-observing stations overseen by the National Weather Service
DOE	Department of Energy	
DOE	Department of Energy	
DOH	Department of Health	GIS data sets for DOH
DOI	Department of the Interior	
DOL	Department of Labor	US federal department - maintains mine location data
EHD	Environmental Health Disparities	
EPA	Environmental Protection Agency	
ETC	Equitable Transportation Community Explorer	designed to compliment CEQ's CEJST as part of the Justice40 initiative, created by Executive Order 14008 Tackling the Climate Crisis at Home and Abroad
FAA	Federal Aviation Administration	
FAF5	Freight Analysis Framework	
FARS	Fatal Motor Vehicle Accidents	a data set maintained by NHTSA
FEMA	Federal Emergency Management Agency	
FHWA	Federal Highway Administration	
FRA	Federal Railroad Administration	

FRS	Facility Registry Service	sites that pose environmental risk and fall under EPA jurisdiction
FTA	Federal Transit Administration	
FUDS	Formerly Used Defense Site	dataset maintained by the USACE
HIFLD	Homeland Infrastructure Foundation-Level Data	
HOLC	Home Owner's Loan Corporation	established redlines between 1935-1940
HPMS	Highway Performance Monitoring System	
HRVI	Hazard Vulnerability & Resilience Institute	housed at the University of South Carolina & maintainer/distributor of multiple hazard, vulnerability, & resilience data sets
HUD	Housing and Urban Development	
IBL	Information by Location	interactive online map that presents EHD and other WTN data
ICBA	Intercity Bus Atlas	data shared/presented via NTAD, but underlying ICBA scheduled GTFS data tables found here
IPCD	Intermodal Passenger Connectivity Database	BTS data product based on other NTAD data files
IRA	Inflation Reduction Act	passed in 2022 - EJScreen houses a layer following IRA assessment guidelines & based on combo of CEJST & 90th percentile EJScreen Supplemental Indices (state OR national comparisons)
IRSAD	Index of Relative Socio-Economic Advantage/Disadvantage	developed by ABS using a PCA
LAR	Land Area Representation	dataset maintainted by the BIA in the DOI designating land areas for Federally Recognized Tribes
LATCH	Land Area Transportation Characteristics for Households	data product published by the BTS
LEAD	Low-Income Energy Affodability Data	maintained by the DOE
LHJ	Local Health Jurisdictions	spatial unit used by WA DOH
LQGs	Large Quantity Generators	hazardous waste proximity sources data
MDRS	Mine Safety and Health Administration	US federal administration
MRLC	Multi-Resolution Land Characteristics Consortium	maintain the NLCD
NAA	Non-attainment areas	designated by EPA
NARN	North American Rail Network	
NATA	National Air Toxics Assessment	EPA's modeled data
NCHS	National Center for Health Statistics	managed by the CDC
NCRC	National Community Reinvestment Coalition	
NHTSA	National Highway Traffic Safety Administration	
NLCD	National Land Cover Database	
NOAH	National Oceanic and Atmospheric Administration	
NPL	National Priorities List	Superfund Sites
NREL	National Renewable Energy Laboratory	product of DOE and Clean Cities coalitions and stakeholders - details
NRI	National Risk Index	the social vulnerability index used in the NRI is the one developed by ATSDR

NTAD	National Transportation Atlas Database	maintained by the BTS
NTD	National Transit Database	maintained by the FDA
NTM	National Transit Map	based on all scheduled GTFS data tables in US
NTNM	National Transportation Noise Map	a Volpe product maintained by the BTS
NWCC	Northwest Interagency Coordination Center	
NWS	National Weather Service	
OAQPS	Office of Air Quality Planning and Standards	part of the EPA
OFM	Washington State Office of Financial Management	
OPPT	Office of Pollution Prevention and Toxics	part of the EPA
ORLN	Oak Ridge National Laboratory	maintain LanScan for daytime population estimates
OSPI	Washington Office of the Superintendent of Public Instruction	
OUST	Office of Underground Storage Tanks	part of the EPA
RMP	Risk Management Plan	facility proximity - derived from EPA's FRS
RSEI	Risk-Screening Environmental Indicators	model of environmental exposure risk maintained by the EPA
SEIFA	Socio-Economic Indexes for Areas	IRSAD is one of four (4) SEIFAs developed by ABS
SEMS	Superfund Enterprise Management System	database
STEAP	Screening tool for Equity Analysis of Projects	maintained by FHWA - interactive online GUI tool w/ simple buffer analysis report generator
TIAT	Transportation Insecurity Analysis Tool	a page of the ETC Explorer that aggregates and presents ETC data according to set or user-specified thresholds
TMAS	Travel Monitoring Analysis System	
TRI	Toxics Release Inventory	
TSDFs	Treatment, Storage, and Disposal Facilities	hazardous waste proximity sources data
USACE	U.S. Army Corps of Engineers	
USALEEP	U.S. Small-area Life Expectancy Estimates Project	seemingly only 2010-2015 data set developed by CDC
USCB	United States Census Bureau	
USDA	United States Department of Agriculture	
USDOT	United States Department of Transportation	
USTs	Underground Storage Tanks	also: LUSTs - leaking USTs
WSIO	Watershed Index Online	maintained by the EPA
WSIPP	Washington State Institute for Public Policy	conducted a comparative review of EHD to other state's and EJ Screen tools
WTN	Washington Tracking Nework	Data Portal contains an array of public-health related data from various sources - some are up-to-date, but many include indices (Community-Community-Neighborhood) or assessments (Community-Community-Emergency) that are single-date, out-of-date data sets

A.4.2. Detailed table of transportation equity indicators

Citation	Leading	Lagging	Metric	Concept Measured						Transport Components							Inferred Analysis		
				Access	Mobility	Environ.	Health	Safety	Econ.	Object	Facility	Service	LandUse	Finance	Policy	Engagement	Summary	Place	Person
Martens, K., Bastiaanssen, J., & Lucas, K. (2019) p. 15	Potential	Explicit	[distance] reached by public transit considering route network, frequency, hours of operation, cost of trip	X					X		X	X	X					X	
Martens, K., Bastiaanssen, J., & Lucas, K. (2019) p. 17, 24	Potential	Explicit	# bus stops w/in XXX-ft walking distance AND by [service frequency]	X							X	X	X				X	X	
Martens, K., Bastiaanssen, J., & Lucas, K. (2019) p. 17	Potential	Explicit	Area that can be reached within a XXmin walk	X							X		X					X	
Martens, K., Bastiaanssen, J., & Lucas, K. (2019) p. 17, 24	Potential	Explicit	# of parks/grocery stores/entertainment that can be safely reached within a XXmin [non-motorized mode]	X				X			X		X				X	X	
Martens, K., Bastiaanssen, J., & Lucas, K. (2019) p. 17, 24	Potential	Explicit	# of jobs/schools that can be reached in XXmin travel time	X					X		X		X				X	X	
Martens, K., Bastiaanssen, J., & Lucas, K. (2019) p. 17	Potential	Explicit	# of health care facilities that can be reached in XXmin travel time	X			X				X		X				X	X	
Martens, K., Bastiaanssen, J., & Lucas, K. (2019) p. 17	No	Explicit	Avg. # of trips per day per person		X												X		
Martens, K., Bastiaanssen, J., & Lucas, K. (2019) p. 17	No	Explicit	Total trip distance per week per household		X												X		
Martens, K., Bastiaanssen, J., & Lucas, K. (2019) p. 17	No	Explicit	% of income spent on transport per year		X												X		
Martens, K., Bastiaanssen, J., & Lucas, K. (2019) p. 17	No	Explicit	Avg # of out-of-home activities per week per household		X												X		
Martens, K., Bastiaanssen, J., & Lucas, K. (2019) p. 17	No	Explicit	Self-reported satisfaction with ownership of a motor vehicle							X									X
Martens, K., Bastiaanssen, J., & Lucas, K. (2019) p. 17	No	Explicit	Self-reported satisfaction with transport experience																X
Martens, K., Bastiaanssen, J., & Lucas, K. (2019) p. 17	No	Explicit	Self-reported satisfaction with participation in out-of-home activities																X
Martens, K., Bastiaanssen, J., & Lucas, K. (2019) p. 19	Potential	Explicit	Level of NOx/SOx/COx/PMxx exposure from transportation at [spatial level]			X	X				X							X	
Martens, K., Bastiaanssen, J., & Lucas, K. (2019) p. 19	Potential	Explicit	Experienced levels of NOx/SOx/COx/PMxx dependent on travel behavior by person		X	X	X				X								X
Martens, K., Bastiaanssen, J., & Lucas, K. (2019) p. 19	Potential	Explicit	Level of dB(A) at [spatial level]			X	X				X							X	
Martens, K., Bastiaanssen, J., & Lucas, K. (2019) p. 19, 22	No	Explicit	# life years lost due to transportation exposure measured at [spatial level]				X				X							X	
Martens, K., Bastiaanssen, J., & Lucas, K. (2019) p. 19	No	Explicit	Avg. life expectacy				X										X		
Martens, K., Bastiaanssen, J., & Lucas, K. (2019) p. 19	Potential	Explicit	% increase in [negative health outcome] risk level at [spatial level]				X											X	

Martens, K., Bastiaanssen, J., & Lucas, K. (2019) p. 19	No	Explicit	Incidence of [negative health outcome] at [spatial level]				X											X	
Martens, K., Bastiaanssen, J., & Lucas, K. (2019) p. 19	No	Explicit	Self-reported satisfaction with local environmental quality			X	X												X
Martens, K., Bastiaanssen, J., & Lucas, K. (2019) p. 19, 24	No	Explicit	Self-reported stress levels by XXX-ft proximity to transportation facilities OR intensity of [mode] use		X	X	X			X	X		X					X	X
Martens, K., Bastiaanssen, J., & Lucas, K. (2019) p. 19, 24	No	Explicit	Prescriptions of stress-reducing medication by [spatial level] OR intensity of [mode] use		X		X			X	X		X					X	X
Martens, K., Bastiaanssen, J., & Lucas, K. (2019) p. 20	Potential	Potential	Permitted travel speeds near household		X		X				X							X	
Martens, K., Bastiaanssen, J., & Lucas, K. (2019) p. 20	Potential	Potential	Width of streets		X			X			X		X					X	
Martens, K., Bastiaanssen, J., & Lucas, K. (2019) p. 20	Potential	Potential	Quality of pavements		X			X			X							X	
Martens, K., Bastiaanssen, J., & Lucas, K. (2019) p. 20	Potential	Potential	Prevalence of safety features: zebra crossings, street bumps, chicanes, etc.					X			X		X					X	
Martens, K., Bastiaanssen, J., & Lucas, K. (2019) p. 21	Potential	Potential	Access to bike-sharing facility OR shared fleet	X						X	X	X						X	
Martens, K., Bastiaanssen, J., & Lucas, K. (2019) p. 22	Potential	Explicit	Avg. safety rating of vehicles owned by household					X		X							X		
Martens, K., Bastiaanssen, J., & Lucas, K. (2019) p. 22, 24	Potential	Explicit	Walkability index - derived from length & quality of pavements & pedestrian paths	X				X			X		X					X	
Martens, K., Bastiaanssen, J., & Lucas, K. (2019) p. 22	Potential	Explicit	Distance to nearest separated bicycle lane	X				X			X							X	
Martens, K., Bastiaanssen, J., & Lucas, K. (2019) p. 24	Potential	Explicit	Bikeability index - derived from length & quality of (dedicated) bicycle infrastructure	X				X			X		X					X	
Martens, K., Bastiaanssen, J., & Lucas, K. (2019) p. 22	Potential	Explicit	Level of traffic (collision) risk exposure by [mode] and by [spatial level]					X			X							X	
Martens, K., Bastiaanssen, J., & Lucas, K. (2019) p. 22	Potential	Explicit	Level of traffic (collision) risk exposure by actual travel behavior					X			X								X
Martens, K., Bastiaanssen, J., & Lucas, K. (2019) p. 22	No	Explicit	# of traffic collision injuries AND/OR deaths by [mode]					X			X						X		
Martens, K., Bastiaanssen, J., & Lucas, K. (2019) p. 22	No	Explicit	Costs related to treatment of injuries by [mode] and lost work days					X	X		X						X		
Martens, K., Bastiaanssen, J., & Lucas, K. (2019) p. 22	No	Explicit	Self-reported feeling of traffic safety by [mode] OR [facility]					X			X						X		X
Martens, K., Bastiaanssen, J., & Lucas, K. (2019) p. 24	No	Explicit	Total miles walked per year		X		X				X						X		
Martens, K., Bastiaanssen, J., & Lucas, K. (2019) p. 24	No	Explicit	Avg # of bicycle trips per day		X		X				X						X		
Martens, K., Bastiaanssen, J., & Lucas, K. (2019) p. 24	No	Explicit	Share of trips made by public transit		X		X				X	X					X		
Martens, K., Bastiaanssen, J., & Lucas, K. (2019) p. 24	No	Explicit	Self-reported satisfaction w/ health				X												X

