SUSTAINABLE TRANSPORTATION PLANNING DURING AN ERA OF TECHNOLOGICAL EVOLUTION

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ABSTRACT

"Sustainable Transportation Planning During an Era of Technological Evolution" provides an in-depth analysis spanning three pivotal chapters, each focusing on the nexus of climate change, transportation, and metropolitan planning.

Chapter 2 delves into climate change's role in transportation plans. The literature reviews transportation's effects on climate change and the significance of Metropolitan Planning Organization (MPO) transportation planning. After identifying research gaps and ethical considerations, the chapter outlines a methodology employing Latent Dirichlet Allocation (LDA) model construction, text preprocessing, and evaluation metrics. Python's Natural Language Processing (NLP) toolbox is utilized to analyze the contents of 42 long-range transportation plans. Semantic interpretations emphasize word frequencies, climate keywords, transportation plan similarities, and data visualizations, culminating in a discussion of the findings and research conclusions.

Chapter 3 shifts to the modeling of autonomous vehicles (AV) concerning sustainable development. It reviews the implications of technological advancements on mobility, long-term planning, and urban expansion. The methodology presents land use forecasts, transportation modeling, and AV simulation parameters. Various scenarios, such as increased auto availability and decreased parking costs, are explored. A detailed discussion synthesizes the findings, leading to a research conclusion.

Chapter 4 targets current MPO transportation planning activities, accentuating climate action. Data is collected via a PDF survey completed and returned by 13 of Wisconsin's 14 MPOs. A description of the survey methodology is followed by an examination of the findings, offering key insights and latent thematic comparisons to the findings documented in Chapter 2

concerning climate action currently being taken by Wisconsin’s MPOs via their long-range transportation planning activities.

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CHAPTER 1: INTRODUCTION

The American roadway network, embodied by its transformative Interstate Highway System, is foundational to both the nation's economy and the daily lives of its citizens. By facilitating the rapid and efficient movement of people and goods within and across states, this infrastructure system has not only spurred economic growth but also fostered regional cohesion.

As the 21st century progresses, further integrating climate change action into long-range transportation planning is increasingly vital. Tools like Natural Language Processing can be applied to aid in understanding how agencies currently incorporate climate change mitigation in long-range transportation plans. It's equally important to consider how climate change mitigation actions are being implemented across various metropolitan areas to fully understand their interrelation and how different planning organizations are approaching climate change within their regions and diverse populations.

Moving forward, technological advancements, including the advent of driverless vehicles, foreshadow a major reshaping of the nation’s transport system and its supporting infrastructure. Travel demand modeling completed decades ago set the foundation for today's highway system landscape. Transportation is again poised for a significant transformation driven by new and emerging technologies across different modes. Innovative vehicle and highway systems have the potential to radically improve travel safety and societal mobility.

Scenario planning and exploratory modeling provides the ability to anticipate and manage the potential risks and benefits associated with the widespread use of technologies such as autonomous vehicles (AVs) before they materialize. However, modeling future transportation scenarios often has a key limitation: the reliance on a single future land development projection, with an assumption that these patterns will remain unchanged over time. This approach neglects the complex interplay between land use and transportation, where each influences the other reciprocally. In reality, land use decisions and transportation systems exist in a constant state of interaction, each influencing the other. Land use decisions can reshape travel patterns and alter transportation demand. Conversely, investments in transportation infrastructure can drive new land development, leading to modifications in existing land use plans.

Autonomous vehicles stand to further influence the shape and pace of future land development. For example, there is general agreement that rural and suburban areas may see improved accessibility, while densely populated urban centers will face unique and unprecedented traffic management challenges. Moreover, since historical advancements in transportation technology have resulted in expanding urban areas, consequences for resource consumption and environmental sustainability are significant. As AV technologies continue to evolve, it becomes increasingly important to conduct detailed scenario forecasting and impact planning to ensure we are providing a sustainable future for generations that follow.

The importance of transportation planners and their regional planning efforts is pivotal and cannot be overstressed. For example, Wisconsin's fourteen Metropolitan Planning Organizations (MPOs) are responsible for coordinating transportation planning across 17 metropolitan areas on a regional scale. To gain insights into their strategic approaches, a survey was distributed to these MPOs, containing 11 targeted questions. The survey's goal was to identify key themes in long-range transportation plans, with a particular focus on climate action. This not only establishes a standard for future initiatives but also promotes the exchange of knowledge between the MPOs.

The remainder of this dissertation centers on three major areas: 1) climate change and transportation planning, 2) modeling AV impacts on sustainability, and 3) MPO plans and climate action.

CHAPTER 2: CLIMATE CHANGE AND TRANSPORTATION PLANNING

2.1. Introduction

The United States roadway network plays a pivotal role in its economy and its citizens' everyday life. The Interstate Highway System transformed American surface transportation, making the movement of goods and people across states faster and more efficient. The existing roadway system supports numerous industries and fosters regional integration. Furthermore, modernization of infrastructure and incorporation of new technologies (like self-driving vehicles) will continue to reshape the United States transport system.

Transportation has a significant role in influencing land development patterns (the built environment) and the natural environment, shaping residential and business location decisions, urban congestion, resource consumption, air and water quality, and overall societal quality of life (Eberts, 2000). New transportation technologies, population growth, renewable energy sources, system sustainability and resilience, and health and social equity are prominent topics in social policy discourse at all levels (National Academies of Sciences, Engineering, and Medicine, 2018).

Urban transportation is being rethought, with increased focus on public transit, cycling infrastructure, pedestrian-friendly street planning, and efficient ride-sharing services. For all its rich history of progressive societal influences and individual benefits, the transportation sector is also accountable for a significant amount of worldwide pollution and greenhouse gases emitted annually. Given the nature of the current situation, there is an impetus to adopt more sustainable, low-carbon means of transportation. This has produced growth in electric vehicles and hybrid technologies and a heightened interest in alternative fuels like hydrogen.

As cities grow, so do challenges like traffic, pollution, and infrastructure strain. The United Nations influential report "Our Common Future" (Brundtland Commission, 1987) articulated this when it defined sustainable development as development that "*meets the needs of the present without compromising the ability of future generations to meet their own needs*." The Brundtland Commission definition has gained widespread acceptance and extends to sustainability aspirations in numerous domains (Barbosa et al., 2014). However, the Brundtland Commission definition also faces criticism from detractors who argue that despite its widespread use, it encompasses an anthropocentric perspective and introduces the subjective metric of "needs" to the discourse (Wheeler, 2000).

The pursuit of environmental conservation and sustainable growth has historically been a societal challenge. Tertullian, a prolific early Christian author around AD 200, has been widely credited for writing: "*One thing is sure. The earth is now more cultivated and developed than ever before. There is more farming with pure force, swamps are drying up, and cities are springing up on an unprecedented scale. We've become a burden to our planet. Resources are becoming scarce, and soon nature will no longer be able to satisfy our needs.*"[1]

Contemporary environmentalists began appearing in the mid-20th century. One of the first was Rachel Carson, who published "*Silent Spring*" in 1962. Carson's book was a trailblazing publication, calling the public's attention to the irreversible ecological harm resulting from man's exploitation of nature. She delved into the widespread use of chemical pesticides and their damaging effects on the environment, arguing that their unimpeded use posed an existential threat to humankind's wellbeing. Carson's work triggered novel federal environmental

[1] The Complete works of Tertullian, specifically "*A Treatise on the Soul*", Chapter 30, contains a quotation that seems to echo the modernized sentiment above. To be clear, the quoted text's actual origin is unknown. While similar, Tertullian's original work was an argument against reincarnation, a prevalent belief at the time.

protection legislation by elevating public awareness of the catastrophic consequences of man's rapid destruction of the planet's life-sustaining natural systems.[2]

Environmental awareness steadily advanced throughout the 20th century. Present-day environmental advocates continue to expand the trailblazing contributions of Rachel Carson and her contemporaries. A renowned environmental activist is former Vice President Al Gore, who published "*An Inconvenient Truth*" in 2006. Gore's book portrayed the phenomenon of global warming as an uncomfortable reality that, if ignored, would result in severe societal and environmental repercussions. Gore recognized the underlying need for society to change its long-established consumption habits. To do so, it first had to accept the dire consequences of inaction. In Gore's words, "*Each one of us is a cause of global warming, but each of us can make choices to change that. With the things we buy, the electricity we use, the cars we drive, we can make choices to bring our individual carbon emissions to zero. The solutions are in our hands.*"

The expansion of transportation infrastructure continues to trigger significant environmental concerns over the depletion of non-renewable natural resources. The construction of roads, airports, and other forms of transport infrastructure necessitates the use of fossil fuels and other natural resources in limited supply. Exponential growth in motor vehicle travel has been directly linked to escalating levels of air and water pollution (Congressional Budget Office, 2022). In this context, regional transportation planning takes on great significance. Metropolitan Planning Organizations (MPOs) oversee the process of transportation planning in urbanized areas having populations exceeding 50,000. MPOs were established in the Federal-Aid Highway

[2] In 1970, President Richard Nixon signed an executive order creating the Environmental Protection Agency (EPA). The creation of the EPA was the result of a growing concern among the public and policymakers over the impacts of pollution and other environmental problems; an awareness for which "Silent Spring" was a key contributor (Berman and Carter, 2018).

Act of 1962 as a provision for states receiving federal highway funding. The 1962 Act established the “3C” planning process. This process necessitates comprehensive, cooperative, and continuous transportation planning between state and local governments, facilitated by an MPO (Weiner, 2016). Since then, the role of MPOs has consistently evolved. Subsequent federal transportation funding legislation has reinforced and expanded MPO responsibilities in the transportation planning process.

Gradually, MPOs have been integrating climate change considerations into their transportation planning documents. These considerations include assessing the impacts of climate change on transportation systems, identifying strategies to curtail emissions, promoting adaptation, and collaborating with other regional planning entities on climate-related issues. However, critics argue that MPOs have several shortcomings. For example, they lack proportional representation of their constituencies and face structural constraints that limit their effectiveness (Griffith, 2021).

Thus far, MPOs have not led the nation toward more climate friendly, cohesive, high-quality mobility systems (Freemark and Tregoning, 2022). Prior to Griffith (2021), Sciara (2017) also found that MPOs face numerous constraints on their ability to expand environmentally friendly transportation benefits for their members. Obstacles originate from a variety of factors, including lack of authority to choose transportation projects, limited ability to endorse land uses that promote system efficiency, no power to levy taxes or fees to fund transportation initiatives, weak organizational structures, limited transit agency participation, and serving diverse metropolitan communities while ensuring a fair distribution of benefits between them.

Despite these limitations, federally mandated MPOs also possess unique attributes that make them particularly well-suited to address the impacts of global warming. MPOs play a vital role with their regional perspective, their ability to bring together stakeholders from various sectors, their long-range planning outlook, increasing authority over transportation investment programming, and opportunities to widely promote sustainable transportation options (Mason and Fragkias, 2018; Mullin et al., 2020).

One of the principal responsibilities of an MPO is to produce the region's long-range transportation plan and to update it at regular intervals. These plans are typically text-heavy, comprehensive documents requiring substantial time and effort to read. This is especially true if searching multiple regional plan documents for specific themes, topics, and/or details related to transportation sustainability.

Content analysis is defined as "*the systematic, objective, quantitative analysis of message characteristics*" (Neuendorf, 2017). Content analysis can be done by humans, computers, or a combination of both. Human-based content analysis requires people to manually scrutinize and code textual themes, applying pre-established criteria to extract relevant information. Computer-assisted content analysis, on the other hand, leverages automated tools and algorithms to quickly process and analyze large amounts of textual data. Text classification techniques using Natural Language Processing (NLP) and machine learning have been employed by scholars and researchers to identify patterns, themes, and other notable attributes of digital data (Boyd-Graber et al., 2017; Kang et al., 2020). Machine learning falls under the larger umbrella of Artificial Intelligence (AI), which applies the knowledge acquired through content analysis to support and streamline the decision-making processes (Huntingford et al., 2019).

Clearly, these technologies can significantly assist in navigating the expansive amount of information embedded within planning documents. In Chapter 2, NLP tools are instrumental to advancing transportation planning and climate change research. NLP tools are used to identify central themes and topics within several volumes of textual planning data, increasing the efficiency and effectiveness of content analyses.

Specifically, NLP techniques are used to analyze 42 MPO long-range transportation planning documents, revealing topics associated with environmental preservation, green infrastructure, conservation initiatives, and strategies aimed at emission reduction. In addition, NLP is deployed to highlight topics associated with system sustainability, including elements related to infrastructure maintenance and investments in alternative modes of transportation. Crucial societal themes embedded within each document such as equity, safety, and public health are also extracted to gain a broader understanding of climate change within the context of long-range transportation planning.

Fu et al. (2022) recently conducted a study testing NLP topic identification on regional planning reports, comparing the computer findings with those of human readers. They concluded that while NLP does not match the precision of human-led content analysis, it does provide valuable insights into the content of transportation planning documents. They noted that the primary advantage of NLP is the ability to swiftly extract and condense information from vast amounts of data. This enabled the researchers to discern patterns and trends that would have been difficult to detect through manual reading alone. Fu et al. (2022) concluded that the insights garnered through use of NLP complements human analyses, providing an even greater understanding of the material.

By employing NLP tools, this research advances efficient plan analysis, exploring similarities and differences between the 42 MPO long-range transportation plan documents. Furthermore, the research contributes to current academic literature by identifying several determinants of transportation system sustainability and climate change action within the context of long-range transportation plans.

2.1.1. Research Questions

The following questions will be addressed in the investigation of long-range metropolitan transportation planning and climate mitigation:

- What common long-range determinants of sustainability are being applied in current MPO transportation planning documents?
- Can NLP be used to analyze long-range transportation plan similarities and differences in terms of environmental sustainability for different states and MPO locations?
- How inclusive are existing transportation plan documents of projects and policies that lessen the depletion of natural resources and the predominant use of automobiles?

By applying Python-based NLP modelling techniques, a climate-related collection of keywords is classified by major theme or topic area. The chapter documents how topic classification is completed to discover latent themes. In machine learning science, this is known as an unstructured query. An unstructured query is exploratory; that is, designed to extract research answers directly from the raw data itself.

2.1.2. Research Benefits

The accelerated advancement of AI capabilities has propelled NLP research in several fields, including business, education, economics, engineering, medicine, and law (Cioffi et al., 2020). Machine learning algorithms are no longer limited to just internet enthusiasts. Innovation in NLP techniques, propelled by the growing availability of big data and cloud computing, has opened AI access to mainstream users.

A significant body of literature exists exploring sustainable development on a metropolitan and regional scale, including work by Barbour (2015), Sciara (2017), Wheeler (2000), Mason & Fragkias (2018), and Griffith (2021).

In the domain of climate change analysis, NLP techniques have been shown to be effective in analyzing climate action at a municipal level, as demonstrated by Siddharth et al. (2022) and Fu and Li (2022). However, research exploring the relationship between regional planning and climate change uncertainty using NLP is limited, with only a few recent studies available. These include an analysis of California climate plans (Brinkley and Stahmer, 2021), corporate net-zero emissions reduction targets (Sachdeva et al., 2022), and infrastructure resiliency planning (Fu and Li, 2022; Fu et al., 2022).

Analyzing climate mitigation approaches contained in MPO planning documents from Iowa, Illinois, Minnesota, North Dakota, South Dakota, and Wisconsin provides an opportunity to expand this research space within the Midwest using natural language processing tools. It provides a foundation for monitoring progress over time, gauging the evolution of climate change-related goals and objectives within transportation plans. Establishing this benchmark, future researchers will have the opportunity to examine how MPO planners are progressing with the urgent need for climate change mitigation within the transportation sector.

2.2. Literature Review

This section reviews scholarly literature delving into the connection between climate change mitigation, long-range transportation planning, and natural language processing. The literature review sets the stage for the applied research section of the chapter, providing a deeper understanding of the current state of research activity and the thought leaders in the subject matter.

2.2.1. Climate Change and Infrastructure

The term "anthropogenic" refers to the effects, processes, and materials that originate from human activity. It is often used in the context of climate change, and in the case of transportation, it includes greenhouse gases emitted from burning fossil fuels in internal combustion engines. The atmospheric level of greenhouse gases continues to increase, posing a significant threat to climate stability. At the same time, the global economy continues to grow, lacking accountability for its detrimental impact on the planet. Responsible and sustainable management of the planet's resources is the essence of good stewardship, yet such practices have not been effectively implemented on a large scale (Steffen et al., 2015). Given its escalating threat, the topic of human-induced climate change is a focal point in contemporary research and scholarly discourse.

Researchers overwhelmingly agree that climate change is real, that it is almost entirely caused by human activity, and that it has already done irreparable harm to the planet (Environmental Protection Agency, 2023; Intergovernmental Panel on Climate Change, 2022). However, despite its prominence in scientific discourse, the extent of climate change impact is the subject of intense public debate, with significant implications for long-term social and economic disruption (Stede and Patz, 2021). Scientists have concluded that urgent action is needed to reduce greenhouse gas emissions and limit global temperatures to 1.5°C above pre-industrial levels by 2050 (Intergovernmental Panel on Climate Change, 2022). Policymakers, businesses, academics, and society at-large are increasingly recognizing this urgency and the need to address the situation swiftly and decisively (Sheffi, 2021; Stern et al., 2022).

According to the Environmental Protection Agency (EPA), transport activity accounts for about 30% of total United States greenhouse gas emissions and has increased more than any other sector over the past two decades (Environmental Protection Agency, 2023). Most of the greenhouse gas emitted from the transportation sector consists of carbon dioxide, released into the atmosphere through tailpipe emissions. Carbon dioxide has a long atmospheric lifespan, remaining in place for centuries. This longevity promotes the so-called greenhouse effect, trapping heat and intensifying the pace of global warming.

Human economic activity experienced a significant acceleration during the mid-20th century due to several factors, including population growth, industrialization, urbanization, and cheap energy. This exponential growth has resulted in a significant increase in atmospheric concentrations of carbon dioxide and other greenhouse gases (Yuan et al., 2022). Scientific research has extensively documented the impacts of climate change on a wide range of physical and biological systems, including rising global temperatures, higher sea levels, changes in rainfall patterns, and complete shifts in ecosystems and biodiversity (de Abreu et al., 2022; Environmental Protection Agency 2023, Freemark & Tregoning, 2022, Mullin and Feiock, 2020). These impacts will worsen in the coming years, particularly if greenhouse gas emissions are allowed to rise at current rates. It is noteworthy that despite significant increases in vehicle miles traveled, emissions associated with the transportation sector have not risen proportionately (Congressional Budget Office, 2022). In fact, the Congressional Budget Office is projecting a decline in carbon dioxide emissions from transportation over the next decade, driven largely by increased adoption of electric vehicles and other fuel-efficient mobility alternatives.

Critics have expressed concern regarding the energy-intensive manufacturing process and raw material extraction associated with electric vehicle (EV) batteries. Detractors argue that the electricity grid powering EVs remains heavily reliant on fossil fuels, particularly in countries dominated by coal-based energy generation. However, studies show that even when EVs are charged using electricity from coal-based sources, they still account for lower greenhouse gas emissions per mile traveled compared to conventional internal combustion engine vehicles

(International Council on Clean Transportation, 2021). Moreover, the ongoing shift toward cleaner energy sources in electricity generation will only enhance the climate benefits of EVs over time. Despite the progress made in reducing emissions in some areas, much more needs to be done to address the root causes of climate change and to mitigate its effects. The literature emphasizes the importance of multidisciplinary collaboration in finding sustainable solutions to the complex problem of climate change (AASHTO, 2021; National Academies of Sciences, Engineering and Medicine, 2018; USDOT, 2022; United States Climate Alliance, 2022). Attaining a more sustainable future requires collective accountability across all sectors, necessitating unified action by various agencies and organizations.

No doubt, the transport sector continues to contribute significantly to the causes of climate change. However, transport is also increasingly vulnerable to the impacts of climate change such as extreme heat and heavy precipitation (Jacobs et al., 2018). The accelerating occurrences of extreme weather events further exacerbates already insufficient levels of funding for critical infrastructure improvements (American Society of Civil Engineers, 2021). The impact of climate change on infrastructure is particularly acute considering the long lifespan of these systems. Pavements, for example, are typically designed to have an expected life of at least two decades. With proactive maintenance, concrete bridges can operate for over a century.

A novel suggestion for infrastructure replacement comes from Givoni and Perl (2020), who propose that when transportation infrastructure reaches half its life expectancy point, it is evaluated for potential alternatives to enhance its sustainable functionality. The proposed options include 1) refurbishing the existing infrastructure to maintain its current function, 2) redesigning it to accommodate transportation modes beyond its original purpose, 3) repurposing it for new uses, or 4) removing it entirely if it is no longer viable or necessary. Essentially, their proposal incorporates sustainability reviews as a fundamental part of infrastructure lifecycle planning and design.

2.2.2. Role of Transportation Planning

It is essential to recognize the ability of Metropolitan Planning Organizations to define regional strategies and direct efforts towards mitigating the harmful effects of carbon emissions and other greenhouse gases. Long-range transportation plans have the potential to establish a forward-thinking framework for allocating funds towards the implementation of regional mobility improvements that are environmentally friendly. Major transportation infrastructure funding flows through the federal government to state departments of transportation. These funds are then either utilized by state agencies themselves, or further distributed to other governmental entities. MPOs are gaining an increasing role in project selection and funding decisions (Kirk et al., 2016). The long-range transportation plan evaluates the existing system's effectiveness, projects future demand for person and freight movement, identifies future transportation network deficiencies, and develops strategies to alleviate anticipated congestion (Griffith, 2021). While MPO transportation plans are asked to achieve a multitude of public transport system goals such as safety, mobility, accessibility, equity, sustainability, and preservation, they must now do so during a period of dynamic change in transport technologies and under conditions of significant uncertainty.

To produce a forward-looking planning document, MPOs forecast future transportation demand on their regional transportation networks. Travel demand projections that rely on historical trends are effective during periods of stability. However, those forecasts become much less reliable when underlying conditions are prone to disruptive changes and lack clear direction and magnitude (USDOT, 2022). Evaluating future conditions poses a significant challenge for transportation planners, especially with the increasing likelihood of disruptive weather and rapid technological changes in mobility, as previously noted.

Typically, projected land use patterns are treated as static inputs for future travel demand estimation. Instead, it would be better to consider land use as a variable that can influence transportation system usage in unforeseen ways. The traditional approach is commonly known as "predict and provide," which leads to expanding infrastructure to accommodate the projected growth (Barbour, 2015). However, the "predict and provide" approach fails when confronting complex problems like global warming. Global warming is a wicked problem; that is, it has no straightforward solution and consists of a multitude of seemingly interrelated factors.[3]

Addressing issues like global warming requires a nuanced approach to transportation planning that considers several interconnected social, economic, and environmental factors contributing to the problem. Rather than focusing on accommodating the ever-increasing demand for automobile travel, it requires collaborative efforts among civil engineers, transportation planners, and social workers to develop more comprehensive and holistic solutions (Fields et al., 2020). This requires departing from the historically narrow focus on highway infrastructure expansion and transitioning to an approach that promotes alternative modes like walking, cycling, and public transit. It also involves embracing the development and integration of emerging technologies such as autonomous and connected vehicles, electric vehicles, smart mobility apps, and mobility-as-a-service operations (Nikitas et al., 2017).

The relationship between MPO transportation planning and climate change has received limited study to-date. Mullin et al. (2020) examined various MPO transportation plans and

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[3] Use of the "wicked problem" reference was originated by Horst Rittel and Melvin Webber in the 1970s (Horst and Webber, 1973).

identified a strong correlation between MPOs that demonstrated a long-term commitment to climate change mitigation in their long-range transportation plans and MPOs that direct short-range transportation improvement funds toward reducing emissions. But more importantly, they found that the majority of MPOs do not include explicit climate change mitigation strategies in their transportation plans, instead concentrating on recommendations that promote car-centric mobility policies and projects.[4]

Political factors significantly influence the adoption of sustainable infrastructure policies and the funding of sustainable infrastructure projects (de Rugy and Miller, 2017). For the most part, the United States has lacked a national mandate to reduce greenhouse gas emissions from mobile transport sources. The 1973 oil crisis sparked an era of energy awareness in the U.S., leading to the passage of significant federal legislation such as the Energy Policy and Conservation Act of 1975, which mandated higher automobile fuel efficiency and established Corporate Average Fuel Efficiency (CAFE) standards (Feldman, 2005). By 1980, the United States Department of Transportation required energy conservation to be considered for all federally funded transportation infrastructure projects. New travel demand management strategies started to address methods to reduce single-occupant vehicle travel (Amekudzi et al., 2007; Ferguson, 1990). Table 2.1 summarizes major federal legislation pertaining to transportation and air pollution enacted between 1975 and 1985.

[4] Notably, the data sample was limited, comprising only six MPOs across three states (California, Florida, and North Carolina).

Table 2.1

Federal Action on Transportation and Air Pollution (1975-1985)

Year	Action
1975	Congress passes the National Energy Policy Conservation Act, setting the first fuel economy goals. The Corporate Average Fuel Economy (CAFE) program establishes a phase-in of more stringent fuel economy standards beginning with 1975 model vehicles.
	The "first generation" catalytic converters are built, significantly reducing vehicle emissions. Unleaded gasoline is also introduced because lead in gasoline may cause disintegration of catalytic converters. This results in dramatic reductions in ambient lead levels and alleviates many serious environmental and human health concerns associated with lead pollution.
1977	Congress amends the Clean Air Act which set a schedule for continued reductions in emissions from automobiles.
1981	New cars meet the amended Clean Air Act standards for the first time. Sophisticated three-way catalysts with on-board computers and oxygen sensors appear in most new cars, helping to optimize the efficiency of the catalytic converter.
1983	Inspection and Maintenance (I/M) programs are established in areas with air pollution problems, requiring passenger vehicles to undergo periodic testing for malfunctioning emission control systems.
1985	EPA sets stringent standards for emissions of NO_x from heavy-duty engines and of PM from heavy-duty diesel-powered trucks and buses.
	EPA issues final regulations to cut the amount of lead in gasoline by 90 percent starting January 1, 1986. The new standard is 0.10 grams per gallon.

Source: United States Environmental Protection Agency. "Timeline of Major Accomplishments in Transportation, Air Pollution, and Climate Change." Available at https://www.epa.gov/transportation-air-pollution-and-climate-change/timeline-major-accomplishments-transportation-air. [Accessed 23 May 2023].

Operational enhancements for roadway projects have historically focused on improving vehicle travel speeds and reducing motorist delays. Safety enhancements were primarily aimed at decreasing automobile crashes (AASHTO, 2010). Eventually, federal transportation project approval became contingent on 1) evaluating a project's environmental impacts, 2) an alternative's ability to meet predefined purpose and need criteria, and 3) a fiscally constrained cost and budget analyses (AASHTO, 2016). In 2021, the American Association of State and Highway Transportation Officials (AASHTO) recognized the need to work collaboratively with government agencies to incorporate project evaluation metrics that also supported lowering greenhouse gas emissions. The new AASHTO policy recognizes the importance of reducing vehicle miles traveled, reducing the carbon intensity of fuels, increasing vehicle fuel efficiency, incorporating carbon sequestration, and providing low- or zero-emission modes of travel (AASHTO, 2021).

State and local governments have a considerable degree of control over transportation funds awarded for projects on their jurisdictional roadways. While the federal government sets national transportation policies and allocates funding, state and local governments have been primarily responsible for planning, developing, and maintaining the transport system (Krause, 2010). Consequently, sustainable transport planning is largely delegated to state and regional agencies. In response, these entities have proposed a wide variety of measures attempting to mitigate climate change impacts, such as carbon taxes, fossil fuel pricing strategies, promoting alternative fuels, new vehicle technologies, phasing out fossil fuel usage, regional growth management policies, revitalizing urban areas, and investing in public transit systems (Deakin, 2011).

The United States Climate Alliance is a bipartisan coalition consisting of 24 state governors collectively striving to mitigate increasing global temperatures (United States Climate Alliance, 2022). The policies and programs of the Alliance focus on decarbonizing the transportation sector and reducing Vehicle Miles Traveled. Seventeen Alliance states have implemented low-emission vehicle standards, sixteen have introduced zero-emission vehicle standards, nine have established clean truck standards, and four have instituted clean fuel standards (United States Climate Alliance, 2022).

MPOs are well-positioned to address the reduction of regional transportation carbon emissions (Barbour, 2015; Griffith, 2021). Despite their significant influence in directing hundreds of billions of dollars in annual transportation investments, they operate relatively unnoticed by the public (Sciara, 2017). Mason and Fragkias (2018) surveyed 137 out of 405 MPOs and collected data analyzing the likelihood of an MPO incorporating climate change into their long-range plans. Positive factors included higher numbers of MPO staff, higher numbers of policy board members, the level of climate change concern within the region, favorable political climates and voting patterns, and geography.

In summary, MPOs have the potential to address environmental sustainability threats due to their long-term perspective, interdisciplinary problem-solving approach, and ability to balance environmental, economic, and social planning objectives (Wheeler, 2000). On the other hand, weak MPO governance structures contribute to technical skill limitations and insufficient funding to address complex problems like greenhouse gas emission reduction (Frankel and Wachs 2017; Stead, 2016). As relatively weak institutions comprised of multiple local governments who are voluntarily associated, they lack independent authority (Barbour (2015) and control over budget execution (Sciara, 2017).

2.2.3. Natural Language Processing

Regional transportation plans are large technical documents, spanning hundreds of pages in length. Natural Language Processing is a subfield of artificial intelligence that facilitates interaction between computers and humans using everyday language (Rancho Labs, 2021). NLP is used to search, analyze, comprehend, and extract information from vast amounts of textual data (corpora). NLP involves using textual information as data to analyze content within various sources such as news media, social media, political speech and debate, and institutional texts and reports. Climate change is a complex and multifaceted issue that lends itself well to AI-aided analysis (Huntingford et al., 2019). NLP has been an effective tool for investigating climate change discourse across three distinct and diverse groups: the public in general, policymakers, and the scientific community (Stede and Plaz, 2021). NLP enables researchers to gain valuable insights into the language, opinions, and trends within each of these groups.

NLP supports researchers and practitioners having time constraints for analyzing multiple plan documents, offering useful insights without the need for extensive manual reading and analysis (Fu et al., 2022). The digitization and online availability of various documentation have greatly contributed to the growing application of NLP techniques. It has also enabled the development of sophisticated exploratory methods for extracting information and conducting comparative analyses on high-dimensional documents across multiple sources (Antons et al., 2020; Brinkley and Stahmer, 2021). Scholars, industry data analysts, and corporate marketers have drawn topical inferences from keyword algorithms which have supplemented traditional methods of qualitative data collection regarding preferences, opinions, sentiments, biases, and trends (Han et al., 2021; Siddharth et al., 2022).

NLP methodologies are typically classified in two primary categories: unsupervised learning and supervised learning. Within these categories, considerable research has been dedicated to unsupervised learning methodologies. A prominent example is Latent Dirichlet Allocation (LDA), which aims to uncover hidden structures or patterns from unlabeled data. LDA operates on the principle of identifying latent topics within a corpus of text, providing insight into the underlying themes in the data (Blei et al., 2003).

LDA is a probabilistic topic modeling process that operates on a three-tier Bayesian framework, encompassing words, topics, and documents (Wang et al., 2014). Documents are viewed as mixtures of topics, with each topic characterized by a probability distribution over a set of words within the corpus. The model assigns probabilities to each word in the corpus vocabulary for each topic, basically measuring the likelihood of that word being present in a document and associated with a specific topic.

"Crawling the web" refers to the automated process of collecting data from different online sources like websites, social media platforms, and online repositories. Researchers use text crawling techniques to gather data from diverse sources, enabling them to conduct NLP analyses and investigations (Brunello, 2012). The application of text crawling techniques has been notable in various research studies. For instance, researchers have used it to extract data from Scopus scholarly literature databases (Zulkarnain, 2021). Text crawling has also been employed to collect Facebook feed data (Baumer et al., 2017; Han et al., 2021). Researchers have utilized text crawling to explore historical events and language evolution. They've also conducted sentiment analysis of past public discourse by leveraging text data from newspaper archives and historical records (Boyd-Graber et al., 2017). Researchers have used text crawling techniques on email records and Twitter data (Bender & Friedman, 2018; Blair et al., 2020; Hodorog et al., 2022; Uthirapathy & Sandaman, 2023), seeking insights into communication patterns, language usage, sentiment analysis, trending topics, and social network dynamics.

While the review of literature on open-source NLP methods and applications illustrates its frequent use in analyzing large volumes of social media text data (el Alaoui et al., 2018), only more recent research has applied NLP tools to corpora such as regional planning documents. Brinkley and Stahmer (2021) acknowledged the rapid advancement of NLP techniques as documents are routinely digitized and made accessible online. Their research utilized NLP tools to identify a wide array of primary planning topics and their interrelationships from a comprehensive dataset of over 450 city general plans in California. Fu and Zhai (2022) later employed NLP techniques to analyze resiliency strategies found in community planning documents. They compared NLP computer-read results to human-read content analysis (using two human “coders”) and discovered that although human-read content analysis yielded more accurate results, it required substantially more time and labor investments.

It is well-established in the literature that NLP algorithms are widely used to capture conceptual dimensions within vast amounts of digitally available documentation. However, the interpretation of these dimensions relies on broad knowledge and previous specialized research, typically conducted by an experienced analyst (Kang et al., 2020). For example, social media may represent a viable source of information on a topic like “smart growth”, but ascertaining its degree of reliability may depend on input from specialists such as computer programmers, municipal engineers, city planners, and industry leaders. Collaborative efforts and expertise are required for accurate interpretation of NLP latent topics and derivation of useful information that meets the unique needs of a specific area of investigation (Hodorog et al., 2022).

2.3. Research Gaps

The literature review revealed several significant studies emphasizing the imperative need to tackle global warming and cut greenhouse gas emissions. Lamb et al. (2020) identified a difference between scientific discussions that aim to delay climate action and those that express extreme denialism, skepticism, and personal attacks regarding climate change. Axsen et al. (2020) concentrated on transportation’s role in climate change mitigation and underscored the importance of promoting robust, integrated policy mixes to diminish greenhouse gas emissions and other less quantifiable climate change aspects. Bassi et al. (2022) explored the potential of sustainable transportation in delivering societal value, providing insights via case study analyses. Sheffi (2021) contributed to the literature by examining the role of logistics and supply chain management in mitigating greenhouse gas emissions.

To further this research, it's important to explore and identify key tools such as Natural Language Processing and Latent Dirichlet Allocation that can aid in understanding the degree to which agencies are facilitating climate change mitigation. Additionally, it's important to examine potential synergies and compromises between climate change adaptation and mitigation strategies to fully understand their interrelation. For example, Fields et al. (2020) studied the need for planners and social workers to interact on transportation equity issues in anticipation of transformative transportation technologies for mobility disadvantaged populations. Researchers such as Dulal et al. (2011) focused on urban design to reduce travel demand but lack the longitudinal perspective necessary to evaluate its long-term impact on sustainable infrastructure.

In summary, while NLP techniques are extensively discussed in academic research (Bird et al., 2009; Boyd-Graber et al., 2014; Chang et al., 2009; Shah et al., 2020), their application for understanding climate change awareness within the long-range transportation plan context provides several areas for further scholarly inquiry. Advancements in computing technology present notable opportunities for future research, especially in guiding effective climate change mitigation within the realm of long-term transportation planning. Huntingford et al. (2019) studied the exponential progression of artificial intelligence and its potential for amplifying climate research activities. Preskill (2011) introduced "quantum supremacy," referring to the potential of quantum computing and its immense processing power to tackle problems that current digital computer technologies find impossible to solve. Williams (2023) extended Preskill's work by integrating quantum computing with "general collective intelligence." He speculated that this approach could offer universal problem-solving capabilities, specifically in addressing climate change challenges by mimicking the complex problem-solving skills found in natural systems.

The remainer of this chapter addresses one of the research gaps identified above: the need to further explore and apply key tools such as Natural Language Processing and Latent Dirichlet Allocation that can help understand the degree to which transportation planning agencies are facilitating climate change mitigation within their plans. To reduce the knowledge gap, digital copies of long-range transportation plans are collected from forty-two MPO websites in six states. An analysis of each plan is conducted using Python NLP libraries widely available in academia and industry to reveal twelve climate change mitigation and sustainability latent themes frequently included within the long-range transport plan corpora.

2.4. Ethical Considerations

For all their benefits, natural language processing systems lack the ability to engage in reasoning or draw upon pre-existing knowledge as humans do. Acknowledging the significant limitations of NLP applications is necessary at this point. A commonly employed approach to validating the output of LDA topic modeling is to involve multiple reviewers in assessing the results. After the reviewers evaluate the topics generated by the model, the degree of agreement among the reviewers is measured to gauge the reliability and consistency of the generated topics. This helps ensure that the topics identified by the LDA model align with common human interpretation (Lipton, 2018). Similarly, reliance on a single expert's judgment to evaluate the results comes with its own set of cautions.

Natural language processing is subject to several other ethical considerations, including intrinsic bias in textual data (Bolukbasi, et al., 2016; Caliskan et al., 2017), amplification of biases (Bender and Friedman, 2018), moral ambiguity (Jentzsch et al., 2019), and flat-out misrepresentation of facts (Wang et al., 2018). Shah et al. (2020) identified four areas in LDA topic modeling where bias may inadvertently originate:

- Label bias occurring with annotators lacking subject matter expertise or having preconceived notions and stereotypes.
- Selection bias occurring with the dataset that is not representative of the broader context or population.
- Overamplification bias occurring with minor differences in human attributes becoming exaggerated in the predicted outcomes, leading to skewed interpretations.
- Semantic bias occurring with word representations containing unintended or undesirable associations and societal stereotypes.

Importantly, Shah et al. (2020) noted that bias in NLP models is not seen as a growing problem, but rather, viewed as an inevitable element of statistical modeling. Therefore, it is essential that researchers understand and address potential inadvertent sources of model bias and be prepared to implement proactive strategies to mitigate their negative effects if detected.

2.5. Methodology

In this section, the research methodology is explained, including the selection of the MPOs included in the study, methods of collecting textual data from long-range transportation plans, specifications of the NLP models used, application of the NLP models, and metrics used to evaluate the performance of the NLP models. The section explains how NLP models can be used to evaluate long-range transportation plans with respect to climate change action.

2.5.1. MPO Plan Selection

For the purposes of this research, forty-two long-range transportation plans in PDF format were retrieved from urbanized areas located in North Dakota, South Dakota, Iowa, Minnesota, Wisconsin, and Illinois, resulting in a total of 15,693 pages of material, with an average of approximately 370 pages per document. This dataset provides a substantial textual corpus for analysis, providing a meaningful opportunity to investigate transportation planning and climate change topics within the specified regions. Figure 2.1 provides a location map of the research MPOs and states. Collectively, the MPO planning areas cover 20,821 square miles and encompass a population of 20,823,017, according to the 2020 Census. The average population density is 1,000 individuals per square mile. Additional demographic information for each MPO in the research sample can be found in Table 2.2.

The transportation plans typically included three components: the plan itself, several appendices, and additional documentation dedicated to active transportation modes (i.e., bicycle and pedestrian systems). Transit Development Program (TDP) and Transportation Improvement Program (IP) documents are not included, since they represent short-range periods, typically two to five years. Additional long-range transportation plan information is presented in Table 2.3.