Lira, B. M. (2019)	Potential	Explicit	Self-reported transportation experiences (capabilities & functionings)	X		X	X	X	X		X	X	X						X
Karner, A., & Golub, A. (2019) p. 283	Explicit	Potential	# of transportation projects by [type]		X						X	X	X				X		
Karner, A., & Golub, A. (2019) p. 283	Explicit	Potential	Cost of transportation projects by [type]		X				X		X	X	X				X		
Karner, A., & Golub, A. (2019) p. 283	Explicit	Potential	% cost of transportation projects by [type]		X				X		X	X	X				X		
Karner, A., & Golub, A. (2019) p. 283	Explicit	Potential	Average cost of transportation projects by [type]		X				X		X	X	X				X		
Karner, A., & Golub, A. (2019) p. 278, 280, 285	Explicit	Potential	# of carless households within XXX-ft of [mode] capacity expansion project per [spatial level]		X		X		X	X	X	X	X				X	X	
Karner, A., & Golub, A. (2019) p. 278, 280, 286	Explicit	Potential	Difference in median distance to project for carless households minus all other households BY total project cost AND # of carless households per [spatial level]		X		X		X		X	X	X				X	X	
Zhao, P., & Zhang, Y. (2019), pp. 78:79	Potential	Explicit	Affordability of transit fares considering trip, trip purpose, and median monthly income of riders by [socio-dem attribute]	X					X			X	X						X
Zhao, P., & Zhang, Y. (2019), pp. 78:79	Potential	Explicit	travel time by [mode] and [spatial unit]		X						X	X						X	
Zhao, P., & Zhang, Y. (2019), pp. 78:79	Potential	Explicit	travel cost by [mode] and [spatial unit]	X					X		X	X						X	
Zhao, P., & Zhang, Y. (2019), pp. 78:79	Potential	Explicit	travel distance by [mode] and [spatial unit]		X						X	X						X	
Dianin, A., Ravazzoli, E., & Hauger, G. (2021). Figure 2	Potential	Potential	# and type of car use restrictions		X			X		X			X		X		X		
Dianin, A., Ravazzoli, E., & Hauger, G. (2021). Figure 2	Potential	Potential	prevalence of car-free areas		X			X			X		X				X	X	
Dianin, A., Ravazzoli, E., & Hauger, G. (2021). Figure 2	Potential	Potential	affordability of road-pricing schemes	X					X		X				X		X		X
Dianin, A., Ravazzoli, E., & Hauger, G. (2021). Figure 2	Potential	Potential	perceived travel time disutility	X					X		X	X							X
Dianin, A., Ravazzoli, E., & Hauger, G. (2021). Figure 2	Potential	Potential	utilization of roadway capacity		X						X		X					X	
Dianin, A., Ravazzoli, E., & Hauger, G. (2021). Figure 2	Potential	Potential	prevalence of vehicle automation by level of automation					X	X	X							X		
Dianin, A., Ravazzoli, E., & Hauger, G. (2021). Figure 2	Potential	Potential	level of digitalization of booking AV [mode] trips	X					X			X					X		
Dianin, A., Ravazzoli, E., & Hauger, G. (2021). Figure 2	Potential	Potential	level of digitalization of purchasing AV [mode] trips	X					X			X					X		
Dianin, A., Ravazzoli, E., & Hauger, G. (2021). Figure 2	Potential	Potential	availability of off-line booking systems for AV [mode] trips	X					X			X					X		
Dianin, A., Ravazzoli, E., & Hauger, G. (2021). Figure 2	Potential	Potential	availability of prepaid payment methods for AV [mode] trips	X					X			X					X		
Dianin, A., Ravazzoli, E., & Hauger, G. (2021). Figure 2	Potential	Potential	travel time for urban trips		X						X	X					X		

Dianin, A., Ravazzoli, E., & Hauger, G. (2021). Figure 2	Potential	Potential	cost of urban trips	X					X			X					X		
Dianin, A., Ravazzoli, E., & Hauger, G. (2021). Figure 2	Potential	Potential	access, egress, and waiting times		X				X		X	X					X		
Dianin, A., Ravazzoli, E., & Hauger, G. (2021). Figure 2	Potential	Potential	change in location of [households, activities]	X					X		X		X					X	
Dianin, A., Ravazzoli, E., & Hauger, G. (2021). Figure 2	Potential	Potential	perceived comfort of private modes	X					X	X									X
Dianin, A., Ravazzoli, E., & Hauger, G. (2021). Figure 2	Potential	Potential	affordability of purchasing a private AV	X					X	X							X		
Dianin, A., Ravazzoli, E., & Hauger, G. (2021). Figure 2	Potential	Potential	accessibility of [mode] AV systems by [spatial unit]	X					X		X	X	X					X	
Dianin, A., Ravazzoli, E., & Hauger, G. (2021). Figure 2	Potential	Potential	cost of insurance for non-autonomous car owners	X					X	X					X		X		
Dianin, A., Ravazzoli, E., & Hauger, G. (2021). Figure 2	Potential	Potential	utility associated with ability to work/not work while riding in an AV	X					X	X									X
Dianin, A., Ravazzoli, E., & Hauger, G. (2021). Figure 2	Potential	Potential	perceived ease of booking AV [mode] trips	X								X							X
Dianin, A., Ravazzoli, E., & Hauger, G. (2021). Figure 2	Potential	Potential	perceived ease of paying for AV [mode] trips	X					X			X							X
Dianin, A., Ravazzoli, E., & Hauger, G. (2021). Figure 2	Potential	Potential	travel time spent reaching manadory activities		X				X		X	X							X
Dixit, M., & Sivakumar, A. (2020). pp. 3:4	Potential	Explicit	logsum measure of maximum utility derived by an individual for a [mode] given a choice set based on destination	X					X		X	X							X
Dixit, M., & Sivakumar, A. (2020). p. 7	Potential	Explicit	travel time by [mode] and [spatial unit]		X						X	X						X	
Dixit, M., & Sivakumar, A. (2020). p. 7	Potential	Explicit	travel cost by [mode] and [spatial unit]	X					X		X	X						X	
Dixit, M., & Sivakumar, A. (2020). p. 7	Potential	Explicit	travel distance by [mode] and [spatial unit]		X						X	X						X	
Chen, Z., & Li, X. (2021). p. 7	Potential	Explicit	travel time for commute time by [mode]		X				X		X	X						X	
Chen, Z., & Li, X. (2021). p. 9	Potential	Explicit	composite index of accessibility weighted by socio-demographic and trip related attributes by [spatial unit]	X					X		X	X	X					X	
Karner, A., & London, J. (2014). p. 91	Potential	Explicit	composite index of accessibility weighted by socio-demographic and trip related attributes by [spatial unit]	X					X		X	X	X					X	
Karner, A., & London, J. (2014). p. 91	Potential	Explicit	cumulative accessibility to [location of interest] by [mode] and [spatial unit]	X					X		X	X	X					X	
Karner, A., & London, J. (2014). p. 95	Potential	Explicit	average commute trip time by [spatial unit] AND [household types]		X				X		X	X						X	
Karner, A., & London, J. (2014). p. 95	Potential	Explicit	average commute trip cost ($) by [spatial unit] AND [household types]	X					X		X	X						X	
Karner, A., & London, J. (2014). p. 95	Potential	Explicit	average commute trip distance by [spatial unit] AND [household types]		X				X		X	X						X	

Karner, A., & London, J. (2014). p. 95	Potential	Explicit	non-SOV mode share (%) by [spatial unit] AND [household types]		X						X	X						X	
Karner, A., & London, J. (2014). p. 95	Potential	Explicit	% of household income spent on commuting by [spatial unit] AND [household types]	X					X		X	X						X	
Golub, A., & Martens, K. (2014). p. 12	Potential	Explicit	cumulative accessibility to [location of interest] by [mode] and [spatial unit]	X					X		X	X	X					X	
Golub, A., & Martens, K. (2014). p. 12	Potential	Explicit	accessibility ratio: cumulative accessibility by [non-SOV mode] divided by cumulative accessibility by CAR	X					X		X	X	X					X	
Wu, Y., Rowangould, D., London, J. K., & Karner, A. (2019). p. 533	Explicit	Potential	population attributable friction (PAF) for physical activity		X		X	X			X								X
Wu, Y., Rowangould, D., London, J. K., & Karner, A. (2019). p. 533	Explicit	Potential	population attributable friction (PAF) for traffic injury					X			X								X
Wu, Y., Rowangould, D., London, J. K., & Karner, A. (2019). p. 533	Explicit	Potential	population attributable friction (PAF) for health outcomes				X				X								X
Wu, Y., Rowangould, D., London, J. K., & Karner, A. (2019). p. 534	Potential	Potential	% increase in roadway lane miles		X						X							X	
Wu, Y., Rowangould, D., London, J. K., & Karner, A. (2019). p. 534	Potential	Potential	% increase in transit vehicle service hours		X				X			X					X		
Wu, Y., Rowangould, D., London, J. K., & Karner, A. (2019). p. 534	Potential	Potential	$ for funding and operating [facility type]						X		X						X		
Wu, Y., Rowangould, D., London, J. K., & Karner, A. (2019). p. 534	Potential	Potential	% of new homes by [land-use area type]										X					X	
Wu, Y., Rowangould, D., London, J. K., & Karner, A. (2019). p. 534	Potential	Potential	% of new jobs by [land-use area type]						X				X					X	
Lowe, K. (2014). p.	Potential	Explicit	source & allocation of tax $						X					X			X		
Boisjoly, G., & Yengoh, G. T. (2017). p. 7	Potential	Explicit	# of consultation meetings open to citizens and community groups by location	X												X		X	
Boisjoly, G., & Yengoh, G. T. (2017). p. 7	Potential	Explicit	Survey use & reach (# of respondents by identity AND location)	X												X		X	X
Boisjoly, G., & Yengoh, G. T. (2017). p. 7	Potential	Explicit	Use of information website	X												X	X		
Boisjoly, G., & Yengoh, G. T. (2017). p. 7	Potential	Explicit	# of focus groups w/ combination of experts & citizens	X												X	X		
Boisjoly, G., & Yengoh, G. T. (2017). p. 7	Potential	Explicit	Use of platform for citizen comment on transportation issues (not tied to an event)	X												X	X		
Boisjoly, G., & Yengoh, G. T. (2017). p. 7	Potential	Explicit	# of citizen forums	X												X	X		
Boisjoly, G., & Yengoh, G. T. (2017). p. 9	Potential	Potential	frequency of transit service		X							X						X	

Boisjoly, G., & Yengoh, G. T. (2017). p. 9	Potential	Potential	reliability of transit service		X							X						X	
Boisjoly, G., & Yengoh, G. T. (2017). p. 9	Potential	Potential	regulariry of maintenance of bicycle paths					X			X	X						X	
Boisjoly, G., & Yengoh, G. T. (2017). p. 9	Potential	Potential	spatial coverage of separated bicycle paths		X			X			X		X					X	
Boisjoly, G., & Yengoh, G. T. (2017). p. 9	Potential	Potential	prevalence of "special" pedestrian crossings		X			X			X		X					X	
Boisjoly, G., & Yengoh, G. T. (2017). p. 9	Potential	Potential	spatial coverage of street lights	X				X			X		X					X	
Boisjoly, G., & Yengoh, G. T. (2017). p. 10	Potential	Potential	spatial coverage of sidewalks wide enough for people with disabilities		X			X			X		X					X	
Boisjoly, G., & Yengoh, G. T. (2017). p. 10	Potential	Potential	spatial coverage of well-maintained greenery (heat island and aesthetic)			X	X				X		X					X	
Boisjoly, G., & Yengoh, G. T. (2017). p. 10	Potential	Potential	access to key destinations by [mode]	X					X		X	X	X					X	
Boisjoly, G., & Yengoh, G. T. (2017). p. 10	Potential	Potential	comfort of transit service	X							X	X						X	
Boisjoly, G., & Yengoh, G. T. (2017). p. 10	Potential	Potential	level of traffic congestion by [spatial unit]		X						X		X					X	
Boisjoly, G., & Yengoh, G. T. (2017). p. 10	Potential	Potential	increase in car-sharing (to reduce traffic)		X						X	X					X		
Boisjoly, G., & Yengoh, G. T. (2017). p. 10	Potential	Potential	parking regulation zones (to reduce traffic)		X						X		X		X			X	
Boisjoly, G., & Yengoh, G. T. (2017). p. 14	Potential	Potential	# of community organizations working specifically on transportation issues	X												X	X		
Boisjoly, G., & Yengoh, G. T. (2017). pp. 9,16	Potential	Potential	clear equity goals and associated guidelines for local planners	X											X		X		
Boisjoly, G., & Yengoh, G. T. (2017). pp. 9,16	Potential	Potential	presence of skilled facilitator to engage stakeholders with tranportation-related social issues	X												X	X		
Boisjoly, G., & Yengoh, G. T. (2017). pp. 9,17	Potential	Potential	resources provided to communtiy groups to "meaningfully take part in participatory process"	X												X	X		
Griffin, G. P., & Jiao, J. (2019). p. 463	Potential	Explicit	# of citizen forums	X												X	X		
Griffin, G. P., & Jiao, J. (2019). p. 463	Potential	Explicit	# of persons involved in [public engagement method]	X												X	X		
Griffin, G. P., & Jiao, J. (2019). p. 463	Potential	Explicit	community-identified barriers and difficult routes for [mode]		X			X			X	X	X					X	
Griffin, G. P., & Jiao, J. (2019). pp. 463:465	Potential	Explicit	[summary statistics] of [spatial unit] attributes that fall within a standard deviational ellipse (SDE) of geographical area of participation by [public engagement method]	X												X		X	
Iroz-Elardo, N., Schoner, J., Fox, E. H., Brookes, A., & Frank, L. D. (2020). pp. 2:3	Explicit	Potential	weekly transport walking minutes per person		X		X				X								X

Iroz-Elardo, N., Schoner, J., Fox, E. H., Brookes, A., & Frank, L. D. (2020). pp. 2:3	Explicit	Potential	weekly leisure walking minutes per person		X		X				X								X
Iroz-Elardo, N., Schoner, J., Fox, E. H., Brookes, A., & Frank, L. D. (2020). pp. 2:3	Explicit	Potential	average BMI				X				X								X
Lempert, R., Syme, J., Mazur, G., Knopman, D., Ballard-Rosa, G., Lizon, K., & Edochie, I. (2020). p. 319	Explicit	Potential	thousands of tons of CO2 emissions per day by [mode]			X					X	X							X
Lempert, R., Syme, J., Mazur, G., Knopman, D., Ballard-Rosa, G., Lizon, K., & Edochie, I. (2020). p. 319	Explicit	Potential	# person-trips per day		X						X	X							X
Lempert, R., Syme, J., Mazur, G., Knopman, D., Ballard-Rosa, G., Lizon, K., & Edochie, I. (2020). p. 316	Explicit	Potential	distance to transit	X							X	X						X	
Lempert, R., Syme, J., Mazur, G., Knopman, D., Ballard-Rosa, G., Lizon, K., & Edochie, I. (2020). p. 319	Explicit	Potential	% EV market penetration						X	X					X		X		
Lempert, R., Syme, J., Mazur, G., Knopman, D., Ballard-Rosa, G., Lizon, K., & Edochie, I. (2020). p. 319	Explicit	Potential	Gas prices						X	X					X		X		
Lempert, R., Syme, J., Mazur, G., Knopman, D., Ballard-Rosa, G., Lizon, K., & Edochie, I. (2020). p. 319	Explicit	Potential	Fuel efficiency			X			X	X					X		X		
Lempert, R., Syme, J., Mazur, G., Knopman, D., Ballard-Rosa, G., Lizon, K., & Edochie, I. (2020). p. 319	Explicit	Potential	VMT elasticity wrt economic growth		X				X		X						X		
Lempert, R., Syme, J., Mazur, G., Knopman, D., Ballard-Rosa, G., Lizon, K., & Edochie, I. (2020). p. 319	Explicit	Potential	VMT elasticity wrt cost of driving		X				X	X	X						X		
Karner, A., & Marcantonio, R. A. (2018). p. 115	No	Explicit	Incidence of [negative health outcome] at [spatial level]				X				X		X					X	
Karner, A., & Marcantonio, R. A. (2018). p. 115	No	Explicit	# of traffic collision injuries AND/OR deaths by [mode]					X			X		X				X		
Karner, A., & Marcantonio, R. A. (2018). p. 115	Potential	Potential	experience of thermal comfort				X				X		X				X		
Karner, A., & Marcantonio, R. A. (2018). p. 115	Potential	Potential	access to key destinations by [mode]	X					X		X	X	X					X	
Karner, A., & Marcantonio, R. A. (2018). p. 115	Potential	Potential	use of local & small businesses						X				X		X		X		
Karner, A., & Marcantonio, R. A. (2018). p. 115	Potential	Potential	housing cost	X					X				X		X		X		