Figure 2.1

MPO Location Map

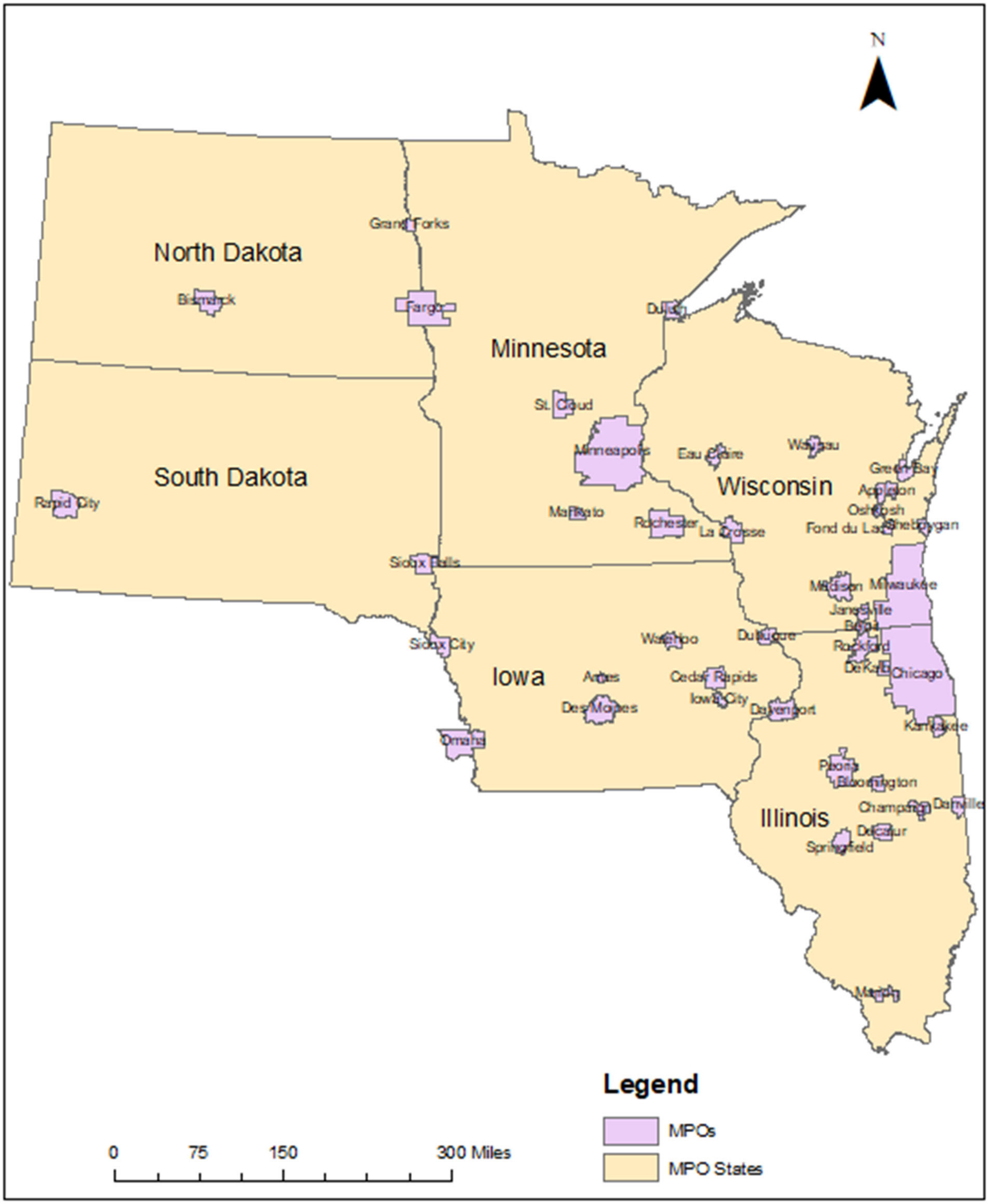

Table 2.2

Select MPO Characteristics

State	MPO	Major City	Designation Year	Area (Sq. Mi.)	2020 Census Population	Density (Pop/Sq. Mi.)
Dakotas (5)	Bismarck-Mandan MPO	Bismarck	1982	386	123,146	319
	Fargo-Moorhead Metropolitan COG	Fargo	1972	1,071	240,394	224
	Grand Forks-East Grand Forks MPO	Grand Forks	1982	113	70,262	622
	Rapid City MPO	Rapid City	1981	478	118,273	247
	Sioux Falls MPO	Sioux Falls	1973	320	233,890	731
Minnesota (5)	Duluth-Superior Metropolitan Interstate Council	Duluth	1975	190	132,768	699
	Mankato/North Mankato Area Planning Organization	Mankato	2013	131	67,974	519
	Metropolitan Council	Minneapolis	1973	2,970	3,231,474	1,088
	Rochester-Olmsted COG	Rochester	1972	657	166,846	254
	St. Cloud Area Planning Organization	St. Cloud	1970	363	139,721	385
Wisconsin (12)	Appleton/Fox Cities MPO	Appleton	1973	268	253,737	947
	Chippewa-Eau Claire MPO	Eau Claire	1982	162	120,166	742
	Fond du Lac Area MPO	Fond du Lac	2002	85	63,272	744
	Brown County Planning Commission	Green Bay	1974	222	240,315	1,083
	Janesville Area MPO	Janesville	1982	128	79,134	618
	La Crosse Area Planning Committee	La Crosse	1967	318	121,315	381
	Madison Area Transportation Planning Board	Madison	1971	425	504,804	1,188
	Oshkosh MPO	Oshkosh	1973	72	79,102	1,099
	Sheboygan MPO	Sheboygan	1982	108	78,067	723
	Southeastern WI Regional Planning Commission	Milwaukee	1961	2,697	2,047,922	759
	State Line Area Transportation Study	Beloit	1974	107	68,418	639
	Wausau Metropolitan Planning Organization	Wausau	1983	160	88,669	554
Illinois (11)	Champaign County Regional Planning Commission	Champaign	1964	182	167,702	921
	Chicago Metropolitan Agency for Planning	Chicago	1962	4,133	8,602,637	2,081
	Danville Area Transportation Study	Danville	2003	173	53,155	307
	Decatur Urbanized Area Transportation Study	Decatur	1964	220	95,393	434
	DeKalb Sycamore Area Transportation Study	DeKalb	2003	132	69,710	528
	Kankakee County Regional Planning Commission	Kankakee	1983	151	84,144	557
	McLean County Regional Planning Commission	Bloomington	1967	149	141,397	949
	Region One Planning Council	Rockford	1964	439	315,302	718
	Southern Illinois Metropolitan Planning Organization	Marion	2013	175	83,768	479
	Springfield Area Transportation Study	Springfield	1962	238	168,581	708
	Tri-County Regional Planning Commission	Peoria	1976	595	298,419	502

Table 2.2

Select MPO Characteristics (Continued)

State	MPO	Major City	Designation Year	Area (Sq. Mi.)	2020 Census Population	Density (Pop/Sq. Mi.)
Iowa (9)	Ames Area Metropolitan Planning Organization	Ames	2003	62	70,312	1,134
	Bi-State Regional Commission	Davenport	1966	391	304,907	780
	Black Hawk Metro Area Transportation Policy Board	Waterloo	1973	174	121,367	698
	Corridor Metropolitan Planning Organization	Cedar Rapids	1964	325	209,707	645
	Des Moines Area Metropolitan Planning Organization	Des Moines	1983	551	574,900	1,043
	East Central Intergovernmental Association	Dubuque	1974	194	85,172	439
	Metropolitan Area Planning Agency	Omaha (NE)	1974	772	853,631	1,106
	Metropolitan Planning Organization of Johnson County	Iowa City	1980	97	130,227	1,343
	Sioux City Metropolitan Planning Organization	Sioux City	1966	237	122,917	519
	Total			20,821	20,823,017	1,000

Source: U.S. DOT Resource Hub. Transportation Planning Capacity Building. Available at https://www.planning.dot.gov/mpo [accessed 17 March 2023].

Table 2.3

Select Long-Range Transportation Plans

State	MPO	Plan Name	Plan Date	Plan Year	Pages
Dakotas	Bismarck-Mandan MPO	Arrive 2045	March 2020	2045	316
	Fargo-Moorhead Metropolitan COG	Metro Grow	November 2019	2045	154
	Grand Forks-East Grand Forks MPO	Street/Highway Plan Update	December 2018	2045	1001
	Rapid City MPO	Rapid TRIP 2040	September 2015	2040	712
	Sioux Falls MPO	GO Sioux Falls 2045 LRTP	November 2020	2045	439
Minnesota	Duluth-Superior Metropolitan Interstate Council	Sustainable Choices 2045	October 2019	2045	551
	Mankato/North Mankato Area Planning Organization	MAPO 2045	November 2020	2045	329
	Metropolitan Council	Thrive MSP 2040 Transportation Policy Plan	July 2020	2040	937
	Rochester-Olmsted COG	Long Range Transportation Plan 2045	September 2020	2045	655
	St. Cloud Area Planning Organization	Mapping 2045	October 2019	2045	781
Wisconsin	Appleton/Fox Cities MPO	Long Range Transportation / Land Use Plan 2050	October 2020	2050	193
	Chippewa-Eau Claire MPO	Long Range Transportation Plan 2045	February 2021	2045	173
	Fond du Lac Area MPO	Long Range Transportation / Land Use Plan 2050	October 2020	2050	173
	Brown County Planning Commission	2045 Long-Range Transportation Plan Update	October 2020	2045	165
	Janesville Area MPO	Janesville Area 2020-2050 Long-Range Transportation Plan	May 2021	2050	337
	La Crosse Area Planning Committee	Beyond Coulee Vision 2040	September 2020	2040	231
	Madison Area Transportation Planning Board	Regional Transportation Plan 2050	April 2017	2050	502
	Oshkosh MPO	Long Range Transportation / Land Use Plan 2050	October 2020	2050	170
	Sheboygan MPO	Update to the Year 2045 Sheboygan Area Transport. Plan	April 2019	2045	466
	Southeastern WI Regional Planning Commission	2020 Review and Update of Vision 2050	June 2020	2050	395
	State Line Area Transportation Study	SLATS 2045 Long Range Transportation Plan	October 2021	2045	384
	Wausau Metropolitan Planning Organization	Wausau Area Long Range Transportation Plan 2050	November 2016	2050	237
Illinois	Champaign County Regional Planning Commission	Long Range Transportation Plan Sustainable Choices 2040	December 2014	2040	686
	Chicago Metropolitan Agency for Planning	On To 2050 Plan Update	October 2022	2050	483
	Danville Area Transportation Study	Danville MPO Connections to 2045	June 2020	2045	74
	Decatur Urbanized Area Transportation Study	2045 Long Range Transportation Plan	January 2020	2045	227
	DeKalb Sycamore Area Transportation Study	2045 Metropolitan Transportation Plan	June 2020	2045	301
	Kankakee County Regional Planning Commission	2045 Long Range Transportation Plan	May 2021	2045	266
	McLean County Regional Planning Commission	BNMobile: Transportation in a Changing Climate	November 2017	2045	190
	Rockford Metropolitan Agency for Planning	2050 Metropolitan Transport. Plan for the Rockford Region	July 2020	2050	188
	Southern Illinois Metropolitan Planning Organization	An Urban Beginning: Moving Forward Together	June 2020	2045	119
	Springfield Area Transportation Study	2045 Long Range Transportation Plan	June 2020	2045	336
	Tri-County Regional Planning Commission	Long-Range Transportation Plan 2045	June 2020	2045	292

Table 2.3

Select Long-Range Transportation Plans (Continued)

State	MPO	Plan Name	Plan Date	Plan Year	Pages
Iowa	Ames Area Metropolitan Planning Organization	Forward 45 Metropolitan Transportation Plan	October 2020	2045	209
	Bi-State Regional Commission	Connect QC 2050: Quad Cities Long Range Transport. Plan	March 2021	2050	452
	Black Hawk Metro Area Transportation Policy Board	2045 Long-Range Transportation Plan	November 2018	2045	220
	Corridor Metropolitan Planning Organization	Corridor MPO 2045 Long Range Transportation Plan	July 2020	2045	209
	Des Moines Area Metropolitan Planning Organization	Mobilization Tomorrow 2020-2050	November 2019	2050	741
	East Central Intergovernmental Association	DMATS Long Range Transportation Plan	October 2021	2050	287
	Metropolitan Area Planning Agency	2050 Long Range Transportation Plan	October 2020	2050	607
	Metropolitan Planning Organization of Johnson County	Future Forward 2045 Long Range Transportation Plan	May 2017	2045	290
	Sioux City Metropolitan Planning Organization	2045 Long Range Transportation Plan	January 2021	2045	215
	Total				15,693

2.5.2. Token Parsing

Each digital PDF plan first needed to be processed using a Python word parser. Multiple applications were tested to evaluate which would work best for long-range transportation plan conversion. The results of the PDF parser testing are shown in Table 2.4. PyMuPDF was selected for use in the LDA analyses of MPO long-range transportation plans. While all applications provided the basic functionalities for working with PDFs, PyMuPDF provided several other features that made it a good choice for transportation plan text modeling (Artifex, 2023):

- PyMuPDF extracts both searchable text and text embedded within images.
- PyMuPDF's raw text output enables important data preprocessing steps.
- PyMuPDF is Python based, which easily integrates with other Python libraries.
- PyMuPDF is known for its stability and efficient performance.

Table 2.4

Python PDF Parser Test Results

Python PDF Parser	Characters		Words		Data Frame Rows	Run Time [1] (seconds)
	Console [2]	MS [2]	Console [2]	MS [2]		
PDFminer	6,249,228	5,975,582	900,143	892,387	176,544	171.0
pdfplumber	6,095,909	6,091,872	877,564	869,708	101,862	223.2
PDFtotext	6,138,175	5,725,446	876,172	868,229	152,037	8.3
PyMuPDF	6,089,422	5,906,574	878,933	870,956	153,904	8.1
PyPDF2	6,045,716	5,969,964	880,210	872,853	64,903	146.1
TextTract	6,138,175	5,725,446	876,172	868,229	152,037	14.4
TIKA	6,268,289	6,039,538	910,490	902,511	135,679	6.3

1. Test data is all WI MPO plans joined into a single PDF document.
2. Console = Spyder console results, MS = Microsoft Word results
(shaded) = Selected PDF Parser

Table 2.5 provides additional insights into the strengths and weaknesses associated with each of the PDF parsers considered for analyzing the MPO long-range transportation plans.

After the data is parsed, tokenization is the next step in NLP modeling. Tokenization converts the textual data into discernible units, thereby facilitating subsequent analysis and processing. Tokens commonly consist of words or characters that possess specific semantic significance. They are the foundational elements upon which the remainder of the NLP analysis is based upon. Tables 2.6 - 2.11 provide the tokenized results for the MPOs and states included in the study. The number of unique tokens represents instances of a particular word appearing once, while total tokens represent the number of word appearances in the respective corpus.

Table 2.5

PDF Parser Strengths and Weaknesses

PDF Parser	Strengths	Weaknesses
PDFminer	• Extracts text, images, and metadata from PDF files. • Supports a wide range of PDF file formats, including those with complex layouts and encrypted content. • Has a flexible and customizable API.	• Has a complex API that can be difficult to learn and use. • Requires additional dependencies to be installed. • Code to extract text is tedious and longer compared to others.
pdfplumber	• Extracts text, tables, and metadata from PDF files. • Handles PDF files with complex layouts and non-std fonts. • Has built-in OCR functionality.	• Does not support editing or creating PDF files. • Difficulty handling PDF files with large page numbers/tables.
PDFtotext	• Simple and easy-to-use • Extracts text from PDF files, including those with complex layouts and encrypted content. • Preserves PDF text structure as well as table structure format.	• Does not support editing or creating PDF files. • Has difficulty handling PDF files with non-standard fonts.
PyMuPDF	• Extracts text, images, and metadata from PDF files. • Maintains original document structure. • Edits, annotates, and converts PDF files. • Removes unnecessary spaces from text. • Supports complex layouts and encrypted content.	• Has a complex API that can be difficult to learn and use. • Requires additional dependencies to be installed.
PyPDF2	• Simple and easy-to-use • Extracts text and metadata from PDF files. • Merges, splits, crops, and rotates PDF pages. • Has a simple and easy-to-use API.	• Limited support for complex PDF files or encrypted content. • Extracts text but does not preserve original text or table structure. • Includes unnecessary spaces and newlines in extracted text. • Does not support editing or creating PDF files.
TextTract	• Extracts text from a wide range of file formats. • Uses OCR to extract text from scanned PDFs. • Maintains original document structure. • Supports multiple programming languages.	• Extracts information in byte format, requiring other Python packages for decoding (codecs). • Does not support editing or creating PDF files. • Has difficulty with complex layouts or non-standard fonts.

Source: Python Packages for PDF Data Extraction. https://medium.com/analytics-vidhya/python-packages-for-pdf-data-extraction-d14ec30f0ad0 [accessed 4-16-2023].

Table 2.6

North and South Dakota Tokens

MPO	Unique Tokens	Total Tokens	% Unique
Bismarck	2,575	20,205	12.7%
Fargo	3,152	22,249	14.2%
Grand Forks	6,306	85,186	7.4%
Rapid City	7,381	67,116	11.0%
Sioux Falls	4,267	46,726	9.1%

Table 2.7

Illinois Tokens

MPO	Unique Tokens	Total Tokens	% Unique
Champaign	7,115	76,688	9.3%
Chicago	5,868	57,158	10.3%
Danville	2,250	9,177	24.5%
Decatur	3,632	25,126	14.5%
DeKalb	4,569	35,100	13.0%
Kankakee	3,789	26,914	14.1%
Bloomington	4,109	23,838	17.2%
Rockford	4,985	41,581	12.0%
Marion	2,253	11,281	20.0%
Springfield	4,996	33,806	14.8%
Peoria	4,912	30,537	16.1%

Table 2.8

Iowa Tokens

MPO	Unique Tokens	Total Tokens	% Unique
Ames	2,713	15,969	17.0%
Davenport	6,324	45,794	13.8%
Waterloo	4,066	25,554	15.9%
Cedar Rapids	4,303	30,130	14.3%
Des Moines	8,908	94,872	9.4%
Dubuque	4,756	35,161	13.5%
Omaha (NE)	6,242	52,410	11.9%
Iowa City	4,560	29,025	15.7%
Sioux City	3,556	18,182	19.6%

Table 2.9

Minnesota Tokens

MPO	Unique Tokens	Total Tokens	% Unique
Duluth	5,083	47,023	10.8%
Mankato	3,723	28,256	13.2%
Minneapolis	6,185	98,436	6.3%
Rochester	5,575	64,554	8.6%
St. Cloud	6,679	64,391	10.4%

Table 2.10

Wisconsin Tokens

MPO	Unique Tokens	Total Tokens	% Unique
Appleton	2,846	15,514	18.3%
Eau Claire	4,182	23,811	17.6%
Fond du Lac	2,840	13,574	20.9%
Green Bay	3,321	19,440	17.1%
Janesville	5,038	38,258	13.2%
La Crosse	3,682	22,977	16.0%
Madison	6,017	54,377	11.1%
Oshkosh	2,732	13,185	20.7%
Sheboygan	5,441	56,856	9.6%
Milwaukee	4,295	46,645	9.2%
Beloit	4,546	45,391	10.0%
Wausau	4,546	31,512	14.4%

Table 2.11

Statewide Tokens

State	Unique Tokens	Total Tokens	% Unique
Illinois	17,749	394,790	4.5%
Iowa	15,042	289,803	5.2%
Minnesota	13,210	356,241	3.7%
North Dakota	7,530	125,916	6.0%
South Dakota	8,808	112,627	7.8%
Wisconsin	14,916	366,425	4.1%

2.5.3. LDA Model Construction

Latent Dirichlet Allocation (LDA) is an unsupervised NLP learning algorithm that identifies topics within a large corpora of text data (tokens). In unsupervised learning, the algorithm is given data without explicit instructions on what to do with it. The system learns patterns and structure from the data without the use of pre-labeled topics to guide its learning process. LDA falls into this category because it tries to find topics within a collection of documents without being told in advance what these topics might be. It assigns topics to words such that the likelihood of the resulting collection belonging together maximized, given certain assumptions and probabilistic models. LDA is a valuable tool used by researchers and data scientists working in a variety of fields (Chang et al., 2009).

David Blei, Andrew Ng, and Michael I. Jordan introduced LDA modeling in their seminal paper "Latent Dirichlet Allocation" published in 2003. As described by the authors, the concept involves representing documents as random combinations of hidden, or latent topics, and each topic is characterized by a unique distribution of words, or tokens. The basic LDA schematic is depicted in Figure 2.2, as adapted from Blei et al. (2003).[5]

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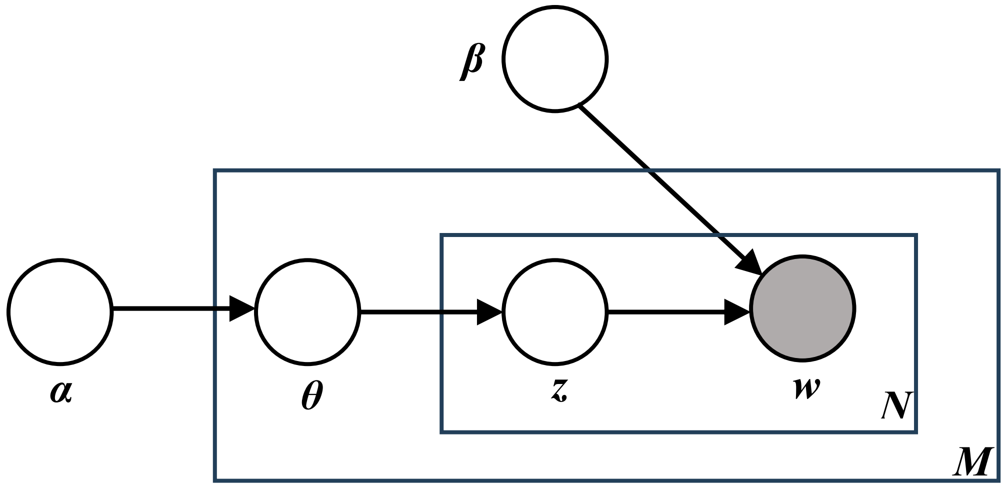
[5] Permission is granted to copy, distribute and/or modify under the terms of the GNU Free Documentation License, Version 1.2 or any later version published by the Free Software Foundation; with no Invariant Sections, no Front-Cover Texts, and no Back-Cover Texts. A copy of the license is included in the section entitled GNU Free Documentation License. https://commons.wikimedia.org/wiki/File:Latent_Dirichlet_allocation.svg; https://commons.wikimedia.org/wiki/Commons:GNU_Free_Documentation_License,_version_1.2

Figure 2.2

LDA Model in Plate Notation



The variable names are defined as follows:

M	=	number of documents
N	=	number of words in a document
α	=	the parameter of the Dirichlet prior on the per-document topic distributions
β	=	the parameter of the Dirichlet prior on the per-topic word distribution
θ	=	the topic distribution for a document
z	=	the topic for the nth word in a document
w	=	the specific word

The rectangular boxes, referred to as "plates", symbolize repeated or iterated objects within the model. Specifically, the outer plate M represents the documents, while the inner plate N represents the recurring word positions within each document. Each respective position is associated with the selection of a topic and a word. The grayed out "w" indicates that words (tokens) are the only observable variables in the model. The rest of the variables are not directly observable.

LDA data is in a so-called bag-of-words format. This format preserves word counts, but the ordering of the words is lost (Pavlinek & Podgorelec, 2017; Tijare & Rani, 2020). Each word is assigned a unique number, so the document converts to a mathematical collection of word vectors having variable lengths, characterized by latent (hidden) topic distributions (Kim et al., 2019). In LDA, a document can be a line, a paragraph, an article, a blog post, a research paper, or any piece of coherent text.

An empirical Bayes approach is used to estimate the model hyperparameters (alpha and beta) in LDA modeling. In Bayesian analysis, the inherent uncertainty about the model parameters is expressed through regeneration of probability distributions, referred to as prior distributions. The initial prior distribution is based on a researcher's subjective beliefs and knowledge before observing the data. The observed data is then combined with the prior distribution to obtain a posterior distribution, signifying the relative plausibility of each potential combination of model parameter values (Blei et al., 2003). The resulting posterior distribution is a balance between the prior beliefs about the parameter values and their compatibility with the observed data. An advantage of Bayesian analysis is that it makes the elements of statistical subjectivity transparent, rather than concealed or hidden. Since prior beliefs and subjective judgments are explicitly incorporated into the analysis, researchers openly account for their assumptions and prior knowledge. This provides a clearer understanding of the subjective aspects of the analysis and allows for a more comprehensive assessment of the results (Rouder et al., 2009).

MALLET (McCallum, 2002) and GenSim (Rehurek, 2009) are Python implementations of the LDA algorithm. Both were utilized in the transportation plan analyses described in this chapter due to their different strengths in latent topic identification.[6]

2.5.4. Text Preprocessing

The next step in LDA modeling is to prepare the corpus by cleaning and preprocessing the raw text data. This typically includes normalizing the text by removing numbers, punctuation, short words (in this case, words less than two characters), and converting the text to all lowercase. Preprocessing the text data is crucial to ensure that the LDA model can effectively identify the topics within the text.

Stopwords are removed, which helps to create the "bag-of-words" representation of the text data. Python's Natural Language Processing Toolkit (NLPT) library provided the initial list of stopwords. The list includes words such as "the", "is", "in", "to", and "of". These are considered low-information words that provide little value to the analysis of the corpus. In addition to the basic list of stopwords, specific additional stopwords were removed which represented 1) low-information words, 2) domain-specific words, 3) ambiguous words, and 4) generally uninformative words specific only to the MPO itself. Proper names often refer to specific entities or people that are not relevant to the topic being modeled and introduce noise that obscures the underlying structure of the data in topic modeling. Since the research interests in this paper did not involve identifying topics related to specific entities or individuals, removing proper names did not result in the loss of important information or reduced topic

[6] See Appendix A for the Python code used to perform the LDA MALLET base modeling and coherence testing on the MPO transportation plans.

interpretability. The additional stopwords removed from the long-range transportation plan corpora were placed in one of twelve groups as indicated in Table 2.12.

Table 2.12

LRTP-Specific Extended Stopwords

Additional Stopword Categories	
Minor Civil Division words	Survey words
Chapter, list, and chart words	Internet and computer words
Street names and landscape words	Calendar and season words
Governmental agency words	Proper name words
Directional reference words	Nonsense words
MPO-specific words	Geopolitical entity words

It is noted, however, research exists showing that while removal of corpus-specific stopwords before topic inference may improve computational efficiency, it doesn't significantly enhance the quality of topic inference (Schofield et al., 2017). Similarly, additional studies have found that enriching topic descriptions by retaining named entities like specific people, organizations, and locations can positively impact the overall quality of topics by increasing their clarity, distinctiveness, and variety (Krasnashchok and Jouili, 2018). The final step required in the preprocessing stage of model construction is to remove bigram stopwords. Bigrams are pairs of consecutive words frequently occurring together in a document. Examples of bigram stopwords removed from the long-range transportation plan corpora include "south_dakota", "jarod_larson", "social_media, and "bis_man".

A text data preprocessing technique referred to as "stemming" was also considered. Word stemming is intended to decrease vocabulary size by consolidating words with similar meanings based on their common root. For example, "walking", "walked", and "walker" can all be stemmed to "walk". However, research indicates that word stemming can also introduce confusion, unreliability, and potentially detrimental effects in language models, so word stemming was not implemented. A frequent concern with word stemming arises when different forms of the same word are meant to convey notably different meanings (Schofield & Mimno, 2016).

2.5.5. Model Training

Training LDA models is a computationally intensive process that requires significant computer processing power and memory. This step ensures that the model has been statistically validated and possesses the ability to analyze data it hasn't yet seen. As a result, the model's interpretations become more reliable and representative of real-world topics. During training, the model "learns" the distribution of topics within the corpus and the distribution of words within the topics. Typically, a small data set is selected, and topic modeling is used to sample features which are passed through a self-training algorithm. Once trained, the model is used to identify topics within the full body of the corpus (Hagen, 2018; Pavinek & Podgorelec, 2017; Rüdiger et al., 2022).

LDA MALLET models apply Gibbs sampling as their training algorithm. This is a specific type of Markov chain Monte Carlo technique used to estimate the posterior distribution of hidden variables. Through an iterative process, the Gibbs method samples the conditional distribution of each hidden variable based on the current assignments of all the other variables. This progressive refinement of assignments enhances the likelihood of the observed data matching the modeled results (Griffiths and Steyvers, 2004). Griffiths and Steyvers observed that compared to alternative approaches, Gibbs sampling tends to yield superior results in the log likelihood test, resulting in latent topics easier to interpret.

2.5.6. Number of Topics

The number of topics in an LDA model is referred to as *K*, which must be specified by the modeler. There is no single agreed-upon method of predicting the optimal number of topics in an LDA model. Instead, selecting the best *K* for an LDA model requires cross validation by applying different values of *K* within a given set of possibilities. The results of each *Kth* iteration are then examined for improvement in the overall model coherence score.

It is crucial to choose an optimal number of topics that capture the most significant themes in the text corpus. Too few topics result in models too coarse to accurately identify latent topics. Too many topics result in models that are too complex, overfitted, and difficult to interpret (Zhao et al. 2015). Zhao et al. explored several methods for establishing the optimal number of topics in topic modelling. They propose utilizing model perplexity rate of change as a function to aid optimal topic number determination. They also acknowledge that no established heuristic exists for selecting the optimal number of topics. As such, researchers resort to educated estimations or lengthy processes of trial and error to evaluate the optimal number of topics in their LDA models.

The optimal number of topics was evaluated for each individual MPO plan by examining coherence score elbow plots. Each model was run forty times, indicating 1-40 possible *K*-values, stepping through by increments of one. Coherence scores for each iteration were calculated and the results were plotted against the number of topics. The point where coherence scores peaked or began to level off were noted (i.e., the plot's "elbow"). The highest coherence *K*-value (taken from a range between 20-40 topics) was selected to continue with the hyperparameter optimization routine, as described in the next section. Figures 2.3 and 2.4 illustrate two examples (Fargo and Minneapolis) of *K*-value coherence plots.

Figure 2.3

Coherence Scores for 1-40 Topics (Fargo)

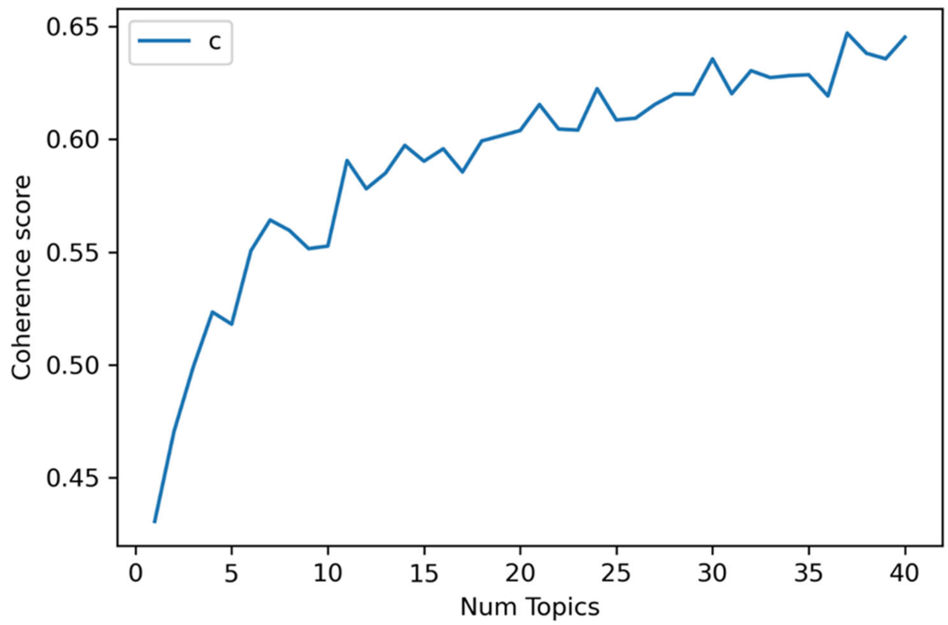
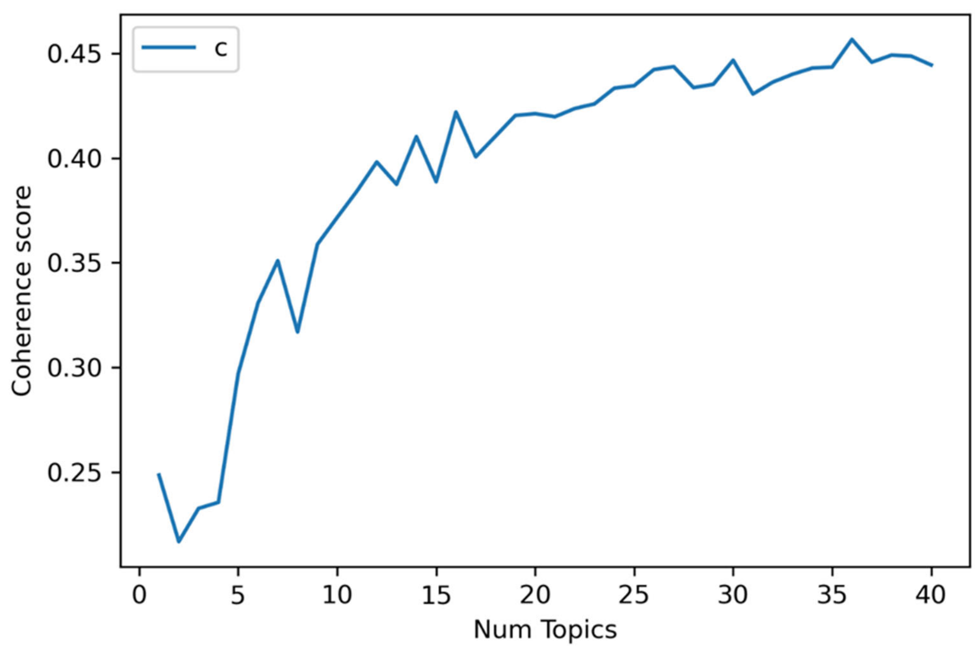


Figure 2.4

Coherence Scores for 1-40 Topics (Minneapolis)



2.5.7. Hyperparameters

The LDA model hyperparameters cannot be directly obtained through the data training phase. Instead, they must be predefined before the training occurs since they are needed to establish the initial structure of the model (Yang & Shami, 2020). As previously noted, the Greek letters alpha and beta are used to denote the Dirichlet priors used to adjust the LDA model distributions over 1) corpus topics and 2) topic words, respectively (Blei et al. 2003).

The alpha hyperparameter influences the shape and sparsity of the LDA document-topic distribution. A higher alpha value results in a more uniform distribution of topics across documents, implying that each document likely contains a similar proportion of topics. A lower alpha value promotes sparsity, making documents more likely to have a smaller subset of dominant topics (Blei et al., 2003; Rehurek, 2009).

The beta hyperparameter controls the sparsity of the topic-word distribution. A beta value of 1.0 indicates that all topics share the same prior belief about word frequency distribution, while a beta value of 0.01 specifies a fixed prior belief about the expected frequency of each word across all topics. A higher beta value creates a more uniform distribution of words across all topics, while a lower beta value promotes sparsity by favoring topics associated with a smaller subset of words (Blei et al., 2003; Rehurek, 2009).

Balancing sparsity with semantic coherence is important. Finding the right balance between sparsity and coherence is a critical aspect of LDA modeling (Boyd-Graber et al., 2017). Hyperparameter optimization for the MPO plan corpora was initially carried out using a grid search technique in Python. The script loops through several possible combinations of alpha and beta values in a grid-like fashion, with alpha and beta grid values assigned as [0.01, 0.1, 0.2, 0.4, 0.6, 0.8, 1.0]. After each pass, the script checks the model coherence value for improvement, and the process culminates with the combination of hyperparameters that maximizes coherence performance.[7]

Following the Python grid search conducted over all initial model hyperparameter combinations, each LDA model was initialized using the MALLET (MAchine Learning for LanguagE Toolkit) wrapper in the Python GenSim library. The alpha value (the Dirichlet prior on the per-document topic distributions) established in the grid search and the optimized number of topics (based on maximized coherence scores) were carried over for each MPO plan document model. The beta parameter was allowed to reoptimize accordingly. The MALLET training process consisted of 40 iterations, with optimization occurring every 10 iterations. Because the MALLET training process does not utilize a held-out test dataset (as previously noted), a log likelihood function serves as the criterion for optimization improvement. Log likelihood is a statistical measure that indicates the degree of compatibility between the model and the observed data. It estimates the probability of the model matching the observed data based on successive adjustments to the model's hyperparameters.

During MALLET model optimization, the goal is to maximize the log likelihood function. Higher log likelihood values indicate improvement in the fit between the model and the observed test data. Several researchers caution that while log likelihood informs the goodness of statistical fit, it does not provide insight into the model's actual coherence in terms of semantic similarity of words within a topic (McCallum, 2002; Schofield and Mimno, 2016; Tijare and Rani, 2020). A brief example of the MALLET training module output from one iteration is

[7] See Appendix A for the Python code used to perform the hyperparameter optimization grid searches on the MPO transportation plans.

shown in Figure 2.5, followed by an interpretation of the example MALLET training output in Table 2.13.

Figure 2.5

Sample Log Likelihood Training Algorithm Output

```
Mallet LDA: 39 topics, 6 topic bits, 111111 topic mask
Data loaded.
max tokens: 14
total tokens: 28434
<10> LL/token: -10.90783
<20> LL/token: -10.52928
<30> LL/token: -10.37987
<40> LL/token: -10.26344

Total time: 2 seconds
```

Table 2.13

LDA MALLET Training Model Interpretation

Line	**Interpretation**
Mallet LDA: 39 topics, 6 topic bits, 111111 topic mask	The model is trained to extract 39 topics from the dataset. The ‘topic bits’ and ‘topic mask’ are internal implementation details specific to Mallet.
Data loaded	The data has been successfully loaded into the Mallet LDA model.
max tokens: 14	The maximum number of unique words in a document within the corpus is 14.
total tokens: 28434	There are 28,434 total words in the entire dataset.
<10> LL/token: -10.90783 *<20> LL/token: -10.52928* *<30> LL/token: -10.37987* *<40> LL/token: -10.26344*	The log likelihood per token at different stages (10, 20, 30, 40 iterations) of the process. The model is getting “better” since the log likelihood per token is increasing.
Total time: 2 seconds	The total computation time for this training run was 2 seconds.

For further explanation, see Mallet documentation available at https://mimno.github.io/Mallet/

In summary, Python code sets up an LDA model using MALLET via the Gensim wrapper, specifying various parameters like the number of topics and optimization intervals.

Once initialized, the trained model is used to fit topics to the corpus, and subsequently, inspection of the latent topics uncovered by the LDA MALLET process is conducted. Tables 2.14 - 2.19 provide the optimized number of topics and parameters for each MPO model.

Table 2.14

North and South Dakota Optimized Results

MPO	Topics	Alpha	Beta
Bismarck	35	1.00	1.00
Fargo	37	0.80	1.00
Grand Forks	27	0.80	0.60
Rapid City	34	0.40	0.20
Sioux Falls	30	0.60	0.60

Table 2.15

Illinois Optimized Results

MPO	Topics	Alpha	Beta
Champaign	28	0.60	0.01
Chicago	30	0.20	0.80
Danville	40	0.20	0.01
Decatur	34	0.10	0.60
DeKalb	40	0.20	0.10
Kankakee	36	0.10	0.40
Bloomington	39	0.60	1.00
Rockford	39	0.10	0.60
Marion	36	0.40	0.10
Springfield	38	1.00	0.40
Peoria	32	0.10	0.40

Table 2.16

Iowa Optimized Results

MPO	Topics	Alpha	Beta
Ames	38	0.40	0.01
Davenport	21	0.20	1.00
Waterloo	26	0.60	0.10
Cedar Rapids	24	0.80	0.10
Des Moines	36	0.40	0.20
Dubuque	33	0.10	0.01
Omaha (NE)	35	0.40	0.01
Iowa City	25	0.10	1.00
Sioux City	35	0.10	0.60

Table 2.17

Minnesota Optimized Results

MPO	Topics	Alpha	Beta
Duluth	24	0.10	0.01
Mankato	37	0.01	0.40
Minneapolis	36	0.20	0.01
Rochester	34	0.40	0.60
St. Cloud	40	0.10	0.20

Table 2.18

Wisconsin Optimized Results

MPO	Topics	Alpha	Beta
Appleton	35	0.20	0.80
Eau Claire	40	0.40	0.40
Fond du Lac	33	0.01	0.20
Green Bay	39	0.10	1.00
Janesville	30	0.60	0.20
La Crosse	39	0.60	0.40
Madison	40	0.20	0.80
Oshkosh	22	0.40	0.80
Sheboygan	21	0.60	0.80
Milwaukee	28	0.80	0.40
Beloit	33	0.40	0.60
Wausau	39	0.80	1.00

Table 2.19

Statewide Optimized Results

State	Topics	Alpha	Beta
Illinois	39	0.01	0.20
Iowa	37	0.80	0.80
Minnesota	23	1.00	0.10
North Dakota	40	0.60	0.80
South Dakota	29	0.40	0.10
Wisconsin	39	0.80	0.20

2.6. Model Evaluation

While topic modeling offers significant benefits to the research community, it is also important to acknowledge it has significant limitations. Topics generated by algorithms can be challenging to interpret due to their overreliance on mathematical functions. Ultimately, the interpretation of latent topics is based on the specific goals of the analysis, the perspectives and experiences of the researcher, and the extent of their domain knowledge (Hagen 2017).

To leverage the potential of topic modeling, a systematic evaluation of each model's interpretability and validity was undertaken. Only afterwards can a topic model be considered a reliable tool to discover underlying patterns and themes within large textual corpora.

2.6.1. Semantic Coherence

Coherence is frequently regarded as an appropriate measure for evaluating the quality of generated topics. However, it's important to acknowledge that coherence metrics also have their limitations. While they can be effective at identifying poorly defined topics, they may have difficulty distinguishing genuinely coherent ones. Therefore, a high topic coherence score does not always equate to model accuracy (Rüdiger et al., 2022). As previously described, MALLET does not have a specific convergence value that the algorithm pursues before considering the model to be "trained." Instead, it iterates a specified number of times and stops when it reaches the last iteration, irrespective of whether the model has reached a preset degree of convergence. If the model is stable, similar results should be attained if the model is tested using a held-out dataset (as with GenSim) as it does by dividing the corpus into subsets used for both training and topic modeling (as with MALLET).

Coherence scores for LDA models range from 0 to 1. The higher the score, the better the model coherence. The specific range of coherence scores deemed "good" varies, depending on the dataset, coherence algorithm used, and data application. While a coherence score above 0.55 was considered a good result for the purposes of this research, what is more important is the relative comparison of coherence scores between different models and configurations. The optimized model coherence scores are presented in Tables 2.20 - 2.25.

Table 2.20

North and South Dakota Coherence Results

MPO	A/B Optimized
Bismarck	0.7174
Fargo	0.6768
Grand Forks	0.6087
Rapid City	0.6411
Sioux Falls	0.6309

Table 2.21

Illinois Coherence Results

MPO	A/B Optimized
Champaign	0.6253
Chicago	0.6014
Danville	0.7371
Decatur	0.6663
DeKalb	0.6664
Kankakee	0.6707
Bloomington	0.6808
Rockford	0.6448
Marion	0.7473
Springfield	0.6771
Peoria	0.6889

Table 2.22

Iowa Coherence Results

MPO	A/B Optimized
Ames	0.6826
Davenport	0.6582
Waterloo	0.6605
Cedar Rapids	0.6240
Des Moines	0.5739
Dubuque	0.6730
Omaha (NE)	0.6569
Iowa City	0.7066
Sioux City	0.7210

Table 2.23

Minnesota Coherence Results

MPO	A/B Optimized
Duluth	0.6679
Mankato	0.6734
Minneapolis	0.4555
Rochester	0.5942
St. Cloud	0.6538

Table 2.24

Wisconsin Coherence Results

MPO	A/B Optimized
Appleton	0.7197
Eau Claire	0.6851
Fond du Lac	0.7246
Green Bay	0.6988
Janesville	0.6508
La Crosse	0.6967
Madison	0.6154
Oshkosh	0.7192
Sheboygan	0.6138
Milwaukee	0.6375
Beloit	0.6212
Wausau	0.6471

Table 2.25

Statewide Coherence Results

MPO	A/B Optimized
Illinois	0.4279
Iowa	0.4318
Minnesota	0.5167
N. Dakota	0.5559
S. Dakota	0.5700
Wisconsin	0.4059

2.6.2. Significance Testing

A paired sample t-test was completed to assess whether optimizing the LDA models led to a statistically significant improvement in their performance. All forty-two MPOs were included in the examination. For statistical significance testing, the unoptimized coherence scores represented the “before” condition, and the A/B Optimized scenario coherence score results represented the “after” or improved model condition. The hypothesis is that there would be a significant improvement in coherence data scores between the initial and A/B Optimized scenarios. The test results show a significant improvement, having a t-statistic of 14.64, degrees of freedom (df) = 41, and a p-value less than 0.05. The p-value is much less than the alpha level of 0.05, so the null hypothesis – that there is no significant difference in coherence scores between the scenarios - is rejected. Finally, the effect size for this difference was calculated using the Cohen's d metric, which resulted in a value of 2.26. According to Cohen's guidelines for interpreting d, this indicates an exceptionally large effect size, suggesting that the mean difference between the two data sets is not only statistically significant, but also has significant practical importance and relevance.

2.6.3. Human Evaluation

In specialized corpora collections like long-range transportation plans, mathematical measures of topic coherence are not sufficient for identifying the best model or determining the ideal number of topics. This is especially true in exploratory research whereby model quality cannot be confirmed by comparing it to ground truth data (Doogan and Buntine, 2021; Rüdiger et al., 2022).

A significant portion of computational analysis in topic modeling revolves around optimizing specific metrics, such as log probabilities and topic coherence. Only after the computational optimization is complete does the skillful application of linguistic, contextual, and interpretive acumen become prominent. This underscores the fundamental role of human expertise in the LDA model evaluation process, which emerges as an indispensable step at the concluding stages of topic model interpretation (Baumer et al., 2017). In this case, the human topic evaluator was the researcher, having considerable experience with the subject matter.[8]

2.7. Semantic Interpretation

In this section, several semantic interpretation analyses are conducted using multiple measures for each MPO transportation plan. Additionally, a compilation of MPO plans for their respective states was created and examined. Interpreting the linguistic elements of LDA model topics involves statistical analysis, visualization techniques, and domain expertise. It requires examining the keywords associated with each topic and studying the interrelationships between topics. NLP semantic interpretation incorporates word frequencies, n-grams, inferred topic assessment, and climate-specific keyword analyses.

2.7.1. Word Frequency

Word frequency analysis is a simple yet powerful quantitative technique that yields insights into the prominence and importance of certain terms within each document. The approach entails counting the occurrences of each word and determining their relative frequencies, providing perspectives on their usage and importance. By identifying the most frequently used terms, a better understanding of the central themes and subjects discussed within the corpus is gained.

2.7.2. N-grams

"N-gram" is a comprehensive term encompassing various sequences of words such as unigrams, bigrams, trigrams, and so forth. The analysis of n-grams enables the examination of the relationships between individual words and their broader linguistic context. This technique

[8] Chapter 4 also provides a comparison of the LDA-determined latent themes and the sustainability themes each Wisconsin MPO identified as significantly included in their current long-range transportation plan documents.

proves particularly valuable in LDA topic modeling as it provides greater contextual information from within the corpus. To demonstrate, consider the frequent occurrence of “transportation” and “management” within a long-range transportation plan. When these words are considered in isolation, their intended meanings are limited and without context. However, when combined as “transportation_management”, a more insightful interpretation is provided based on the frequencies of their co-occurrence. When extending this example to the trigram “transportation_demand_management”, an even more distinct and informative meaning is conveyed.

Figures 2.6 and 2.7 demonstrate the different patterns and contextual insights gleaned from the n-grams in the Fargo and Minneapolis transportation plans. Each plot illustrates the top-30 occurrences of the n-gram results.

Figure 2.6

N-gram Plots (Fargo)

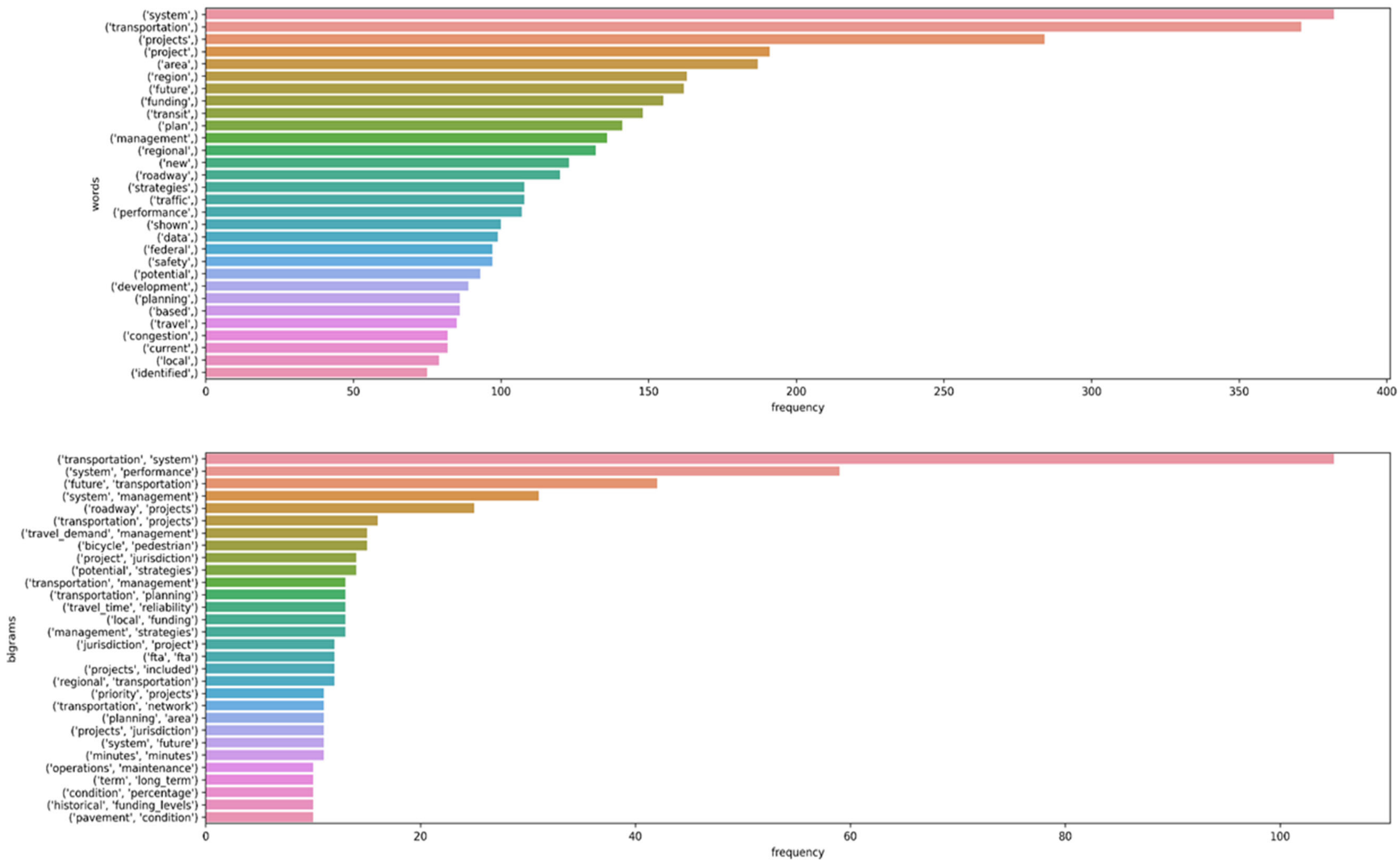
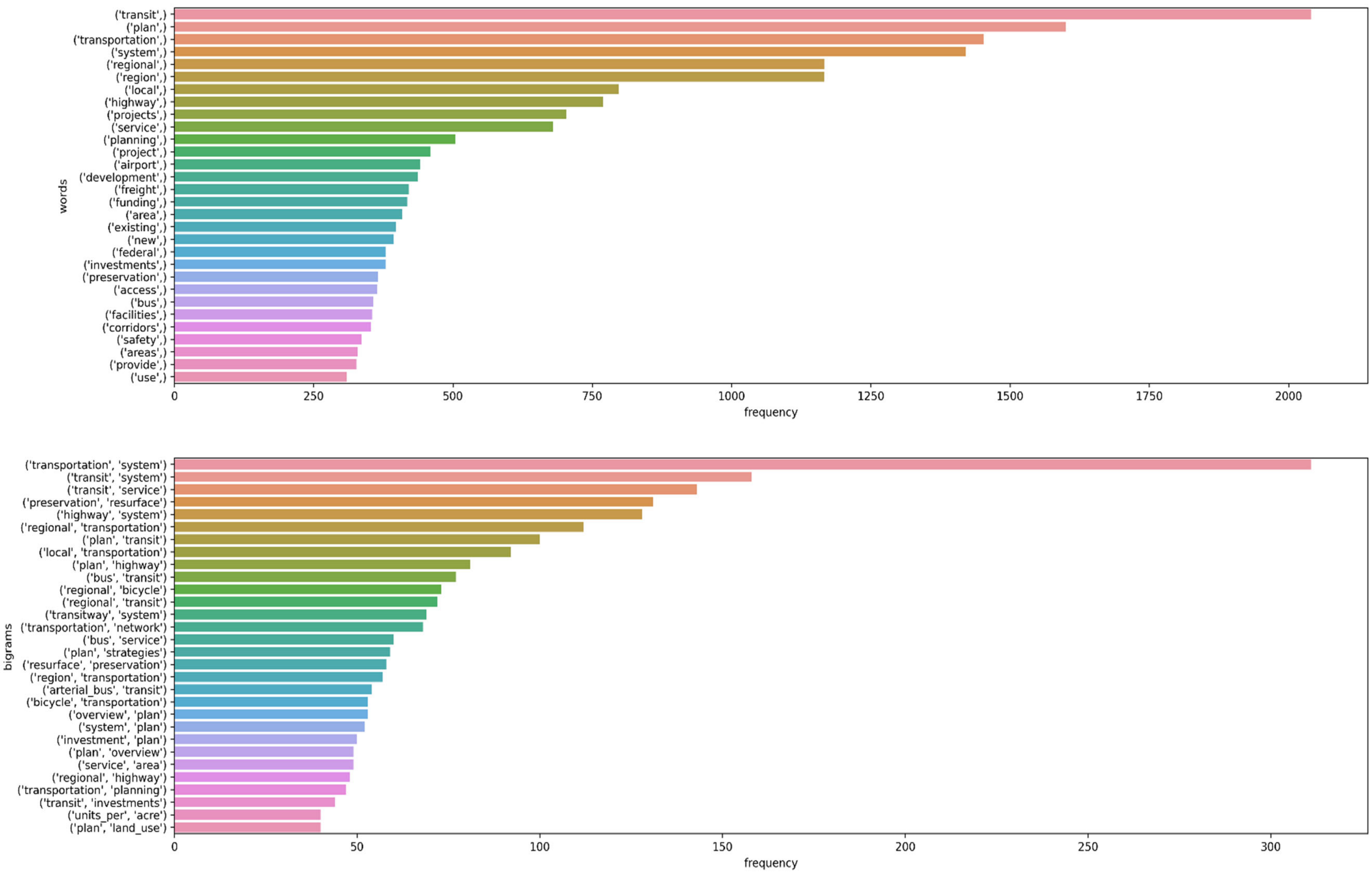


Figure 2.7

N-gram Plots (Minneapolis)



2.7.3. Climate Keywords

MPO long-range plan documents typically emphasize regional transportation and infrastructure needs. As previously noted in the introduction, these components are broadly acknowledged as essential elements within the framework of climate change. Not all MPO transportation plans exhibit strong or direct connections to climate change, however. While transportation and infrastructure play important roles in the climate change discourse, the level of emphasis on climate-related aspects within MPO transportation plans varies, reflecting diverse regional priorities and mandates of local policymakers.

To ascertain the extent to which climate change topics were addressed in the MPO transportation plans, a set of climate-specific keywords was developed. Table 2.26 provides a list of forty-five climate related keywords utilized in a search through all the long-range transportation plans. While initial keyword queries included additional terms such as global warming, greenhouse gases, carbon dioxide, nitrous oxide, carbon footprint, carbon sequestration, carbon capture, carbon offset, emission reduction, and renewable energy, these specific terms did not emerge in the corpora dataset. Also, terms like "bike" and "walk" were omitted from the climate keyword queries because active transportation keywords would likely appear in other climate topic areas, for example, in those concerning quality of life or regional mobility options.[9] Table 2.27 provides a detailed matrix of the frequency of climate-related keywords, broken down by states and MPOs.

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[9] See Appendix A for the Python code used to identify the latent topics which included the climate keywords plans.

Table 2.26

Climate Related Keywords and Corpus Frequencies

Climate Keywords	Description	Number
climate, climate_change	Keywords directly related to the changes in the Earth's climate that are occurring due to global warming.	349
greenhouse, greenhouse_gas, carbon, carbon_monoxide, oxides, methane, nitrous, nitrogen, fossil_fuels	Keywords related to the warming of the planet through the greenhouse effect caused by the buildup of these gases in the atmosphere.	534
emissions, air, air_quality, air_pollution, pollution, pollutants, clean_air, tailpipe	Keywords related to the quality of the air we breathe and how it is impacted by the emissions of greenhouse gases and other pollutants.	3159
resilience, resiliency	Keywords related to how well ecosystems and human communities can adapt to the changing climate and its impacts.	358
energy, hybrid_electric, electrification, electrified, electric, electric_buses, electric_bikes, evs, cng	Keywords related to reducing emissions from transportation, reliance on fossil fuels, and transitioning to cleaner forms of energy.	1107
greening, green, green_design, conservation, natural, habitat, wetland, watershed, runoff	Keywords related to reducing greenhouse gas emissions and improving the health of the environment.	2803
extreme_weather, environment, environmental, sustainability, sustainable, quality_life	Keywords related to climate change as they seek to minimize the impact of human activities on the natural environment and mitigate the effects of climate change.	4472

Table 2.27

Climate Related Keyword Occurrences by State and MPO

	Illinois											IA	MN/ND/SD	WI	
Keyword	Bloomington	Chicago	Danville	Decatur	DeKalb	Kankakee	Marion	Peoria	Rockford	Springfield	Urbana		*(See next pages.)*		**Totals**
climate	6	24	4	1		9		2	9	1	6				**236**
climate_change	7					7					8				**113**
greenhouse	8	1			4	1		1	3		5				**90**
greenhouse_gas		26							10		7				**95**
carbon	1	5				7	5	5	2	1	5				**192**
carbon_monoxide									7						**33**
oxides		5						2	2						**29**
methane		2							1						**15**
nitrous		1							1						**7**
nitrogen	2	5				1		3	7		3				**60**
fossil_fuels											7				**13**
emissions	10	115	1	7	7	5		21	21	2	89				**813**
air	9	15	3	21	4	16	17	39	34	21	57				**1003**
air_quality	8	38		15	9	29	6	30	48		41				**783**
air_pollution								15							**77**
pollution		4		2	2			10	15	1	12				**232**
pollutants	4	9		1	4	6		21	15		11				**167**
clean_air									10						**73**
tailpipe															**11**
resilience	1	15				3		1	9		1				**126**
resiliency	3	1		5		8		4	20	1					**232**
energy	8	19	2	3	6	10	9	4	16	2	27				**457**
hybrid_electric									12						**27**
electrification		2													**17**
electrified											2				**8**
electric		4		4	6	11	1	2	14	1	10				**371**
electric_buses								6							**43**
electric_bikes															**6**
evs						8			1						**56**
cng	1	2								2					**122**
greening															**4**
green	2	27	2	2	24	2	3	22	7	3	269				**825**
green design															**27**
conservation	3	25	1	14	9	11		12	25	1	6				**512**
natural	5	13	4	12	14	28	5	29	55	14	35				**824**
habitat		2		3	11	7	1	7	5	6	3				**145**
wetland				5		15	2	4	3	2	5				**233**
watershed		9			1			4	3						**94**
runoff	5			1	1			8	4	1					**139**
extreme_weather															**44**
environment	7	18	15	10	27	9	8	62	64	20	70				**1304**
environmental	42	10	13	37	20	44	15	40	88	15	47				**1825**
sustainability	27	1	2		7	2	3	6	16	3	22				**376**
sustainable	30	11	2	2	3		17	4	22	3	102				**499**
quality_life	9	8	8	10			4	15	24	6	14				**424**
Totals	**198**	**417**	**57**	**155**	**159**	**239**	**96**	**379**	**573**	**106**	**864**				**12782**

Table 2.27

Climate Related Keyword Occurrences by State and MPO (Continued)

	IL	Iowa									MN/ND/SD	WI	
Keyword	*(See previous page.)*	Ames	Cedar Rapids	Davenport	Des Moines	Dubuque	Iowa City	Omaha	Sioux City	Waterloo	*(See next pages.)*		**Totals**
climate			5	10	12	4	11	11	2				**236**
climate_change				8	9		8						**113**
greenhouse		2	3	5	2	3	4	2	1				**90**
greenhouse_gas					9								**95**
carbon		2		63	13	4	2	1	2				**192**
carbon_monoxide						6							**33**
oxides			1		1	4		2	1				**29**
methane					2	4	1		2				**15**
nitrous								1					**7**
nitrogen			1		6	3			1				**60**
fossil_fuels													**13**
emissions		7	12	11	31	108	14	6	3	1			**813**
air		12	7	50	24	59	20	28	25	28			**1003**
air_quality			9	22	29	79	14	24	9	6			**783**
air_pollution					8								**77**
pollution		3	4	4	21	8	5	5	3	3			**232**
pollutants			4	1	14	14	1	1		1			**167**
clean_air				6	17	14							**73**
tailpipe		2	1		1								**11**
resilience				34	14		1						**126**
resiliency		4	16	2	22	2	1	1	3	2			**232**
energy		5	9	18	69	29	5	3	17	5			**457**
hybrid_electric													**27**
electrification		2			3								**17**
electrified		1				1							**8**
electric		18	5	5	24	5	6	3	26	1			**371**
electric_buses				7					7				**43**
electric_bikes													**6**
evs					1	7							**56**
cng				3		7			9				**122**
greening					2								**4**
green		1	6	5	66	15	7	5	3	6			**825**
green design			27										**27**
conservation		7	8	9	94	24	2	7	7	11			**512**
natural		14	8	27	77	16	11	17	18	20			**824**
habitat		3	1	4	21	5	1	1	3	4			**145**
wetland		1	5	3	13	1		5		2			**233**
watershed			7		29			4	1				**94**
runoff			2	2	41			1	11				**139**
extreme_weather				31	7								**44**
environment		8	26	24	109	23	20	29	14	17			**1304**
environmental		25	41	46	98	90	33	17	23	45			**1825**
sustainability		2	5	11	53	15	2	3	2	1			**376**
sustainable		5	9	10	55	40	5	3	4	5			**499**
quality_life			9		25	12	15	13	6				**424**
Totals		**124**	**231**	**421**	**1022**	**602**	**189**	**193**	**203**	**158**			**12782**

Table 2.27

Climate Related Keyword Occurrences by State and MPO (Continued)

	IL	IA	Minnesota					ND			SD		WI	
Keyword	*(See previous pages.)*		Duluth	Mankato	Minneapolis	Rochester	St. Cloud	Bismarck	Fargo	Grand Forks	Rapid City	Sioux Falls	*(See next page.)*	**Totals**
climate			10	8	20	5	6			5	1	3		**236**
climate_change				9	18									**113**
greenhouse				1	3	1	2		1	2		3		**90**
greenhouse_gas					28		8			7				**95**
carbon			3		6	9	5		1	4	5	10		**192**
carbon_monoxide					20									**33**
oxides					5									**29**
methane							1							**15**
nitrous							1							**7**
nitrogen			1		10		3			3	3			**60**
fossil_fuels			6											**13**
emissions			6	2	101	6	24	4	1	22	9	23		**813**
air			35	10	128	7	36	13	10	6	19	23		**1003**
air_quality					92	8	46			24	19	27		**783**
air_pollution					12		12							**77**
pollution			23	3	12	6	31			3	5	4		**232**
pollutants			3		14	4	16		1		1			**167**
clean_air					10	8								**73**
tailpipe					2	1	1			3				**11**
resilience				9	4		3	4		4		1		**126**
resiliency			18	11	1	6	6		14	18		6		**232**
energy			7	9	26	11	10	5	5	14	3	15		**457**
hybrid_electric					7							8		**27**
electrification					4				2	1		1		**17**
electrified					2	1						1		**8**
electric			5	7	25	24	20		17	3	1	52		**371**
electric_buses					6									**43**
electric_bikes						6								**6**
evs				3	4	5	20					6		**56**
cng							62							**122**
greening					2									**4**
green			20	3	45	8	11		1	24	14	20		**825**
green design														**27**
conservation			3	7	1	12	91	8	5		11	10		**512**
natural			10	12	29	36	40	7	8	17	11	3		**824**
habitat						2	18	2	7	1	4			**145**
wetland			1	12	2	2	72	3	4		9			**233**
watershed					2	9	20							**94**
runoff			1	1	2	4	23					1		**139**
extreme_weather														**44**
environment			106	8	70	45	112	15	21	68	34	26		**1304**
environmental			56	40	89	71	92	24	33	60	45	47		**1825**
sustainability			29	10	29	4	7	2	4	7	11	34		**376**
sustainable			51	2	17	7	6	1	3	11		7		**499**
quality_life			6		16	10	25		6	47	11	9		**424**
Totals			**400**	**167**	**864**	**318**	**830**	**88**	**144**	**354**	**216**	**340**		**12782**

Table 2.27

Climate Related Keyword Occurrences by State and MPO (Continued)

	IL	IA	MN/ND/SD	Wisconsin												
Keyword	*(See previous pages.)*			Appleton	Beloit	Eau Claire	Fond du Lac	Green Bay	Janesville	LaCrosse	Madison	Milwaukee	Oshkosh	Sheboygan	Wausau	**Totals**
climate				1	4	4	1		32	1	3	7	1	6	1	**236**
climate_change					11				22	6						**113**
greenhouse				2	2	5	2		5	2	2	7	2	1	2	**90**
greenhouse_gas																**95**
carbon				2	6	1	2		3	3	2	8	2	2		**192**
carbon_monoxide																**33**
oxides												2		4		**29**
methane												2				**15**
nitrous					1							2				**7**
nitrogen											1	3		4		**60**
fossil_fuels																**13**
emissions				3	9	13	3	3	10	4	9	33	3	50	4	**813**
air				4	10	34	3	21	14	28	34	14	4	46	15	**1003**
air_quality				7	10	7	8		8	11	14	24	7	55		**783**
air_pollution				8		6	8						8			**77**
pollution				2	2	7	2	1	1	1	10	6	2	6	3	**232**
pollutants									2	1	3	6		9		**167**
clean_air														8		**73**
tailpipe																**11**
resilience				1	4	1	1		9		1	3	1	1		**126**
resiliency				3	17	1	3	1	6	3	2	11	3	5	2	**232**
energy				7	4	7	7	2	7	4	13	15	7	9	4	**457**
hybrid_electric																**27**
electrification											2					**17**
electrified																**8**
electric					26			3	3	11	8	16		2	2	**371**
electric_buses					9						8					**43**
electric_bikes																**6**
evs									1							**56**
cng														36		**122**
greening																**4**
green				29	6	10	22	3	15	13		26	23	43	12	**825**
green design																**27**
conservation				6	6	7	6	1	10	8	15	8	6	11	4	**512**
natural				4	24	23	7	11	26	17	26	21	4	56	10	**824**
habitat					1	7	1			4	2	5		2	1	**145**
wetland				3		11	4	7		2	10	3	3	15	4	**233**
watershed					1			1			1			2		**94**
runoff					7	3		1	4		4	5		5	1	**139**
extreme_weather									6							**44**
environment				13	46	18	17	7	23	15	26	7	7	21	19	**1304**
environmental				25	46	52	26	30	33	25	87	37	25	60	33	**1825**
sustainability				1	3	9	2	1	1	4	10	20	2	1	2	**376**
sustainable				3	8	3	3	3	2		16	15	3	3	3	**499**
quality_life				8	23	16	7			7	48		7			**424**
Totals				**132**	**286**	**245**	**135**	**96**	**243**	**170**	**357**	**306**	**120**	**463**	**122**	**12782**

2.7.4. LDA Model Topic Inference

The topic distribution results obtained from LDA MALLET (McCallum, 2002) and the pyLDAvis library (Mabey, 2015) provide the central topics found within each corpus. A fundamental assumption in topic modeling is that each topic captures word co-occurrences that are semantically related. It is also expected that a specific topic's distribution of words differs from that of other topics (Wallach et al., 2009). Words associated with each topic represent the most significant terms or words that characterize that topic. These words are distributed based on their relevance or importance within each topic. The model assigns probabilities to different potential topics in the document as well as different words within the topic.

Tables 2.28 and 2.29 illustrate examples of latent topics related to climate change, revealed using the LDA MALLET model, from the Fargo and Minneapolis transportation plans.

Table 2.28

Document and Topic Probability (Fargo Example)

Category	Answer/Output
Plan Name	Metro Grow 2045, FMCOG, November 2019
Topic Number	1
Topic Probability	0.03141794051833944
Interpretation	Topic 1 was revealed in the document with a probably of 0.0314. This means that roughly 3.14% of the words in the Fargo plan are estimated to be about this topic.
Keyword Weighting	0.095*"project" + 0.050*"impacts" + 0.047*"potential" + 0.045*"projects" + 0.044*"environmental" + 0.037*"populations" + 0.027*"jurisdiction" + 0.026*"impact" + 0.021*"benefits" + 0.016*"roadway" + 0.015*"based" + 0.015*"types" + 0.015*"identified" + 0.015*"location" + 0.015*"determined" + 0.015*"operations" + 0.011*"diversion" + 0.011*"effects" + 0.011*"field" + 0.011*"evaluate" + 0.011*"areas" + 0.010*"long" + 0.010*"pavement_target" + 0.010*"economic" + 0.010*"aircraft" + 0.010*"social" + 0.010*"section" + 0.010*"municipal" + 0.010*"mitigation" + 0.008*"project_scoring"
Interpretation	Topic 1 is related to project planning and assessment, with a particular emphasis on environmental impacts, jurisdiction, roadways, operations, and other aspects like mitigation and economic/social benefits.

Table 2.29

Document and Topic Probability (Minneapolis Example)

Category	Answer/Output
Plan Name	Thrive MSP Transportation Policy Plan 2040, Metropolitan Council, 2020 Update
Topic Number	0
Topic Probability	0.01517961511294891
Interpretation	Topic 0 was revealed in the document with a probably of 0.0152. This means that roughly 1.52% of the words in the Minneapolis plan are estimated to be about this topic.
Keyword Weighting	0.046*"emissions" + 0.041*"transportation" + 0.036*"impacts" + 0.024*"reduce" + 0.022*"air" + 0.022*"related" + 0.020*"greenhouse_gas" + 0.019*"mitigation" + 0.017*"health" + 0.015*"construction" + 0.015*"benefits" + 0.014*"environmental" + 0.014*"climate" + 0.013*"reducing" + 0.013*"natural" + 0.013*"energy" + 0.013*"noise" + 0.013*"climate_change" + 0.012*"communities" + 0.011*"operations" + 0.011*"sustainability" + 0.010*"avoid" + 0.010*"quality" + 0.010*"regional" + 0.009*"potential" + 0.009*"environment" + 0.008*"impact" + 0.008*"mitigate" + 0.008*"protect" + 0.008*"costs"
Interpretation	Topic 0 is related to environmental impacts, specifically focusing on transportation emissions and environmental mitigation. It includes aspects such as greenhouse gas emissions, air quality, health impacts, and mitigation strategies related to environmental factors. Words like “climate_change”, “sustainability”, and “mitigate” suggests actions to be taken to address and reduce environmental damage and promote sustainable practices.

The process of assigning latent topics to plausible climate topic groups was generally clear and straightforward. In a properly trained model, when a set of keywords are assigned to a climate change topic, the latent groupings usually exhibit several instances of similar and contextually consistent word placements. For this research, in cases where multiple keywords in the output could be associated with different climate-oriented topics, the keyword having the highest probability of belonging to that topic group was often chosen.

Table 2.30 presents a summary of the outcomes of the LDA model’s latent topic analysis. The table displays each of the twelve climate topics, accompanied by the frequency of those topic occurrences within the entire study corpora, ranked from highest to lowest. Figure 2.8

offers a graphic illustration of the frequencies of each identified climate change topic as they appear across the entire corpora of MPO long-range transportation plans.

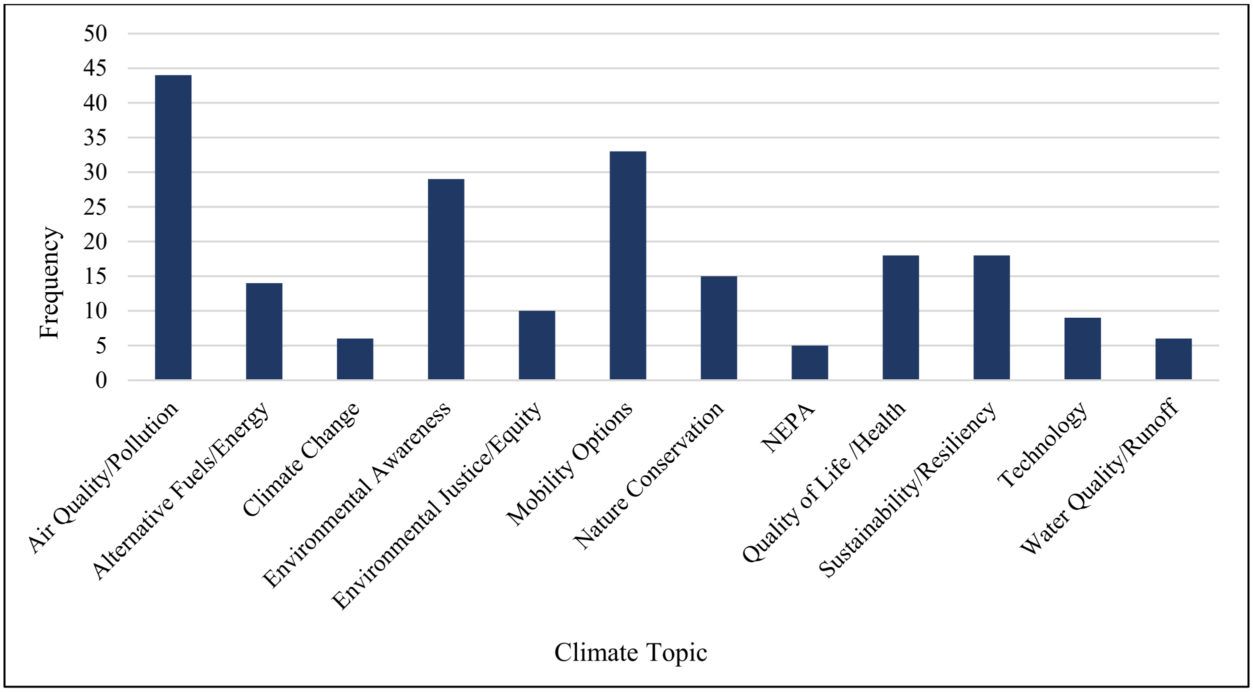
Table 2.30

LDA Revealed Climate Topics

LDA Climate Topic	Frequency
Air Quality/Pollution	44
Mobility Options	33
Environmental Awareness	29
Quality of Life /Health	18
Sustainability/Resiliency	18
Nature Conservation	15
Alternative Fuels/Energy	14
Environmental Justice/Equity	10
Technology	9
Climate Change	6
Water Quality/ Runoff	6
NEPA	5

Figure 2.8

LDA Revealed Climate Topics by Frequency



NLP and LDA models are not flawless and can produce false positives. Instances included climate keywords appearing to be intruders amongst the rest of the words in the topic group, climate keywords placed out of context within their surrounding words, climate keywords included in nonsensical topic collections, and a solitary climate keyword having a very weak association within their topic probability distributions. Several examples of each of these for cases are illustrated in Table 2.31.

Table 2.31

Four Cases of NLP False Positive Keywords

Case 1	**Keywords as topic intruders**
Topic36	million, vehicle_miles, **green**, traveled, offers, plan, evaluation, volunteer, movement, smile, dividend, identified, events, workshops, people, public_input, volunteers, donations, package, meals, combination, prior, host, future, annual, simple, approval, waste, opportunity, get_involved
Topic7	committee, advisory, place, range, wayfinding, incident, system, group, implementation, evaluation, residence, commuter, work, **environment**, partners, trade, team, management, signage, study, review, working, monitoring, involves, increasing, install, discussion, prepare, responders, passenger
Topic18	transportation, planning, plan, area, projects, federal, long_range, project, local, lrtp, investment, policy, plans, development, regional, factors, analysis, organization, **environmental**, investments, objectives, district, based, work, developed, requirements, included, agencies, interstate, programs
Topic18	funded, intersection, urban, public_review, unfunded, mile, illustrative, interchange, feeney, sincerely, high, **sustainability**, dear, weighted, portions, capitol, planner, vitality, highway, resident, priority, tac, time_band, target, committee, factype, meetings, decent_pavement, shoulder, extension
Case 2	**Keywords in non-climate context**
Topic18	freight, truck, network, **air**, transportation, facilities, mode, water, primary, system, numerous, region, tonnage, long, shipments, commodities, rail, commodity, begin, bulk, gas, cargo, trends, intermodal, transport, expected, zone, future, options, ports
Topic30	rail, goods, freight, commodities, truck, region, facilities, traffic, roads, barge, **air**, water, access, mixed, result, frontage, high, operations, terminals, limited, grain, fertilizers, global, tonnage, products, fertilizer, projects, lower, cargo, coal
Topic15	projects, transportation, funding, plan, planning, public, project, federal, plans, mapping, local, funds, goals, area, proposed, document, specific, review, identified, **environmental**, potential, identify, study, regional, agencies, section, program, development, goal, general
Topic2	project, impacts, potential, projects, **environmental**, populations, jurisdiction, impact, benefits, roadway, based, types, identified, location, determined, operations, diversion, effects, field, evaluate, areas, long, pavement_target, economic, aircraft, social, section, municipal, mitigation, project_scoring
Case 3	**Keywords in a nonsensical topic list**
Topic9	delay, hcm_control, approach, hcm_ctrl, intersection, downtown, photo, ramp, neighborhood, elementary, theforksmpo, bnsf, university, herald, greenway, campus, **green**, tracks, bridge, kittson, sertoma, agassiz, language, garden, gateway, home, sherlock, frequently, connects, visitors
Case 4	**Keywords having low probability in topic distribution**
Topic31	region, community, residents, communities, future, system, place, strategy, economic, regional, create, role, support, goal, building, existing, area, ensure, places, walkable, neighborhoods, character, continue, resources, people, development, **environment**, strong, work, corridors
Topic25	projects, transportation, transit, programs, funding, program, funds, eligible, grant, agency, agencies, public, federal, fund, areas, assistance, improvements, infrastructure, organizations, support, construction, local, development, services, include, **conservation**, activities, acquisition, provide, grants
Topic30	alternatives, study, technical, project, identified, analysis, review, held, college, committee, contact, input_meetings, location, week, serves, railway, project_phasing, options, efforts, direction, evaluation, ash, depending, capitol, coulee, **wetland**, information, agency, evaluate, foods

2.8. Transportation Plan Similarities

The results of the quantitative data analysis conducted using various mathematical and statistical techniques are presented in this section.

2.8.1. Cosine Similarity (Corpora)

Transportation plan content comparisons involve assessing cosine similarities between word vectors and creating data heat maps (color-coded matrix tables) to visualize the results. Larger documents naturally tend to contain a greater frequency of common words, leading to an overestimation of their similarity when compared to other documents. This phenomenon is referred to as "length bias" in statistical analyses and can adversely affect the accuracy of tasks such as similarity comparisons, text mining, or document clustering (Losada and Azzopardi, 2008). In vector space modeling, words are mapped to numerical vectors within a space characterized by multiple dimensions (Jentzsch et al., 2019). In the context of unstructured data, such as the bag-of-words representations, the vectors are often characterized by sparsity and high dimensionality, which presents analytical challenges (Rüdiger et al., 2022).

To address these challenges, a cosine similarity analysis can be applied on only the latent topic spaces determined by the LDA model, rather than the entire word space, therefore making more pertinent document comparisons. Cosine similarity can also be measured not on the entire corpus, but rather on a subset of specific words residing within the corpus. Both these techniques focus the analysis on specific points of interest and can help mitigate the impact of corpus word sparsity and exceedingly high dimensionality (Pavlinek and Podgorelec, 2017).

Cosine similarity quantifies the degree of semantic similarity between words and phrases based on their vector representations. The more similar the words are, the higher the cosine value. If specific word vectors appear with the same surrounding words (perfect overlap) the cosine value is 1.0. If specific word vectors never appear with the same surrounding words (no overlap), then the cosine value would be zero (Schutze, 1998).[10] Deciding if two documents are similar when their cosine similarity score is 0.5 can be a subjective process and depends on specific factors like the number of topics, the words related to each topic, and the model's posterior distributions (Liu et al., 2018).

Table 2.32 provides an example of cosine similarity results obtained from the analysis of Wisconsin MPO transportation plans. This analysis was conducted on the complete corpus of each plan, after completing the necessary text cleaning procedures.[11] The cosine similarity table is a symmetric matrix. The diagonal elements represent the cosine similarity between a document and itself, which is always 1.0. Cells off the diagonal represent the cosine similarity between different documents within the corpus; in this case, individual Wisconsin MPO transportation plans. A higher value indicates that the documents are more similar in terms of their topic weightings, while a lower value indicates that the documents are less similar.

The results are shown as a heatmap, colorfully representing how similar the documents are. Each cell in the heatmap represents the similarity between a pair of documents, with values ranging from 0 to 1. The darker red cells represent high cosine similarity values, indicating the documents have more commonalities in their content. The darker green cells represent lower cosine similarity values, indicating that the pair of documents have fewer commonalities in their content.

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[10] Technically, cosine similarity could also be negative if vectors point in completely opposite directions, although in most applications with text (especially in bag-of-words models) the value is constrained between 0 and 1.
[11] See Appendix A for the Python code used to perform the cosine similarity test on the MPO transportation plans.

Table 2.32

Cosine Similarity Results - WI MPOs (Corpora)

	Appleton	Beloit	Eau Claire	Fond du Lac	Green Bay	Janesville	La Crosse	Madison	Milwaukee	Oshkosh	Sheboygan	Wausau
Appleton	1.00	0.44	0.38	0.74	0.47	0.44	0.47	0.38	0.33	0.81	0.44	0.45
Beloit	0.44	1.00	0.44	0.44	0.47	0.56	0.48	0.44	0.33	0.48	0.47	0.55
Eau Claire	0.38	0.44	1.00	0.38	0.44	0.44	0.43	0.39	0.26	0.42	0.39	0.48
Fond du Lac	0.74	0.44	0.38	1.00	0.46	0.42	0.47	0.38	0.32	0.80	0.44	0.44
Green Bay	0.47	0.47	0.44	0.46	1.00	0.51	0.48	0.44	0.39	0.50	0.50	0.56
Janesville	0.44	0.56	0.44	0.42	0.51	1.00	0.51	0.46	0.36	0.47	0.47	0.63
La Crosse	0.47	0.48	0.43	0.47	0.48	0.51	1.00	0.42	0.37	0.52	0.47	0.48
Madison	0.38	0.44	0.39	0.38	0.44	0.46	0.42	1.00	0.32	0.41	0.40	0.48
Milwaukee	0.33	0.33	0.26	0.32	0.39	0.36	0.37	0.32	1.00	0.35	0.31	0.33
Oshkosh	0.81	0.48	0.42	0.80	0.50	0.47	0.52	0.41	0.35	1.00	0.49	0.49
Sheboygan	0.44	0.47	0.39	0.44	0.50	0.47	0.47	0.40	0.31	0.49	1.00	0.48
Wausau	0.45	0.55	0.48	0.44	0.56	0.63	0.48	0.48	0.33	0.49	0.48	1.00

An examination of the color-coded heatmap of cosine similarity values reveals that the Fond du Lac, Oshkosh, and Appleton transportation plans have very high degrees of similarity. This is expected, because the MPOs represented by those cities, while located within separate MPOs, share the same staff. Wausau and Green Bay share similarities in their long-range transportation plans, as do Janesville and Beloit. Janesville and Beloit are adjacent MPOs, both located in Rock County, Wisconsin. The state's two largest MPOs, Madison and Milwaukee, are notably dissimilar to the other ten Wisconsin MPOs, which is understandable given their differences in size, budgets, and staffing resources. In fact, the cosine similarity scores for Milwaukee indicate a high amount of dissimilarity when compared to the other state MPOs.