Karner, A., & Marcantonio, R. A. (2018). p. 115	Potential	Explicit	travel cost by [mode] and [spatial unit]	X					X		X	X						X	
Karner, A., & Marcantonio, R. A. (2018). p. 115	Potential	Potential	cost of energy						X						X		X		
Karner, A., & Marcantonio, R. A. (2018). p. 115	Potential	Potential	access to transit	X							X	X	X					X	
Karner, A., & Marcantonio, R. A. (2018). p. 115	Potential	Potential	reliability of transit service		X							X						X	
Karner, A., & Marcantonio, R. A. (2018). p. 115	Potential	Potential	proximity of jobs to housing	X					X				X					X	
Karner, A., & Marcantonio, R. A. (2018). p. 115	Potential	Potential	projects in jurisdictions with antidisplacement policies in place	X											X			X	
Karner, A., & Marcantonio, R. A. (2018). p. 115	Potential	Explicit	Level of NOx/SOx/COx/PMxx exposure from transportation at [spatial level]			X	X				X		X					X	
Karner, A., & Marcantonio, R. A. (2018). p. 115	Potential	Potential	zero-emission vehicle projects in high diesel air pollution areas			X	X				X				X			X	
Karner, A., & Marcantonio, R. A. (2018). p. 117	Potential	Explicit	% change in population by [type] over XX-years	X									X					X	
Karner, A., & Marcantonio, R. A. (2018). p. 118	Potential	Potential	resources provided to communtiy groups to "meaningfully take part in participatory process"	X												X	X		
Boisjoly, G., & El-Geneidy, A. (2021). pp. 227,229	Potential	Potential	access to key destinations by [mode]	X					X		X	X	X					X	
Boisjoly, G., & El-Geneidy, A. (2021). p. 229	Potential	Potential	access to transit	X							X	X						X	
Boisjoly, G., & El-Geneidy, A. (2021). p. 229	Potential	Potential	frequency of transit service		X							X						X	
Boisjoly, G., & El-Geneidy, A. (2021). p. 229	Potential	Potential	Composite index of [mode] provision and vulnerability	X			X		X		X	X	X					X	
Boisjoly, G., & El-Geneidy, A. (2021). p. 237	Potential	Explicit	infrequent transit service outside of peak hours	X								X					X		
Lucas, K., Van Wee, B., & Maat, K. (2016). p. 477	Potential	Explicit	socially relevant accessibility impacts (SRAIs) of transport - gravity-based (decay function) composite measure of accessibility to key destinations - buffer & cluster methods	X			X		X		X	X	X					X	
Lucas, K., Van Wee, B., & Maat, K. (2016). p. 485	Potential	Explicit	% of total population within accessibility [threshold]	X					X		X	X	X					X	
Beiler, M. O., & Mohammed, M. (2016). pp. 288:289	Potential	Explicit	Composite index of place-based accessibility Transportation Justice Threshold Index Framework (TJTIF)	X					X		X	X	X					X	
Beiler, M. O., & Mohammed, M. (2016). p. 290	Potential	Explicit	% of area within XX-mi buffer of a fixed route transit stop	X							X		X					X	
Beiler, M. O., & Mohammed, M. (2016). p. 290	Potential	Explicit	% of area within XX-mi buffer of a school	X			X				X		X					X	
Beiler, M. O., & Mohammed, M. (2016). p. 290	Potential	Explicit	% of area within XX-mi buffer of a highway access point	X					X		X		X					X	
Beiler, M. O., & Mohammed, M. (2016). p. 290	Potential	Explicit	% of crashes per year that are fatal					X			X		X				X		

Beiler, M. O., & Mohammed, M. (2016). p. 290	Potential	Explicit	% of truck traffic per current annual average daily traffic rate		X				X		X						X		
Beiler, M. O., & Mohammed, M. (2016). p. 290	Potential	Explicit	% of transportation facilities with two or more types of connecting modes		X						X						X		
Beiler, M. O., & Mohammed, M. (2016). p. 290	Potential	Explicit	% of commuters spending more than the median travel time to work		X				X		X	X	X				X		
Luna, M. (2015). p. 284	Potential	Explicit	vote share of each MPO member from a given jurisdiction relative to total number of votes for all jurisdictions	X											X	X		X	
Luna, M. (2015). p. 284	Potential	Explicit	population share of a member jurisdiction relative to total population of MPO	X												X		X	
Luna, M. (2015). p. 285	Potential	Explicit	representation ratio - vote share/population share	X												X		X	
Anderson, K., Blanchard, S. D., Cheah, D., & Levitt, D. (2017). p. 67	Explicit	Potential	multi-criteria analysis for mobility hub site selection	X					X		X	X	X	X				X	
Anderson, K., Blanchard, S. D., Cheah, D., & Levitt, D. (2017). p. 67	Explicit	Potential	index of low automobility		X						X		X					X	
Anderson, K., Blanchard, S. D., Cheah, D., & Levitt, D. (2017). p. 67	Explicit	Potential	index of disadvantaged populations				X		X				X					X	
Anderson, K., Blanchard, S. D., Cheah, D., & Levitt, D. (2017). p. 67	Explicit	Potential	index of transportation connectivity	X							X	X	X					X	
Anderson, K., Blanchard, S. D., Cheah, D., & Levitt, D. (2017). p. 67	Explicit	Potential	index of land use intensity						X				X					X	
Anderson, K., Blanchard, S. D., Cheah, D., & Levitt, D. (2017). p. 67	Explicit	Potential	index of resiliency						X				X					X	
Anderson, K., Blanchard, S. D., Cheah, D., & Levitt, D. (2017). p. 67	Explicit	Potential	index of new service viability		X				X			X						X	
Anderson, K., Blanchard, S. D., Cheah, D., & Levitt, D. (2017). p. 67	Explicit	Potential	index of future growth potential						X				X					X	
Anderson, K., Blanchard, S. D., Cheah, D., & Levitt, D. (2017). p. 70	Explicit	Potential	% change in population by [type] over XX-years						X				X					X	
Anderson, K., Blanchard, S. D., Cheah, D., & Levitt, D. (2017). p. 70	Explicit	Potential	# of jobs by [type] within XX-mi	X					X		X	X	X					X	
Anderson, K., Blanchard, S. D., Cheah, D., & Levitt, D. (2017). p. 70	Explicit	Potential	change in jobs by [type] over XX-years						X				X					X	
Anderson, K., Blanchard, S. D., Cheah, D., & Levitt, D. (2017). p. 70	Explicit	Potential	# of public housing projects in [spatial unit]	X									X					X	

Anderson, K., Blanchard, S. D., Cheah, D., & Levitt, D. (2017). p. 70	Explicit	Potential	Kernel density score for proximity to commercial destinations	X					X				X					X	
Anderson, K., Blanchard, S. D., Cheah, D., & Levitt, D. (2017). p. 70	Explicit	Potential	distance to [point of interest]		X						X		X					X	
Anderson, K., Blanchard, S. D., Cheah, D., & Levitt, D. (2017). p. 70	Explicit	Potential	Transportation costs as a percentage of national median income						X		X	X	X				X		
Anderson, K., Blanchard, S. D., Cheah, D., & Levitt, D. (2017). p. 70	Explicit	Potential	# of buses stopping at all stops in [spatial unit] during weekday		X							X						X	
Anderson, K., Blanchard, S. D., Cheah, D., & Levitt, D. (2017). p. 70	Explicit	Potential	# of current car-share locations in [spatial unit]		X						X	X						X	
Murray, A. T., & Davis, R. (2001). pp. 589:592	Explicit	Potential	Public Transport Need Index	X			X		X		X	X	X					X	
Murray, A. T., & Davis, R. (2001). pp. 593:594	Potential	Explicit	Public Transport Access Index	X							X	X	X					X	
Murray, A. T., & Davis, R. (2001). pp. 595:596	Explicit	Potential	Transport disadvantaged areas (overlap of Need & Access indices)	X			X		X		X	X	X					X	
Bills, T. S., Sall, E. A., & Walker, J. L. (2012). p. 22	Explicit	Potential	value of time model of 24-hr microsimulation transportation tours by mode choice and socio-econ variables	X					X		X	X	X						X
Bills, T. S., Sall, E. A., & Walker, J. L. (2012). p. 22	Explicit	Potential	cost of parking						X		X				X			X	
Bills, T. S., Sall, E. A., & Walker, J. L. (2012). p. 22	Explicit	Potential	time needed to park		X						X								X
Bills, T. S., Sall, E. A., & Walker, J. L. (2012). p. 21	Explicit	Potential	marginal cost of visiting [activity locations]						X		X	X	X						X
Bills, T. S., Sall, E. A., & Walker, J. L. (2012). p. 23	Explicit	Potential	travel time for commute time by [mode]	X					X		X	X	X						X
Heyer, J., Palm, M., & Niemeier, D. (2020). p. 4	Potential	Explicit	% change in population by [type] over XX-years	X					X				X					X	
Heyer, J., Palm, M., & Niemeier, D. (2020). p. 5	Potential	Explicit	% change in workers by [type] commuting via automobile		X				X		X		X					X	
Heyer, J., Palm, M., & Niemeier, D. (2020). p. 8	Potential	Explicit	Average travel time by [trip type] and [time of day]		X						X	X	X					X	
Heyer, J., Palm, M., & Niemeier, D. (2020). p. 8	Potential	Explicit	Average daily VMT per population sq mi within XX-ft of heavily used roadway		X						X		X					X	
Heyer, J., Palm, M., & Niemeier, D. (2020). p. 8	Potential	Explicit	%SOV/HOV work trips <= XX-min during [time of day]		X				X		X		X					X	
Heyer, J., Palm, M., & Niemeier, D. (2020). p. 8	Potential	Explicit	% population within XX-min accessibility thresholds for [points of interest]	X							X	X	X		X			X	
Heyer, J., Palm, M., & Niemeier, D. (2020). p. 8	Potential	Explicit	% homes within XX-mi of transit stop	X							X							X	
Heyer, J., Palm, M., & Niemeier, D. (2020). p. 8	Potential	Explicit	estimated cost of [mode] investment per person within XX-mi of [mode] project						X		X	X	X	X				X	

Heyer, J., Palm, M., & Niemeier, D. (2020). p. 8	Potential	Explicit	% VMT at level of service E or worse		X						X		X					X	
Heyer, J., Palm, M., & Niemeier, D. (2020). p. 8	Potential	Explicit	# of households within XX-ft of class 1 or 2 roadway				X				X		X					X	
Heyer, J., Palm, M., & Niemeier, D. (2020). p. 8	Potential	Explicit	change in % person miles traveled on [mode] over XX-years		X						X		X				X		
Heyer, J., Palm, M., & Niemeier, D. (2020). p. 8	Potential	Explicit	Transportation investment by [mode]						X		X	X		X			X		
Heyer, J., Palm, M., & Niemeier, D. (2020). p. 8	Potential	Explicit	change in # of multifamily housing options over XX-years	X									X				X		
Cronley, C., Miller, V. J., Fields, N., & Mattingly, S. P. (2021). p. 3	Explicit	Potential	# transportation equity planning-specific meetings w/ diverse community representatives	X												X	X		
Berg, A., & Newmark, G. L. (2020). p. 771	Potential	Explicit	# and type of public engagement used to enforce agency accountability for equity acknolwedgement	X											X	X	X		
Berg, A., & Newmark, G. L. (2020). p. 771	Potential	Explicit	# and clarity of goals used to enforce agency accountability for equity promise	X											X	X	X		
Berg, A., & Newmark, G. L. (2020). p. 771	Potential	Explicit	# and clarity of performance measures used to enforce agency accountability for equity goals	X											X		X		
Berg, A., & Newmark, G. L. (2020). p. 772	Potential	Explicit	# sidewalk miles built by [spatial unit] and by [comparison group]		X			X			X							X	
Berg, A., & Newmark, G. L. (2020). p. 772	Potential	Explicit	# of traffic collision injuries AND/OR deaths by [mode] and by [comparison group]					X			X		X				X		
Berg, A., & Newmark, G. L. (2020). p. 773	Potential	Explicit	# of people who walk		X						X		X				X		
Ahmed, Q. I., Lu, H., & Ye, S. (2008). p. 130	Potential	Explicit	length of project by [facility type]		X				X		X						X		
Ahmed, Q. I., Lu, H., & Ye, S. (2008). p. 130	Potential	Explicit	Cost of transportation projects by [facility type]						X		X			X			X		
Ahmed, Q. I., Lu, H., & Ye, S. (2008). p. 131	Potential	Explicit	% increase in length by [facility type]		X				X		X						X		
Ahmed, Q. I., Lu, H., & Ye, S. (2008). pp. 131:132	Potential	Explicit	total private vehicles, cars, and motorcycles by GDP/capita		X				X	X							X		
Ahmed, Q. I., Lu, H., & Ye, S. (2008). p. 132	Potential	Explicit	total trips per day per capita		X				X		X	X	X				X		
Ahmed, Q. I., Lu, H., & Ye, S. (2008). p. 132	Potential	Explicit	total trips per day		X						X	X	X				X		
Ahmed, Q. I., Lu, H., & Ye, S. (2008). p. 132	Potential	Explicit	% daily trip split by [mode]		X						X	X	X				X		
Ahmed, Q. I., Lu, H., & Ye, S. (2008). pp. 133:134	Potential	Explicit	# of public transit lines in operation		X				X		X	X					X		
Ahmed, Q. I., Lu, H., & Ye, S. (2008). pp. 133:134	Potential	Explicit	# of public transit vehicles in operation		X				X			X					X		
Behbahani, H., Nazari, S., Kang, M. J., & Litman, T. (2019). p. 179	Explicit	Potential	Accessibility Index - activity-weighted measure of accessibility	X					X		X	X	X	X				X	