By examining patterns in the cosine similarity heatmaps, insights into which documents are most similar or dissimilar to each other can be gained. This section only shows the Wisconsin MPO comparisons. Comprehensive cosine similarity comparisons of MPO transportation plans were completed and reviewed.[12] The groupings of long-range transportation plans examined in this manner are shown in Table 2.33.

[12] See Appendix C: Cosine Similarity Test Results for a complete set of heat map tables for all groupings.

Table 2.33

Cosine Similarity Test Groups

Similarity Group	States/MPOs Included
All States	Illinois, Iowa, Minnesota, North Dakota, South Dakota, Wisconsin
Dakotas	Bismarck, Fargo, Grand Forks, Rapid City, Sioux City
Illinois	Bloomington, Chicago, Danville, Decatur, DeKalb, Kankakee, Marion, Peoria, Rockford, Springfield, Urbana
Iowa	Ames, Cedar Rapids, Davenport, Des Moines, Dubuque, Iowa City, Omaha, Sioux City, Waterloo
Minnesota	St. Cloud, Minneapolis, Mankato, Duluth, Rochester
Wisconsin	Appleton, Beloit, Eau Claire, Fond du Lac, Green Bay, Janesville, La Crosse, Madison, Milwaukee, Oshkosh, Sheboygan, Wausau
Hi-Low Density (MPO Pop./Sq. Mile)	Lowest: Bismarck, Danville, Rochester, Rapid City, Fargo Highest: Chicago, Iowa City, Madison, Ames, Omaha
Most Sustainable Cities[13]	Minneapolis (12/11),Chicago (13/6), Des Moines (36/95), Madison (44/17), Milwaukee (47/56)

2.8.2. Cosine Similarity (Climate Keywords)

A subsequent set of tests specifically examined the same groupings of plans but focused instead on identifying cosine similarities only for climate change keywords. The forty-five climate change keywords are repeated in Table 2.34. The Python script was modified to remove words in the corpus that are not included in the climate keyword list. To facilitate this analysis, the resulting corpus was transformed into a document-term matrix (DTM).[14] The cosine similarity matrix was then derived from the DTM and visualized as a heatmap, as shown in Table 2.35. Plans with higher scores are more closely related in their climate change themes.

[13] Source for 2023 Most Sustainable City Ranking available at https://www.lawnstarter.com/blog/studies/most-sustainable-cities/#rankings [Accessed 23 May 2023]. Parenthetical references indicate overall sustainability rank and transportation sustainability rank.

[14] See Appendix A for the Python code used to perform the cosine similarity test on the climate keywords in the MPO transportation plans.

Table 2.36 presents the differences in values between the results derived from the entire Wisconsin MPO corpora and those obtained using only the key climate words identified in the Wisconsin MPO corpora.

Table 2.34

Climate Change Determinate Keywords

climate	pollution	greening
climate_change	pollutants	green
greenhouse	clean_air	green_design
greenhouse_gas	tailpipe	conservation
carbon	resilience	natural
carbon_monoxide	resiliency	habitat
oxides	energy	wetland
methane	hybrid_electric	watershed
nitrous	electrification	runoff
nitrogen	electrified	extreme_weather
fossil_fuels	electric	environment
emissions	electric_buses	environmental
air	electric_bikes	sustainability
air_quality	evs	sustainable
air_pollution	cng	quality_life

Table 2.35

Cosine Similarity Results - WI MPOs (Climate Words Only)

	Appleton	Beloit	Eau Claire	Fond du Lac	Green Bay	Janesville	La Crosse	Madison	Milwaukee	Oshkosh	Sheboygan	Wausau
Appleton	1.00	0.63	0.77	0.98	0.59	0.66	0.73	0.77	0.76	0.99	0.69	0.83
Beloit	0.63	1.00	0.73	0.68	0.16	0.83	0.76	0.88	0.82	0.68	0.68	0.85
Eau Claire	0.77	0.73	1.00	0.82	0.25	0.81	0.84	0.93	0.85	0.80	0.88	0.93
Fond du Lac	0.98	0.68	0.82	1.00	0.46	0.69	0.78	0.81	0.79	1.00	0.73	0.87
Green Bay	0.59	0.16	0.25	0.46	1.00	0.23	0.29	0.27	0.33	0.48	0.29	0.34
Janesville	0.66	0.83	0.81	0.69	0.23	1.00	0.76	0.90	0.79	0.69	0.76	0.89
La Crosse	0.73	0.76	0.84	0.78	0.29	0.76	1.00	0.84	0.91	0.75	0.87	0.86
Madison	0.77	0.88	0.93	0.81	0.27	0.90	0.84	1.00	0.86	0.81	0.87	0.99
Milwaukee	0.76	0.82	0.85	0.79	0.33	0.79	0.91	0.86	1.00	0.77	0.84	0.84
Oshkosh	0.99	0.68	0.80	1.00	0.48	0.69	0.75	0.81	0.77	1.00	0.71	0.86
Sheboygan	0.69	0.68	0.88	0.73	0.29	0.76	0.87	0.87	0.84	0.71	1.00	0.86
Wausau	0.83	0.85	0.93	0.87	0.34	0.89	0.86	0.99	0.84	0.86	0.86	1.00

Table 2.36

Cosine Similarity Results - WI MPO Corpora Versus Keyword Differences

	Appleton	Beloit	Eau Claire	Fond du Lac	Green Bay	Janesville	La Crosse	Madison	Milwaukee	Oshkosh	Sheboygan	Wausau
Appleton	0.00	0.19	0.38	0.25	0.13	0.22	0.25	0.39	0.43	0.18	0.25	0.37
Beloit	0.19	0.00	0.29	0.24	-0.31	0.27	0.29	0.43	0.49	0.19	0.21	0.30
Eau Claire	0.38	0.29	0.00	0.44	-0.19	0.38	0.40	0.54	0.58	0.38	0.49	0.45
Fond du Lac	0.25	0.24	0.44	0.00	0.01	0.27	0.31	0.44	0.47	0.20	0.29	0.43
Green Bay	0.13	-0.31	-0.19	0.01	0.00	-0.28	-0.19	-0.17	-0.06	-0.02	-0.22	-0.22
Janesville	0.22	0.27	0.38	0.27	-0.28	0.00	0.26	0.45	0.43	0.22	0.29	0.26
La Crosse	0.25	0.29	0.40	0.31	-0.19	0.26	0.00	0.42	0.55	0.22	0.40	0.37
Madison	0.39	0.43	0.54	0.44	-0.17	0.45	0.42	0.00	0.54	0.39	0.47	0.51
Milwaukee	0.43	0.49	0.58	0.47	-0.06	0.43	0.55	0.54	0.00	0.42	0.54	0.51
Oshkosh	0.18	0.19	0.38	0.20	-0.02	0.22	0.22	0.39	0.42	0.00	0.23	0.37
Sheboygan	0.25	0.21	0.49	0.29	-0.22	0.29	0.40	0.47	0.54	0.23	0.00	0.37
Wausau	0.37	0.30	0.45	0.43	-0.22	0.26	0.37	0.51	0.51	0.37	0.37	0.00

The data suggests that when only including the climate change-related words in the cosine similarity tests, the Milwaukee and Madison MPOs show greater similarity to the other Wisconsin MPOs. Likewise, the long-range transportation plans from the Wausau and Fond du Lac MPOs exhibit increased similarity to other MPOs within the state. However, based on its climate change indicator content, the Green Bay MPO now appears to be more dissimilar when compared to its counterparts.

The cosine similarity matrices derived from both the complete corpora and the isolated climate words offer significant insights in comparing planning documents. They reveal how these documents differentially incorporate various determinants of climate change and strategies for climate change mitigation within their scopes. This analysis can act as a foundational benchmark for longitudinal study as MPOs formulate and implement future long-range transportation plans. This potential application was underscored as one of the research benefits in Section 2.1.2 of this chapter. A progressive increase in cosine similarity scores over time could potentially denote an intensifying focus on climate-related issues within the realm of each MPO's regional planning area.

Future research could further benefit by incorporating cosine score results with other data sources for a more holistic analysis. For example, examining the correlation between cosine similarity scores and emissions data might reveal whether plans with a greater emphasis on climate change yield lower regional emissions levels. However, while cosine similarity provides valuable research insights, it's not a definitive measure of a plan's effectiveness in addressing climate change. A high cosine similarity score simply indicates that the two plans include similar climate change themes; it does not reflect effectiveness in reducing emissions or achieving other climate goals.

2.8.3. K-means Clustering (Corpora)

A final analysis was completed to compare similarities among the MPO long-range transportation plans. Rather than deriving rankings from cosine similarity measurements, the transportation plans were classified into distinct groups based on their similarities. This approach facilitates the identification of recurring themes and strategies across different sets of plans.

A Python implementation of the k-means clustering algorithm, a well-established tool in data clustering studies, was used in this analysis. The algorithm groups the data into distinct clusters based on their similarity. K-means is also an unsupervised machine learning algorithm; it determines data clustering patterns without being programed for a specific outcome, but the process does require a predefined number of clusters to be identified. The predetermined number of clusters to be generated is denoted as "k". The algorithm iterates through a process designed to minimize the variance within each cluster and maximize the variance between different clusters (Sinaga and Yang, 2020).

For this research, the creation of five clusters was deemed appropriate. The k-means clustering results for the Wisconsin MPO plans are shown in Table 2.37.

Table 2.37

K-means Clustering - Wisconsin MPOs

Cluster 0	Cluster 1	Cluster 2	Cluster 3	Cluster 4
Eau Claire	Appleton	Beloit	La Crosse	Milwaukee
	Fond du Lac	Green Bay		
	Oshkosh	Janesville		
		Madison		
		Sheboygan		
		Wausau		

Milwaukee again stands out as the sole member of Cluster 4. This indicates that Milwaukee's long-range transportation plan contains unique features that set it apart from the other Wisconsin transportation plans. La Crosse, similarly, is the only MPO plan in Cluster 3, suggesting that it also possesses distinctive characteristics not observed in the other plans.

Beloit, Green Bay, Janesville, Madison, Sheboygan, and Wausau all fall into Cluster 2. These plans share notable similarities, distinguishing them from the rest. Appleton, Fond du Lac, and Oshkosh form Cluster 1. These plans appear to be like each other, yet different from those in the other clusters. Interestingly, this grouping aligns with the findings from the cosine similarity testing, which also grouped the MPOs who share the same staff together. Lastly, Eau Claire is the only plan in Cluster 0, implying that it has unique features not found in the other plans.

Subsequent investigation could entail a more detailed look at the long-range transportation plans within each cluster, discerning the underlying rationale for their co-clustering. For example, do they exhibit common thematic elements or strategic approaches or are they derived in comparable urban environments? Correspondingly, for the plans that did not congregate within any cluster, it might be insightful to delve into their distinctive characteristics.

2.8.4. K-means Clustering (Climate Keywords)

In alignment with the cosine similarity tests, the k-means analysis was replicated for the Wisconsin MPOs, this time utilizing only the climate change keywords. The k-means clustering results, derived from only including the previously identified climate-related keywords, are shown in Table 2.38. It is apparent that when classifying the plans according to their similarities in climate change topics, La Crosse, Milwaukee, and Sheboygan exhibit shared characteristics. Appleton, Fond du Lac, and Oshkosh are still being grouped together. The plans from Eau Claire, Janesville, Madison, and Wausau are incorporated into Cluster 2, suggesting these plans possess shared features or themes related to climate change that are different than the plans from other MPOs. Clusters 3 and 4 include only Green Bay and Beloit, respectively. This implies that these MPOs possess distinctive climate change features that set them apart from all other plans and are not closely aligned with any other Wisconsin MPOs.

Table 2.38

K-means Clustering - Wisconsin MPOs (Climate Words Only)

Cluster 0	Cluster 1	Cluster 2	Cluster 3	Cluster 4
La Crosse	Appleton	Eau Claire	Green Bay	Beloit
Milwaukee	Fond du Lac	Janesville		
Sheboygan	Oshkosh	Madison		
		Wausau		

2.9. Data Visualizations

Visualization techniques provide spatial insights into the data, which include word clouds, high-frequency term relevance charts, and Intertopic mapping. Data visualization helps in comprehending data patterns and relationships. Techniques like word clouds aid in identifying important terms within topics. Interactive visualization tools allow the exploration of data, application of filters, and gaining deeper insights into the data. Matplotlib, a fundamental Python chart library, is frequently used to visualize NLP results (Kang and Kim, 2022). Matplotlib was used to produce coherence plots and n-gram bar charts, as previously discussed.

2.9.1. Word Clouds

A word cloud visually represents text data where keywords are displayed in varying sizes and colors. The size and color of each word are usually determined by its frequency or importance within the given text. A word's probabilistic weighting corresponds to its graphical (font) size. Word clouds are often used to convey quickly and easily the most important or frequently occurring words in a corpus. Word clouds were developed to visualize the most important words within each topic that the LDA model identified. The next two pages present examples of the latent topic word clouds derived from the Fargo and Minneapolis transportation plans (Figures 2.9 and 2.10). It is notable that the word cloud from Fargo exhibits an emphasis on areas such as transit development, system operation, funding and revenue, safety, travel demand management, and pavement condition, among others. These are characteristics of smaller MPOs concerned with future infrastructure needs and system requirements. Contrarily, Minneapolis, being a sizable metropolitan area, shows markedly different focal points. Several topics revolve around airports and air travel, transit service areas and facilities, and transportation emissions, showcasing the diverse interests and challenges inherent in a larger urban context.

Figure 2.9

Word Cloud Plot (Fargo)

Figure 2.10

Word Cloud Plot (Minneapolis)

2.9.2. LDAVis

LDAvis was designed as a standalone JavaScript library for the inspection of topic-term relationships derived from the LDA algorithm (Sievert and Shirley, 2014).[15] LDAvis facilitates an interactive graphical representation of words that constitute each topic. LDAvis provides two main visualizations: 1) intertopic distance maps and 2) topic-term frequencies and relevance charts. Multidimensional scaling (MDS) is a statistical technique used to visualize the similarities and differences between sets of data points. It is used in natural language processing to create intertopic distance maps. Intertopic distance maps are two-dimensional plots where each circle represents a topic from the corpus. The distance between points indicates the degree of similarity between topics, so points that are closer together represent topics that share similar keywords. A larger circle indicates that the corresponding topic is more prevalent, that is, it comprises a greater proportion of the overall word count in the set of documents. Conversely, a smaller circle indicates a less prevalent topic.

The topic-term frequencies and relevance charts list the most relevant terms for that topic. The most relevant terms are a key output of the Sievert and Shirley (2014) method for visualizing and interpreting topics in a corpus of text. These terms represent the most distinctive and informative words associated with each topic and provide more insights into the underlying themes and concepts in the corpus. Relevance is calculated based on a combination of the term's frequency within the topic and its distinctiveness across topics. Sievert and Shirley (2014) found that ranking terms in descending order of probability was suboptimal for effectively interpreting topics, so a relevance metric was introduced in LDAvis, represented by the Greek letter lambda

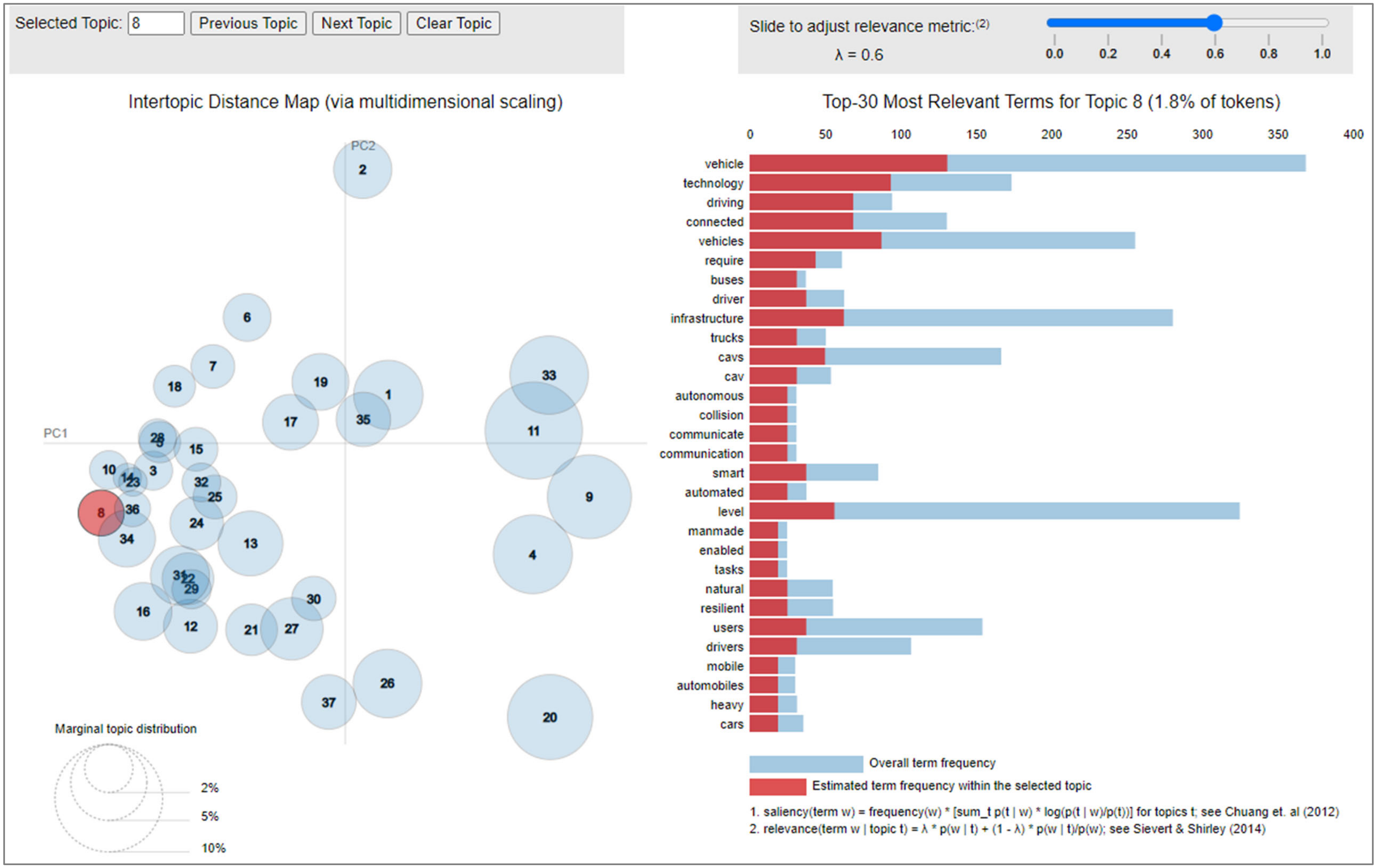
[15] pyLDAvis is a Python library created as a port of the LDAvis package (Mabey, 2015).

(λ). A term's relevance to a topic is the weighted sum of the term's probability within the topic and the ratio of the topic's marginal probability across the entire corpus. When lambda is set to 1.0 using the sliding bar on the top of the graphic, the terms are ranked purely by their probability within the topic, and the terms most likely to appear in the topic are shown first. This can result in more generic terms appearing at the top of the list. However, when lambda is set to a value less than 1.0 (0.6 in the following examples), it brings the more exclusive or distinctive terms nearer to the top of the list - terms more likely to appear in this topic than in the others. Adjusting lambda allows for finetuning the balance between showing the most probable terms for each topic and the most exclusive terms for each topic.

The utility of the LDAvis tool for visualizing the results of Latent Dirichlet Allocation models is significant. However, considering the extensive range of forty-eight discrete models having a cumulative total of 1,440 topics (48 models, each with 30 topics), the task of presenting all corresponding visualizations is daunting. As a result, four representative figures (Figures 2.11 - 2.14) were chosen to illustrate the practicality of LDAvis for long-term transportation plan and climate change data analyses. Each of these cases illustrates unique topic clusters and demonstrates the power of LDAvis to extract and visualize meaningful themes from a complex dataset. Of course, the intrinsic value of LDAvis resides in its interactive user interface and a dynamic environment is best suited for data scrutiny, enabling the quick and selective examination of LDA model output down to its individual topic affiliations.

Figure 2.11

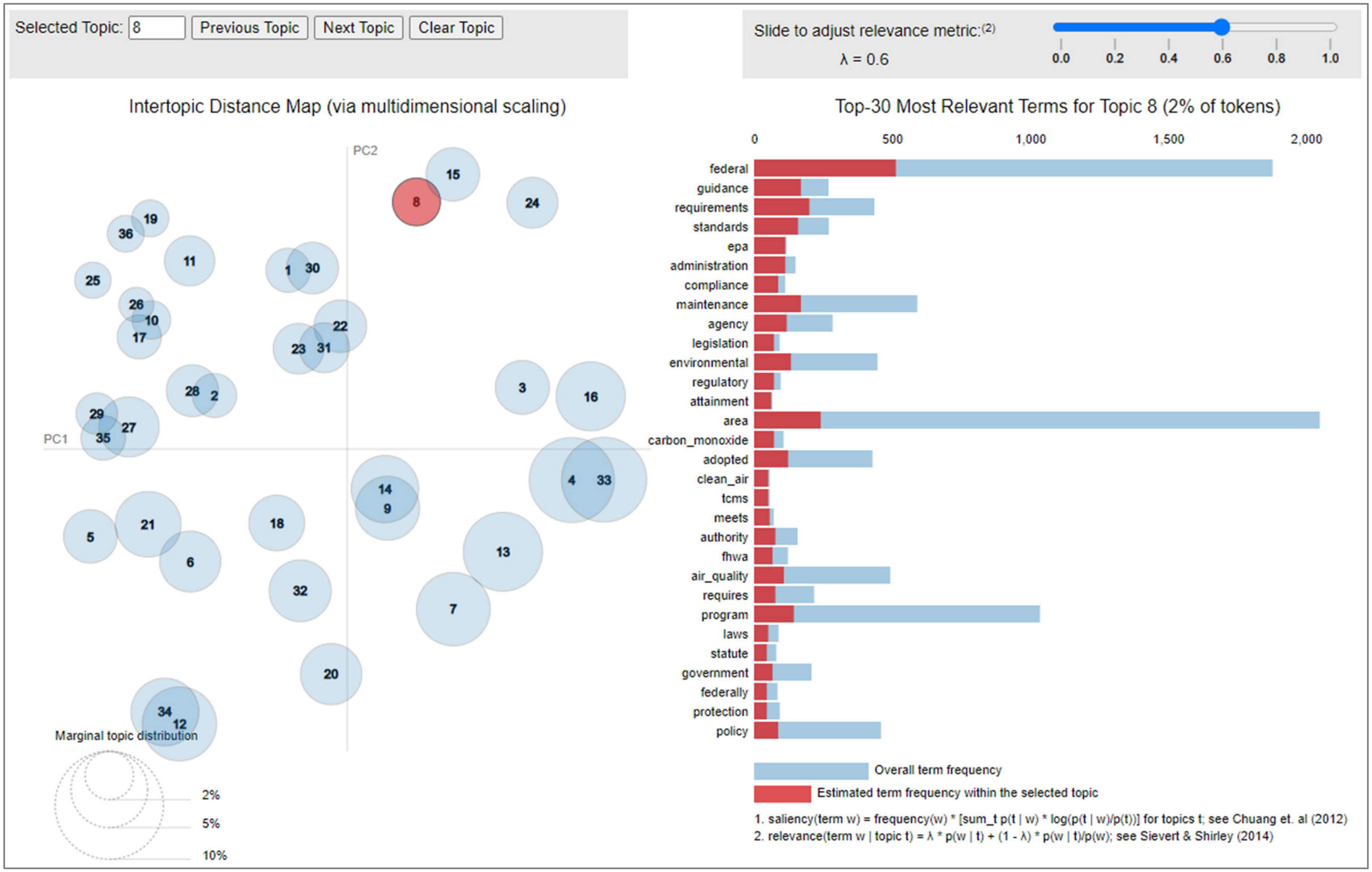
Output for Fargo (Technology)



The graphical representation in Figure 2.11 shows one of five discovered climate-related topics pertinent to Fargo. Topic 8, depicted by a small circle, is situated in the far lower-left quadrant of the visualization in proximity to several lesser circles. This spatial distribution suggests a degree of commonality in terms shared between Topic 8 and these lower-weighted topics. The keywords “vehicle”, “technology”, “connected”, “infrastructure”, “cavs”, “autonomous”, “smart”, “automated”, “resilient”, “mobile”, and “cars” point towards a topic pertaining to various aspects of connected and autonomous vehicles.

Figure 2.12

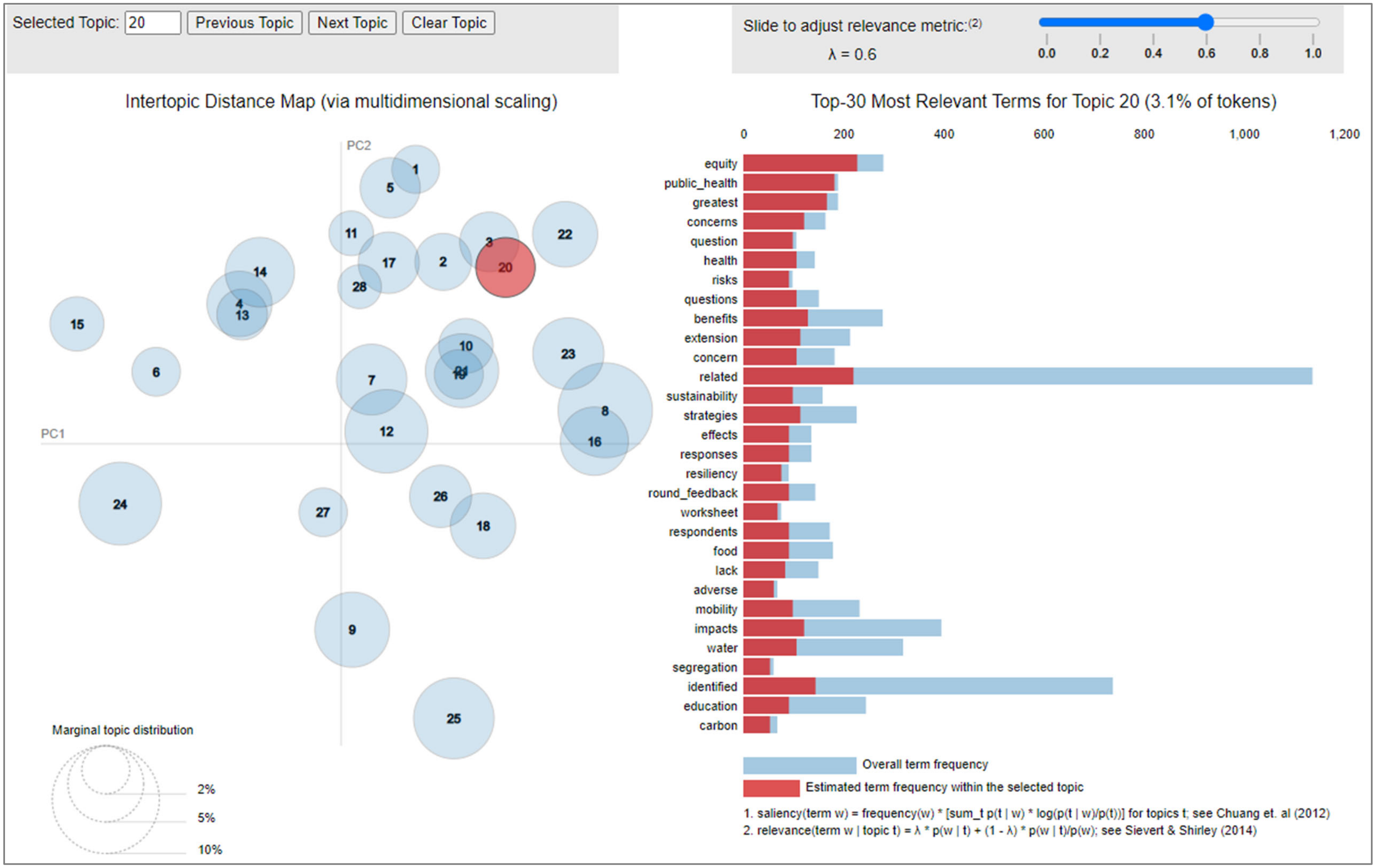
Output for Minneapolis (Air Quality)



The graphical representation in Figure 2.12 shows one of the recognized climate-related topics pertinent to Minneapolis. Topic 8, as depicted by a circle of small magnitude, is situated in the upper-right quadrant of the visualization located away from most of the other topic circles. It is near Topic 24, which is also an air quality topic. Key terms include “EPA”, “environmental”, “regulatory”, “carbon monoxide”, “clean air”, “air quality”, “laws”, “statutes”, “legislation”, and “agency”, suggesting documents in this topic are discussing laws and regulations related to air pollution, with a possible specific focus on carbon monoxide.

Figure 2.13

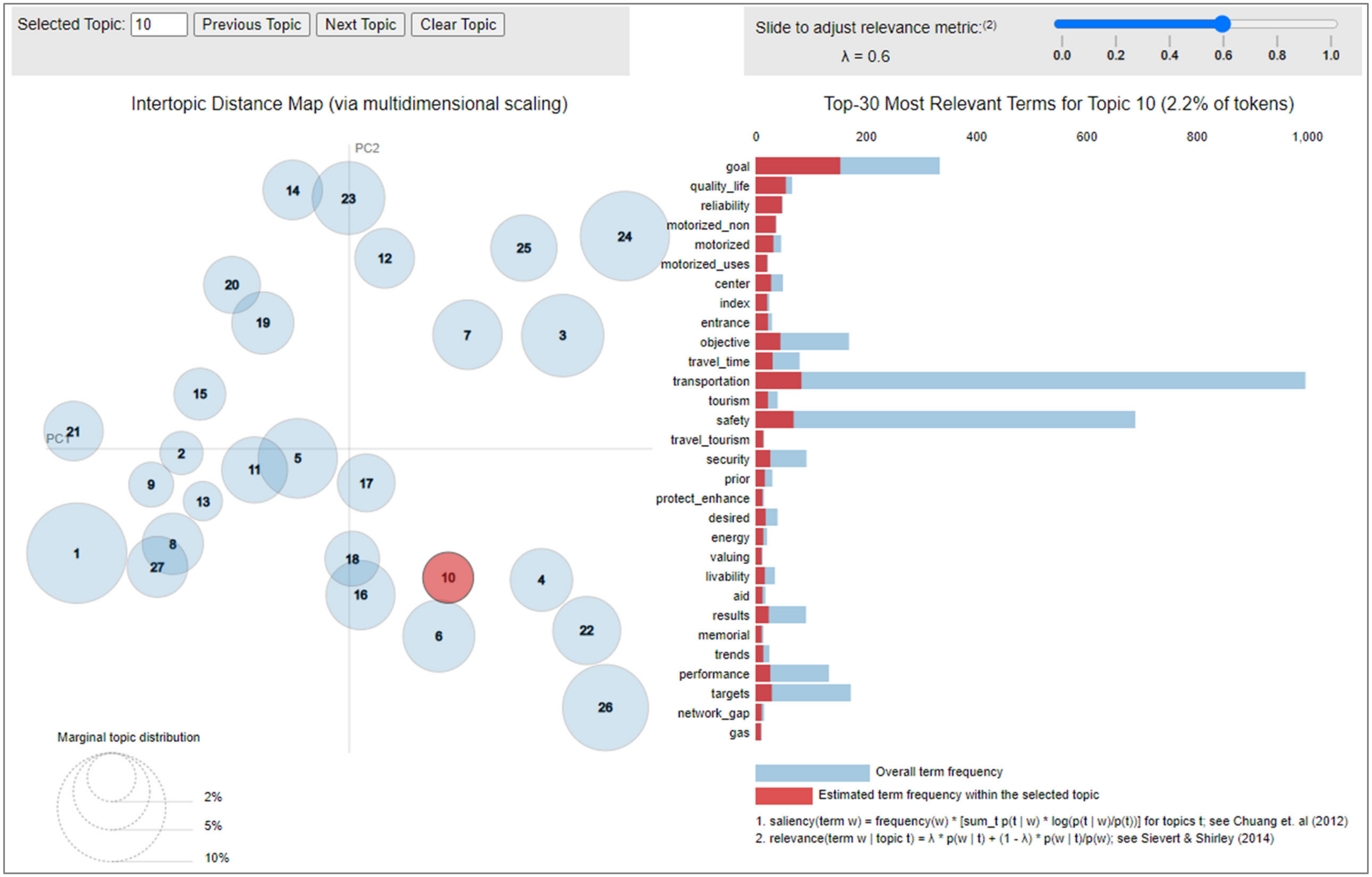
Output for Milwaukee (Environmental Justice/Equity)



The graphical representation in Figure 2.13 shows one of the recognized climate-related topics pertinent to Milwaukee. Topic 20, as depicted by a circle of moderate magnitude, is centered in the upper-right quadrant of the visualization. The keywords “equity”, “public health”, “concerns”, “risks”, “sustainability”, “resiliency”, “food”, “lack”, “adverse”, “mobility”, “impacts”, “water”, “education”, and “carbon” appear to revolve around the broad theme of social, environmental, and health-related factors in the context of sustainable development and social equity. It may focus on sustainable mobility options.

Figure 2.14

Output for Grand Forks (Quality of Life)



The graphical representation in Figure 2.14 shows one of the recognized climate-related topics pertinent to Grand Forks. Topic 10 is depicted by a small circle located in the lower-right quadrant of the visualization. The keywords "goal", "quality_life", "reliability", "nonmotorized uses"', "travel time", "safety", "security", "protect_enhance", "energy", "trends", "performance", and "targets" suggests the overarching theme of strategic transportation planning or policy with a focus on sustainability and quality of life.

2.10. Discussion

This chapter drew inspiration from the research of Fu et al. (2022), which leveraged topic modeling to extract pertinent information from 78 resilience plans within the Resilient Cities Network. Despite certain limitations, Fu et al. were able to demonstrate the effectiveness of these techniques as tools planners could use to identify key themes, pinpoint priorities, and relevant policies within vast textual datasets. Another inspirational source was work completed by Mason and Fragkias (2018), in which they used surveys to investigate the potential of MPOs to take a leadership role in regional climate change mitigation, identifying several factors that indicated the level of an MPO's commitment to addressing climate change mitigation in their regions.

NLP and LDA models proved to be viable tools for examining vast corpuses of documents related to transportation planning and climate change in Midwest MPOs, shedding light on latent patterns and insights within the data. They enabled efficient processing and analysis of large amounts of text, extracting salient topics and keywords that might otherwise have remained obscured within complex documents. The significant value of applying these methods resides in their ability to reveal recurring patterns and intrinsic connections among concepts that may appear unrelated at first glance. These methods offer a structured yet adaptable framework, facilitating a comprehensive understanding of the diverse aspects of transportation planning and climate change mitigation strategies.

The research provides critical insights into the extent to which MPOs across North Dakota, South Dakota, Iowa, Minnesota, Wisconsin, and Illinois are planning for long-term transportation needs under escalating threats of climate change. The strategies, challenges, and opportunities these MPOs face have been revealed through their long-range transportation plans, as they strive to balance efficient mobility provision with the urgency of environmental sustainability. Recurrent topics emerged across multiple MPO documents, suggesting a shared commitment to mitigating transportation-induced climate change. Moreover, MPO-specific themes reveal unique regional approaches and priorities within the broader context of climate-responsive transportation planning.

The combination of NLP, LDA, and data analytics offers a promising approach to understanding and navigating the complex interplay between long-range transportation planning and climate change mitigation. Moving forward, these tools will be instrumental in monitoring the evolution of MPO strategies, identifying best practices, and informing policy development to ensure a sustainable and climate-resilient future for transportation within the six states and beyond. The chapter's research questions were as follows:

- What common long-range determinants of sustainability are being applied in current MPO transportation planning documents?
- Can NLP be used to analyze long-range transportation plan similarities and differences in terms of environmental sustainability for different states and MPO locations?
- How inclusive are existing transportation plan documents of projects and policies that lessen the depletion of natural resources and the predominant use of automobiles?

Common long-range determinants of sustainability being applied in current metropolitan transportation planning documents were found by employing the LDA models. Latent topics such as "Air Quality/Pollution", "Alternative Fuels/Energy", "Environmental Justice/Equity", "Mobility Options" and "Quality of Life/Health" were identified across multiple MPO documents. These topics illustrate a broad commitment to reducing emissions, promoting alternative forms of transportation, enhancing resilience to climate change impacts, and addressing environmental justice issues within transportation planning.

The examination of transportation planning documents indicated supportive stances towards projects and policies aimed at reducing the depletion of natural resources caused predominantly by automobile use. Keywords such as “greenhouse_gas, “electrification”, “sustainability”, “tailpipe”, and “air_pollution” reflect the consideration of strategies to lessen dependence on automobiles, promote alternative transportation modes and reduce the environmental footprint of the transportation sector. Nevertheless, the degree of support varied among the MPOs, underscoring the need for continued research and monitoring to enhance the sustainability of individual transportation plans in the Midwest.

While notable strides have been made in the realm of NLP and LDA modeling, considerable advancements are still needed. Significant challenges include a computer’s inability to fully comprehend the intricacies of human language as it struggles with the use of abstract representations and creation of new concepts by blending seemingly disjointed ideas together. Future innovations will address these challenges, enhancing the capabilities of NLP and LDA in “reading” and interpreting the latent themes contained within transportation planning document corpora.

2.11. Conclusion

This chapter has underscored the increasing recognition of climate change as a central challenge within the domain of transportation planning. MPOs across the six states are demonstrating an evolving consciousness and commitment towards integrating environmental sustainability, resilience, and equity within their long-range strategies. Divergent themes are indicative of unique regional priorities, setting the stage for a diverse yet unified approach towards climate-responsive transportation planning. The utility of NLP and LDA in this manner provides an analytical framework capable of monitoring future shifts in the public narrative around transportation and climate change, thereby guiding policy evolution, informing best practices, and facilitating benchmarking.

Amid escalating climate-related challenges, the application of advanced methodologies is essential. By understanding the complex blend of themes, viewpoints, and priorities within long-term transportation plans, the decision-making process can be better guided. The convergence of AI technology, regional transportation planning, and supportive climate policies holds great potential. The efforts presented in this chapter only mark the beginning of a long but encouraging journey.

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CHAPTER 3: MODELING AV IMPACTS ON SUSTAINABILITY

3.1. Introduction

The nation's transportation infrastructure is deteriorating. According to the American Society of Civil Engineers' 2021 Infrastructure Report Card, the United States received a C-grade for its infrastructure condition, indicating significant room for improvement. In terms of transportation infrastructure, 43% of U.S. roadways are in poor or mediocre condition (American Society of Civil Engineers, 2021).

Transportation system planning and travel demand forecasting conducted over half a century ago shaped a significant portion of today's system. Decades later, Autonomous Vehicle (AV) technologies present a promising opportunity to enhance road safety and increase societal mobility. AVs are likely to improve transportation safety by eliminating human error, a factor involved in a large proportion of highway accidents. They could also enhance accessibility for those who are currently unable to drive or find it difficult, such as the elderly and those with mobility impairments. It's likely that the advent of AV travel will also significantly alter land development patterns. While the extent of societal impact is unclear, it is generally agreed that rural and suburban areas could see notable increases in accessibility, while dense urban areas such as Central Business Districts (CBD) will face greater challenges.

From the standpoint of resource consumption and sustainability, history suggests that major shifts in transportation technology result in increased land accessibility, leading - both directly and indirectly - to urban expansion. Therefore, it's crucial to plan thoughtfully for a future that will increasingly rely on AV technology. Partially autonomous vehicles are already a part of our daily lives, although fully autonomous vehicle travel continues to pose numerous challenges and uncertainties regarding safety, regulation, and social and economic impacts. The future cannot be predicted with certainty, but it is plausible that widespread autonomous vehicle travel may be as disruptive to social mobility as the introduction of the automobile itself was in the early 20th century.

From an urban planning perspective, AVs could transform the shape of cities. For example, with potential reductions in the need for parking spaces (since AVs could drop off passengers and park themselves in remote locations), there might be significant shifts in downtown land use. Alternatively, comfortable, affordable autonomous vehicles may offer increased productivity and leisure opportunities for their occupants, thereby triggering a rise in trip lengths and frequencies. This, in turn, could necessitate additional infrastructure and energy consumption to accommodate more cars, further heightening the unsustainable implications of vehicular travel growth (Cugurullo et al., 2020).

The prevailing approach to addressing traffic congestion by expanding roadway infrastructure is unsustainable. The financial, environmental, and public health costs are significant, burdening local governments with long-term maintenance liabilities. A crucial challenge will be to determine the optimal time to curtail or entirely abandon plans for adding new highway capacity. Autonomous vehicles present a compelling alternative. Their potential for optimizing traffic flow, enhancing shared transportation services, and possibly improving energy efficiency can help alleviate some of the strain on our existing infrastructure. However, while AVs represent a significant stride towards more sustainable transportation, they cannot be the sole solution. Incorporating a mix of sustainable transportation strategies is essential, with AVs being one integral component.

Despite the challenges associated with deploying AV technology, advancing these innovations is critical to avoid incurring significant and unnecessary infrastructure costs (Igliński and Babiak, 2017; Kopelias et al., 2020). Both industry and academia have been called upon to equip a new workforce with the skills necessary to develop and manage an automated transport system. State and metropolitan transportation agencies must also embrace this transformation, staying ahead of technology to proactively manage the rapid advancement of a 21st-century automated transportation system (Miller, 2023). Adapting to this technology reaches beyond the realms of the civil engineering workforce and governmental policy modification, impacting the core principles of urban planning and land development. As autonomous vehicles revolutionize the transportation landscape, it is imperative to explore the integration of these technologies with land use policies and urban mobility strategies.

Researchers are enhancing models to determine long-term residential location preferences based on transport costs as well as for making short-term decisions like where to shop. With the rise of autonomous vehicles, integrated land use-transportation models are being developed to predict AV's influence on future land development patterns. It is evident there is a notable gap between widely used land use-based traffic forecasting models and the methods required to analyze new vehicle technologies and their impact on land development. For example, travel behavior is highly influenced by the perceived value of the time spent inside a vehicle. The introduction of autonomous vehicles may prompt people to live further from their workplaces, shifting the paradigm of residential location theory.

This chapter begins with a general examination of the relationship between land use and transportation. It then reviews literature that delves into the anticipated impacts of autonomous vehicles as their presence in urbanized areas grows. Insights gained from the literature review are then implemented utilizing the Madison travel demand model. The chapter concludes with an examination of the results from several transportation network modeling scenarios, followed by a summary that encapsulates the key findings of the chapter's research.

3.2. Literature Review

There is an abundant body of literature providing optimistic perspectives regarding the long-term advantages that autonomous vehicles could introduce to urban areas. In recent years, numerous researchers and practitioners have refined planning methodologies in anticipation of the impacts of fully autonomous vehicles on traveler behavior. Comprehensive analyses of stated preference and choice studies concerning AV adaptation have shed light on both the advantages and challenges presented by fully autonomous vehicles. This body of work includes significant research regarding broader societal trust in AV technologies (Gkartzonikas and Gkritza, 2019; Kolarova and Cherchi, 2021).

Researchers generally agree that extensive deployment of AVs will lead to fewer crashes, reduced carbon emissions, improved fuel economy, and enhanced in-vehicle productivity. Pimenta et al. (2023) documented several significant impacts AVs will have on the built environment by conducting a systematic scoping review of 78 peer-reviewed journal articles concerning AV impacts. Causal loop diagrams illustrate AV impacts on six built environment dimensions including parking, destination accessibility, density, distance to CBD, diversity of land uses, and changes in urban geometry and infrastructure. Specific assumptions are documented for each diagram, including tendencies to induce travel demand, changes in vehicle ownership, and increases in vehicle miles traveled.

The potential obstacles to society embracing AV technologies are widely recognized. These include legal liability issues, privacy concerns, apprehension over cybersecurity, and the risk of system hacking (Cugurullo et al., 2020; Harb et al., 2021; Othman, 2021; Sousa et al., 2018). Despite extensive study and documentation on fully autonomous vehicle deployment, a consensus on the future effects of AVs on mobility and trip demand has not yet been reached. Some argue that AVs will significantly increase travel opportunities for the elderly, disabled, and children (Bahamonde-Birke et al., 2018, Dianin et al., 2021; Harper et al., 2016). Other researchers suggest that widespread increases in private autonomous vehicle use will increase vehicle miles traveled; extending commuting distances and exacerbating urban sprawl (Cordera et al., 2021; Meyer et al., 2017).

Gruel and Stanford (2016) suggest that if the overarching goal is to achieve a greener, more sustainable future, new regulations will be required to counteract the potential for AVs to catalyze urban sprawl. Several possible strategies exist, including increasing the cost of AV travel through road use charges or tiered road-pricing models; extending travel time by lowering speed limits; reducing the comfort and utility of in-vehicle time to make public transit more appealing; implementing land-use regulations that discourage long commutes; putting limits on individual driving; and banning empty AV trips. It can be safely asserted that none of these strategies would be politically favorable.

3.2.1. Advancing Technology

A desirable outcome of advanced transportation technology should be enhancing the sustainability of personal travel. Developing emerging mobility technologies in an environmentally responsible way, focusing on reduced resource consumption and polluting emissions, is critical for a sustainable future (Sultana et al., 2017).

Research interest in vehicle automation goes back to the 1920s, when vehicle-to-vehicle radio wave communication was being developed (Othman, 2022). Since those early beginnings, research on smart cars and smart highways has spanned decades. However, understanding the system-wide and long-term impacts of autonomous vehicles on urban development patterns remains largely speculative. This uncertainty exists due to the amount of time still needed before widespread, fully autonomous, self-driving car deployment can occur. Peter Attia, in his book "*Outlive: The Science and Art of Longevity*," drew an analogy between advancements in medicine and the evolution of self-driving vehicles. Noting that the concept of self-driving cars has been part of discussions ever since "vehicles started colliding," he humorously quipped, *"If you had wanted to create a self-driving car in the 1950s, your best option might have been to strap a brick to the accelerator*" (Attia, 2023, p. 30). While this would certainly have made the car move forward on its own, it would have been unable to avoid obstacles. Only in recent times has technology advanced enough to allow vehicles to operate autonomously - and safely - utilizing computers, sensors, artificial intelligence, and machine learning systems.

Available academic research illustrates the potential of automated vehicles to advance societal mobility needs while contributing to a more sustainable future. Yet, AV's tremendous potential is not a certainty, and largely depends on meticulous design, economical implementation, and seamless integration of AVs into a wide array of existing transportation and energy systems. Optimistically, the widespread use of fully autonomous vehicles could have transformative impacts well beyond the basic function of transportation; its far-reaching impacts could reshape urban life, sustainable development, ecological improvement, and transit service (Othman, 2022).

Faisal et al. (2019) observed existing AV literature focuses on six areas: 1) technological advancements, 2) policy and legislative evaluations, 3) transport modeling and simulations, 4) user surveys and interviews, 5) scenario analyses, and 6) case study explorations. In total, the researchers reviewed 61 peer-reviewed journal articles. Sixteen studies were dedicated to analyzing AV capabilities, 32 studies investigated the impacts of AVs, and 12 studies explored AV deployment from a regulation and policy perspective. Only one paper was found to specifically address urban planning or planner interventions aimed at minimizing the disruptive impacts of AVs on communities.

The integration of autonomous vehicle technologies into current transportation systems ushers in far-reaching implications and new challenges. Changes to infrastructure, alterations in traffic flow characteristics, the identification of new funding sources, both positive and negative environmental impacts, and entrenched personal perspectives on what personal mobility looks like will all need to be addressed. No other country depends as heavily on affordable motor vehicle travel as does the United States (International Comparisons, n.d.).[16] The average American drives about 14,000 miles each year (Federal Highway Administration, 2019). While it appears owning and driving a car is relatively inexpensive in the U.S. compared to the rest of the world, American motorists do not bear anywhere near the full cost of their driving decisions when factors like infrastructure maintenance, environmental impacts, and congestion costs are added (Garner, 2021).

Echoing a bygone era, cars still embody notions of romanticism, freedom, and success. Hancock (2019) recognized the automobile as a symbol of personal identity. Automobiles, with all their advantages and disadvantages, are deeply embedded in the fabric of society. The vehicle one owns is not just a means of transport from one location to another, but also an expression of individual and societal identity. Consequently, Hancock concluded that changing the deeply ingrained affinity for automobile driving will be a slow and complex process.

Researchers have frequently explored how ready society is to adopt and utilize AVs. For example, Das et al. (2017) delineated three groups most likely to be early adopters of AVs. The first group, labeled as "long commute drivers", consists of full-time workers who spend a significant portion of their day traveling. These individuals could greatly benefit from the "relax

[16] According to the web site "International Comparisons" out of the twelve advanced democracies monitored, the United States ranks first in lowest price for gasoline, vehicle kilometers traveled per capita, and road fuel consumed per capita.

and leave the driving to the machine" nature of AVs. The second group, known as "long transit commuters", includes those who primarily depend on public transportation and face lengthy commute times. AVs could potentially offer a more efficient and quicker commute, appealing to these individuals. The third group comprises older adults who, due to age-related limitations, may no longer drive and would be more inclined to adopt AVs for their transportation needs.

3.2.2. Long-Term Planning

Before full integration of autonomous vehicles is reached, several critical considerations must be addressed. Medina-Tapia and Robusté (2018) stress the need to align urban planning with emerging AV technologies. They identify this area as understudied in the context of "Smart Cities." Their research finds this knowledge gap is preventing academics and practitioners from effectively informing policymakers and proactively shaping urban policies to address the challenges of the new transportation technology.

Uncertainty adds to this challenge. McAslan et al. (2021) highlight the unrecognized complexities surrounding the development, deployment, implications, and projected uses of AVs. Their investigation uncovered various reasons for omitting AV travel modes in regional transportation plans, including 1) the rapid pace of technological advancement, 2) ambiguous impacts on regional development, 3) disruption of existing planning assumptions, and 4) AVs being considered outside the planning agency's scope. To navigate these uncertainties, a common strategy among many MPOs is to incorporate broad policies into their plans, like monitoring the evolution of AV technology. Their intent is to address the topic more directly in subsequent regional transportation plan updates after the technology is further advanced and its impacts are more certain.

Scenario planning and exploratory modeling have proven effective in providing transportation agencies the ability to anticipate and manage the potential risks and benefits associated with the spread of autonomous vehicles before they materialize. However, a limitation is that these strategies often rely on a single future land use allocation forecast, assuming land use patterns will remain in-place once established; unaffected by transportation investments and other external influences (Bernardin, et al., 2019; Hutchinson et al., 2018; Miller and Kang, 2019). This approach ignores the complex, two-way relationship between land use and transportation. In reality, land use decisions and transportation systems are in a constant state of interaction, each influencing the other. Decisions about land use can alter travel patterns and transportation demand, and conversely, investments in transportation and infrastructure can stimulate land development and modify land use patterns.

Acknowledging this reciprocal relationship, advanced land use-transportation scenario planning takes a more holistic approach. The methodology treats both land use and transportation systems as parts of an interconnected system, where alterations in one instigate changes in the other. Advanced modeling techniques are used to forecast and evaluate future land use and transportation scenarios, considering their potential interactions and mutual influences. In doing so, integrated land use-transportation planning allows for more thorough and realistic forecasts and assessments, providing a better foundation for advising policymakers on the strategic use of public dollars (Bartholomew and Ewing, 2009).

AV scenario definitions typically begin with the pace and extent of vehicle automation. The Society of Automotive Engineers (SAE, 2021) identified six levels that describe the increasing capabilities of autonomous vehicles:

- Level 0: No automation is present, and the driver is solely responsible for all driving tasks.

- Level 1: Driver assistance systems are introduced, where a single aspect of driving is automated, such as adaptive cruise control, but the human driver must remain engaged.
- Level 2: Partial automation, where the vehicle can control both steering and acceleration/deceleration, but human monitoring is still needed.
- Level 3: Conditional automation, where the vehicle can perform all driving tasks under certain conditions, but human intervention may still be required.
- Level 4: High automation, where the vehicle can handle all driving tasks in most environments and conditions, with no need for human intervention in those scenarios.
- Level 5: Full automation, where vehicles autonomously handle all driving tasks across all environments and conditions without the need for human intervention.

Major automobile manufacturers such as Tesla, BMW, Cadillac, Ford, and GM are currently developing vehicles with Level 3 automation or higher. Meanwhile, technology companies like Waymo, May Mobility, and TuSimple are working on advanced levels of automation, aiming to create systems capable of excelling in all driving conditions. In the ride-sharing industry, companies like Lyft are forming collaborations with both manufacturers and technology developers to explore models for fleet-based shared-ride autonomous vehicle operation (Nexus, n.d.). Reflecting this growing momentum, by 2021, approximately 30 vehicle manufacturers or IT companies obtained permits to test AVs in real-world conditions (Zhang and Guhathakurta, 2021).

Narayanan et al. (2020) caution that all technologies, regardless of their nature, present both positive and negative aspects, a reality from which AVs are not exempt. Despite the widespread enthusiasm found in academic literature concerning the emergence of fully autonomous vehicle travel, challenges related to their deployment and integration into existing built environments are also readily acknowledged. This complexity is especially apparent in densely populated urban areas. For example, the autonomous parking capabilities of AVs could result in substantial time and cost savings for urban commuters. On the other hand, high downtown parking costs might prompt vehicle owners to find it more economical to have their AV continuously circle the block unoccupied, a potential behavioral shift pointed out by Millard-Ball (2019). Moreover, the introduction of fully autonomous vehicles may lead to unforeseen indirect consequences. This includes shifts in transportation demand resulting in additional trip making and unexpected social equity issues, as highlighted by Bahamonde-Birke et al. (2018).

3.2.3. Safety, Efficiency, and Accessibility

When fully mature, autonomous vehicle technology has the potential to provide substantial safety advantages by removing human driver error, which is a significant factor in road accidents. AVs can be designed to rigorously adhere to traffic rules and be unaffected by human shortcomings such as distraction or fatigue, drastically reducing crash rates (Kockelman, 2017). Test deployments of self-driving vehicles have resulted in only minimal crashes where the vehicles themselves were found responsible, highlighting the positive outlook for road safety benefits with this technology (Wang et al., 2020).

The literature addresses the potential for fully autonomous vehicles to improve accessibility. Dianin et al. (2021) elaborate on this transformative potential, emphasizing the benefits for specific demographic groups such as the elderly, the visually impaired, and those with mobility impairments. However, they also warn that if the deployment of AVs is primarily concentrated in affluent urban centers, it could inadvertently exacerbate social inequities. This would widen the socioeconomic gap, with advancements disproportionately benefiting wealthier segments of society and further marginalizing those in lower strata.

AVs present significant advantages for efficiency, including a reduction in traffic congestion, decreased travel time, and lower fuel consumption. These benefits are amplified when AVs are networked, leveraging on-board vehicle-to-vehicle communication capabilities to manage traffic more proficiently, significantly improving traffic flow after wide-scale deployment occurs. Narayanan et al. (2021) do warn that this increase in efficiency requires careful oversight to avoid a demand surge which could quickly negate initial gains.

Several scholars highlight the appealing prospect of engaging in non-driving activities during travel, a change that many agree could enhance productivity. However, they also note that the reduced travel time cost associated with AVs might encourage commuters to live further away from urban centers. Such a shift would have unforeseen negative consequences on the efficiency of providing public utilities, emergency response services (police, fire, ambulance), education, and public transit (Legêne et al., 2020; Llorca et al., 2022; Medina-Tapia and Robusté, 2018). Also, the presumed increase in AV occupant productivity has been called into question by some researchers, pointing out potential issues such as motion sickness and an uncertain quality of time spent in vehicles when passengers are not actively driving (Diels and Bos, 2016; Singleton, 2019).

Autonomous vehicles (AVs) may be catalysts for a greener future, potentially playing a pivotal role in sustainable transportation and climate change mitigation. By integrating with electric vehicle technology, AVs could provide remarkable environmental benefits. Simulation models, such as those by Kopelias et al. (2020), forecast substantial reductions in pollution and fuel consumption. The impact is further enhanced through shared autonomous vehicle (SAV) use, which reduces both vehicle miles traveled and energy consumption, leading to a smaller carbon footprint (McGrath, 2019). AV technologies can provide substantial energy and environmental benefits compared to conventional vehicles. This signifies a promising solution to a crucial challenge faced by policymakers in their efforts to reduce carbon emissions within the transportation sector (Igliński and Babiak, 2017). Even if individual vehicle energy consumption was to increase with the use of AVs, Greenblatt and Shaheen (2015) contend overall energy consumption could still decrease. This reduction would result from system-wide efficiency gains enabled by connected autonomous vehicles, improving vehicle platooning and optimizing traffic flow. Pavone (2016) emphasizes that opportunities for enhancing efficiency in urban transport systems through autonomous vehicle use cannot be overstated. He points out the current underutilization of most privately-owned vehicles in urban settings, where they remain parked 90% of the time, and are unnecessarily over-engineered with the capability of speeds exceeding 100 mph. These factors highlight just a few areas for optimization and resource conservation with the integration of autonomous vehicles into urban transport systems.

Academic discourse doesn't always agree with the notion that autonomous vehicles will lead to a decrease in public transit ridership. Rather, the advantages of autonomous vehicles could be augmented when they are integrated with sustainable urban design strategies, such as Transit Oriented Development. In this context, shared AV services could potentially function as connector systems for transit hubs, filling a gap between less populated areas and large public transit stations. This would also address the persistent "first mile-last mile" problem, which refers to the difficulty of efficiently and conveniently connecting transit stations with the final start and end points of trips (Duarte and Ratti, 2018).

Many studies emphasize cost as a crucial concern when it comes to the adoption of AVs, particularly shared AVs. However, for shared services to become widely accepted, they must be offered at an appealing price point. Substantial cost savings may be necessary to offset the "privacy premium," a term that describes the extra expense travelers are willing to incur for the privacy afforded by single-occupant vehicle use (Clayton et al., 2020).

The realization of AV benefits hinges on a complex interplay of factors, such as regulatory decisions, the pace of technological advancement, societal acceptance, and the mode of AV deployment (e.g., private ownership versus shared ride services). Early and collaborative planning is crucial to leverage the opportunities that exist for the efficient integration of AVs into existing transport systems (McAslan et al., 2021). Policymakers may need to embrace politically unpopular demand management policies like mileage-based fees, carbon taxing, and cordon tolling, and increased investment in multimodal transport options (Byars et al., 2017).

3.2.4. Influence on Urban Expansion

A city and its transportation system are inherently interconnected, with each profoundly affecting how the other is designed and functions. This connection between a city and its transportation system is evident throughout history and becomes particularly pronounced when emerging transportation technologies drive substantial changes in urban design and structure. In "*A Brief History of Motion: From the Wheel, to the Car, to What Comes Next*," author Tom Standage (Standage, 2021) describes the innovative ways ancient civilizations improved the transport of people and goods. From the early crafting of log boats and the utilization of animals for travel to the revolutionary invention of the wheel, he traces the continuous evolution of transportation technologies. As human societies progressed, the exploration and adoption of new energy sources led to dramatic transformations in how people and goods moved, marked by the development of ships, trains, cars, and airplanes. These transportation breakthroughs not only reshaped urban landscapes and economies but also profoundly influenced the daily lives of people globally. Standage emphasizes how these developments underscore the critical role of transportation in the advancement of human civilization.

In "*The Geography of Transport Systems*," Rodrigue (2020) offers similar insights, demonstrating the interrelationship between different eras of American economic growth and the dominant modes of transportation at the time. The emergence of steam-powered locomotives in the 19th century led to the development of an extensive railway network that significantly influenced urban expansion and land development patterns through improved accessibility. This advancement transformed city structures, enhanced connectivity, and boosted trade. Similarly, the advent of the automobile in the early 20th century led to the development of an expansive federal interstate highway system, whose influence on urban neighborhoods persists to this day.

The increased accessibility provided by freeways led to significant transformations in suburban cities, greatly contributing to the phenomena of urban decentralization and sprawl, reshaping the way communities were structured and connected. Construction of the Interstate Highway System began soon after the enactment of the Federal-Aid Highway Act of 1956, signed by President Eisenhower. Its primary objectives were to enhance transportation efficiency, bolster national defense capabilities, alleviate traffic congestion, improve road conditions, and foster regional and national unity (Weingroff, 2000). The magnitude and cost associated with this ambitious undertaking quickly generated controversy. The Act initiated a fundamental change in the funding of major highway projects. It supplanted the prior 50/50 federal-state cost sharing formula with a new 90/10 ratio for Interstate construction. States were given control over routing decisions, enabling the design and construction of Interstate highways with minimal consultation with the communities directly affected. As a result, many cities experienced the dislocation of entire neighborhoods due to freeway construction, which had a disproportionate impact on low-income and marginalized populations (National Academies of Sciences, Engineering, and Medicine, 2019).

The transformation of urban development extends beyond large-scale infrastructure projects. In recent years, there have been notable increases in innovative, low-cost strategies aimed at improving societal mobility. For instance, bike-sharing programs, electric scooter sharing systems, and ride-sharing services have gained popularity as practical, flexible, and eco-friendly alternatives to conventional transportation methods. These initiatives represent a shift towards more sustainable urban mobility solutions, catering to the changing needs and preferences of city dwellers. These contemporary advancements underscore the dynamic interplay between the evolving needs of urban areas and the development of new transportation modes. Collectively, these innovations not only enhance accessibility within cities but also play a crucial role in reducing environmental impacts (Shaheen et al., 2020).

The extent to which AVs will impact urban expansion is still a matter of ongoing debate and exploration. One viewpoint posits that autonomous vehicles may encourage urban sprawl by enabling people to live further away from city centers, drawn by the allure of natural spaces and the comfort of single-family homes with backyards. This trend, facilitated by the convenience offered by AVs, might adversely impact the availability and efficiency of public transit services (Cugurullo et al., 2020; Gruel and Stanford, 2016; Shafiei et al., 2023; Sousa et al., 2018). Alternatively, AVs could potentially lead to the revitalization of urban centers. By programming autonomous vehicles to prioritize pedestrian safety and adhere to speed limits and traffic regulations, downtown living could become safer and more attractive. Such an approach would likely encourage more diverse social interactions within core urban areas, thereby enhancing their appeal and possibly countering a tendency towards sprawl (Duarte and Ratti, 2018; Kockelman, 2017; Park, 2023).[17]

[17] Currently, pedestrian detection is offered on some models as part of advanced driver assistance system options which use sensors, cameras, and artificial intelligence to identify pedestrians near vehicles. It is notable, however, that a study completed by the American Automobile Association found current pedestrian detection systems perform inconsistently and are "completely ineffective" at night (American Automobile Association, 2019).

3.2.5. Location Choice Theory

The relationship between geographical location and the use of fully autonomous vehicles is an aspect that has received relatively little attention in modern academic discourse. To better understand this connection, it is beneficial to review historical theories that have focused on the interplay between transportation and land use. One prominent example is Johann Heinrich von Thünen's "*Isolated State*," first published in 1826. Von Thünen posited that transportation costs influenced rent differentials across various forms of production, such as agriculture, dairy, and forestry, and these differences were directly correlated with the distance from the marketplace.

Von Thünen's pioneering theory provided a foundational understanding of location pricing that continues to resonate in modern day discussions on the spatial implications of transportation, including the advent of AVs. Von Thünen measured transportation costs in "natural units," a method associating the cost of feeding a horse for the round trip plus the equivalent cost in grain for men's wages (Clark, 1967). This concept led to the emergence of a valuation structure known as "location rent" (O'Kelly and Bryan, 1996). Von Thünen's theory became particularly intriguing when he acknowledged exceptions to his model. For example, he noted that the presence of a navigable river could disrupt his location rent theory by lowering transportation costs along the waterway, thus reshaping the concentric land-use patterns initially proposed. The acknowledgement of variable transportation costs remains a poignant topic in contemporary urban planning.

In a more recent context, William Alonso (1964) proposed a theory that patterns of land use and population density are shaped by two pivotal factors: 1) commuting expenses and 2) the amount individuals are willing to pay for land at varying distances from the urban core. Alonso's insights concerning urban land use, location, and pricing echo the foundational principles articulated by von Thünen, underscoring the lasting relevance of "the father of locational economics" and his pioneering developments in spatial economics (Gwamna et al., 2015; McDonald, 2007).

Though von Thünen's foundational principle remains relevant today, its chief component, the cost of transport to the market, is no longer the primary influence shaping land use patterns in metropolitan areas. In today's modern societies, the continuous expansion of cities has become a common phenomenon, leading to a steady increase in areas designated for urban use. As Robert Sinclair (1967) observed, the nature of urban expansion is determined by a complex interplay of factors, the most fundamental of which include:

- disparities between urban and rural land prices,
- flexibility afforded by automobiles, and
- the unpredictable behavior and preferences of human beings.

These elements highlight evolving considerations in urban transportation planning and land development. Focusing on the interplay between transportation and land development, Adams (1970) delineated four key transportation eras, each of which had a significant impact on residential growth patterns during its time:

- the walking/horsecar era,
- the electric streetcar era,
- the recreational auto era, and
- the freeway era.

The evolving spatial patterns of residential growth in the United States during these historical eras underscore the dynamic interconnection between transportation evolution and urban development, highlighting how changes in mobility influence the configuration of cities over time. Patterns of urban growth during Adams' streetcar era and the freeway era are characterized by star-like structures emanating outward from the urban core along new infrastructure routes (rail and highways). This pattern marks a departure from the concentric growth models identified by von Thünen and Alonso. In contrast, Adams" eras of foot travel and recreational automobile usage are associated with patterns of densely populated circular growth, aligning more closely with the theoretical locational models posited by von Thünen and Alonso.

Noussan et al. (2020) introduce a contemporary aspect to Adams' characterization of residential growth distortion by considering the impact of digitalization across various transport-related sectors. They propose that the digital era represents a fifth stage of transportation and city expansion distinct from the previous phases. According to their views, the digital transformation of the 21st century conjures images of an advanced "smart city," where high levels of automation once again reshape the existing urban framework. Noussan et al.'s additional perspective underscores the ongoing evolution of transportation and its continuing influence on the form and function of cities.

Jordaan et al. (2004) investigated the availability of developable land on the periphery of cities and its effect on housing costs. Their findings challenge the conventional assumption that households looking for more living space in outlying areas are willing to bear higher transportation costs in return. They explain that while these households may value the additional space, their willingness to accept increased transportation expenses as a trade-off is not as straightforward as some theories might suggest. This insight adds complexity to the understanding of the decisions people make about where to live and the factors that influence those choices. Zhang and Guhathakurta (2021) offer additional perspectives on the factors shaping housing location choices. They found that households with children are generally more responsive to changes in vehicle travel time than those without children. If travel times decrease due to the increased efficiency of autonomous vehicles, these households may be more inclined to move to areas with diverse land uses, ample amenities, and high-quality school districts -

features commonly found in suburban neighborhoods. Their research also indicated that the wide availability of shared autonomous vehicles could prompt households to relocate to neighborhoods with superior property characteristics and schools, even if those locations are further away from their workplaces.

In their 2017 research, Giuliano and Agarwal explored the complex interplay between land use and integrated transportation systems. Acknowledging the slow nature of significant changes in this area, they introduced three methodologies designed to monitor and understand the progression of this relationship over time:

- examining travel outcomes, an approach they consider to be the least effective,
- observing fluctuations in property values, which they regard as the most reliable indicator, and
- monitoring shifts in employment or population density, as well as changes in commercial and residential development.

The third bullet would be the most direct approach; however, it can also be affected by external factors such as economic conditions and public policy changes. This research adds to the understanding of how to effectively study the relationship between land use and transportation, and it highlights the challenges in observing these changes over time.

Sultana and her colleagues (2017) make a noteworthy observation: while cities have substantial control over land use (and hence, the locational options available to their residents), their influence over transportation infrastructure is significantly more limited. Therefore, they underscore the crucial need to integrate transportation and land use planning, a point conceded as not exactly groundbreaking. Sultana et al. (2017) note that urban transportation sustainability concerns were once centered on overgrazing shared pastures and dealing with horse droppings. Contemporary sustainable goals now emphasize managing finite resources, the environment's capacity to absorb waste, reimagining urban spatial layouts, and addressing a wide array of impacts on the economy, social equity, and public health.

3.2.6. Travel Demand Models

The traditional four-step traffic forecasting model enjoys a rich scholarly history. Pioneers such as Stopher (1976) were instrumental in integrating aspects of time valuation into travel demand models. Researchers determined the perceived value of time spent traveling in a vehicle varied based on factors such as income levels and the length of commutes. Thomas and Thompson (1971) determined that a 15-minute reduction in commute time for a work trip was valued at 28% of the prevalent wage rate for low-income earners, and 50% of the prevalent wage rate for high-income earners. Another example of early travel demand procedures still prevalent today is the incorporation of "terminal time" at the beginning and end of each journey. Terminal times are typically assigned based on the type of area in which trip origins and destinations are located, accounting for the extra time required for activities like parking and walking to the ultimate trip destination point (Bouchard and Pyers, 1965).

Harb et al. (2021) provide a good summary of the challenges encountered in using a travel demand model to forecast the effects of emerging technologies such as autonomous vehicles. Contemporary researchers have demonstrated how travel models can provide critical insights into the future implications of autonomous vehicles. Despite their limitations, four-step models continue to be the benchmark for modeling in many states and metropolitan areas. Their analytical framework, which involves trip generation, distribution, mode choice, and route assignment, is still predominantly used for urban travel demand forecasting (Nair et al., 2018).

As per Dias et al. (2020), the assumptions of the four-step model introduce few constraints, thus simplifying their estimation compared to more sophisticated methods currently available. They provide flexibility and transparency, especially in terms of how travel demand

and supply factors interact, and they are relatively straightforward to use. State transportation departments in Florida (Hutchinson et al., 2018), Texas (Dias et al., 2018), and Virginia (Miller and Kang, 2019) have explored modifications to the four-step model, attempting to analyze AVs as a distinct mode of travel. Bernardin et al. (2019) demonstrated how improving trip-based travel demand models can provide a more nuanced view of widespread CAV adoption, even considering the various uncertainties still associated with their implementation. Building on this, Dias et al. (2020) further expand the conventional four-step model's ability to address autonomous vehicle impacts, providing urban planners and transportation demand modelers with a more effective tool to analyze the impacts of extensive AV deployment.

While the details of how fully autonomous vehicles will be used are still uncertain, there is a broad consensus that key travel metrics, including vehicle ownership, miles traveled per person, vehicle occupancy, vehicle size, and commute distances, are likely to undergo significant changes compared to historical patterns (Greenblatt and Shaheen, 2015). The absence of AV usage data is particularly critical, as many travel demand models rely on historical data for projecting future trends, a process commonly known as model calibration. Sotiropoulos et al. (2019) completed a comprehensive review of international modeling studies to get a wider perspective on the state of AV travel forecasting. The studies in their research came from various countries, including 20 from the United States, 14 from Europe, 2 from Asia, and 1 from Australia. A common finding was that AVs will increase vehicle miles traveled and decrease public transit usage. Furthermore, the findings suggested a strong association between the prevalence of privately-owned AVs and population growth in suburban and rural areas.

Hiramatsu (2022) postulated that as transportation costs decline with the widespread use of autonomous vehicles, suburban living could appeal to a wider demographic. To validate his hypothesis, he employed transportation modeling. He found that initially, high-income workers who place a high value on their time would be especially attracted to suburban living. As the costs of AVs decrease, his research indicates that potential users from all income brackets would develop a preference for suburban living. Financial strategies such as low-income subsidies could encourage more equitable AV access across income groups. To capitalize on the benefits of AVs without exacerbating urban sprawl, Hiramatsu (2022) suggested implementing strict urban growth boundaries as a management strategy.

Török et al. (2020) used travel demand modeling to investigate changes in increased highway capacity due to fully autonomous vehicle travel. They found that if the traffic stream consists of autonomous vehicles that can communicate with each other, the space or "headway" between them can be substantially decreased. They determined the capability of vehicles safely traveling close together resulted in up to a 60% reduction in the roadway's volume-to-capacity ratio, a common measure of road congestion. This means that an existing highway can accommodate significantly more traffic before reaching its "capacity" and becoming congested.

Hasnat et al. (2023) used household survey data and regional travel demand modeling to predict the impact of deployed Connected Autonomous Vehicles (CAVs) on roadway network travel. Their results proved to be particularly sensitive to empty vehicle trips, suggesting that if AVs generate a significant number of unoccupied trips, escalations in travel delays would occur and offset the traffic flow benefits gained with vehicle-to-vehicle connectivity. Additionally, their model analyses determined increasing highway capacity due to CAVs resulted in a 9.5% increase in households moving to suburban and rural locations, as compared to their baseline "business as usual" scenario. Hasnat et al.'s (2023) determination is consistent with results from other researchers which suggest that roughly 11% of households would move further away from the central city if autonomous vehicles were widely available (Bansal and Kockelman, 2018; Kim et al., 2020; Krueger et al. 2019).

Fagnant and Kockelman (2015) led model-based investigations into various features of autonomous vehicle technologies, including adaptive cruise control (ACC) systems. They noted how these systems can mitigate sudden acceleration and deceleration in highway traffic, fostering a smoother and more efficient traffic flow. Their research further underscored the advantages of AVs regarding enhanced safety and improved fuel economy. The benefits of fuel efficiency start to materialize when AVs make up 13% of the traffic mix, increasing up to 25% when AVs reach 90% market penetration. The savings are attributed to an AVs' ability to select optimal routing and synchronize movement with traffic signal cycles. They also modeled road-train drag reductions, where a leading vehicle is closely trailed by several additional autonomous vehicles, forming a "road train." The closely spaced, synchronized motion reduces aerodynamic drag, leading to fuel savings. Even non-autonomous vehicles on freeways experienced an 8% improvement in fuel economy during peak traffic times under a 10% AV market penetration rate, increasing to 13% when AV market penetration rates ranged between 50% and 90%.

Harper et al. (2016) used travel demand modeling to quantify the impacts on vehicle miles traveled (VMT) due to the new mobility provided to non-drivers, the elderly, and individuals with restricted travel conditions. They estimated that VMT would increase by up to 14% in serving those groups' travel needs with AVs. Othman (2022) also recognized the potential advantages AVs could offer to the elderly and mobility impaired individuals. But more uniquely, he recognized there is a knowledge gap concerning the acceptance of AV travel by such groups, hence challenging the assertion that the elderly, in particular, would become early adopters of emerging transportation technologies.

Tan et al. (2020) emphasized the need to incorporate new model variables to test potential AV user characteristics and consumers' likelihood to purchase AVs. This included aspects such as income, having a valid driver's license, level of driving skill, positive view of

AVs, and access to transit hubs. These often-overlooked factors in traditional travel demand models significantly influence societal acceptance and integration of AVs into travel routines.

Travel model researchers generally concur with the importance of integrating land use and transportation demand models (Giuliano and Agarwal, 2017; Sultana et al., 2017). Integrated models could account for spatial and temporal transportation shifts and their influence on regional development in the wake of full AV deployment. Travel demand models that treat future land use allocations as fixed inputs significantly limit their ability to determine the effects of AV travel on sustainable urban development (Nadafianshahamabadi et al., 2021).

The inconvenience associated with automobile driving carries an opportunity cost which is crucial in shaping travel decisions, particularly when choosing modes of travel (Kraus, 1977). As autonomous vehicles become more commonplace, the perceived discomfort associated with travel time may diminish. This idea is based on the notion that AVs will allow individuals to multitask during their commute, thereby making commuting time more productive and enhancing in-vehicle time value. This improved utilization of travel time, whether for leisure or work, could increase the overall satisfaction derived from travel (thus reducing its "disutility"), especially for long-distance journeys (Dianin et al., 2021; Kolarova and Cherchi, 2021; Singleton, 2019). Rashidi et al. (2020) raise concern with accounts of increased AV travel time utility. They argue that future travelers will not just encounter technological advancements in transportation, but also in every other aspect of their lives. Due to the broad and uncertain nature of future changes, stated preference survey responses regarding the value of time spent in autonomous vehicles are inconclusive. Therefore, conclusions drawn from those instruments related to specific future scenarios like valuation of AV travel time may not be reliable. This skepticism is echoed by other researchers critiquing a broad spectrum of possible future technological advancements which are not only unpredictable but also highly interconnected and ubiquitous (Yigitcanlar et al., 2019).

Despite these reservations, substantial research has been published examining potential AV user perceptions of the value of time. Kolarova et al. (2019), combined online surveys with revealed and stated preference sampling to anticipate potential shifts in the value of time spent traveling in AVs. They identified a 41% reduction in perceived value for work trips taken in AVs compared to traditional car travel. Time spent commuting in an AV was equated to time spent on public transit. Kolarova and Cherchi (2021) made significant contributions to the body of survey research. Their study found that previous exposure to Advanced Driving Assistance Systems (ADAS) and being under 30 years old were positively associated with trust in AV technology. Notably, younger respondents assigned less importance to travel time savings compared to older respondents. A higher level of education was linked to an increased value placed on time. Gender differences were also evident, as men exhibited a higher level of trust in technology and a greater inclination towards AV use as compared to women. These findings shed light on the diverse factors influencing public attitudes and perceptions towards AVs and are valuable in guiding future policies and strategies.

While these findings emphasize the crucial role of demographic and attitudinal factors in determining the perceived value of travel time savings, existing four-step travel demand models are largely unequipped to assess human behavior and the acceptance of future technologies. This reveals a need for more comprehensive modeling approaches that incorporate user attitudinal dimensions to adequately gauge the societal impact of emerging transport technologies.

3.3. Research Gaps

Understanding the transformative potential of autonomous vehicle technology necessitates extensive research. Studies play a crucial role in formulating appropriate strategies and policies to navigate the anticipated societal transformations and ramifications resulting from widespread AV use, emphasizing their ability advance sustainable mobility solutions under various deployment scenarios (Faisal et al., 2019). Researchers are advancing sophisticated transportation decision-making models that simulate long-term residential location choices based on transportation costs, as well as short-term mobility decisions made for activities like shopping and recreation (Chen et al., 2016).

With the emergence of autonomous vehicles, these already intricate behavior models become even more complex as they attempt to predict how paradigm shifts in movement will influence future land development (Dias et al., 2020). A significant gap remains between the conventional travel demand forecasting models currently utilized by industry professionals and the rapidly evolving analytical methods required to study advancements vehicle functionally, on-demand mobility services, and land development. This disparity highlights a critical area that requires continuing research and refinement.

3.4. Research Questions

Drawing upon the research gaps identified in the literature review, the remainder of this chapter delves into the following questions, specifically concerning the influence of autonomous vehicles on sustainable urban development:

- How might the potential widespread deployment of fully automated cars impact efficient land use planning and development practices?
- Can traditional regional travel demand modeling tools provide planners and policymakers with useful insights on future AV use?
- How should the “value of time parameter” in existing regional travel demand models be adjusted to account for perceived increases in productivity during travel in self-driving cars?

- How does the increased productivity potential in self-driving cars influence sustainable urban growth practices, particularly in relation to urban sprawl?

The choice of travel purpose, transportation mode, routing, and timing are significantly influenced by perceived value (or cost) of in-vehicle travel time. It is speculated that a shift in time valuation due to AV modes could potentially encourage commuters to reside further away from their workplaces. To investigate this phenomenon, the parameters of the 2050 Greater Madison MPO (Dane County, Wisconsin) travel demand model (Bentley Systems CUBE modeling software) are adjusted based on insights collected from the literature review to simulate various changes to travel parameters accountable to AV use.

This holds considerable advantages for practitioners. Leveraging an existing travel demand model allows for application of methods and presentation of results in a format already familiar to transportation planners and modelers. Any MPO currently using a four-step regional transportation model can readily implement the methodologies proposed here.

3.5. Ethics and Limitations

George Box, the renowned British statistician, famously stated, "*All models are wrong, but some are useful*" (Box, 1979). Box suggests that although no model can flawlessly represent reality, well-designed models can provide valuable insights and effective approximations of the systems they represent. Travel forecasting models, often described as "black boxes", are intricate mathematical structures. They are susceptible to biases and other issues that can unintentionally influence the accuracy of the traffic forecasts they generate (Beimborn et al., 1996). The well-known saying "garbage in, garbage out" is frequently attributed to computer models, indicating that inaccurate input inevitably results in unreliable and flawed output.

Mackett (1998) studied travel demand model inaccuracies and errors arising from both internal and external factors. Internal factors include incorrect inputs, omission of important variables, model misspecification, improper model application, and inadequate disaggregation. External factors stem from intent to reach a specific outcome, political pressures, and lack of technical expertise. In response to what she perceived as the politicization of scientific modeling during the COVID-19 crisis, Saltelli (2020) outlined several principles that those modeling complex systems should be aware of:

- Evaluating model uncertainty and sensitivity is crucial.
- Increasing complexity can potentially undermine relevance.
- Every model reflects the interests, orientations, and biases of its developers.
- Indiscriminate use of statistical tests is not a substitute for sound judgement.
- Conveying the unknown is just as important as sharing what is known.

In Saltelli's words, "*Asking models for certainty or consensus is more a sign of the difficulties in making controversial decisions than it is a solution and can invite ritualistic use of quantification. Models' assumptions and limitations must be appraised openly and honestly. Process and ethics matter as much as intellectual prowess.*"

3.6. Methodology and Data

The next section describes the methodologies and data sources used to evaluate simulated AV travel in Dane County, Wisconsin. The section is divided into three parts: 1) the land use forecasts, 2) the transportation model, and 3) the AV simulation parameters.