Behbahani, H., Nazari, S., Kang, M. J., & Litman, T. (2019). p. 179	Explicit	Potential	flow of traffic		X						X							X	
Behbahani, H., Nazari, S., Kang, M. J., & Litman, T. (2019). p. 179	Explicit	Potential	travel time by [mode]		X						X							X	
Behbahani, H., Nazari, S., Kang, M. J., & Litman, T. (2019). p. 179	Explicit	Potential	Cost of transportation projects by [facility type]						X		X			X			X		
Behbahani, H., Nazari, S., Kang, M. J., & Litman, T. (2019). p. 179	Explicit	Potential	Total funds allocated for program (set of projects)						X					X			X		
Guo, Y., Chen, Z., Stuart, A., Li, X., & Zhang, Y. (2020). p. 4	Potential	Explicit	ratio of service area for [facility type] to total area of [spatial unit]		X						X		X					X	
Guo, Y., Chen, Z., Stuart, A., Li, X., & Zhang, Y. (2020). p. 4	Potential	Explicit	"connecting power" of a transit station - sum inbound and outbound weighted by frequency, speed, distance, capacity, transfers		X						X	X	X					X	
Guo, Y., Chen, Z., Stuart, A., Li, X., & Zhang, Y. (2020). p. 4	Potential	Explicit	"connecting power" of a [spatial unit] - average of all stations in [spatial unit]		X						X	X	X					X	
Guo, Y., Chen, Z., Stuart, A., Li, X., & Zhang, Y. (2020). p. 5	Potential	Explicit	measured concentration of [air pollutant] by [spatial unit]			X	X						X					X	
Guo, Y., Chen, Z., Stuart, A., Li, X., & Zhang, Y. (2020). p. 5	Potential	Explicit	travel-demand modelled rate of [air pollutant] generation by [spatial unit]			X	X				X		X						X
Guo, Y., Chen, Z., Stuart, A., Li, X., & Zhang, Y. (2020). p. 5	Potential	Explicit	area-based emission inventories modelled concentration of [air pollutant] but [spatial unit]			X	X				X		X						X
Guo, Y., Chen, Z., Stuart, A., Li, X., & Zhang, Y. (2020). p. 5	Potential	Explicit	dispersion modelling of [air pollutant] by [spatial unit] - integrates generation & concentration w/ wind and land use considerations			X	X				X		X						X
Guo, Y., Chen, Z., Stuart, A., Li, X., & Zhang, Y. (2020). pp. 5,6	Potential	Explicit	traffic density by [spatial unit]		X						X		X					X	
Guo, Y., Chen, Z., Stuart, A., Li, X., & Zhang, Y. (2020). p. 5	Potential	Explicit	exposure to traffic pollution estimate by distribution of [air pollutant] and population estimates by space and/or time			X	X				X		X						X
Guo, Y., Chen, Z., Stuart, A., Li, X., & Zhang, Y. (2020). p. 5	Potential	Explicit	exposure to traffic pollution by XX-ft buffer zone around [transportation facility]			X	X				X		X					X	
Guo, Y., Chen, Z., Stuart, A., Li, X., & Zhang, Y. (2020). p. 5	Potential	Explicit	Land use regression (LUR) estimates of [air pollution] concentration (intra-urban analysis) by [roadway segment]			X	X				X		X					X	
Guo, Y., Chen, Z., Stuart, A., Li, X., & Zhang, Y. (2020). p. 5	Potential	Explicit	vehicle volume by [roadway segment]		X						X							X	

Guo, Y., Chen, Z., Stuart, A., Li, X., & Zhang, Y. (2020). p. 5	Potential	Explicit	travel speeds by [roadway segment]		X			X			X				X			X	
Guo, Y., Chen, Z., Stuart, A., Li, X., & Zhang, Y. (2020). p. 6	Potential	Explicit	road type by [roadway segment]		X			X			X							X	
Guo, Y., Chen, Z., Stuart, A., Li, X., & Zhang, Y. (2020). p. 6	Potential	Explicit	elevation of [roadway segment]		X			X			X							X	
Guo, Y., Chen, Z., Stuart, A., Li, X., & Zhang, Y. (2020). p. 6	Potential	Explicit	land cover near [roadway segment]			X					X		X					X	
Guo, Y., Chen, Z., Stuart, A., Li, X., & Zhang, Y. (2020). p. 6	Potential	Explicit	fixed-location [pollutant] exposure - exposure by [group] and by [spatial unit]			X	X						X					X	
Guo, Y., Chen, Z., Stuart, A., Li, X., & Zhang, Y. (2020). p. 6	Potential	Explicit	activity-based [pollutant] exposure - exposure by individual by location and duration of time spent			X	X				X	X	X						X
Guo, Y., Chen, Z., Stuart, A., Li, X., & Zhang, Y. (2020). p. 6	Potential	Explicit	road density by [spatial unit]		X						X							X	
Guo, Y., Chen, Z., Stuart, A., Li, X., & Zhang, Y. (2020). p. 6	Potential	Explicit	# crashes per 100,000 people by [spatial unit]					X			X		X					X	
Guo, Y., Chen, Z., Stuart, A., Li, X., & Zhang, Y. (2020). p. 6	Potential	Explicit	# injuries and fatalaties					X			X		X				X		
Guo, Y., Chen, Z., Stuart, A., Li, X., & Zhang, Y. (2020). p. 8	Potential	Explicit	Comparative Environmental Risk Index (CERI)			X	X				X	X	X					X	
Guo, Y., Chen, Z., Stuart, A., Li, X., & Zhang, Y. (2020). p. 8	Potential	Explicit	subgroup index of inequality			X	X		X				X					X	
Guo, Y., Chen, Z., Stuart, A., Li, X., & Zhang, Y. (2020). p. 9	Potential	Explicit	# on-demand service subsidies for vulnerable populations	X					X			X		X	X		X		
Guo, Y., Chen, Z., Stuart, A., Li, X., & Zhang, Y. (2020). p. 9	Potential	Explicit	affordability of transit service	X					X			X							X
Guo, Y., Chen, Z., Stuart, A., Li, X., & Zhang, Y. (2020). p. 9	Potential	Explicit	# AND location of low-emission zones (highly polluted areas/locations of overburdened populations)			X	X				X		X		X			X	
Guo, Y., Chen, Z., Stuart, A., Li, X., & Zhang, Y. (2020). p. 9	Potential	Explicit	distance between "sensitive facilities" (schools, hospitals, etc) and busy traffic corridor			X	X				X				X			X	
Guo, Y., Chen, Z., Stuart, A., Li, X., & Zhang, Y. (2020). p. 9	Potential	Explicit	# good quality, well-maintained, and well-connected non-motorized infrastructure		X			X			X		X				X		

Guo, Y., Chen, Z., Stuart, A., Li, X., & Zhang, Y. (2020). p. 10	Potential	Explicit	coverage/service area by XX-ft distance from stations	X							X	X	X					X	
Guo, Y., Chen, Z., Stuart, A., Li, X., & Zhang, Y. (2020). p. 10	Potential	Explicit	bike drop offs by [group]		X							X					X		
Guo, Y., Chen, Z., Stuart, A., Li, X., & Zhang, Y. (2020). p. 10	Potential	Explicit	bike demand - mean inverse idel time in [spatial unit] per day		X				X	X		X						X	
Guo, Y., Chen, Z., Stuart, A., Li, X., & Zhang, Y. (2020). p. 10	Potential	Explicit	bike supply - mean # of bikes rebalanced in [spatial unit] per day						X	X		X						X	
Guo, Y., Chen, Z., Stuart, A., Li, X., & Zhang, Y. (2020). p. 10	Potential	Explicit	supply - waiting time for ridehail pickup		X							X					X		
Guo, Y., Chen, Z., Stuart, A., Li, X., & Zhang, Y. (2020). p. 10	Potential	Explicit	counts of available bikes		X					X		X					X		
Guo, Y., Chen, Z., Stuart, A., Li, X., & Zhang, Y. (2020). p. 10	Potential	Explicit	bike equity index	X					X	X	X	X	X					X	
Guo, Y., Chen, Z., Stuart, A., Li, X., & Zhang, Y. (2020). p. 10	Potential	Explicit	car sharing density		X				X			X	X					X	
Guo, Y., Chen, Z., Stuart, A., Li, X., & Zhang, Y. (2020). p. 10	Potential	Explicit	tour-based accessibility	X							X	X	X						X
Guo, Y., Chen, Z., Stuart, A., Li, X., & Zhang, Y. (2020). p. 10	Potential	Explicit	accessibility to [point of interest]	X							X	X	X					X	
Guo, Y., Chen, Z., Stuart, A., Li, X., & Zhang, Y. (2020). p. 10	Potential	Explicit	trip duration		X						X	X	X					X	
Guo, Y., Chen, Z., Stuart, A., Li, X., & Zhang, Y. (2020). p. 10	Potential	Explicit	trip distance		X						X	X	X					X	
Castiglione, J., Hiatt, R., Chang, T., & Charlton, B. (2006). p. 40	Potential	Explicit	average daily travel time savings (minutes)		X						X	X	X					X	
Castiglione, J., Hiatt, R., Chang, T., & Charlton, B. (2006). p. 40	Potential	Explicit	change in transit mode share for all trips		X						X	X	X				X		
Castiglione, J., Hiatt, R., Chang, T., & Charlton, B. (2006). p. 40	Potential	Explicit	% change in access to [point of interest] by [mode]	X							X	X	X					X	
Bills, T. S. (2022). p. 11	Explicit	Potential	commute tour travel time (single direction of tour)		X				X		X	X	X						X
Bills, T. S. (2022). p. 11	Explicit	Potential	logsum accessibility/consumer surplus by [destination of interest]	X					X		X	X	X						X

Stewart, A., & Zegras, P. C. (2022). p. 636	Explicit	Potential	estimated travel times for proposed project		X						X	X	X	X				X	
Stewart, A., & Zegras, P. C. (2022). p. 636	Explicit	Potential	estimated cummulative opportunity accessibility for proposed project	X							X	X	X					X	
Stewart, A., & Zegras, P. C. (2022). p. 637	Explicit	Potential	Likert positive/negative expected impact of project on [self, region, transit riders, drivers]	X							X	X	X			X			X
Stewart, A., & Zegras, P. C. (2022). p. 637	Explicit	Potential	Dialogue quality index (engagement process attitude)	X												X			X
Stewart, A., & Zegras, P. C. (2022). p. 637	Explicit	Potential	Likert positive/negative impact perceived efficacy, control, norms, skills	X												X			X
Stewart, A., & Zegras, P. C. (2022). p. 637	Explicit	Potential	change in attitude toward transport project (pre- and post-engagement survey responses to expected impact)	X							X	X	X			X			X
Stewart, A., & Zegras, P. C. (2022). p. 637	Explicit	Potential	change in attitude toward capability and perceptions (pre- and post-engagement survey responses to perceived efficacy etc.)	X												X			X
Stewart, A., & Zegras, P. C. (2022). p. 641	Explicit	Potential	Enthusiasm index - average of change in attitude towards project, capability and perception, and attitude toward engagement process	X							X	X	X			X			X
Stewart, A., & Zegras, P. C. (2022). p. 642	Explicit	Potential	Likert positive/negative impact of use of interactive planning tools	X												X			X
Stewart, A., & Zegras, P. C. (2022). p. 645	Explicit	Potential	Average # of device interactions per user (w/ planning tool) by [touching, pointing] screen	X												X			X
Feng, T., & Zhang, J. (2014). p. 531	Explicit	Potential	upper bound of potential capacity enhancement of network link		X						X							X	
Feng, T., & Zhang, J. (2014). p. 531	Explicit	Potential	average travel time between [spatial units]		X						X							X	
Feng, T., & Zhang, J. (2014). p. 531	Explicit	Potential	travel impedance parameter between [spatial units]		X						X							X	
Feng, T., & Zhang, J. (2014). p. 532	Explicit	Potential	travel time on network link		X						X							X	
Feng, T., & Zhang, J. (2014). p. 532	Explicit	Potential	travel time under free flow on network link		X						X							X	
Feng, T., & Zhang, J. (2014). p. 532	Explicit	Potential	traffic flow on network link		X						X							X	
Feng, T., & Zhang, J. (2014). p. 532	Explicit	Potential	traffic flow between [spatial units]		X						X							X	
Feng, T., & Zhang, J. (2014). p. 532	Explicit	Potential	capacity of network link		X						X							X	
Feng, T., & Zhang, J. (2014). p. 532	Explicit	Potential	choice set of paths between [spatial units]		X						X							X	
Curl, A. (2018). p. 1152	No	Explicit	self-reported journey times to [destinations of interest]		X						X	X	X						X
Curl, A. (2018). p. 1152	No	Explicit	perceived satisfaction w/ accessibility in the local area	X							X	X	X						X
Curl, A. (2018). p. 1156	No	Explicit	self-reported experience of disability impact on personal travel	X							X	X	X						X

Curl, A. (2018). p. 1156	No	Explicit	self-reported access to a private vehicle	X						X									X
Curl, A. (2018). p. 1156	No	Explicit	frequency of going to a given [destination of interest]		X						X	X	X						X
Curl, A. (2018). p. 1156	No	Explicit	Objective JT Accessibility (CAI)	X							X	X	X					X	
Curl, A. (2018). p. 1156	No	Explicit	Objective journey time (from CAI)		X						X	X	X					X	
Bajada, T., Mifsud, D., & Ciommo, F. D. (2016). p. 78	Potential	Explicit	policies subjecting urban developers to fund necessary remedial roadworks at time of development		X						X				X			X	
Bajada, T., Mifsud, D., & Ciommo, F. D. (2016). p. 78	Potential	Explicit	extension of pedestrian priority and access only restrictions		X						X		X		X			X	
Bajada, T., Mifsud, D., & Ciommo, F. D. (2016). p. 78	Potential	Explicit	inclusion of traffic management components in roadway design and construction		X						X		X		X			X	
Bajada, T., Mifsud, D., & Ciommo, F. D. (2016). p. 78	Potential	Explicit	inclusion of bus priority lanes		X						X		X		X			X	
Bajada, T., Mifsud, D., & Ciommo, F. D. (2016). p. 78	Potential	Explicit	use of appropriate bus fleets by roadway type (ex: narrow roadways)		X					X		X			X			X	
Bajada, T., Mifsud, D., & Ciommo, F. D. (2016). p. 78	Potential	Explicit	efficiency of intermodal interchanges		X						X	X	X				X		
Bajada, T., Mifsud, D., & Ciommo, F. D. (2016). p. 78	Potential	Explicit	intentional location of bus hubs		X						X	X	X					X	
Bajada, T., Mifsud, D., & Ciommo, F. D. (2016). p. 78	Potential	Explicit	improved accessibility during and after major urban development projects	X							X	X	X					X	
Bajada, T., Mifsud, D., & Ciommo, F. D. (2016). p. 78	Potential	Explicit	reliable passenger information at bus shelters and stops	X							X	X						X	
Bajada, T., Mifsud, D., & Ciommo, F. D. (2016). p. 78	Potential	Explicit	comfortable and safe waiting conditions at bus shelters and stops	X				X			X							X	
Bajada, T., Mifsud, D., & Ciommo, F. D. (2016). p. 78	Potential	Explicit	bus service that caters to peripheral destinations	X							X	X	X					X	
Bajada, T., Mifsud, D., & Ciommo, F. D. (2016). p. 78	Potential	Explicit	quality night bus services	X								X						X	
Bajada, T., Mifsud, D., & Ciommo, F. D. (2016). p. 78	Potential	Explicit	price discounts for frequent bus users	X					X			X					X		
Bajada, T., Mifsud, D., & Ciommo, F. D. (2016). p. 78	Potential	Explicit	infrastructure [fixed and fleet] dimensions in accord with guidelines for persons with disabilities	X			X	X			X		X					X	
Wang, S., Wu, X., & Chen, Y. (2021). p. 6	Potential	Explicit	Likert of perceptions re: transportation	X												X			X
Wang, S., Wu, X., & Chen, Y. (2021). p. 8	Potential	Explicit	Latent classes of perceived opportunity inaccessibility	X			X	X	X		X	X	X						X
Qi, Z., Lim, S., & Hossein Rashidi, T. (2020). p. 248	Potential	Explicit	Total transit time including walk, wait, transfer, walk		X						X	X	X					X	
Qi, Z., Lim, S., & Hossein Rashidi, T. (2020). p. 249	Potential	Explicit	Total driving time including parking and walking to destination		X						X	X	X					X	
Qi, Z., Lim, S., & Hossein Rashidi, T. (2020). p. 249	Potential	Explicit	relative accessibility (RA) - travel time difference of transit minus driving	X							X	X	X					X	
Qi, Z., Lim, S., & Hossein Rashidi, T. (2020). p. 250	Potential	Explicit	distance to [point of interst]		X						X	X	X					X	

Nahmias-Biran, B. H., & Shiftan, Y. (2020). p. 2298	Explicit	Potential	value of time ($/h)						X										X
Nahmias-Biran, B. H., & Shiftan, Y. (2020). p. 2298	Explicit	Potential	Avg travel time by [mode]		X						X	X	X					X	
Nahmias-Biran, B. H., & Shiftan, Y. (2020). p. 2298	Explicit	Potential	basic level of accessibility (logsum)	X					X		X	X	X						X
Nahmias-Biran, B. H., & Shiftan, Y. (2020). p. 2299	Explicit	Potential	# of available destinations	X							X	X	X						X
Nahmias-Biran, B. H., & Shiftan, Y. (2020). p. 2299	Explicit	Potential	Total change in consumer benefits	X					X		X	X	X						X
Bills, T. S., & Walker, J. L. (2017). p. 64	Potential	Potential	Accessibility by [mode]	X							X	X	X					X	
Bills, T. S., & Walker, J. L. (2017). p. 64	Potential	Potential	travel time by [mode]		X						X	X	X					X	
Bills, T. S., & Walker, J. L. (2017). p. 64	Potential	Potential	Travel distance		X						X	X	X					X	
Bills, T. S., & Walker, J. L. (2017). p. 64	Potential	Potential	Mode share		X						X	X	X					X	
Bills, T. S., & Walker, J. L. (2017). p. 64	Potential	Potential	project investment proximity						X		X	X	X	X				X	
Bills, T. S., & Walker, J. L. (2017). p. 64	Potential	Potential	exposure to vehicle emissions			X	X				X	X	X					X	
Bills, T. S., & Walker, J. L. (2017). p. 64	Potential	Potential	exposure to noise pollution			X	X				X	X	X					X	
Bills, T. S., & Walker, J. L. (2017). p. 64	Potential	Potential	congested VMT			X	X				X		X					X	
Bills, T. S., & Walker, J. L. (2017). p. 64	Potential	Potential	displacement	X					X		X	X	X					X	
Bills, T. S., & Walker, J. L. (2017). p. 64	Potential	Potential	trip-level variables [location, purpose, mode, time-of-day]		X						X	X	X						X
Bills, T. S., & Walker, J. L. (2017). p. 64	Potential	Potential	tour-level trip classifications		X						X	X	X						X
Bills, T. S., & Walker, J. L. (2017). p. 64	Potential	Potential	tour frequency		X						X	X	X						X
Bills, T. S., & Walker, J. L. (2017). p. 64	Potential	Potential	in-vehicle times		X						X	X	X					X	
Bills, T. S., & Walker, J. L. (2017). p. 64	Potential	Potential	wait times		X							X						X	
Bills, T. S., & Walker, J. L. (2017). p. 64	Potential	Potential	access times		X						X	X	X					X	
Bills, T. S., & Walker, J. L. (2017). p. 64	Potential	Potential	vehicle opperating costs						X	X		X		X			X		
Bills, T. S., & Walker, J. L. (2017). p. 64	Potential	Potential	tolls	X					X		X	X	X	X			X		
Bills, T. S., & Walker, J. L. (2017). p. 64	Potential	Potential	parking costs	X					X		X		X	X			X		
Bills, T. S., & Walker, J. L. (2017). p. 64	Potential	Potential	transit fares	X					X			X		X			X		

Bills, T. S., & Walker, J. L. (2017). p. 64	Potential	Potential	VMT		X						X		X				X		
Bills, T. S., & Walker, J. L. (2017). p. 67	Potential	Potential	Average change in consumer benefits (consumer surplus)	X							X	X	X						X
Aparicio, Á. (2018). p. 127	Potential	Potential	locations of network vulnerability and resilience (Climate Change)	X		X					X	X	X					X	
Aparicio, Á. (2018). p. 128	Potential	Potential	accessibility for territiorial cohesion (between EU member states)	X					X		X	X	X		X			X	
Aparicio, Á. (2018). p. 129	Potential	Potential	inclusion of Strategic Environmental Assessment (SEA) in program planning			X					X	X	X		X			X	
Millonig, A., Rudloff, C., Richter, G., Lorenz, F., & Peer, S. (2022). p. 6	Potential	Potential	Average daily distance by [mode]		X						X	X	X				X		
Millonig, A., Rudloff, C., Richter, G., Lorenz, F., & Peer, S. (2022). p. 6	Potential	Potential	equivalent CO2 emissions by [mode]			X					X	X	X				X		
Millonig, A., Rudloff, C., Richter, G., Lorenz, F., & Peer, S. (2022). p. 6	Potential	Potential	Average daily distance BUDGET by [mode] based on equivalent CO2 and emission reduction goals		X	X					X	X	X		X			X	
Millonig, A., Rudloff, C., Richter, G., Lorenz, F., & Peer, S. (2022). p. 7	Explicit	No	projected change in efficiency of [mode] by [future date]			X			X	X							X		
Millonig, A., Rudloff, C., Richter, G., Lorenz, F., & Peer, S. (2022). p. 7	Explicit	No	E-car market penetration rate by [future date]	X		X			X	X							X		
Millonig, A., Rudloff, C., Richter, G., Lorenz, F., & Peer, S. (2022). p. 7	Potential	Potential	Car occupancy rate		X	X				X							X		
Zhang, M., & Zhao, P. (2021). p. 6	Potential	Potential	travel mode choice		X					X	X	X	X						X
Zhang, M., & Zhao, P. (2021). p. 6	Potential	Potential	commute burden (time)		X				X		X	X	X					X	
Zhang, M., & Zhao, P. (2021). p. 6	Potential	Potential	commute burden (cost)	X					X		X	X	X	X			X		
Zhang, M., & Zhao, P. (2021). p. 6	Potential	Potential	accessibility to [point of interest]	X							X	X	X					X	
Zhang, M., & Zhao, P. (2021). p. 6	Potential	Potential	perceived experiences in daily mobility	X							X	X	X						X
Zhang, M., & Zhao, P. (2021). p. 6	Potential	Potential	commute distance		X				X		X	X	X					X	
Zhang, M., & Zhao, P. (2021). p. 6	Potential	Potential	derived activity area	X							X	X	X					X	
Yang, J., Guo, A., Li, X., & Huang, T. (2018). p. 3	Potential	Explicit	travel cost	X					X	X	X	X	X						X
Yang, J., Guo, A., Li, X., & Huang, T. (2018). p. 3	Potential	Explicit	shortest travel time (between destinations)		X						X	X	X					X	
Yang, J., Guo, A., Li, X., & Huang, T. (2018). p. 3	Potential	Explicit	generalized travel time within [spatial unit]		X						X	X	X					X	

Yang, J., Guo, A., Li, X., & Huang, T. (2018). p. 3	Potential	Explicit	GDP per capita per hour by [spatial unit]						X				X					X	
Yang, J., Guo, A., Li, X., & Huang, T. (2018). p. 3	Potential	Explicit	coefficient of variation of accessibility post-investment	X					X		X	X	X					X	
Yang, J., Guo, A., Li, X., & Huang, T. (2018). p. 4	Potential	Explicit	proportion of local fiscal expenditure on education and science						X				X	X				X	
Yang, J., Guo, A., Li, X., & Huang, T. (2018). p. 4	Potential	Explicit	number of buses/total population in [spatial unit]	X						X		X	X					X	
Yang, J., Guo, A., Li, X., & Huang, T. (2018). p. 4	Potential	Explicit	number of hospital beds/total population in [spatial unit]	X									X					X	

A.4.2. Detailed table of communities of concern

Citation	Variable	Specific sub-group(s) identified	Transportation Relation	Outcome
Martens, K., Bastiaanssen, J., & Lucas, K. (2019) p. 17,22	Age	-	-	-
Martens, K., Bastiaanssen, J., & Lucas, K. (2019) p. 18	Age	Children & young people	exposure to high levels of ambient noise pollution	significant defitics in cognition, memory, and executive functions
Martens, K., Bastiaanssen, J., & Lucas, K. (2019) p. 22,25,28	Age	Children & the Elderly	exposure to air & noise pollution caused by transportation and "navigating hostile traffic enviornments"	tend to have an increased risk of negative health outcomes due to pre-existing physical condition
Martens, K., Bastiaanssen, J., & Lucas, K. (2019) p. 28	Age	Children & the Elderly	difficulties "navigating hostile traffic enviornments"	may lead to more injuries and fatalities, limit mobility and accessibility - "Children's independent mobility has been particularly affected by urban envrionments built for motorized traffic"
Martens, K., Bastiaanssen, J., & Lucas, K. (2019) p. 20	Age	Children & the Elderly	experiences of traffic collisions	"serious inequalities in injuries and death rates"
Martens, K., Bastiaanssen, J., & Lucas, K. (2019) p. 21	Age	Elderly	concerns & feelings regarding traffic safety	tend to be more risk averse and avoidant of unsafe-seeming transport facilities
Martens, K., Bastiaanssen, J., & Lucas, K. (2019) p. 29	Age	Elderly	inaccessible design of street environment and public transport vehicles, attitudes of drivers and passengers alighting transit vehicles	severely restricted ability to travel
Martens, K., Bastiaanssen, J., & Lucas, K. (2019) p. 24	Age	Children, young people, & the Elderly	experiences of transport disadvantage	more likely to experience, especially if their identities intersect w/ low-income & cannot drive/access a vehicle
Martens, K., Bastiaanssen, J., & Lucas, K. (2019) p. 27	Age	Children, young people, & the Elderly	access to a private vehicle	more likely to NOT have access
Martens, K., Bastiaanssen, J., & Lucas, K. (2019) p. 28	Age	Children, young people, & the Elderly	access to spatially dispersed activities	tend to make fewer and shorter distance trips AND/OR are dependent on others for transport
Zhao, P., & Zhang, Y. (2019), pp. 79	Age	Over/Under 30yo	-	-
Dixit, M., & Sivakumar, A. (2020). p. 5	Age	<40, 40-60, >60yo	-	-
Chen, Z., & Li, X. (2021). p. 6	Age	<19, 19-34, 35-44, 45-64, >64	-	-
Boisjoly, G., & Yengoh, G. T. (2017). p. 10	Age	Elderly	asked community members in interviews to identify transportation concerns	identified as a vulnerable group
Lempert, R., Syme, J., Mazur, G., Knopman, D., Ballard-Rosa, G.,	Age	generational breaks	-	-

Lizon, K., & Edochie, I. (2020). p. 316				
Boisjoly, G., & El-Geneidy, A. (2021). p. 229	Age	-	-	-
Anderson, K., Blanchard, S. D., Cheah, D., & Levitt, D. (2017). p. 67	Age	% K-12 AND % seniors	experiences of low-automobility	K-12 individuals experience worse automobility than seniors, but both groups identified as priority groups to be considered above rest of population
Murray, A. T., & Davis, R. (2001). pp. 590:591	Age	% young (0-16yo) AND % Aged (>= 65yo)	need for public transit	more likely to need public transit to move freely
Curl, A. (2018). p. 1152	Age	average age	assessment of perceived vs. experienced accessibility (in a UK case study)	older groups noted higher perceived travel times
Bajada, T., Mifsud, D., & Ciommo, F. D. (2016).	Age	elderly population count	assessment of transport equity for elderly and aging IN MALTA	-
Wang, S., Wu, X., & Chen, Y. (2021). p. 8	Age	Older adult (65yo or older)	assessment of perceived vs. experienced accessibility (in a South Carolina case study)	age has a negative and significant COUNTERACTING effect on opportunity inaccessibility (-0.15)
Qi, Z., Lim, S., & Hossein Rashidi, T. (2020). p. 250	Age	Persons aged over 60 years	component of public transport need indicator (PTNI) - weighted function of socio-dem variables used in accessibility analysis	weighted based on 2010 work (0.14)
Bills, T. S., & Walker, J. L. (2017). p. 64	Age	-	data relevant to activity-based travel demand models	-
Yang, J., Guo, A., Li, X., & Huang, T. (2018). p. 4	Age	<15 years old, 15–64 years old, >64 years old	attribute considered in Global Principal Component Analysis (GPCA) to calc social demand index of [spatial unit]	-
Guo, Y., Chen, Z., Stuart, A., Li, X., & Zhang, Y. (2020). p. 4	Age	%children and %older adult populations	common classifications considered in transportation equity literature	"typically more vulnerable to environmental risks such as air pollution"
Boisjoly, G., & El-Geneidy, A. (2021). p. 229	Education level	-	-	-
Guo, Y., Chen, Z., Stuart, A., Li, X., & Zhang, Y. (2020). pp. 4,7	Education level	% adults w/ <HS education, %completed HS, %some college, %college grads	common classifications considered in transportation equity literature	found to contribute to overall inequality
Guo, Y., Chen, Z., Stuart, A., Li, X., & Zhang, Y. (2020). pp. 9,11	Education level	high education	proportionate transportation experiences	fewer vehicle accidents and deaths and enjoy most of the benefits from shared mobility services
Qi, Z., Lim, S., & Hossein Rashidi, T. (2020). p. 250	Education level	HS highest level of education for adults 25-64yo	component of public transport need indicator (PTNI) - weighted function of socio-dem variables used in accessibility analysis	weighted based on 2010 work (0.12)
Martens, K., Bastiaanssen, J., & Lucas, K. (2019) p. 17,22,24,27	Income	-	"Income is strongly correlated with multiple dimensions of mobility and accessibility"	vehicle ownership, trip frequency, trip distance, residential location - pollution and noise
Martens, K., Bastiaanssen, J., & Lucas, K. (2019) p. 18	Income	Lower-income household	tend to live in dense urban environments close to busy roads	exposure to higher levels of exposure to pollutants & associated negative health impacts
Martens, K., Bastiaanssen, J., & Lucas, K. (2019) p. 20,25	Income	Lower-income household	experiences of lower-quality traffic environment & traffic collisions	Tend to travel by more vulnerable means (non-motorized) and face higher risk of collision
Iroz-Elardo, N., Schoner, J., Fox, E. H., Brookes, A., & Frank, L. D. (2020). p. 4	Income	Lower-income household	-	-
Lempert, R., Syme, J., Mazur, G., Knopman, D., Ballard-Rosa, G., Lizon, K., & Edochie, I. (2020). pp. 315:316	Income	Low- and Middle-income household	estimating person-trips under different planning scenarios	use this as a measure of equity