3.6.1. Land Use Forecasts

Dane County, Wisconsin, is the boundary for the Greater Madison MPO regional transportation model. As the state's second-largest city, Madison is the state capital and home to the University of Wisconsin campus. Madison is a center of cultural, governmental, and educational activities within the state. With its progressive history, the city is known for utilizing innovative approaches to guide future urban development. The city's latest comprehensive plan utilized a future scenario modeling tool called "UrbanFootprint." Peter Calthorpe and Joe DiStefano, urban planners with experience in developing sustainable and livable cities, founded UrbanFootprint in 2014. Madison used the UrbanFootprint tool to analyze sustainable, equitable, and livable urban development scenarios. The city applied a broad array of data, including existing land use, demographic data, planned development, climate zones, and environmental constraint data to provide detailed projections of how different city planning decisions on future growth would affect key sustainability outcomes.

The program's transportation module used data derived from the regional transportation model. UrbanFootprint also supports the goals of Complete Streets by allowing planners to see how different transportation system decisions might affect accessibility, mobility, and quality of life in cities (Calthorpe Analytics, 2016).[18] Madison's Comprehensive Plan update combines Land Use and Transportation into one element, acknowledging their inseparable link (City of Madison, 2018). UrbanFootprint was used to analyze three different future growth scenarios:

- Scenario 1 envisioned urban growth expanding to the city's outskirts.
- Scenario 2 offered a balanced approach, mixing edge development with urban core redevelopment.
- Scenario 3 primarily focused on urban core redevelopment.

The newly adopted city plan emphasizes the need to create infrastructure which not only fosters transit-oriented redevelopment but also broadens transit services in emerging neighborhoods. It specifically advocates for land use strategies designed to augment the city's new Bus Rapid Transit (BRT) system. BRT vehicles travel on dedicated lanes, offering efficient,

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[18] According to Smart Growth America "Complete Streets" is a term for the design approach in which streets are planned, designed, and operated to enable safe, attractive, and comfortable access and travel for all users, regardless of their mode of transportation. https://smartgrowthamerica.org/what-are-complete-streets/ [Accessed 27 July 2023]

comfortable, and cost-effective services to meet regional transportation demand. The first BRT route will link the city's major regional shopping centers located on its far east and west sides. The service, initially operating east to west through the Isthmus and University of Wisconsin campus, will run on 15-minute frequencies and is expected to begin operation in 2024.

For the transportation demand model's future land use input data, results of the selected UrbanFootprint scenario modeling were converted from "place type" data to "building type" data. Building types were then sorted to create projected land use inputs in groupings that included the UW campus, urban and non-urban civic, high-rise residential, high-density housing, low-density housing, hospital, hotel, urban and non-urban school, park, main-street, commercial, office, office-industrial, and open space. This information was the basis for the year 2050 trip generation estimates.

3.6.2. Transportation Model

In April 2019, the Madison MPO initiated an extensive overhaul of its regional travel demand model. The MPO uses a traditional four-step, trip-based travel demand modeling approach, incorporating both the street and transit networks within Dane County. It factors in various modes of infrastructure, including highways, arterial and collector roads, and traditional local bus and BRT routes. Validated for the year 2016, the model generates traffic forecasts for the horizon years 2035 and 2050. It estimates trips generated in 1,289 Travel Analysis Zones (TAZs) and 32 External Stations. The model includes a mode choice component that predicts mode shares for single occupancy vehicles, shared rides, transit, bicycling, and walking. Traffic routing assignments are facilitated using a Static User Equilibrium methodology.

The model estimates traffic volumes during both the morning and afternoon peak commuting times, as well as off-peak periods. It provides a variety of key outputs related to transportation system performance, including vehicle miles traveled, average trip length, volume-to-capacity ratios, and average travel speeds.

Figure 3.1 illustrates the sequential flow of a typical trip-based four-step model. The solid red line shows the point at which an analyst would reassess potential revisions to land use forecast inputs due to anticipated changes in travel demand and infrastructure needs. The blue dashed line symbolizes the introduction of a land use feedback loop, adding endogeneity to the transportation-land use modeling process. Neither of these features is present in the current transportation demand forecasting model. The absence of land use feedback loops when analyzing the impact of autonomous vehicles presents a significant limitation. The literature review indicates that changes in travel behavior due to the use of AVs are strongly linked to shifts in land use patterns.

Consider a scenario where AVs significantly reduce the need for parking in densely populated urban areas. This could lead to a substantial amount of land being repurposed for housing, businesses, or green spaces. Additionally, if AVs make long-distance commuting more convenient by enabling multitasking during transit, it may result in people living farther from urban cores. This shift may introduce new patterns in residential development, potentially contributing to the expansion of urban sprawl. Therefore, a model that fails to account for these land use feedback loops cannot fully capture the potential impacts of AVs. It may similarly be neglecting important secondary effects on other facets of the transportation system and urban area, including public transit use, non-motorized travel modes, greenhouse gas emissions, energy consumption, accessibility, and social equity factors.

Figure 3.1

Generalized Four-Step Travel Modeling Process

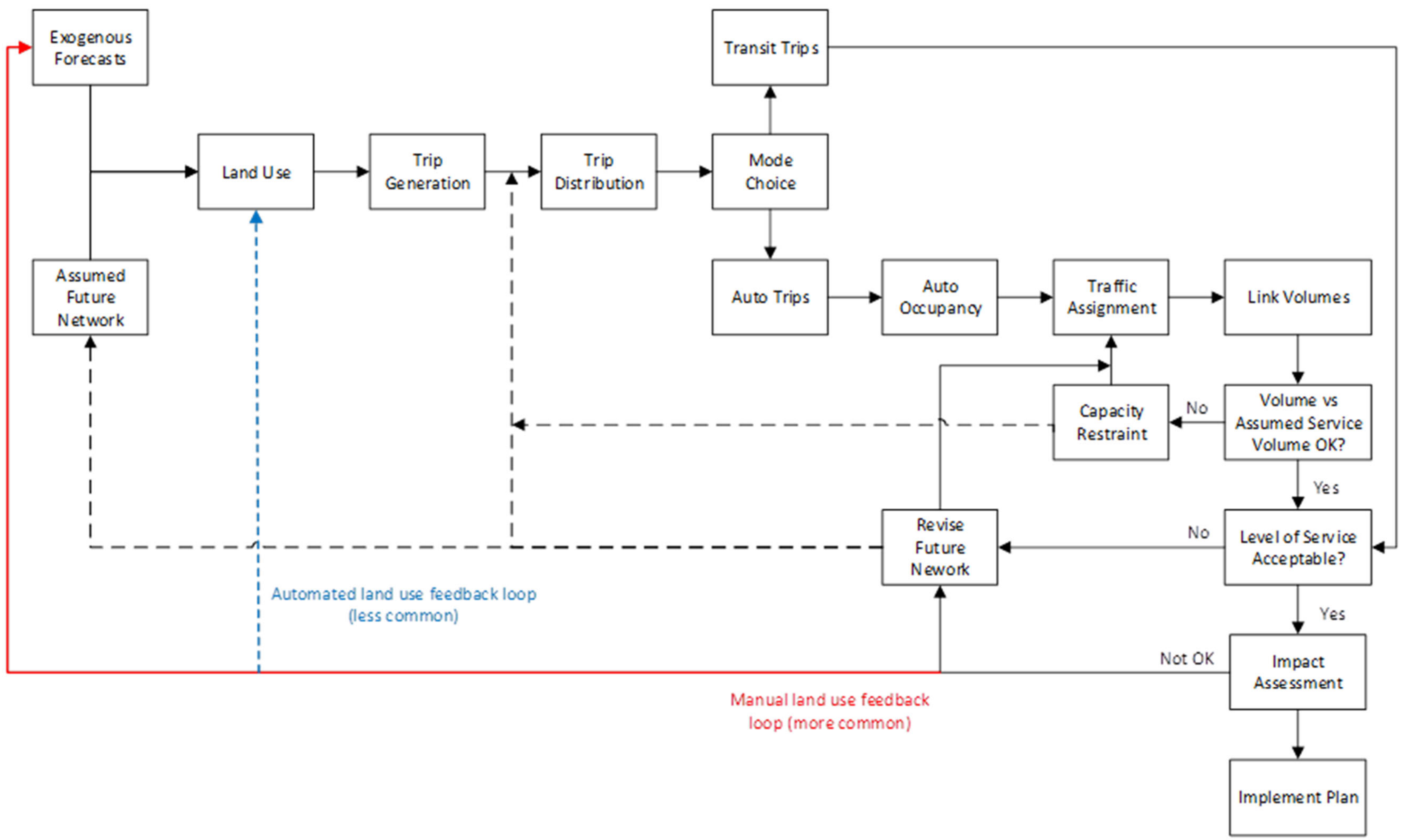


Illustration adapted from: Koepke, F. J., Stover, V. G. (2002). Transportation and Land Development. Institute of Transportation Engineers. Figure 2-1.

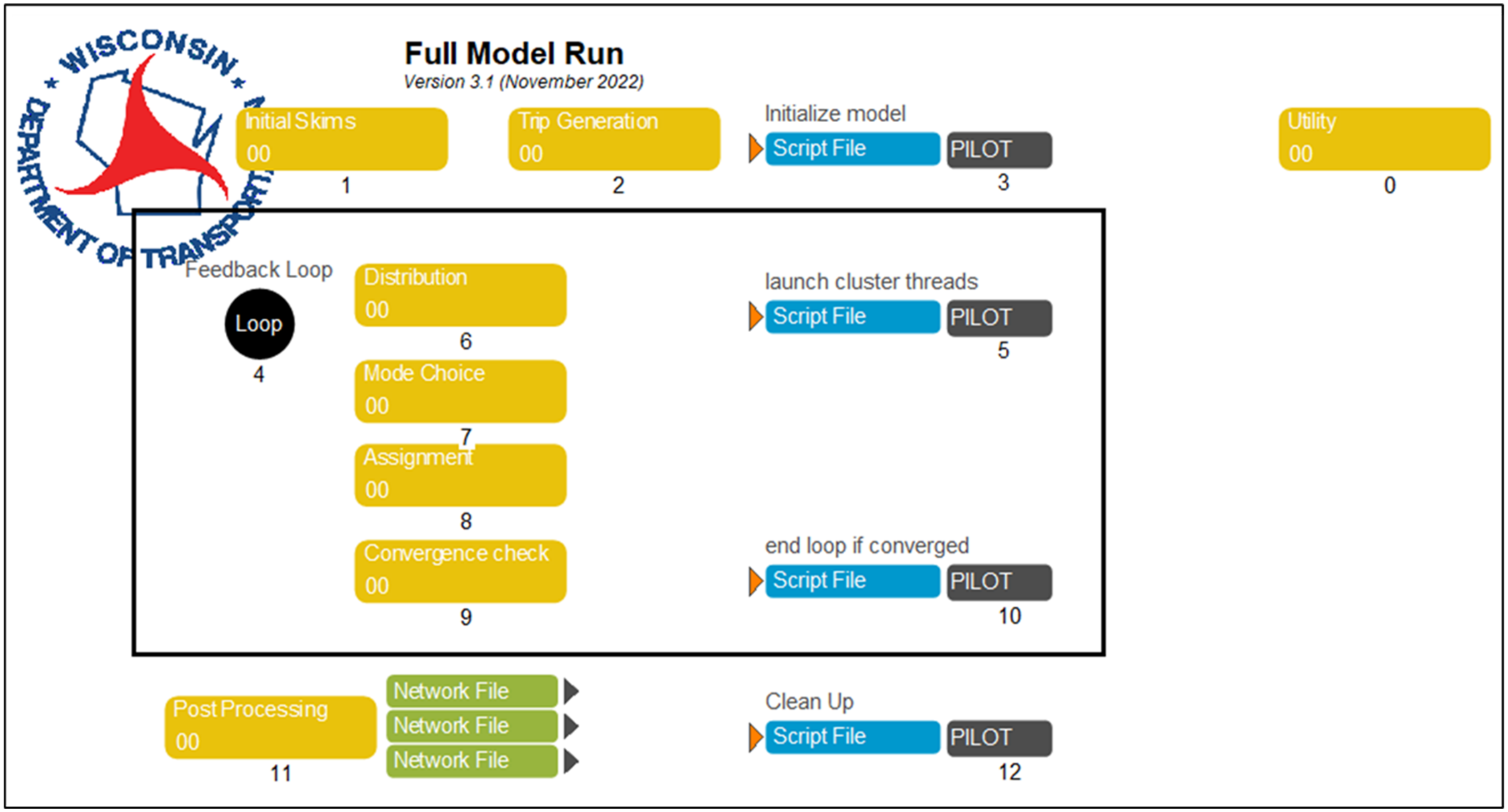
Recent updates to Madison's four-step model process introduced several other significant improvements. A major change was replacing the traditional gravity model used for trip distribution with a destination choice model. More in-line with mode choice models, the destination choice model provides a better depiction of travelers' propensity to travel within transit corridors (Cambridge Systematics, 2022). It also added new travel market segments including households with no vehicles, households with fewer vehicles than workers (insufficient auto households), and households with enough vehicles for each worker (sufficient auto households). These changes allow the model to reflect trip generation and distribution patterns more accurately for a wider variety of household types. Figure 3.2 depicts the opening screen for the Madison model user interface.

3.6.3. AV Simulation Parameters

The simulation of autonomous vehicle travel in Dane County was performed using eight modeled scenarios, each with specific parameters adjusted based on findings from the literature review. In the following section, each scenario includes a summary of the parameter adjustment rationale and resulting model outcomes, using measures of vehicle miles traveled (VMT), average travel speeds and distances, and mode of travel estimates. Maps are included to illustrate changes in scenario average daily traffic volumes compared to the base model, with line thickness indicating accumulating traffic increases on highway facilities. Table 3.1 summarizes the adjustment of model parameters to test fully autonomous vehicle impacts on the 2050 transportation system.

Figure 3.2

Dane County CUBE Model Opening Screen



Source: Greater Madison MPO & Wisconsin Department of Transportation [Accessed July 6, 2023].

Table 3.1

AV Scenario Test Summary

AV Parameter	AV Scenario Description	Parameter Change	References
Auto Availability	Households (HHs) already having vehicle access do not add vehicles. HHs without a vehicle will gain access to one shared car per HH. There would be no change in the operating costs of vehicles. These scenario assumptions may not capture cost and accessibility challenges faced by low-income HHs.	All previous 0 auto HHs increase to having 1 vehicle available.	Bahamonde-Birke et al., 2018; Cohn et al., 2019; Dianin et al., 2021; Kockelman et al., 2017.
Auto Occupancies	AVs traveling without passengers (deadheading) increase for all trip purposes. The average persons per vehicle on shared ride trips is decreased.	Shared ride vehicle occupancies reduced to the equal occupancy rates for single occupant vehicles.	Cohn et al., 2019; Fagnant & Kockelman, 2015; Harb et al., 2021.
Highway Capacity	AVs have a beneficial impact on capacity, allowing lower headways at higher speeds. Freeways benefit from minimum distance between vehicles, reduced lane weaving, and more stable flow. Other functional class roadways operate like current conditions to maintain safety and reduce impacts to other modes.	57% capacity increase (from 2100 to 3300 vplph) on Interstate and other freeway facilities.	Cohn et al., 2019; Dias et al., 2020; Fagnant & Kockelman, 2015; Meyer et al., 2017.
Parking Cost	Driverless vehicles drop off occupants and locate free parking away from destination site, return to their point of origin for other pick-ups, or cruise until needed again. The Dane County model includes peak- and off-peak zonal parking costs but they are not applied. Instead, parking costs are presumed to be included in total auto operating costs by trip purpose.	Decrease operating cost for HB Work, HB Univ., and HB School trips. Assume 15% of auto cost; more specific data not available.	Cohn et al., 2019: Duarte & Ratti, 2018; Gkartzonika & Gkitza, 2019; Millard-Ball, 2019.
Terminal Time	Travelers have control over the arrival and departure times of the AV, receiving door-to-door service to and from the Central Business District (CBD). No adjustment made due to additional congestion driverless vehicles may cause.	CBD zone terminal time reduced by 2 minutes.	Bouchard & Pyers, 1965; Cohn et al., 2019; Shafiei et al., 2023.
Trip Making	Discretionary trips including regional and local Home-Based Shopping and Non-Home-Based trips increase. Additional trips are made by driverless vehicle deliveries. Empty journeys result from trips between users or during auto-parking.	Regional and local HB-Shopping and Non-HB trip rates increased 25%.	Bahamonde-Birke et al., 2018; Cohn et al., 2019; Harb et al., 2022; Meyer et al., 2017; Riggs et al., 2022.
Value of Time	The flexibility offered by AVs allows for other productive or leisure activities during work trip commuting time. There is also increased willingness to utilize AVs for discretionary travel (i.e., social-recreation trips).	Drive alone utility parameter increased by 50% for Home-Based (HB) Work and University trips, and HB Social Rec trips.	Bahamonde-Birke et al., 2018; Bernardin et al., 2019; Cohn et al., 2019; Nair et al., 2018; Rashidi et al., 2020.

3.7. Results

AVs are expected to respond more quickly and efficiently to varying traffic conditions, capitalizing on their capabilities to optimize traffic flow, improve fuel efficiency, and minimize emissions (Fagnant and Kockelman, 2015). Trends in average household vehicle ownership, per capita VMT, vehicle occupancy rates, and commute lengths may experience notable deviations from historical norms (Greenblatt and Shaneen, 2015). Therefore, the modelling of prospective AV impacts necessitates the application of several assumptions. AV parameters encompass the anticipated rate of adoption, alterations in roadway capacity, perceived opportunity costs of travel, public policies pertaining to AV ownership and operation, and adjustments in parking and vehicle operating costs.

In scenario modeling, strategic adjustments of numerous parameters are made, with each one eventually feeding into a holistic future scenario, thereby enabling a comprehensive analysis of the potential impacts AVs might have on regional travel behaviors and patterns (Nadafianshahamabadi et al., 2021). The remainder of this section reviews each of the following travel demand model parameters, as adjusted and analyzed using the Madison MPO transportation demand model:

- Auto Availability
- Auto Occupancy
- Freeway Capacity
- Parking Costs
- Terminal Time
- Trip Making
- Value of Time

It is important to reiterate one point. The fact that land use is not defined as a testable parameter within the Madison MPO model is not casually disregarded. However, as an exogenous parameter to the model process flow, incorporating something different would require the creation of a new and distinct 2050 land use input scenario, constructed outside the regional transportation model framework (i.e., UrbanFootprint). While this is a less-than-ideal condition, it signifies an unavoidable restriction on the scope of this research.

3.7.1. Scenario 1: Increased Auto Availability

Cohn et al. (2019) addressed the implications of automobile availability as a factor in AV modeling. Their proposition was that, under a future scenario of widespread AV adoption, every household will have at least one vehicle at their disposal. Milam et al. (2019) also associated AV usage rates with auto availability. In their study, they contend that the widespread deployment of AVs will boost trip generation rates due to their easy accessibility and convenience. Importantly, this increase, they determined, won't only affect work trips (commuting) but will also result in more vehicle trips being made for purposes like shopping, socializing, leisure activities, and recreation.

Kockelman et al. (2017), however, hypothesized that the elevated expense associated with these vehicles could constitute a potential impediment to automotive accessibility, thereby obstructing their universal adoption among households. They reasoned that the incorporation of advanced technology in AVs would inflate the initial procurement costs, rendering them unaffordable for many households. Nonetheless, they projected a decrease in these costs as production scales up, thereby potentially enhancing the affordability of AVs over time. Furthermore, they examined the role of household income levels on perceptions of AV affordability, investigating the potential usage of AVs across diverse economic strata. For the purposes of this study, it is presumed that by the model's horizon year (2050), pricing will have decreased sufficiently to make the technology broadly accessible to households, at least from a cost perspective.

Sousa et al. (2018) anticipated a transition away from individual ownership of autonomous vehicles to more cost-effective, on-demand AV service systems to mitigate initial cost concerns. Dianin et al. (2021) examined how AVs might address social disparities among individuals lacking driving capabilities and found that while Level 3 AV technology would not substantially improve accessibility for the mobility impaired, Levels 4 and 5 would enable more social participation and flexible transportation options for those unable to drive. They, along with Kockelman et al. (2017) and Sousa et al. (2018), advise caution in projecting significant AV availability increases to mobility impaired people until the high initial acquisition and maintenance costs anticipated with fully autonomous vehicles decline and eventually stabilize.

To gauge the cost differences between private AV ownership and an on-demand service as proposed by Sousa et al. (2018), Golbabaei et al. (2021) compared the costs of vehicle ownership to the use of an on-demand ride-hailing service. They found that driver wages accounted for 40-50% of conventional taxi fares. Thus, they determined that investing in fleets of publicly owned shared AVs could provide affordable transport for individuals with mobility challenges. This strategy would also provide environmental advantages by reducing the number of privately-owned vehicles traversing the network.

In the initial scenario tested, full autonomous vehicle integration is assumed. Every household in Dane County, even those currently projected to lack automobile access, is anticipated to have at least one autonomous vehicle available by 2050. All other household automobile availability forecasts were unchanged, so households expected to have one or more vehicles available in 2050 remained the same in the model.

The results reveal a correlation between households gaining access to more vehicles and an increase in their usage, resulting in a 1.5% increase in vehicle miles of travel compared to the 2050 baseline scenario, shown in Table 3.2. Further, the model results suggest that the increase in automobile trips corresponds to a decrease in trips made using more sustainable modes, including transit ridership, which was expected. As depicted in Figure 3.3, traffic increases are dispersed across Dane County. Although not a drastic rise, it reflects the added convenience of always having a vehicle available and could also account for the potential of autonomous vehicles to provide unoccupied errand-running trips, an adjustment examined in Scenario 2.

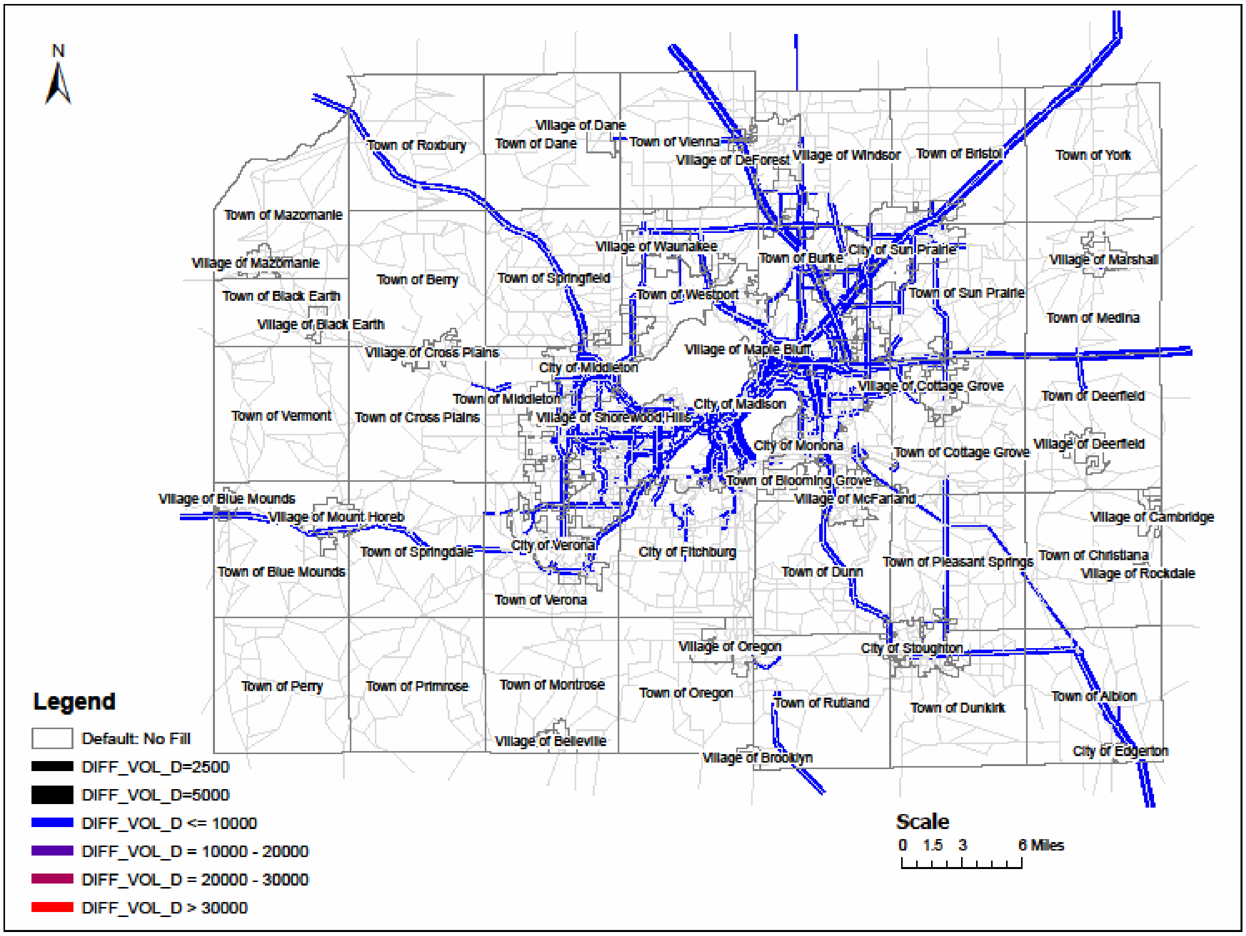
Table 3.2

Scenario 1: Auto Availability Model Results

Metric	2050 Base	Auto Availability	Change	Percent
Auto VMT	18,289,434	18,561,726	272,292	1.5%
Auto Speed (MPH)	31.5	31.2	(0.3)	-1.1%
Daily Trips (All Modes)	3,815,585	3,812,873	(2,712)	-0.1%
Drive Alone	1,662,784	1,730,674	67,890	4.1%
Shared Ride	1,200,511	1,202,823	2,312	0.2%
Walk	606,227	582,832	(23,396)	-3.9%
Bike	185,598	163,463	(22,134)	-11.9%
Bus	68,562	50,125	(18,437)	-26.9%
BRT	20,683	13,869	(6,815)	-32.9%
School Bus	71,219	69,088	(2,131)	-3.0%
Scenario Modification	E+C Network	HHs with 0 cars increased to 1 car		

Figure 3.3

Scenario 1: Auto Availability Volume Increases (ADT >100)



3.7.2. Scenario 2: Decreased Auto Occupancy

Cohn et al. (2019) explored the potential influence of shared AV usage, premised on the implementation of government policies that promote or mandate higher vehicle occupancies. Consequently, they tested a travel mode dubbed "High Occupant AVs", wherein they converted half the single-occupancy vehicle trips to shared ride trips, guaranteeing a minimum of two passengers per vehicle. Fagnant and Kockelman (2015) suggested increasing average vehicle occupancies by consolidating individuals unable to drive into existing trips rather than initiating new ones.

However, it is recognized that the appeal and ease of private car travel could be amplified with AVs, potentially promoting solo travel over carpooling or public transit, and leading to lower average auto occupancies. Many researchers theorize that AVs will trigger an increase in "zero-occupancy" trips as vehicles are dispatched unoccupied to pick up passengers, run errands, or return home after drop-offs. The incidence of zero-occupancy trips would contribute to a decrease in average vehicle occupancy rates (Harb et al., 2021).

Madison's transportation model differentiates vehicle occupancy rates by trip purpose for both drive-alone trips and shared ride trips. For Scenario 2, the shared ride vehicle occupancy rates are adjusted to mirror those of drive-alone trips for all trip purposes. Lowering the auto occupancy rates leads to a rise in VMT. If fewer people are sharing rides for their journeys, it results in an increase in the aggregate amount of driving, exacerbating traffic congestion. The diminished auto occupancies, coupled with increased travel prompted by AV availability, neutralizes some of the traffic flow efficiency benefits anticipated from AV utilization. Additionally, a surge in the volume of vehicles traveling greater distances may require increased public investment in road infrastructure and maintenance. It could also stimulate a greater demand for parking spaces, depending on utilization patterns.

As documented in Table 3.3, VMT experiences a 12.1% increase, congested automobile speeds rise 12.2%, and the total number of daily trips within the system remains unchanged. The average automobile trip length (measured in miles) increases 12.7%. The model suggests a shift of around 13,700 car trips (encompassing both single-occupancy and shared rides) toward more environmentally friendly modes of transportation, primarily walking.

Table 3.3

Scenario 2: Auto Occupancy Model Results

Metric	2050 Base	Auto Occupancy	Change	Percent
Auto VMT	18,289,434	20,506,341	2,216,907	12.1%
Auto Speed (MPH)	31.5	35.3	3.84	12.2%
Daily Trips (All Modes)	3,815,585	3,815,574	(10)	0.0%
Drive Alone	1,662,784	1,656,627	(6,157)	-0.4%
Shared Ride	1,200,511	1,192,942	(7,570)	-0.6%
Walk	606,227	619,231	13,003	2.1%
Bike	185,598	185,981	383	0.2%
Bus	68,562	69,536	974	1.4%
BRT	20,683	20,392	(292)	-1.4%
School Bus	71,219	70,866	(353)	-0.5%
Scenario Modification	E+C Network	SR occupancies lowered to equal all trips by purpose		

The findings appear to suggest travel speeds increase when congestion levels increase, which is counter intuitive. This apparent anomaly warranted further investigation. Figure 3.4 provides a pie chart isolating the distribution of the VMT increases by geographical area. About half of the additional travel miles occur within rural areas, increasing to about three-quarters when rural and suburban areas are combined. This suggests that commuters who continue to use automobiles after a reduction in shared ride occupancies are now traveling longer distances at higher speeds. Furthermore, decreased shared ride occupancies negatively affect routing efficiency, partially explaining the increase in VMT. This is notable, as car and vanpools (i.e., ride sharing) benefit from optimizing multiple stops within a single vehicle trip.

Figure 3.4

Scenario 2: VMT Increases by Area Type

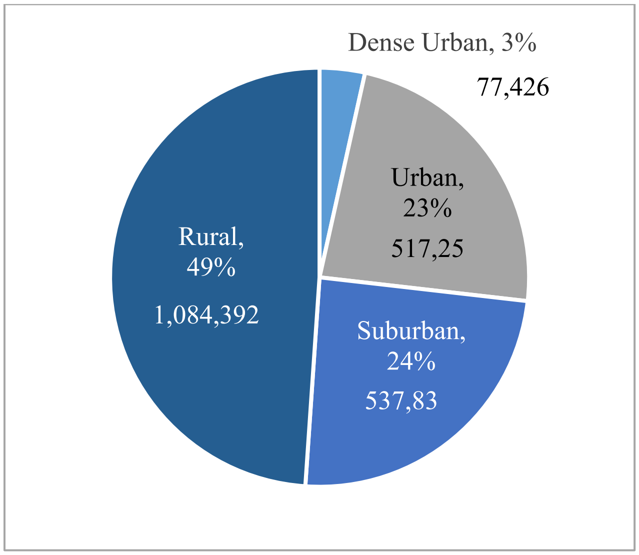
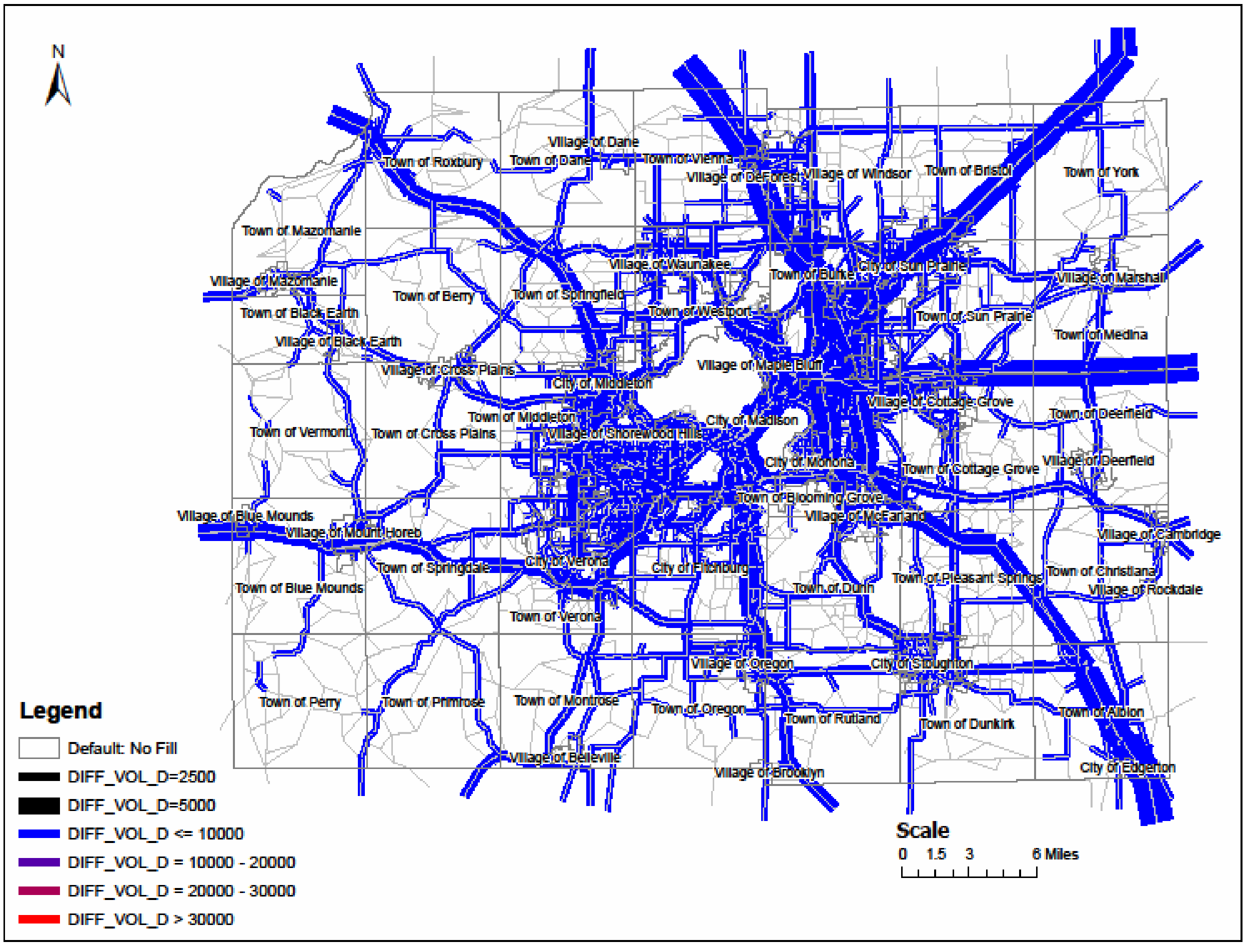


Figure 3.5 illustrates increases in traffic volumes under Scenario 2. The map further supports the notion that the increased VMT is partly attributable to increases in trip distances. Major highways feeding into Madison experience large increases in traffic. Most rural highways also appear to incur increased traffic volumes, which are widely dispersed throughout Dane County.

Figure 3.5

Scenario 2: Auto Occupancy Volume Increases (ADT>100)



3.7.3. Scenario 3: Increased Freeway Capacity

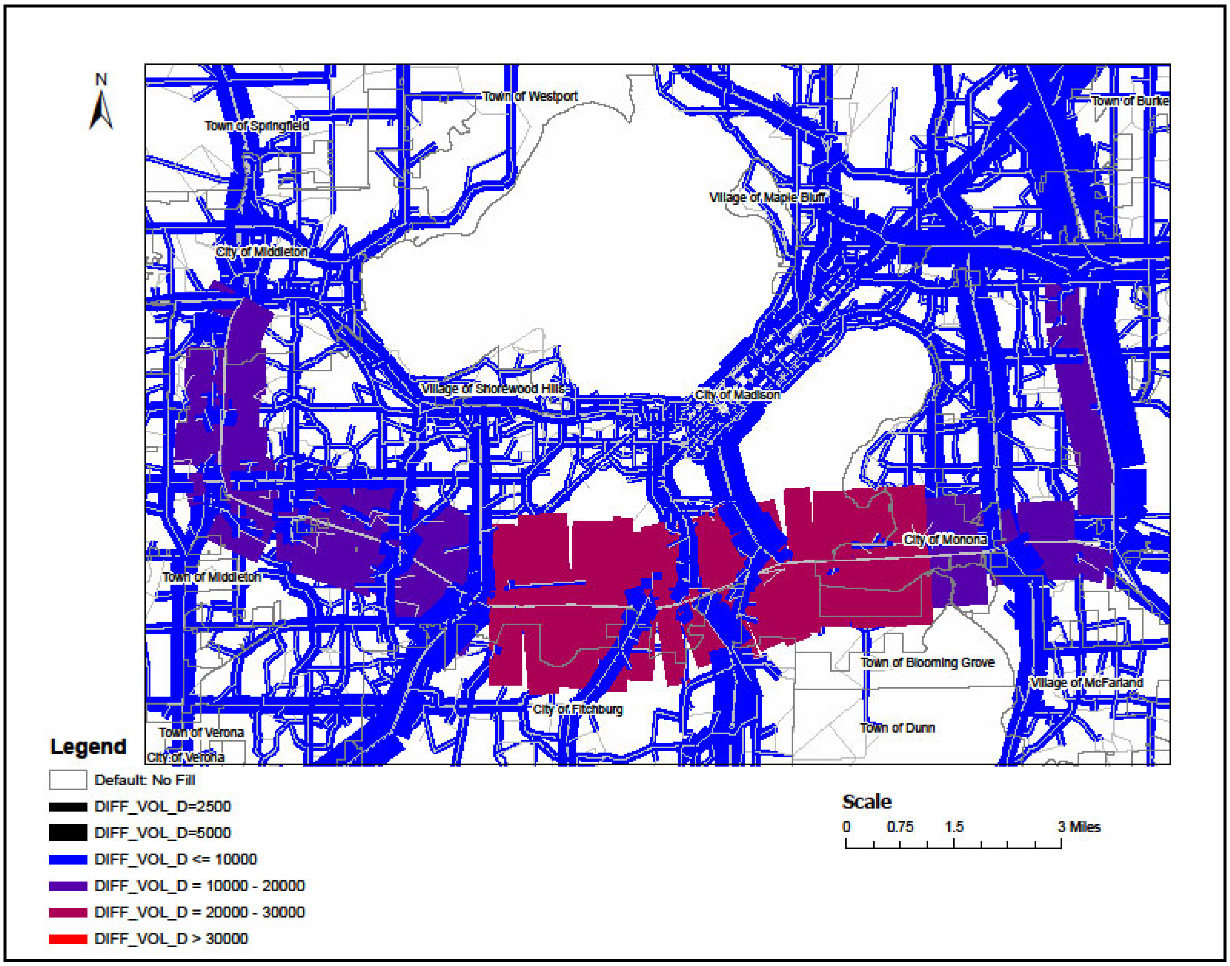
A substantial body of research is concentrated on the impacts AVs will have on highway capacity. Many of these studies have examined potential capacity enhancement facilitated by Cooperative Adaptive Cruise Control (CACC) technology. This technology, which incorporates vehicle-to-vehicle communication capabilities, enables vehicles to dynamically exchange information. As a result, computer algorithms synchronize traffic flow speeds and braking patterns, promoting smoother vehicular movement and optimized utilization of road capacity (Shladover, et al., 2012). Shladover et al. (2012) posited that the maximum freeway lane capacity could potentially rise to approximately 4,000 vehicles per hour, assuming all vehicles are equipped with CACC. Their research demonstrated that lane capacity would gradually increase from 2,000 to 4,000 vehicles per hour, corresponding to an increase from 0 to 100% in the proportion of vehicles in the traffic steam equipped with CACC. Their projections also assume that vehicles not fitted with CACC would instead be equipped with simpler, less costly Vehicle Awareness Devices broadcasting rudimentary "here I am" signals.

Fagnant and Kockelman (2015) underscore multiple traffic management benefits of Connected and Autonomous Vehicles (CAVs), including their potential to reduce incidents of rapid freeway acceleration and deceleration. They postulate this could improve congested traffic speeds by 8-13%. Further, with vehicles' ability to communicate among themselves, freeway capacities would expand by 1%, 21%, and 80% with 10%, 50%, and 90% CAV integration into the traffic mix, respectively. Meyer et al. (2017) echoed Fagnant and Kockelman's (2015) findings, providing further evidence supporting substantial capacity improvements. Their models projected potential capacity escalations of up to 80% on highways and 40% on urban arterials under the assumption of full operating autonomy for all vehicles in the traffic stream. These findings underscore the considerable potential for highway traffic flow enhancements achievable with widespread deployment of fully autonomous connected vehicles.

Cohn et al. (2019) adjusted their model to increase freeway capacity from 2,000 to 3,300 vehicles per hour per lane. They attributed this potential growth to reduced headways, less weaving, and more stable traffic flows. Notably, their assumptions still accounted for a consistent gap in headways between cars while maintaining existing basic vehicle designs. In Scenario 3, freeway capacity is increased from 2,100 vehicles per lane per hour to 3,300 vehicles per lane per hour, approximately a 57% increase. This change allows accommodation of a larger volume of vehicles within the same pavement space. The adjustment alleviates mainline traffic congestion and promotes smoother traffic flow on access-controlled highways. The results revealed a substantial increase in freeway traffic volumes, as both human-operated and autonomous vehicles gravitate towards the better flowing routes. This is particularly evident when examining the heightened traffic volumes on the Beltline, depicted in red on in Figure 3.6.