Anderson, K., Blanchard, S. D., Cheah, D., & Levitt, D. (2017). p. 70	Income	% household income by quartile	indices for multi-criteria analysis for multimodal facilities planning	-
Martens, K., Bastiaanssen, J., & Lucas, K. (2019) p. 24	Income	Lower-income	experiences of transport disadvantage	most likely to experience, especially if they also cannot drive/access a vehicle
Martens, K., Bastiaanssen, J., & Lucas, K. (2019) p. 27	Income	Lower-income	access to a private vehicle or longer-distance travel	more likely to NOT have access due to cost
Martens, K., Bastiaanssen, J., & Lucas, K. (2019) p. 27	Income	Lower-income	access to spatially dispersed activities	tend to make fewer and shorter distance trips
Zhao, P., & Zhang, Y. (2019), pp. 79	Income	low/middle/high (monthly)	-	-
Zhao, P., & Zhang, Y. (2019), pp. 79	Income	Lower-income	fare change from fixed to distance-based	have the lowest transit fare affordability regardless of fare type, but are most severely impacted by change to distance-based
Dianin, A., Ravazzoli, E., & Hauger, G. (2021). Figure 2	Income	Lower-income	ability to pay for AV services or private vehicles	disparities will grow between income groups/less attainable for lower-income groups
Dixit, M., & Sivakumar, A. (2020). pp. 5,8	Income	low/middle/high (monthly per person in household)	-	-
Dixit, M., & Sivakumar, A. (2020). pp. 5,8	Income	Lower-income	utility of travel cost by train	negative utility (-0.209) is still higher than negative utility (-0.230) experienced by the middle and high income groups
Karner, A., & London, J. (2014). p. 93	Income	poverty	-	-
Chen, Z., & Li, X. (2021). p. 6	Income	low/middle/high (<=25K, 25-75K, >75K)	-	-
Golub, A., & Martens, K. (2014). p. 17	Income	Low-income/non-Low-income	identified as a "community of concern" by Bay Area MPO	require analysis of benefits/burdens re: investments
Wu, Y., Rowangould, D., London, J. K., & Karner, A. (2019). p. 531	Income	divided by quartiles	-	-
Lowe, K. (2014). p. 34	Income	Low-income/non-Low-income	-	-
Boisjoly, G., & Yengoh, G. T. (2017). p. 10	Income	Low-income	asked community members in interviews to identify transportation concerns	identified trend of higher-income groups living near metro stations/frequent transit while lower-income tend to live where service is worse (less frequent, less reliable, and does not connect them to key desitnations)
Karner, A., & Marcantonio, R. A. (2018). p. 115	Income	Low-income	exposure to pollution & other negative externatilies of the built environment	disproportionate exposure and associated negative health outcomes (asthma, obesity, heat-related illnesses, collision injuries)
Martens, K., Di Ciommo, F., & Papanikolaou, A. (2014). p. 5	Income	any	activity participation increases as accessibility increases	trend holds for most populations groups whether defined by mode availability, location or income
Boisjoly, G., & El-Geneidy, A. (2021). pp. 224:226	Income	Low-income	relationship between transit accessibility and employment outcomes	transit can be "crucial obstacle" to finding and retaining a job - service disruptions or lack of service relate to unemployment and job loss
Boisjoly, G., & El-Geneidy, A. (2021). p. 227	Income	Low-income	urban sprawl and lack of sufficient transit coverage	people report need to reach employment as major factor to purchasing a car (need not choice)
Boisjoly, G., & El-Geneidy, A. (2021). p. 229	Income	-	-	-
Beiler, M. O., & Mohammed, M. (2016). p. 290	Income	% of households making less money than the average median household income of the area	relationship to accessibility	lower income relates to poorer accessibility
Anderson, K., Blanchard, S. D., Cheah, D., & Levitt, D. (2017). p. 70	Income	% high-income	indices for multi-criteria analysis for multimodal facilities planning (proximity to rail stations)	-

Anderson, K., Blanchard, S. D., Cheah, D., & Levitt, D. (2017). p. 70	Income	% households who receive food stamps or food stamp benefit card	indices for multi-criteria analysis for multimodal facilities planning	index of disadvantaged groups
Murray, A. T., & Davis, R. (2001). pp. 590:591	Income	% classified as lower-income	need for public transit	more likely to need public transit to move freely
Bills, T. S., Sall, E. A., & Walker, J. L. (2012). p. 22	Income	4 classes: <25K, 25-45K, 45-75K, >75K	workplace location model estimation	-
Heyer, J., Palm, M., & Niemeier, D. (2020). p. 5	Income	living below 150% of poverty line	experience of commuting via automobile	-
Heyer, J., Palm, M., & Niemeier, D. (2020). p. 8	Income	low-income	affordability of transportation & housing	potential for displacement due to higher costs relative to income (low-income)
Cronley, C., Miller, V. J., Fields, N., & Mattingly, S. P. (2021). p. 5	Income	lower-income	experience of environmental burdens	tend to have disproportionate exposure rates
Berg, A., & Newmark, G. L. (2020). p. 773	Income	median household income	identify communities for project prioritization	these communities tend to deserve investment priority
Ahmed, Q. I., Lu, H., & Ye, S. (2008). p. 135	Income	mean AND bottom quintile	affordability of transportation	-
Guo, Y., Chen, Z., Stuart, A., Li, X., & Zhang, Y. (2020). pp. 4,7,8	Income	median household income by [spatial unit] OR average household income in quintiles	common classifications considered in transportation equity literature	found to contribute to overall inequality & have lower accessibility
Guo, Y., Chen, Z., Stuart, A., Li, X., & Zhang, Y. (2020). pp. 9,11	Income	high-income	proportionate transportation experiences	have higher relative accessibility, fewer vehicle accidents and deaths, and can have higher exposure to some pollutants, but lower for transport-related (NOx, benzene, butadiene), and enjoy most of the benefits from shared mobility services
Castiglione, J., Hiatt, R., Chang, T., & Charlton, B. (2006). p. 40	Income	Low-income/non-Low-income	socio-demographic classification for trip tour micro-simulation and equity assessment	-
Bills, T. S. (2022). p. 11	Income	Low-income/non-Low-income	socio-demographic classification for trip tour micro-simulation and equity assessment	-
Wang, S., Wu, X., & Chen, Y. (2021). p. 8	Income	households under $25K	assessment of perceived vs. experienced accessibility (in a South Carolina case study)	not statistically or strongly related to high costs & efforts latent variable BUT high costs & efforts strongly related to safety concerns (0.31) which has a significant and large (0.26) relationship with opportunity inaccessibility
Qi, Z., Lim, S., & Hossein Rashidi, T. (2020). p. 250	Income	low income household	component of public transport need indicator (PTNI) - weighted function of socio-dem variables used in accessibility analysis	weighted based on 2010 work (0.10)
Bills, T. S., & Walker, J. L. (2017). pp. 64,69	Income	High/Low household	data relevant to activity-based travel demand models	"While high income travelers derive much more of their utility gains from auto and transit modes, low income travelers gain significantly more utility from walk and bike modes."
Martens, K., Bastiaanssen, J., & Lucas, K. (2019) p. 24	Job Type	"low-skilled workers"	experiences of transport disadvantage	more likely to experience, especially if their identities intersect w/ low-income & cannot drive/access a vehicle
Martens, K., Bastiaanssen, J., & Lucas, K. (2019) p. 27	Job Type	"low-skilled people and the unemployed and underemployed (people in low-hour and low-pay jobs)"	access to a private vehicle or longer-distance travel	more likely to be in the lowest income quintiles, have less travel experience, and "therefore more likely to restrict their travel and job search horizons to their local area"
Martens, K., Bastiaanssen, J., & Lucas, K. (2019) p. 28	Job Type	"low-skilled people and the unemployed and underemployed (people in low-hour and low-pay jobs)"	poor public transit services	limit job opportunities and/or create issues for reliably arriving for job interviews or to work hours - either a risk of not getting/losing a job or losing many hours to commute time
Griffin, G. P., & Jiao, J. (2019). p. 465	Job Type	low-wage workers	participation in non-motorized infrastructure planning efforts	in-person meetings could be just as (if not more) concentrated on collecting observations from populations of interest by design (**at block group level as % of total workers)
Bills, T. S., & Walker, J. L. (2017). p. 64	Job Type	-	data relevant to activity-based travel demand models	-
Yang, J., Guo, A., Li, X., & Huang, T. (2018). p. 4	Job Type	Proportion of non-agricultural workforce	attribute considered in Global Principal Component Analysis (GPCA) to calc social demand index of [spatial unit]	-

Chen, Z., & Li, X. (2021). p. 7	Employment Status	Worker/non-Worker, University student/non-University student	-	-
Iroz-Elardo, N., Schoner, J., Fox, E. H., Brookes, A., & Frank, L. D. (2020). p. 4	Employment Status	employed	-	-
Boisjoly, G., & El-Geneidy, A. (2021). pp. 224:226	Employment Status	unemployed	relationship between transit accessibility and employment outcomes	transit can be "crucial obstacle" to finding and retaining a job - service disruptions or lack of service relate to unemployment and job loss
Boisjoly, G., & El-Geneidy, A. (2021). p. 229	Employment Status	employed/unemployed	-	-
Bills, T. S., Sall, E. A., & Walker, J. L. (2012). p. 22	Employment Status	workers, adult students, children, non-students	tour generation model estimation	-
Qi, Z., Lim, S., & Hossein Rashidi, T. (2020). p. 250	Employment Status	students	component of public transport need indicator (PTNI) - weighted function of socio-dem variables used in accessibility analysis	weighted based on 2010 work (0.09)
Qi, Z., Lim, S., & Hossein Rashidi, T. (2020). p. 250	Employment Status	adults not in the labor force	component of public transport need indicator (PTNI) - weighted function of socio-dem variables used in accessibility analysis	weighted based on 2010 work (0.09)
Bills, T. S., & Walker, J. L. (2017). p. 64	Employment Status	-	data relevant to activity-based travel demand models	-
Yang, J., Guo, A., Li, X., & Huang, T. (2018). p. 4	Employment Status	Registered unemployed population in cities and towns (CHINA)	attribute considered in Global Principal Component Analysis (GPCA) to calc social demand index of [spatial unit]	-
Yang, J., Guo, A., Li, X., & Huang, T. (2018). p. 4	Employment Status	students (primary through high school) (CHINA)	attribute considered in Global Principal Component Analysis (GPCA) to calc social demand index of [spatial unit]	-
Martens, K., Bastiaanssen, J., & Lucas, K. (2019) p. 17,19,22,24	Race/Ethnicity	-	-	-
Martens, K., Bastiaanssen, J., & Lucas, K. (2019) p. 20,25	Race/Ethnicity	minority groups	experiences of traffic collisions	Tend to travel by more vulnerable means (non-motorized) and face higher risk of collision
Martens, K., Bastiaanssen, J., & Lucas, K. (2019) p. 24	Race/Ethnicity	minority groups	experiences of transport disadvantage	more likely to experience, especially if their identities intersect w/ low-income & cannot drive/access a vehicle
Martens, K., Bastiaanssen, J., & Lucas, K. (2019) p. 27,29	Race/Ethnicity	minority groups	access to a private vehicle (including ownership and driver's license)	more likely to NOT have access
Martens, K., Bastiaanssen, J., & Lucas, K. (2019) p. 29	Race/Ethnicity	minority groups	fears for personal safety, racial harassment, lack of knowledge of public transit services and language and cultural (men/women interaction norms) barriers for use	restricted travel areas and modes to those that are familiar (such as higher reliance on private vehicles)
Golub, A., & Martens, K. (2014). p. 17	Race/Ethnicity	Minority/non-Minority	identified as a "community of concern" by Bay Area MPO	require analysis of benefits/burdens re: investments
Wu, Y., Rowangould, D., London, J. K., & Karner, A. (2019). p. 531	Race/Ethnicity	White, Black, Asian, Hispanic, Other	-	-
Anderson, K., Blanchard, S. D., Cheah, D., & Levitt, D. (2017). p. 70	Race/Ethnicity	% non-Hispanic white	indices for multi-criteria analysis for multimodal facilities planning	-
Cronley, C., Miller, V. J., Fields, N., & Mattingly, S. P. (2021). p. 5	Race/Ethnicity	minority groups	experience of environmental burdens	tend to have disproportionate exposure rates
Berg, A., & Newmark, G. L. (2020). p. 773	Race/Ethnicity	% of non-white residents	identify communities for project prioritization	these communities tend to deserve investment priority