Figure 3.6

Scenario 3: Freeway Capacity Volume Increase – Beltline (ADT >100)



The Madison Beltline clearly shows the greatest volume increase. This substantial shift causes the corridor to conspicuously stand out, appearing in stark contrast amidst the blue lines on the traffic volume bandwidth map. Given that there are only three ways to traverse east and west through the Madison urbanized area (the second being through the congested Isthmus, and the third traveling north around Lake Mendota), an expanded capacity Beltline freeway offers much-needed relief for the other two thoroughfares.

The total number of trips being made remains unchanged before and after the freeway capacity is increased, as shown in Table 3.4.[19] Other arterial roadways in the regional network would theoretically see a reduction in congestion (despite their capacities not being increased) as more vehicles opt for the smoother-flowing freeways. However, if corresponding changes are not made to the intracity arterial routes, it would likely lead to heightened congestion and gridlock on those roadways during peak travel periods and at locations where the Beltline ramps connect to the arterial roadway system.

Table 3.4

Scenario 3: Freeway Capacity Model Results

Metric	2050 Base	Freeway Capacity	Change	Percent
Auto VMT	18,289,434	18,510,008	220,574	1.2%
Auto Speed (MPH)	31.5	31.8	0.29	0.9%
Daily Trips (All Modes)	3,815,585	3,815,589	4	0.0%
Drive Alone	1,662,784	1,664,395	1,611	0.1%
Shared Ride	1,200,511	1,202,692	2,181	0.2%
Walk	606,227	602,810	(3,418)	-0.6%
Bike	185,598	185,269	(329)	-0.2%
Bus	68,562	68,414	(148)	-0.2%
BRT	20,683	20,673	(11)	-0.1%
School Bus	71,219	71,337	118	0.2%
Scenario Modification	E+C Network	Freeway capacity increased by 57%		

[19] Incidentally, this is another shortcoming of the sequential four-step model which was encountered in previous Scenario analyses. Step 1 of the 4-step process is trip generation. The number of trips is initially generated based on land use intensities and patterns remains unaffected by alterations in trip distribution, mode split, and traffic route assignment processes that follow.

Metro transit buses do not operate on Dane County freeways, including the Beltline. However, a substantial enhancement in freeway efficiency might promote changes to Metro's transit routing structure. Paradoxically, the improvement in bus speeds and reliability gained by travel on better flowing freeways could make living farther from the urban center a more viable option for individuals reliant on public transportation. This could potentially increase ridership but also encourage urban sprawl.

3.7.4. Scenario 4: Decreased Parking Costs

Autonomous vehicles present a unique advantage in that they may not require parking near their destination, or conceivably, any parking at all. As per Millard-Bell's research (2019), these vehicles could be programmed to drop off passengers before seeking free parking at more distant locations, or alternatively, they could simply continue to circle the block until their services are needed again. Gkartzonikas and Gkritza (2019) referenced survey data indicating a correlation between rising parking costs and increasing interest in AVs among users. Respondents in the survey identified the ease and speed of parking as major advantages of AVs. Operating like an autonomous Uber or Lyft, particularly in densely populated urban areas, these services might seldom require parking, essentially eliminating parking costs for users. However, this could indirectly increase traffic volumes in already congested areas, a potential downside if shared AVs don't park between fares but instead choose to either keep circling or move directly to their next passenger.

In their 2019 study, Cohn et al. pinpointed parking costs as a crucial factor influencing terminal time - a variable in travel disutility calculations - which aligns with Scenario 5, to be reviewed next. They postulated that the advent of AVs could significantly decrease, or even negate the necessity of including terminal time when modeling AV impacts. To reflect this potential change, they modified their model to reflect a reduction in parking costs of 50% in all locations. However, they also pointed out an inconsistency in regional transportation models. These models often do not include parking costs specific to different locations, instead grouping parking costs within a general automobile operating cost value. According to their research, when compared to traditional vehicles, AV use could lead to a reduction in auto operating costs ranging from 25% to 80%. Notably, the upper end of these reductions was associated with a shift towards electric autonomous vehicles.

Extending the discussion beyond mere reductions in parking costs, Duarte and Ratti (2018) suggested that autonomous vehicles could prompt considerable alterations in vehicle design. They contend that AVs may evolve into versatile platforms tailored to accommodate diverse transportation needs. As a demonstration of this perspective, they proposed a novel "container" approach to AV parking. This strategy, like container stacking in shipping yards, seeks to optimize the use of space both horizontally and vertically. In their view, these "containers" or AV platforms could be assembled and disassembled in response to variable parking demands, enabling cities to manage parking based on specific events and fluctuating demand levels.

Scenario 4 assumes that fully autonomous vehicles (AVs) will drop passengers off at their destinations and find cheaper or even free parking spots further away. While this could reduce costs for vehicle owners, it doesn't necessarily mean there would be an overall reduction in municipal parking costs, since fees from downtown parking contribute to city revenue. Consequently, this scenario may decrease parking costs in the Central Business District, but could increase costs elsewhere in the urban area, particularly if electrically powered AVs relocate offsite to park or recharge. In the Madison travel demand model, parking costs aren't directly factored into the calculation of travel disutility. Despite the model including a variable for daily peak and off-peak parking costs in each transportation analysis zone (a legacy from previous model versions), these costs aren't specifically applied in the current model's calculations. For this reason, auto operating costs per mile were reduced by 15% for Home-based Work, Home-based University, and Home-based School trips. This adjustment led to only minor changes in scenario output metrics, as shown in Table 3.5. The increases in traffic volume due to this cost reduction are shown in Figure 3.7, which are predictably concentrated in the Madison Isthmus; an activity hub where automobile parking fees are typically charged during both peak and off-peak periods.

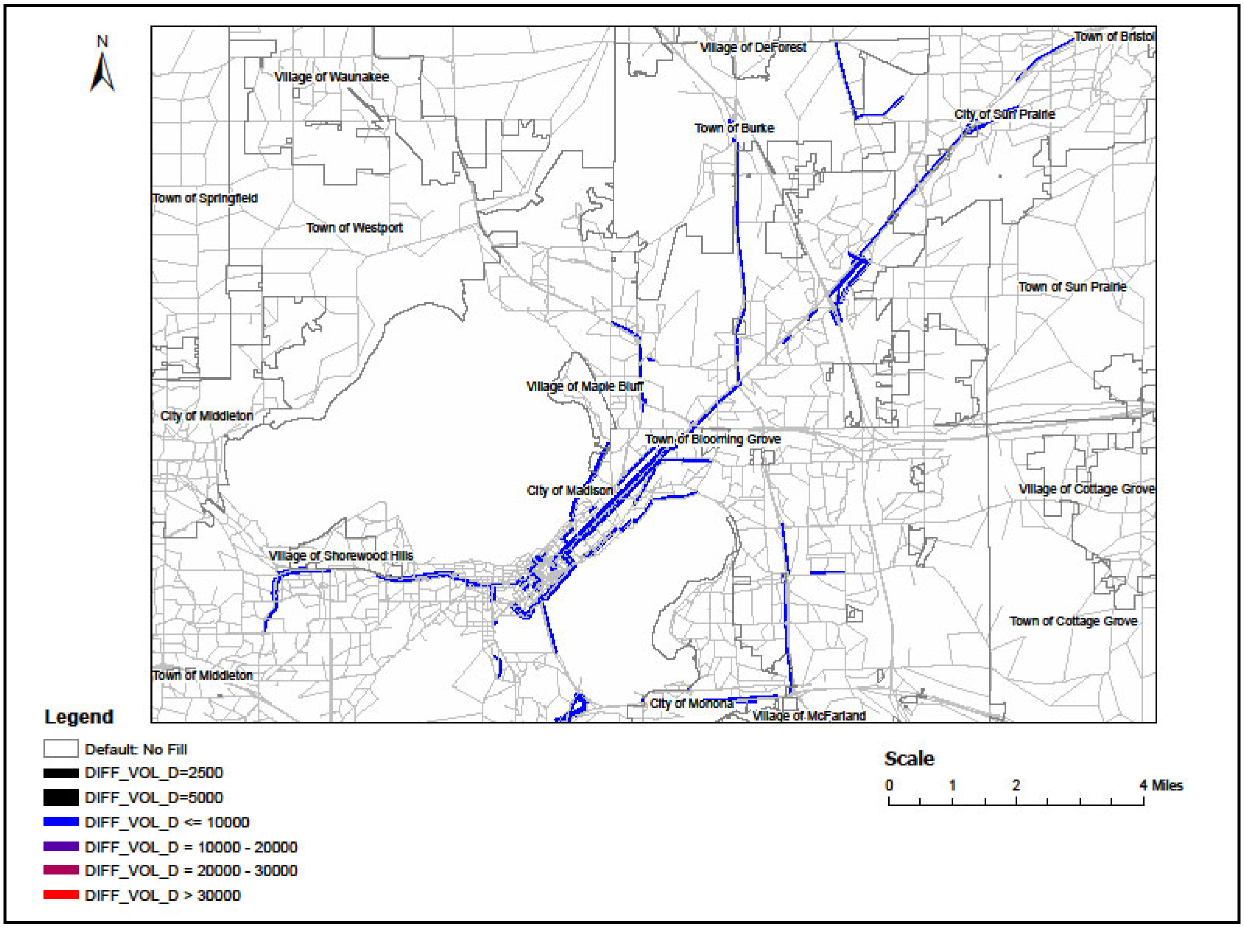
Table 3.5

Scenario 4: Parking Cost Model Results

Metric	2050 Base	Parking Cost	Change	Percent
Auto VMT	18,289,434	18,302,715	13,281	0.1%
Auto Speed (MPH)	31.5	31.5	0.01	0.0%
Daily Trips (All Modes)	3,815,585	3,815,585	0	0.0%
Drive Alone	1,662,784	1,663,372	588	0.0%
Shared Ride	1,200,511	1,200,699	188	0.0%
Walk	606,227	606,012	(216)	0.0%
Bike	185,598	185,101	(496)	-0.3%
Bus	68,562	68,663	101	0.1%
BRT	20,683	20,724	40	0.2%
School Bus	71,219	71,015	(204)	-0.3%
Scenario Modification	E+C Network	Reduce HBW, HBU, HB School auto costs by 15%		

Figure 3.7

Scenario 4: Parking Cost Volume Increases (ADT>100)



3.7.5. Scenario 5: Decreased Terminal Time

Terminal times encompass the additional time required to park and walk to final destinations, which varies depending on the area in which trip origins and destinations are located. Together with in-vehicle travel time, terminal times contribute to the calculation of "travel impedance." The travel impedance factor is commonly applied in trip distribution models, signifying the degree of difficulty or inconvenience associated with travel (Bouchard and Pyers, 1965). Congestion impacts travel time in two main ways: it directly extends in-vehicle time due to slower traffic speeds and longer journey durations, and it can also indirectly lengthen terminal time. For instance, in anticipation of traffic congestion, individuals might choose to park at greater distances from their destinations. This could necessitate either walking further or taking public transit to reach the ultimate trip destination, both of which would add additional time to the journey's total duration.

As AVs become increasingly commonplace, their ability to deliver passengers directly to their destinations and self-park could greatly reduce and even eliminate terminal times. This change would mark a significant deviation from current terminal time models. It would be especially significant in areas characterized by a high concentration of employment or commercial activities, where finding parking is typically difficult and time-consuming. Also, as previously described, while the reduction or elimination of terminal time would enhance convenience for individuals, it could also intensify congestion within downtown activity hubs.

Shafiei et al. (2023) proposes a solution to the potential downtown congestion issue: congestion pricing. This approach would entail levying tolls or fees during peak traffic periods to encourage shifts in travel behavior. The fees could be adjusted based on trip purpose or duration of activity at the destination to manage congestion more efficiently. New York City is pioneering this approach in the United States by implementing a novel congestion pricing program designed to dissuade drivers from worsening traffic congestion in Midtown Manhattan during peak hours. As The New York Times (2023) reports, Manhattan peak hour travelers could face a surcharge of $23, while off-peak travelers could be charged an additional $17.

In the Scenario 5 model, terminal times in the downtown area are reduced by two minutes, representing a 67% reduction for their original values (from three minutes to one minute). This reduction primarily affects trips with origins or destinations within the Isthmus. However, the impacts extend beyond the Madison Isthmus. Systemwide averages at the county level show a 0.6% decrease in average modeled trip length (measured by distance) but a more significant 1.9% decrease occurs when trip length is measured by time, indicating the impact of reduced terminal times. It is also evident that these values are averaged across the entire system. If the results were to focus solely on Madison's CBD area, the changes would likely be much more pronounced. Additional scenario impacts are included in Table 3.6. Overall, the CBD terminal time parameter alterations resulted in little change from the 2050 base model results.

Table 3.6

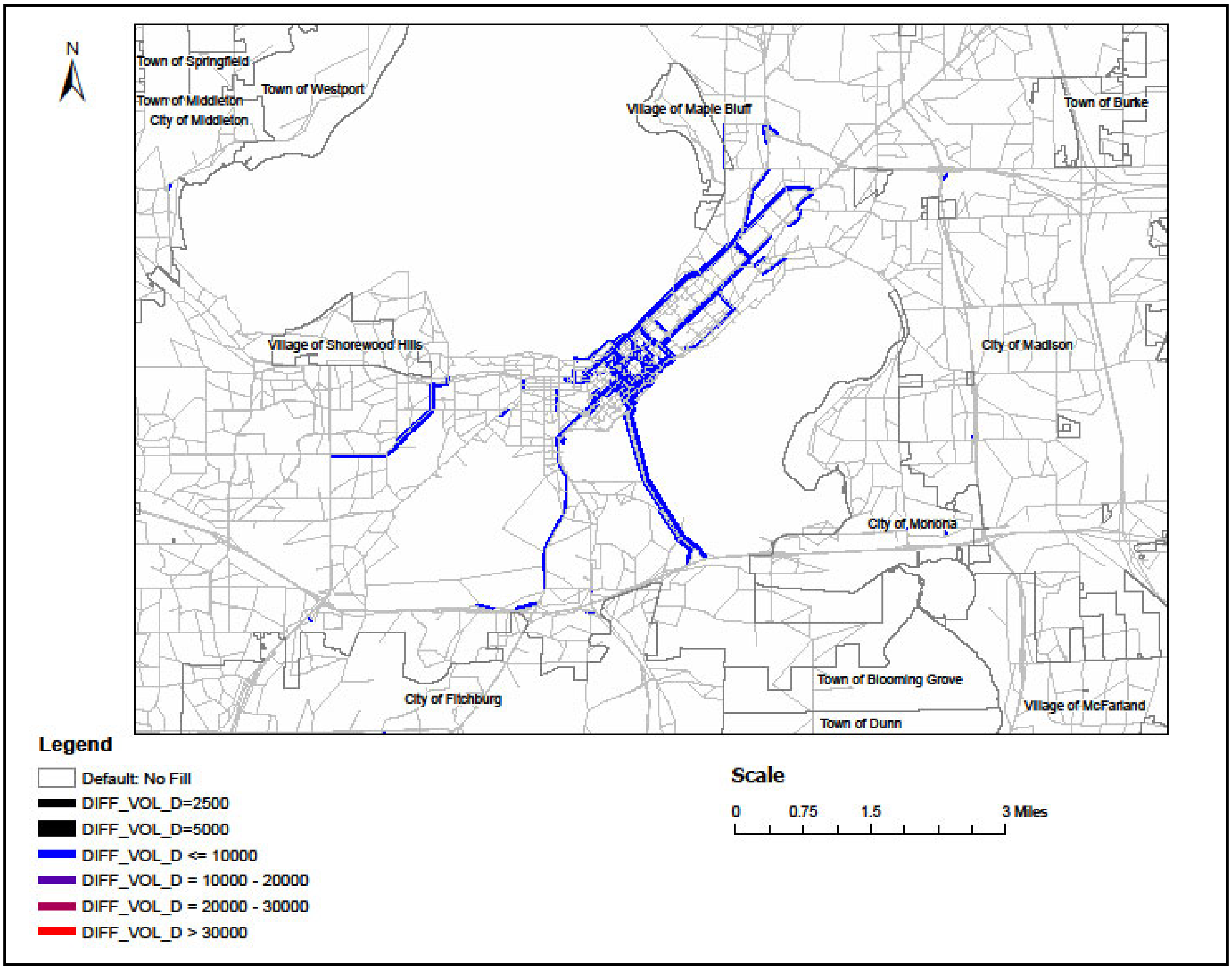
Scenario 5: Terminal Time Model Results

Metric	2050 Base	Terminal Time	Change	Percent
Auto VMT	18,289,434	18,123,242	(166,192)	-0.9%
Auto Speed (MPH)	31.5	31.9	0.43	1.3%
Daily Trips (All Modes)	3,815,585	3,815,582	(2)	0.0%
Drive Alone	1,662,784	1,658,218	(4,566)	-0.3%
Shared Ride	1,200,511	1,196,009	(4,503)	-0.4%
Walk	606,227	615,684	9,457	1.6%
Bike	185,598	184,147	(1,451)	-0.8%
Bus	68,562	69,771	1,210	1.8%
BRT	20,683	21,128	445	2.2%
School Bus	71,219	70,625	(594)	-0.8%
Scenario Modification	E+C Network	Reduced 2 minutes in CBD zones		

Figure 3.8 illustrates an impact area extending beyond the Isthmus, primarily on two of the arterial corridors connecting the CBD to the Beltline (Fish Hatchery Road and Park Street).

Figure 3.8

Scenario 5: Terminal Time Volume Increases (ADT>100)



3.7.6. Scenario 6: Increased Trip Making

Meyer et al. (2017) suggest that additional AV trips could be generated in two primary ways. The first involves children and the elderly switching from other forms of transportation to private autonomous vehicles. The second pertains to the movement of autonomous vehicles without passengers. Bahamonde-Birke et al. (2018) referenced research conducted in both Germany and the United States that suggests the enhanced accessibility provided by AVs could increase travel by 3% - 9% for the mobility-impaired, the elderly, children, and individuals who are unable to secure a valid driver's license. Additionally, the potential for AVs to alleviate traditional driving challenges is significant; including the stress associated with navigating a vehicle in heavy traffic, thus reducing both the emotional and financial costs of driving a conventional vehicle.

Harb et al. (2022) drew a parallel between personal chauffeurs and privately-owned AV use. In their experiment, after making personal chauffeurs available to conduct driving tasks for one household vehicle, they observed a 25% surge in trip making, including trips made on errands while their "owners" stayed home. The experiment involved 43 households as a proxy for privately-owned AVs. Thirty-two households received the service for 60 hours over a one-week period, and nine received the service for 120 hours over a two-week period. The availability of surrogate AVs influenced travel decisions related to time of day. For instance, the convenience and safety of AVs made nighttime driving less daunting, leading to an increase in trips made during the evening. Also, AVs can continue to operate even when occupants are fatigued or under the influence of alcohol - situations that limit or prohibit self-driving. These results emphasize the versatile influence of AVs on travel behavior and safety, and the potential to significantly alter the dynamics of urban transport.

Other research indicates that just the introduction of fully autonomous vehicles will lead to an increase in the number of trips made, due to "induced demand." This posits that as a resource becomes more available, the consumption of the resource increases. In other words, people will adapt their behavior to utilize the newly accessible resource and use it more frequently. When applied to AVs, the increased ease of trip making could stimulate additional travel to additional destinations. As Thill and Kim (2005) put it, transportation induced demand is "*the view that the rate at which trips are generated is linked to the ease of trip making to potential destinations*." This is similar to Jevons' Paradox. Jevons' Paradox suggests that when technological advances make it more efficient to use a resource, this can lead to an increase in that resource's consumption rather than a decrease, as one might expect. This apparent contradiction occurs because increased efficiency often reduces the relative cost of utilizing the resource, thereby leading to its heightened demand and usage. In the context of fuel efficiency improvements in internal combustion engines, Siami and Winter (2021) examine how these improvements have paradoxically resulted in increased carbon emissions. According to Jevons' Paradox, this is due to the lowered cost of using fuel, leading to an increase in driving and, consequently, higher emissions. To counteract this phenomenon, Siami and Winter propose implementing carbon pricing, a financial disincentive for increased fuel usage, with the aim of ensuring that innovations in internal combustion engines lead to improved air quality, not increased driving.

Several researchers have attempted to quantify the anticipated increase in trip making due to the availability of autonomous vehicles. Dias et al. (2020) estimated a 10% increase in trip generation rates, attributable to the ability of AVs to meet the augmented travel needs of the elderly and to fill gaps in existing travel demand. Riggs et al. (2022) estimated an even higher impact, expecting a 23.8% surge in trips made by autonomous vehicles. They attributed this estimation to two key factors: latent demand (an existing, unmet desire for travel) and induced demand. Similarly, Cohn et al. (2019) focused on induced discretionary trip making due to greater convenience and availability. Their research led them to increase non-work trips by 25% in their model tests. The potential to increase in-vehicle travel time utility and improve safety also makes the use of AVs for social/recreational purposes more appealing. This, in turn, stimulates additional trip making demand throughout the system.

In Scenario 6, trip generation rates are increased by 25% for local and regional shopping trips and non-home-based trips, leading to an 11.9% increase in VMT. Meanwhile, the overall number of trips being made increased by 22.8%. These figures imply that even though more trips are now present in the system, the average length of the additional trips may be relatively shorter, or routing efficiencies may have improved in comparison to the base model metrics. The results shown in Table 3.7 indicate a significant increase in automobile usage. Drive alone trips increased by 21.6% as more travelers making shopping and non-home-based trips opt for personal vehicles. Shared ride trips also see a 20.6% increase.

Table 3.7

Scenario 6: Trip Making Model Results

Metric	2050 Base	Trip Making	Change	Percent
Auto VMT	18,289,434	20,460,869	2,171,435	11.9%
Auto Speed (MPH)	31.5	28.8	(2.66)	-8.5%
Daily Trips (All Modes)	3,815,585	4,683,960	868,375	22.8%
Drive Alone	1,662,784	2,022,399	359,614	21.6%
Shared Ride	1,200,511	1,448,153	247,642	20.6%
Walk	606,227	813,448	207,220	34.2%
Bike	185,598	216,705	31,107	16.8%
Bus	68,562	76,570	8,008	11.7%
BRT	20,683	26,217	5,533	26.8%
School Bus	71,219	80,469	9,250	13.0%
Scenario Modification	E+C Network	Local & regional HBShop, NHB trip rates increased 25%		

Local bus and BRT trips increased by 11.7% and 26.8%, respectively.[20] The increased trip making using transit depends on the quality of the service, including factors such as frequency and speed, as well as the location of the additional trip ends. If the additional trip demand coincides with transit corridors, these modes would see increased usage. For example,

[20] Induced demand would lead to increased total trips because auto trips would be easier, but not necessarily trips using other modes of travel. This again demonstrates a shortcoming of the 4-step model as applied in this research.

the new Madison BRT system is designed to connect the city's two largest retail shopping areas - the West Towne Mall and the East Towne Mall. Therefore, when regional shopping trip generation rates increase, it is reasonable to anticipate a corresponding increase in BRT trips, which is demonstrated in the Scenario 6 results. Walking and biking trips also increased by 34.2% and 16.8%, respectively. These modes are likely to experience an increase if the additional shopping and non-home-based trips are localized at the neighborhood level, or in densely populated areas where walking or biking is easier and more convenient.

Figure 3.9 illustrates that the surge in traffic is evenly dispersed throughout the region. However, upon closer inspection of the Madison area as depicted in Figure 3.10, it becomes apparent that higher volumes of traffic are predominantly concentrated on higher functionally classified roadways.

Figure 3.9

Scenario 6: Trip Making Volume Increases (ADT>100)

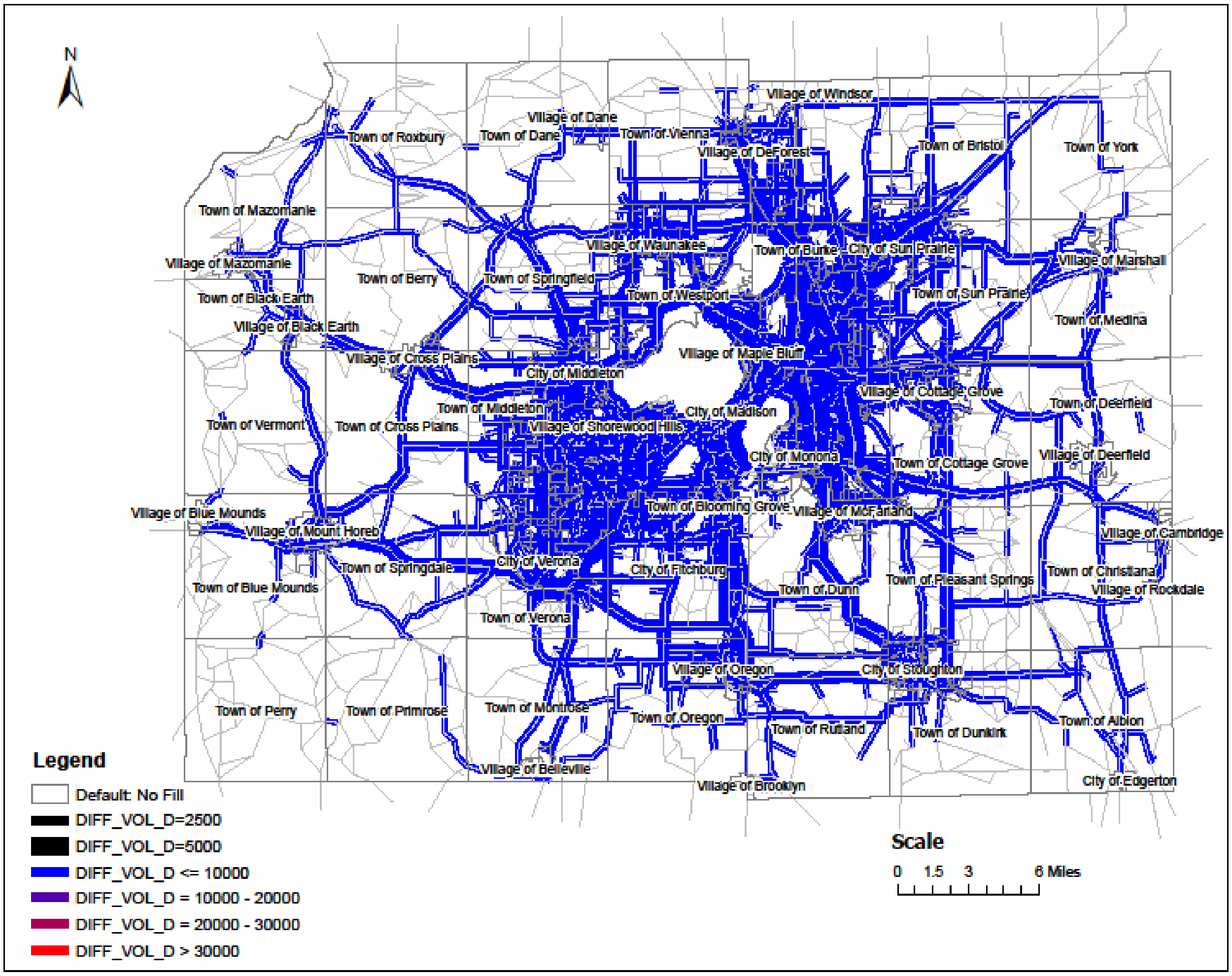
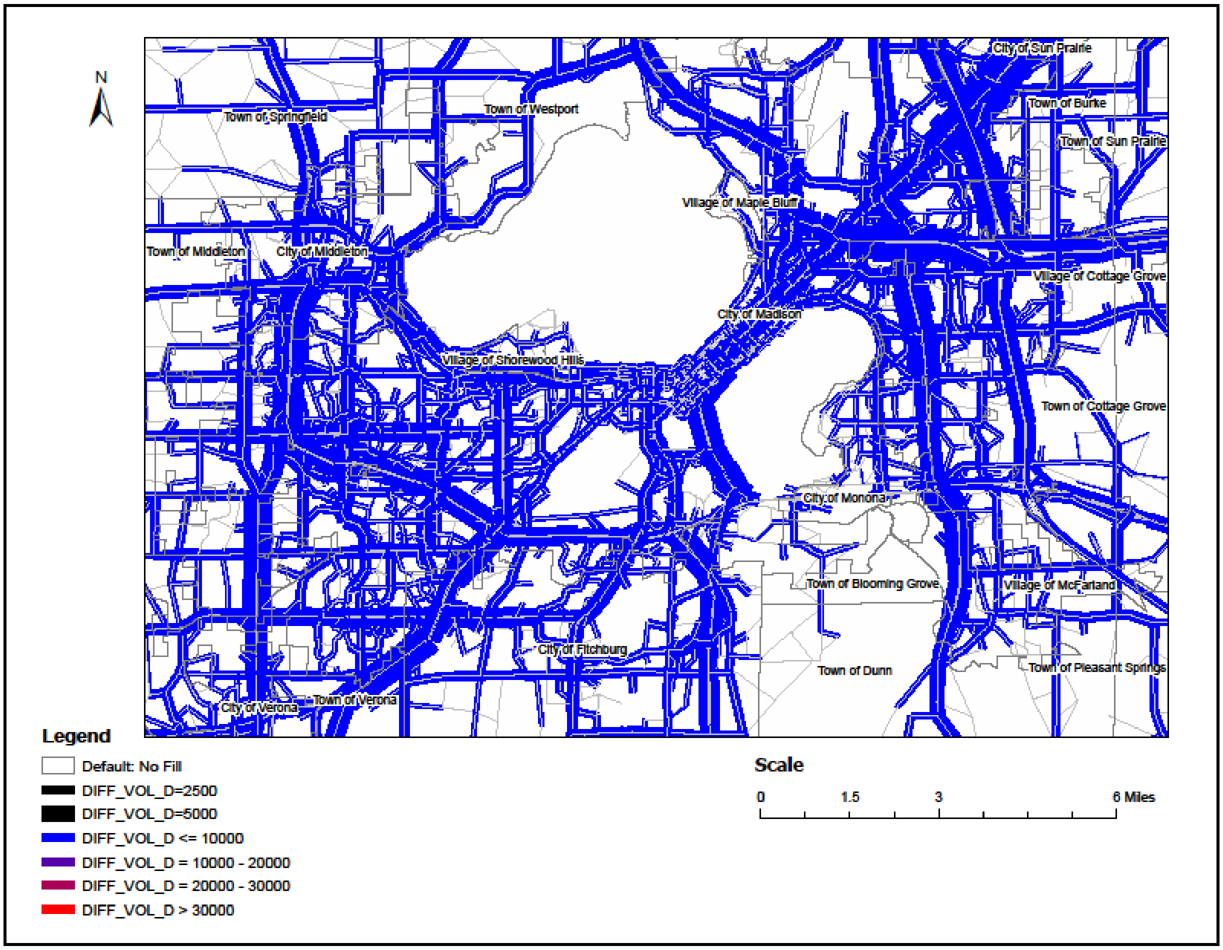


Figure 3.10

Scenario 6: Trip Making Volume Increases – Madison area (ADT >100)



3.7.7. Scenario 7: Decreased Value of Time

Bahamonde-Birke et al. (2018) predicts that AVs will lower the "subjective value of travel time," a concept that pertains to how occupants perceive the cost or burden of time spent in-vehicle. By reducing the attention required for vehicle operation, travel in AVs may feel less strenuous than in conventional vehicles. This aligns with the notion of travel time as "dead time," a common perspective in transportation studies that views commuting time as a wasted resource with an associated opportunity cost. As such, the prevailing belief is that in-vehicle travel time should be minimized to enhance the overall utility of the traveler. AVs can alter this by making travel time feel less burdensome. By transforming travel time into a period that can be used for other productive or more enjoyable activities, AVs would shift our concept of travel time from being a burden to being an opportunity (Bernardin et al., 2019). Supporting this notion, Cohn et al. (2019) used transportation models to project the effects of a 50% decrease in the perceived value of time spent traveling in an AV.

While much of the research concerning the value of time savings with AVs focuses on work-related commutes, studies such as those by Thomopoulos et al. (2021) highlight an increasing interest in using AVs for leisure travel. This shift is significant not only for assessing the value of time spent in an AV but also for understanding the differing dynamics of discretionary trips. These trips exhibit different patterns, occupancies, and parking requirements compared to work commutes and represent an important aspect of the evolving role of AVs in modern transportation. Nair et al. (2018) studied a range of projected reductions in the perceived value of time during AV travel, estimating decreases from 25% to 75%. They acknowledge that these values are subject to several factors, like the purpose of the trip, individual user behavior, and specific travel circumstances. The wide range illustrates the complexity of quantifying AVs' effects on travel time valuation, as perceived impacts can vary widely.

On a much different note, Rashidi et al. (2020) assert that attributing the reduction of perceived travel time solely to AV travel is an oversimplification. They argue for a more comprehensive approach, one that considers the wide-ranging impacts of multiple technological advancements, including AVs, on our lives and lifestyles. Singleton (2019) advises caution regarding the overly optimistic narrative surrounding AV travel. Comfort levels in AVs might not meet expectations. For example, motion sickness could be induced as a result of a decreased sense of anticipation and the loss of control experienced by AV passengers, who would still experience acceleration and braking rates similar to those in driver-controlled vehicles.

This would lead to a more modest change in the valuation of time during AV travel than otherwise assumed. Singleton added that initial societal skepticism towards driverless travel could further complicate matters, suggesting that the optimistic view that AVs will enable multitasking and boost productivity is speculative. Singleton concludes that contrary to prevalent literature, the disutility of travel time in an AV could increase, challenging widely held beliefs regarding the benefits of autonomous vehicle travel. In their 2020 study, Rashidi et al. echo Singleton's reservations about AV travel time valuation. They argue for a more complex approach in assessing the value of travel time in AVs. Specifically, they propose conducting simulation-based studies that incorporate real-world conditions to achieve greater valuation accuracy. Contrasting with the hypothetical scenarios found in stated preference data, Rashidi et al. emphasize the need to use revealed preference data instead. They contend that this approach more accurately captures how people will actually react to traveling in autonomous vehicles.

Within the Madison travel demand model, the value of in-vehicle time is essential for determining travel cost. This cost serves as one of the main inputs for the model's mode choice step. In Scenario 7, the value of time is adjusted for auto trips. Specifically, the disutility factor for home-based work and university trips was changed from -0.044 to -0.022. For home-based social-recreational trips, the adjustment was from -0.020 to -0.010. In this context, a negative coefficient like -0.044 indicates a relationship between time and the attractiveness of a travel choice. The more time it takes to drive, the less appealing that option becomes. Each extra minute of automobile travel time reduces the overall trip utility by a factor of 0.044. The units are abstract measurements, representing subjective perceptions rather than directly measurable quantities. Table 3.8 shows the mode split coefficients and variables used in the model for home-based work and home-based university trip purposes.

Table 3.8

HBW and HB University Mode Choice Parameters

Line Number	Coefficient	Variable
1	-0.255	Bike Constant
2	-1.36	Shared Ride Constant
3	2	Transit Constant
4	-0.75	Walk Constant
5	-0.0324	Bike Level of Stress 1
6	-0.0429	Bike Level of Stress 2
7	-0.0835	Bike Level of Stress 3
8	-0.187	Bike Level of Stress 4
9	-0.022	Auto Travel Time (*ADJUSTED FOR AVs*)
10	-0.088	Wait Time
11	-0.0966	Walk Time
12	-0.0445	Cost
13	-0.0445	Walk less than 5 minutes
14	-5	Bike Intrazonal
15	-1.7	Insufficient Cars DA
16	-0.592	Insufficient Cars SR
17	-2.69	No Cars SR
18	3.35	Prod Zone Low Density Single Family DA
19	2.22	Prod Zone Low Density Single Family SR
20	-0.0334	Attr Zone is Campus College
21	-3.58	HBU Bike
22	-2.5	HBU SR
23	-2.85	HBU Transit
24	-1.25	HBU Walk
25	0.8	MU
26	-0.317	Premium Transit Constant

Traditional four-step models have severe limitations in projecting AV impacts on land use. Never-the-less, Scenario 7 provides some clear insights. As shown in Figure 3.11, the suburban communities surrounding Madison - including Cross Plains, Mount Horeb, Waunakee, Sun Prairie, Cottage Grove, Stoughton, and Verona - all see an increase in daily traffic on highways leading to the urban center. This supports the hypothesis that changes in travel time value (accountable to autonomous vehicle use) will significantly impact suburban travel patterns.

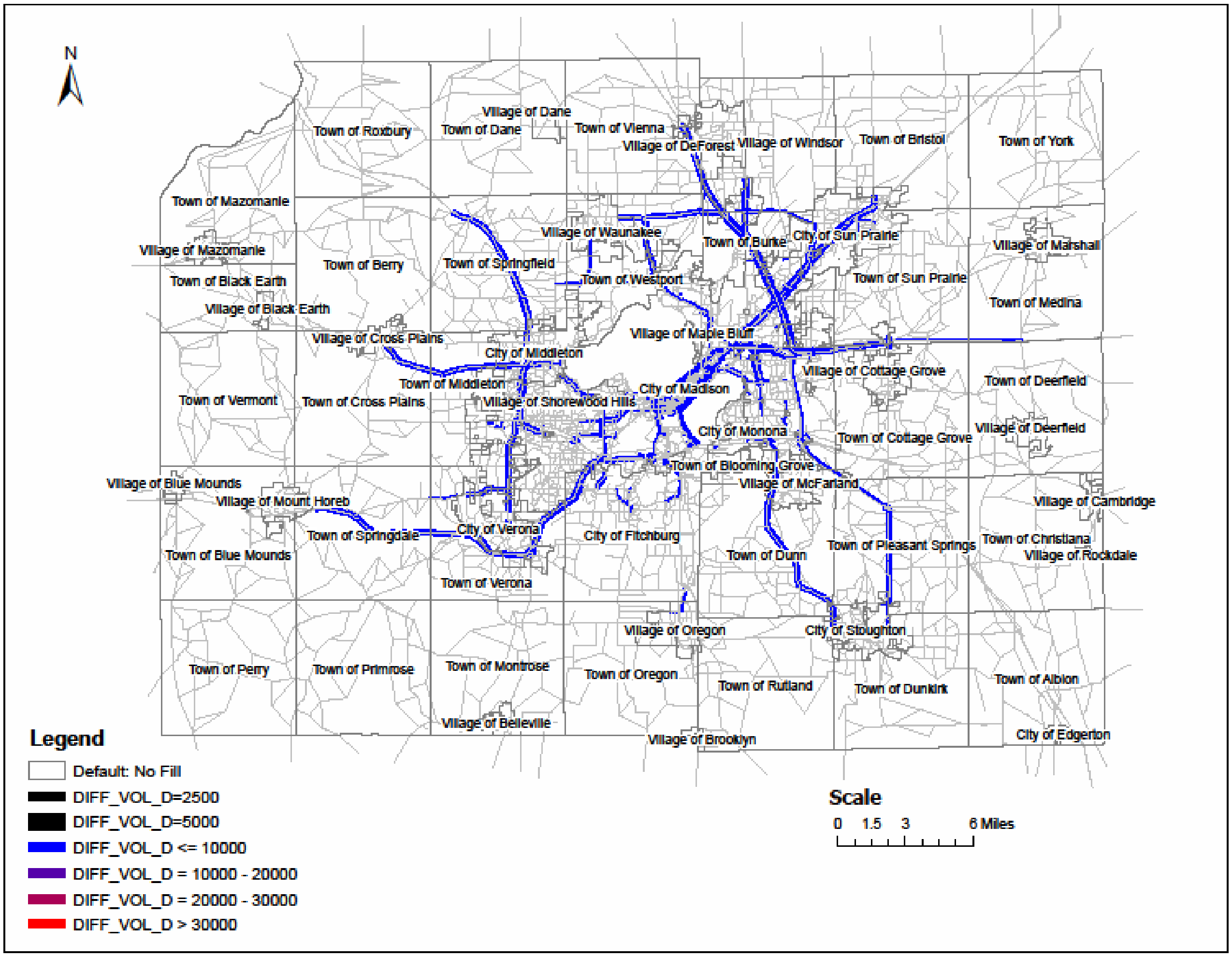
Table 3.9

Scenario 7: Value of Time Model Results

Metric	2050 Base	Value of Time	Change	Percent
Auto VMT	18,289,434	18,380,757	91,323	0.5%
Auto Speed (MPH)	31.5	31.3	(0.16)	-0.5%
Daily Trips	3,815,585	3,815,585	1	0.0%
Drive Alone	1,662,784	1,671,983	9,199	0.6%
Shared Ride	1,200,511	1,204,913	4,402	0.4%
Walk	606,227	601,024	(5,204)	-0.9%
Bike	185,598	170,026	(15,572)	-8.4%
Bus	68,562	74,522	5,960	8.7%
BRT	20,683	22,016	1,333	6.4%
School Bus	71,219	71,102	(117)	-0.2%
Scenario Modification	E+C Network	VOT reduced 50% for HBW, HBU, HBSR trips		

Figure 3.11

Scenario 7: Value of Time Volume Increases (ADT >100)



3.7.8. Scenario 8: All AV Changes

In Scenario 8, all the factors from the previous seven scenarios are combined for a comprehensive evaluation. By integrating these factors into one scenario, it is possible to observe how they interact and anticipate the effects in a future where self-driving vehicles are prevalent. Examining all the factors together is vital, as the advent of self-driving cars is poised to result in significant changes across the entire transportation system, not merely affecting isolated parts. This holistic perspective assists policymakers in formulating strategies and crafting a versatile plan that can adapt to the multifaceted impacts of autonomous vehicles. By adopting a method that considers both specific details and the broader context, a foundation is established that equips policymakers to better comprehend and prepare for the substantial shifts in transport that are looming.