Guo, Y., Chen, Z., Stuart, A., Li, X., & Zhang, Y. (2020). p. 4	Race/Ethnicity	% (each type) black/African American, white, and Hispanic, American Indian or Alaskan native, Asian or Pacific Islander, multiracial	common classifications considered in transportation equity literature	-
Wang, S., Wu, X., & Chen, Y. (2021). p. 8	Race/Ethnicity	Black/every other race	assessment of perceived vs. experienced accessibility (in a South Carolina case study)	being Black does impact opportuntiy inaccessibility (0.08)
Karner, A., & London, J. (2014). p. 95	Race	[spatial unit] with >70% POC	suggested threshold to denote communities of concern re: transportation disadvantage	geographic thresholds more meaningful than demographic when assessing variation between groups
Chen, Z., & Li, X. (2021). p. 7	Race	White, Black, Asian, Other	-	-
Lowe, K. (2014). p. 34	Race	< or >= 50% Black	-	-
Karner, A., & Marcantonio, R. A. (2018). p. 117	Race	Black/every other race	displacement of population	Black population displaced from central urban areas to more peripheral regions in Bay Area 2000-2010
Beiler, M. O., & Mohammed, M. (2016). p. 290	Race	% non-white population	relationship to accessibility	tend to be overburdened and justly deserve higher investments
Luna, M. (2015). pp. 288,291	Race	white/non-white (high white/low white)	MPO representation in-terms of voting board members per population	the more white residents in a region, the more representation (exponential increase)
Guo, Y., Chen, Z., Stuart, A., Li, X., & Zhang, Y. (2020). p. 7	Race	race-based % of elementary school enrollments	study of bivariate linear correlations with NO2 exposure	-
Guo, Y., Chen, Z., Stuart, A., Li, X., & Zhang, Y. (2020). pp. 9,11	Race	high white population density	proportionate transportation experiences	fewer vehicle accidents and deaths and enjoy most of the benefits from shared mobility services
Chen, Z., & Li, X. (2021). p. 7	Ethnicity	Hispanic/non-Hispanic, Native, non-Native	-	-
Boisjoly, G., & El-Geneidy, A. (2021). p. 229	Ethnicity	-	-	-
Bills, T. S., & Walker, J. L. (2017). p. 64	Ethnicity	-	data relevant to activity-based travel demand models	-
Boisjoly, G., & El-Geneidy, A. (2021). p. 229	Immigration status	-	-	-
Karner, A., & London, J. (2014). p. 93	Language	% speaking English less than very well	tend to have more difficulty navigating transportation system	People experiencing linguistic isolation
Beiler, M. O., & Mohammed, M. (2016). p. 290	Language	% of people who speak another language at home and who speak English "less than very well"	relationship to accessibility	tend to be overburdened and justly deserve higher investments
Anderson, K., Blanchard, S. D., Cheah, D., & Levitt, D. (2017). p. 70	Language	% limited English speaking households	indices for multi-criteria analysis for multimodal facilities planning	index of disadvantaged groups
Martens, K., Bastiaanssen, J., & Lucas, K. (2019) p. 17,22	Gender	-	-	-
Martens, K., Bastiaanssen, J., & Lucas, K. (2019) p. 21	Gender	Women	concerns & feelings regarding traffic safety	tend to be more risk averse and avoidant of unsafe-seeming transport facilities
Martens, K., Bastiaanssen, J., & Lucas, K. (2019) p. 27	Gender	Women	access to a private vehicle	more likely to NOT have access
Zhao, P., & Zhang, Y. (2019), pp. 79	Gender	Male/Female	-	-
Dixit, M., & Sivakumar, A. (2020). p. 5	Gender	Male/Female	-	-
Chen, Z., & Li, X. (2021). p. 7	Gender	Male/Female	-	-

Dixit, M., & Sivakumar, A. (2020). p. 8	Gender	Female	travel time walking	negative utility (-0.02) experienced by "females" with children <5yo in household, but only 1/3 of negative utility (-0.06) experienced by remainder of population IN LONDON
Castiglione, J., Hiatt, R., Chang, T., & Charlton, B. (2006). p. 40	Gender	Male/Female	socio-demographic classification for trip tour micro-simulation and equity assessment	-
Curl, A. (2018). p. 1152	Gender	Male/Female	assessment of perceived vs. experienced accessibility (in a UK case study)	-
Wang, S., Wu, X., & Chen, Y. (2021). p. 8	Gender	Female	assessment of perceived vs. experienced accessibility (in a South Carolina case study)	safety concerns are high and highly statistically significant for woment, but have an insignificant and low (0.01) effect on opportunity inaccessibilty BUT safety concerns are stongly related to high costs & efforts (0.31) which has a significant and large (0.26) relationship with opportunity inaccessibility
Bills, T. S., & Walker, J. L. (2017). p. 64	Gender	-	data relevant to activity-based travel demand models	-
Martens, K., Bastiaanssen, J., & Lucas, K. (2019) p. 25	Gender & Sexuality	Women & LGBTQ+	experiences of sexual harrassment while traveling	more likely to experience, especially if their identities intersect w/ low-income & cannot drive/access a vehicle
Martens, K., Bastiaanssen, J., & Lucas, K. (2019) p. 24	Ability	physically or mentally impaired (disabled)	experiences of transport disadvantage	more likely to experience, especially if their identities intersect w/ low-income & cannot drive/access a vehicle
Martens, K., Bastiaanssen, J., & Lucas, K. (2019) p. 25	Ability	physically or mentally impaired (disabled)	experiences of traffic collisions	at increased risk of traffic injuries and fatalities
Martens, K., Bastiaanssen, J., & Lucas, K. (2019) p. 29	Ability	physically or mentally impaired (disabled) permanently or temporarily	inaccessible design of street environment and public transport vehicles, attitudes of drivers and passengers alighting transit vehicles	severely restricted ability to travel
Martens, K., Bastiaanssen, J., & Lucas, K. (2019) p. 29	Ability	physically or mentally impaired (disabled) permanently or temporarily	tend to be dependent on more-expensive modes such as taxis	higher-than-typical transportation costs
Boisjoly, G., & Yengoh, G. T. (2017). p. 10	Ability	Disabled	asked community members in interviews to identify transportation concerns	identified as a vulnerable group
Martens, K., Di Ciommo, F., & Papanikolaou, A. (2014). p. 13	Ability	able-bodied	transportation investments by type (roadway OR transit)	AND NO CAR "do not profit from road investments. They do profit from all public transport investments, but the level of benefit differs by neighborhood."
Martens, K., Di Ciommo, F., & Papanikolaou, A. (2014). p. 13	Ability	disabled	transportation investments by type (roadway OR transit)	AND NO CAR "they do not profit from road investments or public transport improvement. They do profit from DRT introduction or making public transport accessible for the disabled. Again, the benefit level differs between neighborhoods."
Beiler, M. O., & Mohammed, M. (2016). p. 290	Ability	% of civilian non-institutionalized population with a disability	relationship to accessibility	tend to be overburdened and justly deserve higher investments
Anderson, K., Blanchard, S. D., Cheah, D., & Levitt, D. (2017). p. 70	Ability	% population with disabilities	indices for multi-criteria analysis for multimodal facilities planning	index of disadvantaged groups
Murray, A. T., & Davis, R. (2001). pp. 590:591	Ability	% receiving a disability pension (in Australia)	need for public transit	more likely to need public transit to move freely
Cronley, C., Miller, V. J., Fields, N., & Mattingly, S. P. (2021). p. 5	Ability	have a disability	experience of environmental burdens	tend to have disproportionate exposure rates
Guo, Y., Chen, Z., Stuart, A., Li, X., & Zhang, Y. (2020). p. 4	Ability	"need and ability"	common classifications considered in transportation equity literature	-
Bajada, T., Mifsud, D., & Ciommo, F. D. (2016). p. 78	Ability	disabled persons	elderly populations face ability constraints	must consider design requirements for infrastructure and fleet to make bus transit accessible
Qi, Z., Lim, S., & Hossein Rashidi, T. (2020). p. 250	Ability	persons on a disability pension (in AUSTRALIA)	component of public transport need indicator (PTNI) - weighted function of socio-dem variables used in accessibility analysis	weighted based on 2010 work (0.09)
Martens, K., Bastiaanssen, J., & Lucas, K. (2019) p. 24	Household composition	single-parent households	experiences of transport disadvantage	more likely to experience, especially if their identities intersect w/ low-income & cannot drive/access a vehicle

Beiler, M. O., & Mohammed, M. (2016). p. 290	Household composition	single-parent households	relationship to accessibility	tend to be overburdened and justly deserve higher investments
Chen, Z., & Li, X. (2021). p. 7	Household composition	>=2 workers/else, >=1 retired adult/else, no children <16yo/else, >=1 University student/else	-	-
Dixit, M., & Sivakumar, A. (2020). p. 8	Household composition	<5yo in household	travel time walking	negative utility (-0.02) experienced by "females" with children in household, but only 1/3 of negative utility (-0.06) experienced by remainder of population IN LONDON
Castiglione, J., Hiatt, R., Chang, T., & Charlton, B. (2006). p. 40	Household composition	female head w/ children/non-femle head w/ children	socio-demographic classification for trip tour micro-simulation and equity assessment	-
Castiglione, J., Hiatt, R., Chang, T., & Charlton, B. (2006). p. 40	Household composition	single-parent households	socio-demographic classification for trip tour micro-simulation and equity assessment	-
Wang, S., Wu, X., & Chen, Y. (2021). p. 8	Household composition	living with a child younger than 18	assessment of perceived vs. experienced accessibility (in a South Carolina case study)	has an impact opportuntiy inaccessibility (0.07)
Bills, T. S., & Walker, J. L. (2017). p. 64	Household composition	size of household, # workers, # children	data relevant to activity-based travel demand models	-
Chen, Z., & Li, X. (2021). p. 7	Marrital Status	Married, Widowed, Divorced, Separated, Never married	-	-
Zhao, P., & Zhang, Y. (2019), pp. 79	Housing	own home/do not own	-	-
Anderson, K., Blanchard, S. D., Cheah, D., & Levitt, D. (2017). p. 70	Housing	Renter-occupied housing units who are housing choice voucher recipients(%)	indices for multi-criteria analysis for multimodal facilities planning	index of disadvantaged groups
Heyer, J., Palm, M., & Niemeier, D. (2020). p. 8	Housing	% rent-burdened households	affordability of transportation & housing	potential for displacement due to rising housing costs in high-growth areas
Bills, T. S., & Walker, J. L. (2017). p. 64	Housing	residential location	data relevant to activity-based travel demand models	-
Dianin, A., Ravazzoli, E., & Hauger, G. (2021). Figure 2	Credit	unbanked	access to payment methods for trips	likely to experience lower levels of access
Martens, K., Bastiaanssen, J., & Lucas, K. (2019) p. 17	Health risks	CO_2, NO_x, and PM10	exposure to transport-related air pollutants such as CO_2, NO_x, and PM10, particularly in dense urban areas	increased risk of premature motality and chronic diseases such as asthma and atopy
Martens, K., Bastiaanssen, J., & Lucas, K. (2019) p. 23	Health risks	mortality, morbidity, quality-of-life indices	active transport (even when "negative impacts of increased exposure to pollutants and traffic risks are taken into account")	"tremendous" health benefits for individuals and for society - mortality, morbidity, quality-of-life indices
Guo, Y., Chen, Z., Stuart, A., Li, X., & Zhang, Y. (2020). p. 5	Health risks	CO, NO_x, benzene, PM including fine particles (PM2.5) and elemental carbon (EC)	regulated air pollutants included in traffic emissions	adverse health effects
Guo, Y., Chen, Z., Stuart, A., Li, X., & Zhang, Y. (2020). p. 5	Health risks	NO_2 (and NO_x)	estimate of transportation-specific emission risk	" its level has been found to be influenced by traffic counts (Rijnders et al., 2001; Stuart and Zeager, 2011) and it also has greater spatial heterogeneity than some other traffic-related air pollutants (Jerrett et al., 2005)."
Guo, Y., Chen, Z., Stuart, A., Li, X., & Zhang, Y. (2020). p. 5	Health risks	CO, NO_2, PM2.5	estimate of transportation-specific emission risk	routinely-monitored pollutants throughout the US BUT "monitoring networks are very sparse and generally inadequate for intra-urban equity analyses
Guo, Y., Chen, Z., Stuart, A., Li, X., & Zhang, Y. (2020). p. 5	Health risks	exacerbated asthma, potential childhood asthma development, other respiritory, impaired lung function, cardio mortality and morbidity	regulated air pollutants included in traffic emissions	adverse health effects
Martens, K., Bastiaanssen, J., & Lucas, K. (2019) p. 25	Underlying Health Conditions	people w/ respiratory & cardiovascular diseases	exposure to air pollution caused by transportation	tend to have an increased risk of negative health outcomes due to pre-existing physical condition

Lempert, R., Syme, J., Mazur, G., Knopman, D., Ballard-Rosa, G., Lizon, K., & Edochie, I. (2020). p. 319	Economic Development	employment growth	impact on emissions projection estimates	must be assumed as a model parameter
Beiler, M. O., & Mohammed, M. (2016). p. 290	Economic Development	% difference in people employed between two different census years	relationship to accessibility	areas that experience a decrease deserve additional attention for transportation investments/just action
Guo, Y., Chen, Z., Stuart, A., Li, X., & Zhang, Y. (2020). p. 4	Economic Development	unemployment rate	common classifications considered in transportation equity literature	-
Yang, J., Guo, A., Li, X., & Huang, T. (2018). p. 4	Economic Development	regional GDP per capita	attribute considered in Global Principal Component Analysis (GPCA) to calc social demand index of [spatial unit]	-
Martens, K., Bastiaanssen, J., & Lucas, K. (2019) p. 17,19,22,24	Land-use	Neighborhood	-	-
Martens, K., Bastiaanssen, J., & Lucas, K. (2019) p. 23	Land-use	car-oriented & low destination density	car-oriented	poor/low experiences of active transportation opportunities tend to rely MORE on environment and LESS on socio-economic indicators
Martens, K., Bastiaanssen, J., & Lucas, K. (2019) p. 23	Land-use	well-designed, safe, and clean	active transport-oriented	feelings of well-being associated with the quality of the physical environment
Martens, K., Bastiaanssen, J., & Lucas, K. (2019) p. 25:26	Land-use	residential disadvantage: segregation, peripheral location, adverse housing structure	typically associated transportation attributes: worst travel environments, low levels of car ownership, and inadequate public transit	social disadvantage strongly interacts w/ transport disadvantage in a negatively-reinforcing cycle to perpetuate disadvantage HOWEVER some exeptions exist/residential location alone does not capture disadvantage
Zhao, P., & Zhang, Y. (2019), pp. 79	Land-use	Urban/Suburban	-	-
Karner, A., & London, J. (2014). p. 90	Land-use	Rural	often not considered for nonmotorized mode use or adoption	tend to be overlooked in regional planning efforts HOWEVER, do exhibit "surprisingly high levels of nonmotorized travel" currently and potentially
Karner, A., & London, J. (2014). p. 95	Land-use	CDPs (census defined places), Counties, Regions	spatial units of analysis to assess variation in transport equity	IMPORTANT - geographic thresholds more meaningful than demographic when assessing variation between groups
Lowe, K. (2014). p.	Land-use	Urbanized area	-	-
Martens, K., Di Ciommo, F., & Papanikolaou, A. (2014). p. 5	Land-use	any	activity participation increases as accessibility increases	trend holds for most populations groups whether defined by mode availability, location or income
Martens, K., Di Ciommo, F., & Papanikolaou, A. (2014). p. 2	Land-use	urban, suburban, peri-urban, rural	-	-
Iroz-Elardo, N., Schoner, J., Fox, E. H., Brookes, A., & Frank, L. D. (2020). p. 4	Land-use	total retail jobs / 5-tier employment mix / dintersection density	-	-
Lempert, R., Syme, J., Mazur, G., Knopman, D., Ballard-Rosa, G., Lizon, K., & Edochie, I. (2020). p. 316	Land-use	residential density	-	-
Boisjoly, G., & El-Geneidy, A. (2021). p. 227	Land-use	Urban sprawl	-	-
Beiler, M. O., & Mohammed, M. (2016). p. 290	Land-use	mixed land use	relationship to accessibility	the higher the % of mixed land use, the better accessibility will be
Luna, M. (2015). pp. 288,291	Land-use	proportion of regional population (density)	MPO representation in-terms of voting board members per population	the fewer residents in a region, the more representation (exponential increase)
Anderson, K., Blanchard, S. D., Cheah, D., & Levitt, D. (2017). p. 70	Land-use	% Priority Development Area	indices for multi-criteria analysis for multimodal facilities planning	-
Murray, A. T., & Davis, R. (2001). pp. 590:591	Land-use	% classified as suburb	need for public transit	more likely to have poor public transit

Heyer, J., Palm, M., & Niemeier, D. (2020). p. 8	Land-use	high-growth areas	affordability of transportation & housing	potential for displacement due to rising housing costs (rent-burden for already over-burdened households) in high-growth areas
Guo, Y., Chen, Z., Stuart, A., Li, X., & Zhang, Y. (2020). p. 6	Land-use	employment density	common classifications considered in transportation equity literature, specifically re: traffic safety	-
Guo, Y., Chen, Z., Stuart, A., Li, X., & Zhang, Y. (2020). p. 8	Land-use	number of dwellings by [spatial unit]	information considered in spatial autoregressive (SAR) modeling of traffic-related air pollution exposure	spatial correlation found
Guo, Y., Chen, Z., Stuart, A., Li, X., & Zhang, Y. (2020). p. 8	Land-use	population density	information considered in multilevel Poisson regression model including roadway environmental factors to study traffic injuries	-
Curl, A. (2018). p. 1152	Land-use	Lower Super Output Area (LSOA)	nationally-established location designation in UK accessibility dataset	-
Wang, S., Wu, X., & Chen, Y. (2021). p. 6	Land-use	Population density (people/acre), Employment-mixture entropy, Total road network density (miles/mile2)	assessment of perceived vs. experienced accessibility (in a South Carolina case study)	employment-mixture entropy has largest (-0.28) and most statistically significant impact on counteracting opportunity inaccessibility (but other two are also significant - -0.12 and -0.17, respectively)
Qi, Z., Lim, S., & Hossein Rashidi, T. (2020). p. 250	Land-use	population density	component of public transport need indicator (PTNI) - weighted function of socio-dem variables used in accessibility analysis	weighted based on 2010 work (0.19)
Bills, T. S., & Walker, J. L. (2017). p. 64	Land-use	population, # households, employment by [sector], amenities	data relevant to activity-based travel demand models	-
Yang, J., Guo, A., Li, X., & Huang, T. (2018). p. 4	Land-use	population density - Proportion of population accounting for secondary and tertiary industries (CHINA)	attribute considered in Global Principal Component Analysis (GPCA) to calc social demand index of [spatial unit]	-
Beiler, M. O., & Mohammed, M. (2016). p. 290	Environmental Factors	FEMA 100yr floodplain	relationship to accessibility	higher % in floodplain means higher risk to storm events negatively impacting accessibility
Anderson, K., Blanchard, S. D., Cheah, D., & Levitt, D. (2017). p. 70	Environmental Factors	wildfire risk to property	indices for multi-criteria analysis for multimodal facilities planning	resiliency index
Anderson, K., Blanchard, S. D., Cheah, D., & Levitt, D. (2017). p. 70	Environmental Factors	Block-group area that would be underwater given 1-, 3-,and 5-ft sea level rise (%)	indices for multi-criteria analysis for multimodal facilities planning	resiliency index
Anderson, K., Blanchard, S. D., Cheah, D., & Levitt, D. (2017). p. 70	Environmental Factors	Annual flood risk zone (zone suitability 0.2% annual chance flood hazard)	indices for multi-criteria analysis for multimodal facilities planning	resiliency index
Anderson, K., Blanchard, S. D., Cheah, D., & Levitt, D. (2017). p. 70	Environmental Factors	Low liquefaction susceptibility	indices for multi-criteria analysis for multimodal facilities planning	resiliency index
Martens, K., Bastiaanssen, J., & Lucas, K. (2019) p. 17	Mode availability	Avg. # cars per household, Avg. # of bicycles per household	-	-
Martens, K., Bastiaanssen, J., & Lucas, K. (2019) p. 23	Mode availability	active-transport captive	engagement in active transport	an individual is more likely to experience active transport as a positive experience if it is a CHOICE, and as a negative if it is NOT
Martens, K., Bastiaanssen, J., & Lucas, K. (2019) p. 24:25	Mode availability	Cannot drive/access a vehicle	experiences of traffic collisions	at increased risk of traffic injuries and fatalities
Karner, A., & Golub, A. (2019) p. 278	Mode availability	carless households	experienced benefit or burden of transportation program investments	more likely to be burdened rather than benefitted by highway expansion - inverse for transit expansion
Zhao, P., & Zhang, Y. (2019), pp. 79	Mode availability	car ownership yes/no	-	-

Karner, A., & London, J. (2014). p. 94	Mode availability	automobile insufficient households - # automobiles < # licensed drivers	experienced accessibility by mode availability	households with fewer cars than licensed drivers means more transit-captive individuals in region
Martens, K., Di Ciommo, F., & Papanikolaou, A. (2014). p. 5	Mode availability	any	activity participation increases as accessibility increases	trend holds for most populations groups whether defined by mode availability, location or income
Martens, K., Di Ciommo, F., & Papanikolaou, A. (2014). p. 13	Mode availability	with car	transportation investments by type (roadway OR transit)	"do not profit from public transport investments, because car accessibility (or speed) is always better than public transport. They do profit from investment in roads, but size of the benefit may differ between the four neighborhoods we distinguish."
Martens, K., Di Ciommo, F., & Papanikolaou, A. (2014). p. 13	Mode availability	without car	transportation investments by type (roadway OR transit)	AND ABLE-BODIED "do not profit from road investments. They do profit from all public transport investments, but the level of benefit differs by neighborhood." AND DISABLED "they do not profit from road investments or public transport improvement. They do profit from DRT introduction or making public transport accessible for the disabled. Again, the benefit level differs between neighborhoods."
Lempert, R., Syme, J., Mazur, G., Knopman, D., Ballard-Rosa, G., Lizon, K., & Edochie, I. (2020). p. 316	Mode availability	distance to transit	-	-
Boisjoly, G., & El-Geneidy, A. (2021). pp. 224:226	Mode availability	transit-captive	relationship between transit accessibility and employment outcomes	transit can be "crucial obstacle" to finding and retaining a job - service disruptions or lack of service relate to unemployment and job loss
Boisjoly, G., & El-Geneidy, A. (2021). p. 229	Mode availability	car ownership yes/no	-	-
Beiler, M. O., & Mohammed, M. (2016). p. 290	Mode availability	vehicles per household	relationship to accessibility	more vehicles means higher accessibility
Anderson, K., Blanchard, S. D., Cheah, D., & Levitt, D. (2017). pp. 67,70	Mode availability	% households with fewer vehicles than individuals	experiences of low-automobility	identified as top priority groups and weighted above age considerations assuming limitations to vehicle access leads to highest limitation on mobility
Anderson, K., Blanchard, S. D., Cheah, D., & Levitt, D. (2017). pp. 67,70	Mode availability	% households with 0 vehicles	experiences of low-automobility	identified as top priority groups and weighted above age considerations assuming limitations to vehicle access leads to highest limitation on mobility
Murray, A. T., & Davis, R. (2001). pp. 590:591	Mode availability	% households with 0 vehicles	need for public transit	more likely to need public transit to move freely
Bills, T. S., Sall, E. A., & Walker, J. L. (2012). p. 22	Mode availability	Car available (yes/no)	mode choice model estimation	-
Berg, A., & Newmark, G. L. (2020). p. 773	Mode availability	high % of carless households	identify communities for project prioritization	these communities tend to deserve investment priority
Guo, Y., Chen, Z., Stuart, A., Li, X., & Zhang, Y. (2020). p. 4	Mode availability	% of car ownership	common classifications considered in transportation equity literature	-
Castiglione, J., Hiatt, R., Chang, T., & Charlton, B. (2006). p. 40	Mode availability	0 vehicle / >0 vehicle household	socio-demographic classification for trip tour micro-simulation and equity assessment	-
Curl, A. (2018). p. 1152	Mode availability	no car, 1 car, 2 car, 3+ car households	assessment of perceived vs. experienced accessibility (in a UK case study)	differences vary by mode - car is generally the same self-reported vs. objective but transit varies a lot ALSO varies by destination
Wang, S., Wu, X., & Chen, Y. (2021). p. 8	Mode availability	no car in household	assessment of perceived vs. experienced accessibility (in a South Carolina case study)	has high and significant impact opportuntiy inaccessibility (0.18)
Qi, Z., Lim, S., & Hossein Rashidi, T. (2020). p. 250	Mode availability	adults without vehicles	component of public transport need indicator (PTNI) - weighted function of socio-dem variables used in accessibility analysis	weighted based on 2010 work (0.19)
Bills, T. S., & Walker, J. L. (2017). p. 64	Mode availability	# vehicles	data relevant to activity-based travel demand models	-

Millonig, A., Rudloff, C., Richter, G., Lorenz, F., & Peer, S. (2022). p. 11	Mode availability	individuals who perceive driving alone as their only option (periurban/rural settings) and who rely mainly on transit (urban)	perceived mode alternatives and the impact on individual belief in ability to change mode use behavior	respondents who feel confined to a single mode option (driving a car OR transit) have a hard time imagining a modal shift for trips
Martens, K., Bastiaanssen, J., & Lucas, K. (2019) p. 17,22	Primary mode of transport	-	-	-
Martens, K., Bastiaanssen, J., & Lucas, K. (2019) p. 20	Primary mode of transport	Pedestrians & Cyclists	experiences of traffic collisions	"serious inequalities in injuries and death rates"
Martens, K., Bastiaanssen, J., & Lucas, K. (2019) p. 21	Primary mode of transport	Pedestrians, Cyclists, & Transit-users	engagement in active transport	more likely "to acheive the internationally recommended levels of physical exercise"
Stewart, A., & Zegras, P. C. (2022). p. 637	Primary mode of transport	Car user, Transit user	classifications for mobility background in assessment of tools presenting transportation project outcomes in terms of accessibility or travel time	"accessibility version seemed to mitigate skepticism and car users' predispositions against upgrading bus service. It also fostered greater focus on others' travel, perhaps because the familiar user experience of the travel-time version felt simplistic or too similar to individual trip-planning tools."
Martens, K., Bastiaanssen, J., & Lucas, K. (2019) p. 24	Intensity of active mode use	-	-	-
Martens, K., Bastiaanssen, J., & Lucas, K. (2019) p. 22	Mode use	-	-	-
Karner, A., & London, J. (2014). p. 93	Mode use	% non-SOV commute mode share	-	-
Boisjoly, G., & Yengoh, G. T. (2017). p. 10	Mode use	Pedestrians & Cyclists	asked community members in interviews to identify transportation concerns	identified as a vulnerable group
Martens, K., Bastiaanssen, J., & Lucas, K. (2019) p. 19	Street	-	-	-
Martens, K., Bastiaanssen, J., & Lucas, K. (2019) p. 19	Long-term Pollution Levels	-	-	-
Martens, K., Bastiaanssen, J., & Lucas, K. (2019) p. 19	Transport-related exposures	-	-	-
Dianin, A., Ravazzoli, E., & Hauger, G. (2021). Figure 2	Digitalization	low-digitalization rate	access to technology needed to book trips	likely to experience lower levels of access
Beiler, M. O., & Mohammed, M. (2016). p. 290	Cost of living	% people with a median monthly housing costs for occupied housing units below the regional average	relationship to accessibility	assumes that those with lower housing costs experience poorer accessibility (i.e. more expensive housing is better located and accessible)
Heyer, J., Palm, M., & Niemeier, D. (2020). p. 8	Cost of living	% income spent on transportation and housing	affordability of transportation & housing	potential for displacement due to higher costs relative to income (low-income)
Ahmed, Q. I., Lu, H., & Ye, S. (2008). p. 135	Cost of living	% discretionary income spent on transportation	affordability of transportation	-
Eisenberg, A. M. (2020). p. 224	Composite	Declining rural (population, enviro hazard, economic losses), Chronic poverty rural	unique experience of rural America	face disproportionately high and distinct distributive injustices especially re: exposure to hazards and/or low economic opportunities
Yang, J., Guo, A., Li, X., & Huang, T. (2018). p. 4	Economic share	% GDP comprised of secondary and tertiary industries in region	attribute considered in Global Principal Component Analysis (GPCA) to calc social demand index of [spatial unit]	-
Yang, J., Guo, A., Li, X., & Huang, T. (2018). p. 4	Consumption	The total sales of consumer goods/Total population	attribute considered in Global Principal Component Analysis (GPCA) to calc social demand index of [spatial unit]	-
Yang, J., Guo, A., Li, X., & Huang, T. (2018). p. 4	Assets	Investment in fixed assets/total GDP	attribute considered in Global Principal Component Analysis (GPCA) to calc social demand index of [spatial unit]	-

Ghasemlou, K., Ergun, M., & Dadashzadeh, N. (2021). pp. 14,17,18	Transit Card User Types	normal, student, elderly, person w/ disabilities, limited use, others	assessing use of transit system using bus card tap data	"in terms of the average number of boardings, elderly card holders (group 3), and PwD card holders (group 4) have higher (c. 10–15%) boarding rates on weekdays and weekends compared to other card holder groups. This shows that these users need more travel access. Another finding shows that PT routes and lines are not planned based on their travel needs (medical centers, elderly house, organizations for PwD, etc.), consequently, this increases their number of transfers between lines"