In Scenario 8, all previous AV parameters are modeled together for their combined effects on VMT, the number of trips made, and the choice of transportation modes. However, as the results of the preceding scenarios indicate, the influence of each parameter can vary based on the specific location under consideration. For instance, in the heavily populated downtown Madison area, characterized by a robust public transportation system and high parking costs, increasing freeway capacity might not lead to substantial changes in travel patterns throughout the Isthmus. Table 3.10 compiles the impacts of the seven parameters related to autonomous vehicles (AVs). significantly, when combined, these factors are predicted to result in a notable rise in auto VMT (34.5% increase), drive-alone trips (27.2% increase), and shared ride trips (21.8% increase). Scenario 8 also anticipates a 28.0% increase in walking trips.

Table 3.10

Scenario 8: All AV Changes Model Results

Metric	2050 Base	All AV Changes	Change	Percent
Auto VMT	18,289,434	24,593,952	6,304,518	34.5%
Auto Speed (MPH)	31.5	33.9	2.40	7.6%
Daily Trips (All Modes)	3,815,585	4,686,137	870,552	22.8%
Drive Alone	1,662,784	2,115,682	452,898	27.2%
Shared Ride	1,200,511	1,462,065	261,554	21.8%
Walk	606,227	775,859	169,632	28.0%
Bike	185,598	176,394	(9,204)	-5.0%
Bus	68,562	60,205	(8,357)	-12.2%
BRT	20,683	19,119	(1,565)	-7.6%
School Bus	71,219	76,813	5,594	7.9%
Scenario Modification	E+C Network	Combined all AV Scenarios		

Figure 3.12 illustrates widespread increases in regional roadway traffic anticipated after autonomous vehicles are fully deployed in Dane County, Wisconsin..

Figure 3.12

Scenario 8: All AV Changes Volume Increases (ADT>1000)

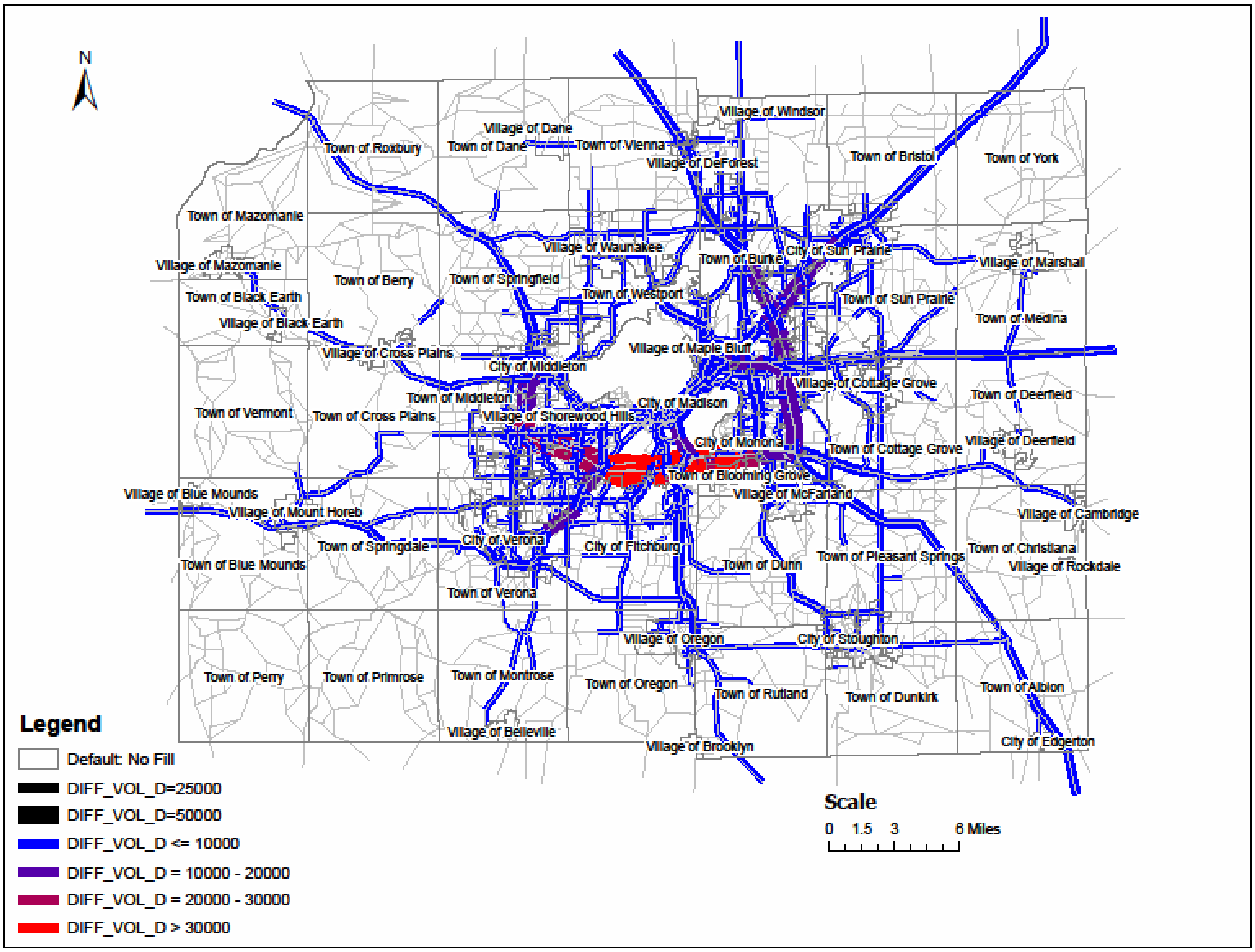


Table 3.11 compares the changes in VMT for each scenario. Simply adding the VMT increases across each individual scenario (1 - 7) results in a total of 4,819,620 vehicle-miles. However, when combining all the factors into one scenario (8), the result is a VMT increase of 6,304,518 vehicle-miles, surpassing the additive result of the individual scenarios by a significant 30.8%. This suggests that there are combined or “synergistic” effects when all

changes are implemented simultaneously, rather than separately. In other words, the individual changes appear to amplify one another when combined, resulting in an effect greater than the sum of the parts. The results indicate opportunities for implementing these improvements collectively to maximize benefits. However, they also underline the importance of understanding each component's potential effects contributing to the higher VMT levels. An increase in traffic volumes, like the one predicted in Scenario 8, would likely present challenges in additional environmental degradation and increased traffic congestion. Clear strategies to mitigate these challenges are essential, especially when the growth in VMT is undesirable in the context of broader social and environmental sustainability goals.

Table 3.11

VMT and Trip Growth Comparisons by Scenario

Number	Scenario	VMT[1] (Change)	% of Sum	Auto Trip[2] (Change)	% of Sum
1	Auto Availability	272,292	5.6%	70,202	10.4%
2	Auto Occupancy	2,216,907	46.0%	-13,726	-2.0%
3	Freeway Capacity	220,574	4.6%	3,792	0.6%
4	Parking Costs	13,281	0.3%	776	0.1%
5	Terminal Time	-166,192	-3.4%	-9,068	-1.3%
6	Trip Making	2,171,435	45.1%	607,257	90.3%
7	Value of Time	91,323	1.9%	13,601	2.0%
	Sum Scenarios 1-7	4,819,620	100.0%	672,834	100.0%
8	All AV Changes	6,304,518		714,452	25.0%
	Difference (All - Sum)	1,484,898		41,618	
	% Difference	30.8%		6.2%	

[1] "VMT Change" is the difference between the Scenario model and the Base 2050 E+C model.
[2] "Auto Trip Change" is the difference between the Scenario model and the Base 2050 E+C model.

Scenario 6 (AV trip making increases) provides the greatest increases in VMT and Auto Trips. Increasing freeway capacity or reducing parking costs, terminal time, or value of time could all lead to induced demand and increased trip making. However, the model does not capture induced demand in those scenarios, while it does account for it in Scenario 6.

3.8. Discussion

This chapter outlined the methods used to integrate features of autonomous vehicles into a regional trip-based travel demand model in Madison, Wisconsin. The modifications to the model encompass numerous adjustments to the sub-models representing various elements of travel demand. Given the multitude of uncertainties linked with the future deployment of fully autonomous vehicles, a scenario-based methodology was utilized. The scenario analysis was not confined to examining only one impact measure, such as VMT. Rather, a multi-dimensional view of individual travel behavior, considering travel time, travel distance, congested speeds, and mode choice, was taken.

The research was shaped by three questions posed in the introduction. Each of these questions is discussed in this section, offering perspectives on the intricate relationship between autonomous vehicles, urban travel, and land development.

Question 1: How might the potential widespread deployment of fully automated cars impact efficient land use planning and development practices?

Response 1: Traditional trip-based four-step models play a crucial role in transportation planning, having provided valuable insights to policymakers for many years. However, as modern mobility provision shifts to more sustainable approaches, the limitations of these legacy models become increasingly apparent. Omission of a land use-transportation feedback loop presented a significant obstacle to fully assessing this question.

Question 2: Can traditional regional travel demand modeling tools provide planners and policymakers with useful insights on future AV use?

Response 2: Well-established four-step models offer proven value in decision making through their simplicity and less costly nature but are becoming outdated in a rapidly changing world of innovative technologies and transport solutions.

Legacy transportation models rely on aggregate data and represent the behavior of the average or typical traveler. Their main advantages are simplicity and cost-effectiveness, making them more accessible than complex methodologies like activity-based or agent-based models and other advanced modeling techniques. However, these benefits also underscore the limitations of four-step models. Specifically, they struggle to accurately reflect the impacts of new technologies such as autonomous vehicles, ride-hailing services, and micro-mobility solutions. Additionally, they often fail to adequately account for policies encouraging active transportation modes, such as cycling and walking.

In the case of the Madison model scenarios, the limitations of the four-step model were evident. For example, while it successfully revealed noticeable shifts in traffic volumes due to changed perceptions of time value in autonomous vehicles, it failed to address implications on land redevelopment or more dynamic changes that might arise from the new mobility paradigm. This isn't to say the Madison model is defective, but it does illustrate a broader issue in transportation modeling. Although these findings are specific to the Madison model, it is probable that similar challenges exist in other urban models across Wisconsin and potentially in the broader Midwest region. There is a growing need for affordable models that accurately represent the complex relationships among new technologies, public policies, land development, and transportation infrastructure.

Question 3: How should the "value of time parameter" in existing regional travel demand models be adjusted to account for perceived increases in productivity during travel in self-driving cars?

Response 3: The scenario analysis conducted for Madison highlights the potential reduction in perceived travel time value with the advent of autonomous vehicles. The prospect of reducing this value by one-half was applied specifically to home-based work and university trips, and social recreational trips. The adjustment was rooted in academic literature, which recognizes the value implications of travelers' ability to engage in in-vehicle activities once freed from the driving task. Considering these adjustments, mode split and trip distance estimates were reevaluated using the regional travel demand model. The resulting increases in traffic volume originating in suburban areas and destined for Madison supports the validity of the reduction employed in the scenario. This confirms the hypothesis that reducing the perceived value of in-vehicle travel time would lead to more frequent and longer trip making.

However, it's crucial to interpret these results with some caution. Several other variables need to be considered in future analyses, including potential disparities in AV adoption rates between central cities and their surrounding areas, as well as the relative accessibility and economic feasibility of AVs across different regions. While the findings herein align with existing literature that supports a 50% reduction in the value of time due to AVs, it does not capture the complete picture. Traffic patterns and individual behaviors are influenced by a myriad of interconnected factors that require further study to fully comprehend. Discussion regarding the extension of in-vehicle travel time value shifts to leisure trips adds to the complexity of this question. As technology continues to advance and society's adoption of autonomous vehicles grows, ongoing research is needed to better understand the profound impacts these transportation innovations will have on regional mobility and land development.

Question 4: How does the increased productivity potential in self-driving cars influence sustainable urban growth practices, particularly in relation to urban sprawl?

Response 4: As the prevalence of self-driving cars increases, their significant influence on the management of sustainable urban growth will become more evident. Throughout history, major shifts in mobility, like the advent of the automobile or the growth of railway networks, have been key drivers in the expansion and evolution of cities. Similarly, self-driving cars are poised to be the next transformative force in urban development.

The convenience, efficiency, and reduced commuting stress offered by self-driving cars might prompt more people to live further from urban centers. This shift could substantially change urban development patterns, potentially leading to increased urban sprawl. Increased urban sprawl leads to greater reliance on vehicles. Relocation away from central cities reduces the effectiveness of public transit systems, as dispersed populations are more difficult to serve efficiently. Such residential dispersals also undermine efforts to create compact, walkable environments that decrease reliance on automobiles. Moreover, the spread of urban development into previously undeveloped areas would have detrimental effects on natural landscapes and ecosystems. Lastly, greater commuting distances might require more infrastructure, which further strains resources. While self-driving cars are likely to facilitate more comfortable and convenient commutes, the long-term consequences of this shift are at odds with many principles of sustainable urban growth. For urban planners, policymakers, and society as a whole, the years ahead will present a formidable challenge in striking a balance between the convenience and appeal of self-driving cars and the pursuit of sustainable, cohesive, and efficient urban growth.

3.9. Conclusion

The complexities inherent in novel transportation systems and unpredictable human behavior present substantial challenges in mathematical modeling. Since the introduction of the first four-step model in the 1950s, the challenge of balancing urban development and emerging technologies has been clear. Today, proactive professionals are striving to understand and address the potential impacts of autonomous vehicles on sustainable development, long before these vehicles become integral to daily life.

This ongoing process necessitates a continual reevaluation and refinement of the foundational assumptions that have shaped our current understanding of the relationship between urban planning, transportation systems, and sustainable development. As research in this field progresses, it is essential to recognize that representations such as the Madison MPO model can, at their best, only provide an abstract glimpse into a technologically advanced future. The implications of autonomous vehicle travel are multifaceted, influenced by diverse factors such as demographics, travel purposes, and specific situations. It is crucial to gather new data and continue this research to better understand the broad consequences of widespread AV use.

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CHAPTER 4: MPO PLANS AND CLIMATE ACTION

4.1. Introduction

Chapter 4 provides the results of a survey created to elicit information from Wisconsin's MPOs on how they are planning for a more sustainable future by addressing the impacts of climate change in their long-range transportation planning documents. Chapter 4 "ground truths" several of the findings in the previous two chapters, tying the research elements together in a way that demonstrates their interrelated nature and culminates with a completed dissertation.

4.2. Methodology

Fourteen federally recognized MPOs operate within the state of Wisconsin, sharing responsibility for transportation planning in 17 metropolitan areas.[21] Each MPO was asked to complete a survey to collect information on their transportation plan contents. The survey was comprised of 11 questions aimed at identifying key long-range transportation planning themes and methods related to climate action.[22] The feedback obtained from the survey provides crucial benchmarking data and promotes knowledge sharing among the MPOs operating within the state.[23]

A fillable PDF survey form was created using Adobe Acrobat Pro. Creating a fillable PDF form using Adobe Acrobat for a survey offered a multitude of advantages, especially as the survey was designed to allow respondents the flexibility to select multiple answers to a single question. Another benefit of using PDF forms is their universal compatibility. PDFs can be

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[21] Wisconsin Department of Transportation. Metropolitan planning organizations. Available at https://wisconsindot.gov/pages/doing-bus/local-gov/plning-orgs/mpo.aspx. [Accessed 10/7/23].
[22] A full copy of the survey is included in Appendix F.
[23] The survey results were presented at the Wisconsin MPO/RPC annual planning conference in Trego, Wisconsin on October 11, 2023. A copy of the meeting agenda is included in Appendix G. Participant comments are included in Appendix H.

opened on almost any device or operating system without compromising the original design or layout of the form, ensuring a consistent and professional appearance. The platform's interactive features, such as checkboxes, radio buttons, dropdown menus, and text fields make surveys more engaging and user-friendly. Text boxes were added for “other” information, allowing respondents to express more detailed or unique responses to capture insights that might not otherwise be gleaned from only predefined answer options. Distribution of the long-range transportation plan climate action survey form was completed by emailing copies to MPO directors and primary transportation planning staff contacts. A typical cover email introducing the survey is provided below:

Hello MPO Planner,

This email is regarding a (non-consulting) project I’m working on. Specifically, I’m doing research for my Ph.D. program and am requesting your assistance in completing a “fill-in-the-blank” PDF survey I’ve created. It’s intended to be short (no more than 20-30 minutes of your time). The attachment provides the survey and some additional helpful information.

My work on this project is solely for academic purposes, and not associated with WisDOT or any consulting firm. I would only note that WisDOT is aware of my research interests but is otherwise not involved with this effort.

The Wisconsin MPO’s are a small survey group (including our two bi-state MPOs), so I am hoping to get a response from all 14 MPO staff contacts. I’m requesting your completed survey responses by Friday, September 29, if you are able to help out.

I understand everyone is overly busy these days, so thank you in advance for your consideration.

Derek Hungness, PE, PTOE, AICP
Ph.D. Candidate, Transportation and Logistics
Transportation Infrastructure and Capacity Planning
North Dakota State University
xxxxx.xxxxxxxx@xxxx.xxx
###.###.####

The initial survey distribution was emailed to MPO contacts on September 9, 2023. A reminder was sent to non-responders on September 25, 2023, with a final reminder to complete and return the survey sent on October 4, 2023. A total of 13 out of 14 completed survey forms were returned, resulting in a response rate of 93%.

4.3. MPO Survey Results

This section of Chapter 4 summarizes the findings of the MPO transportation planning and climate change survey.

Question 1: Does your MPO have an established policy to address climate change as it relates to the transportation system and its use?

YES 1

NO 12

Question 2: Does your MPO use a long-range travel demand model (or related data) to specifically assess the impacts of climate change in your region?

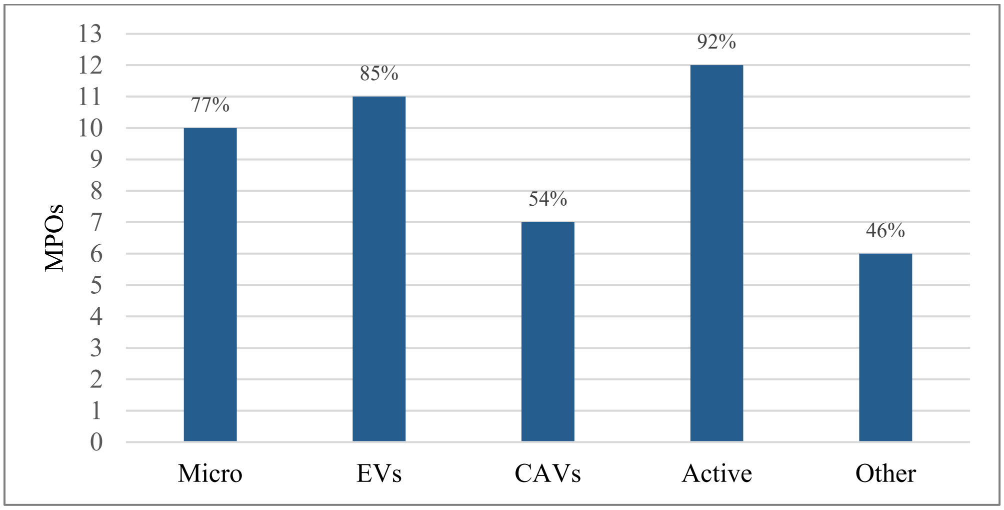
YES 1

NO 12

Question 3: What additional insights or applications would you like to have from your regional transportation demand model?

Figure 4.1

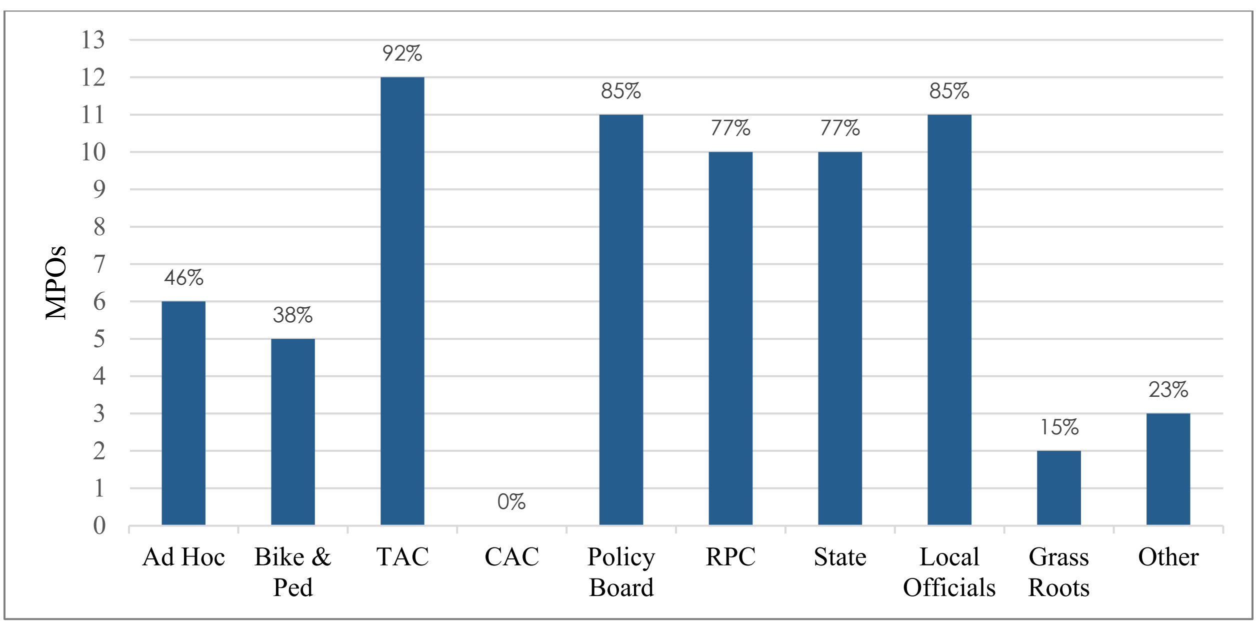
Desirable New MPO Model Applications



Question 4: What advisory structures does your MPO regularly use to synchronize land development, transportation infrastructure, and economic growth?

Figure 4.2

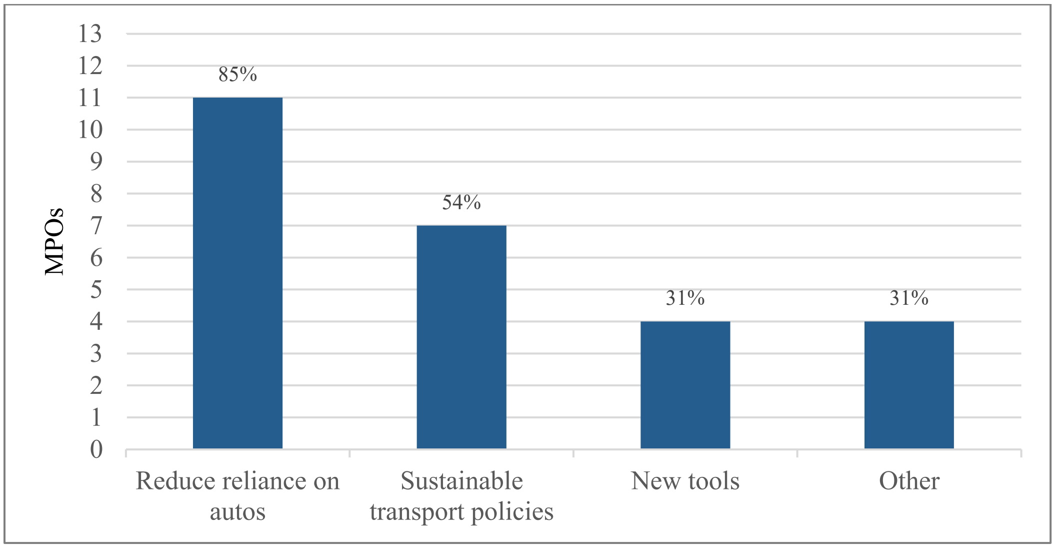
MPO Sustainability Advisory Structures



Question 5: In your next LRTP update, which elements related to regional transportation sustainability will be emphasized?

Figure 4.3

Next LRTP Emphasis Areas



Question 6: How many full-time equivalent staff does your MPO employ?

Table 4.1

Wisconsin MPO Staffing Levels

FTE Staff	# of MPOs
1-2	7
3-4	0
5-6	4
7-8	1
9-10	0
More than 10	1

Question 7: What is your current Long Range Transportation Plan base year?
Varies

Question 8: What is your current Long Range Transportation Plan future or horizon year?
Varies

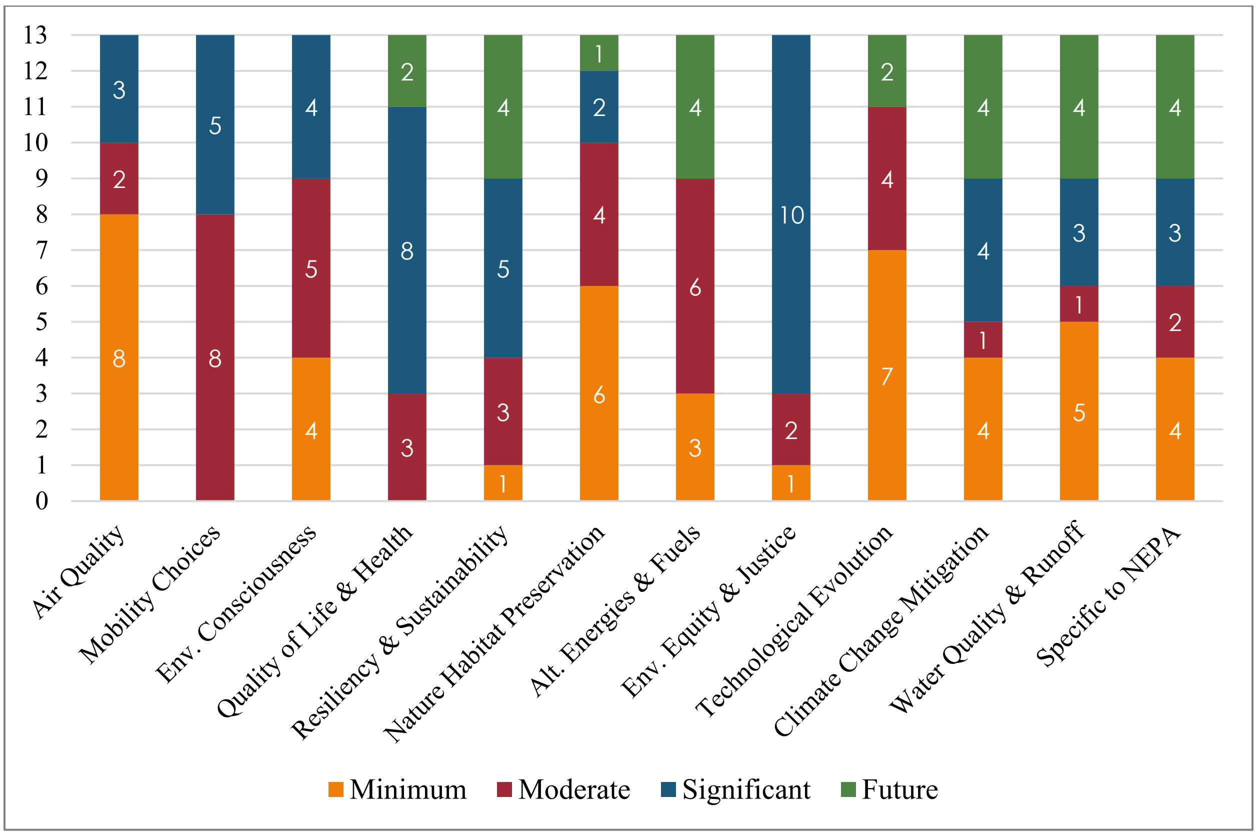
Question 9: When is your next Long Range Transportation Plan update due?

Varies

Question 10: Twelve themes are identified below which have been associated with land use, transportation system sustainability, and resiliency in Long Range Transportation Plans. For each theme, please indicate if it is present in your current Long Range Transportation Plan and to what extent. If not currently included, please indicate if you are considering it for inclusion in your next Plan update.

Figure 4.4

Current LRTP Sustainability Themes



Question 11: The list below outlines planning activities from various regions utilizing travel demand models to better understand the impacts of climate change. Imagining a future where you have the opportunity to enhance your regional travel demand model, please indicate the importance of the following potential model improvements to address climate impacts within your region.

Table 4.2

Emissions and Climate Resilience Model Applications

Regional Planning Activity	**Travel Demand Model Application Example**
Carbon Footprint Reduction	A travel demand model can evaluate transportation choices and their emissions, informing strategies to minimize the carbon footprint.
Air Quality Monitoring	By simulating transport activities and their emissions, the model can predict areas of potential air quality degradation.
Infrastructure Vulnerability Assessment	Travel demand insights highlight infrastructure areas most at risk from climate change-induced transport pattern shifts.
Mitigation Strategy Development	Using the model's predictions, planners can develop strategies to mitigate negative environmental and social impacts of transportation.

Figure 4.5

Emissions and Climate Resilience & Adaption Results

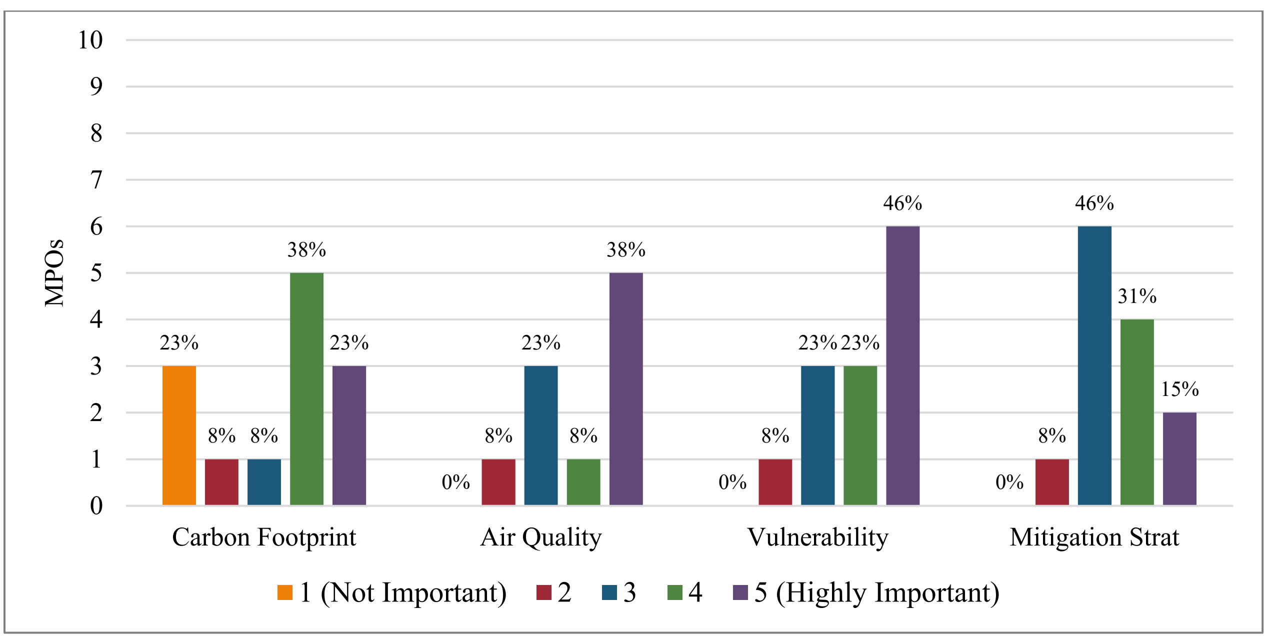


Table 4.3

Sustainable Mobility and Urban Planning Model Applications

Regional Planning Activity	Travel Demand Model Application Example
Shift to Low-Emission Modes	The model can inform on potential transportation shifts, guiding initiatives to promote greener travel alternatives.
Electrification of Transport	Travel demand models can project the growth and spatial distribution of electric vehicle use, informing where infrastructure like charging stations should be prioritized.
Density Enhancement Initiatives	The model can demonstrate the relationship between urban density and travel behaviors, helping urban planners target areas for density enhancement.
Climate-Resilient Urban Development Strategies	By highlighting transportation needs under different climate scenarios, the model can inform resilient urban planning decisions.

Figure 4.6

Sustainable Mobility and Urban Planning Results

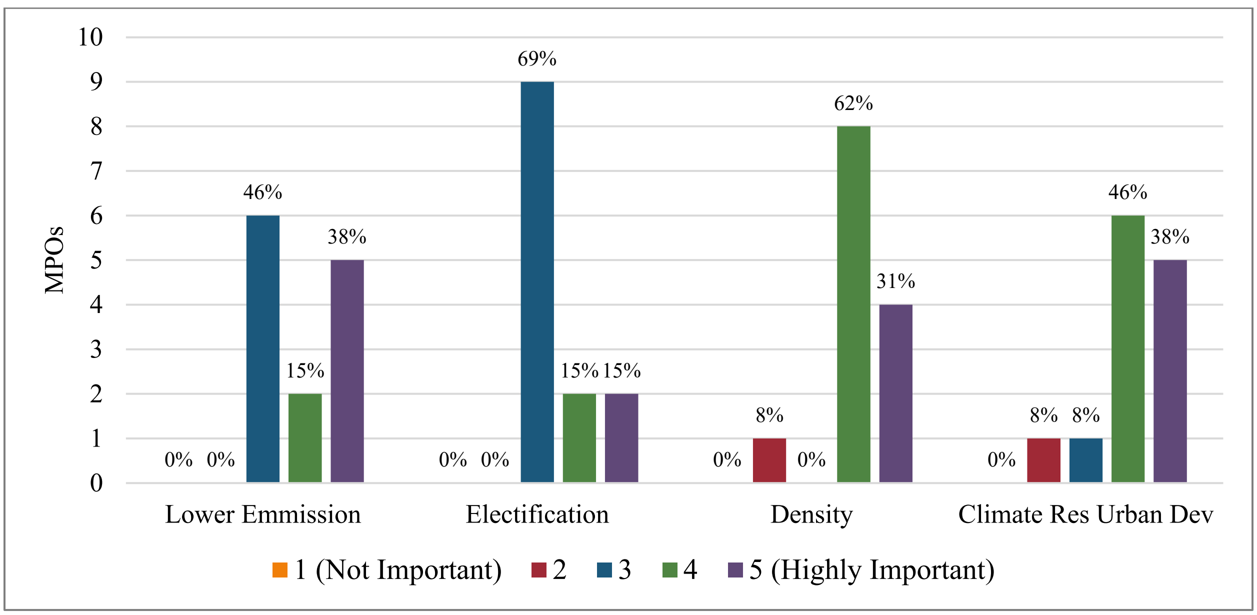


Table 4.4

Travel Behavior and Public Engagement Model Applications

Regional Planning Activity	Travel Demand Model Application Example
Adapting to Travel Pattern Changes	Travel demand models can capture shifts in transportation behaviors, ensuring infrastructure and policies remain relevant.
Climate Impact Visualization Tools	Leveraging model outputs and visualization tools can depict transportation's role in climate impacts, making the data more accessible and actionable.
Cost-Benefit Analysis for Climate Initiatives	The model can provide data on the potential impacts of transportation-related climate initiatives, aiding in a comprehensive economic evaluation.

Figure 4.7

Travel Behavior and Public Engagement Results

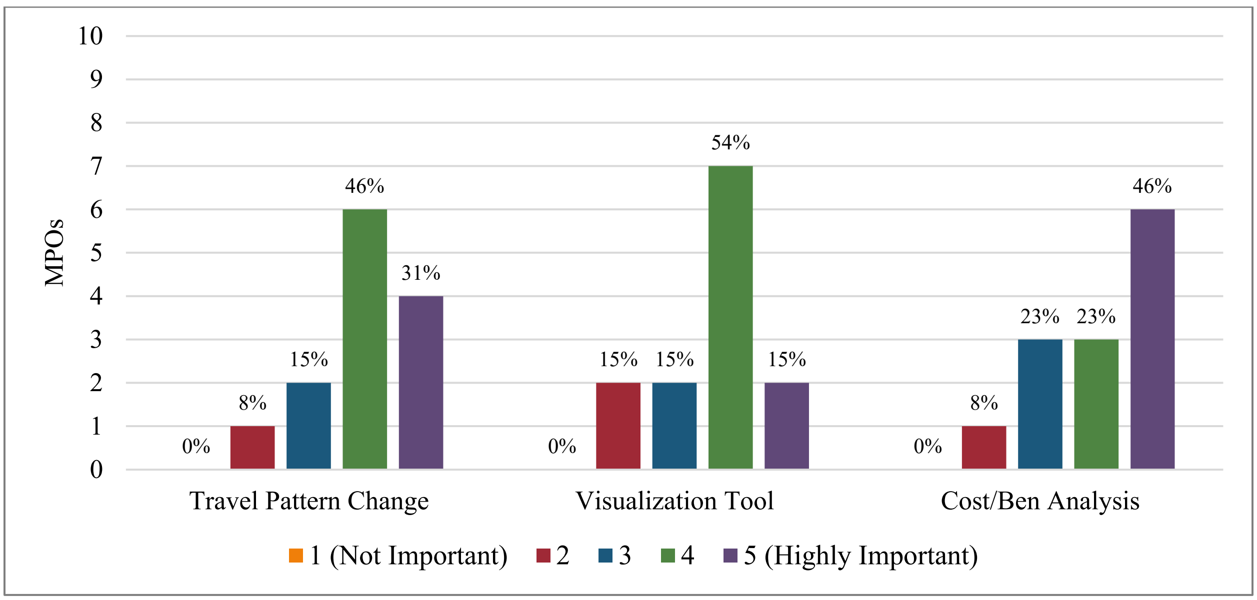


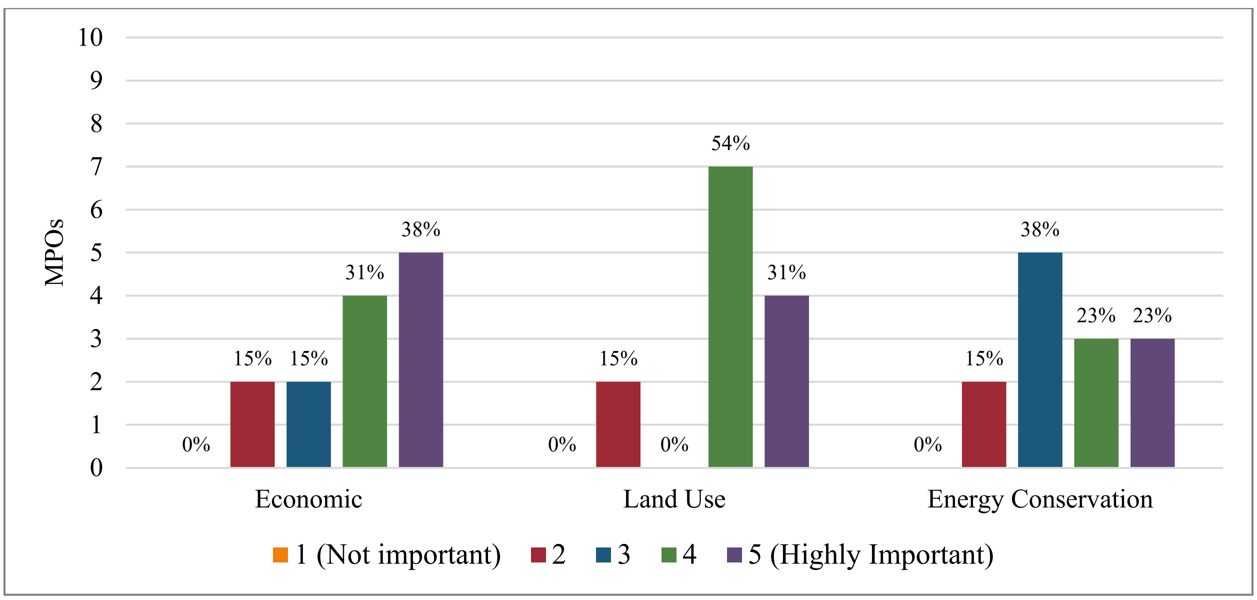
Table 4.5

Model Integration Applications

Regional Planning Activity	Travel Demand Model Application Example
Synchronization with Economic Models	The travel demand model can be harmonized with economic projections to understand the intertwined effects on transportation and the economy.
Alignment with Land Use Models	Integrating with land use models allows the travel demand model to predict how transportation needs change with different land use patterns. Feedback loops allow residential location preference shifts with new technologies such as Connected and Autonomous Vehicle travel.
Incorporation of Energy Consumption Models	Travel demand models can project energy use based on transportation behaviors, guiding energy policy and sustainable energy sourcing decisions.

Figure 4.8

Model Integration Results



4.4. MPO Survey Takeaways

The survey results from Wisconsin's MPO survey revealed the following key findings:

- Environmental Initiatives
    - Only one MPO has established policies to tackle environmental issues stemming from transportation system users.
    - Only one MPO is leveraging their travel demand model to gauge the impacts of climate change within their region.
- Forecasting and Modeling
    - Nearly all MPOs expressed interest in utilizing their travel forecasting models to assess the potential impacts of emerging transport solutions, such as micromobility, electric vehicles, autonomous vehicles, and active transportation, on their networks.
    - More than half of the MPOs put a high emphasis on using the travel demand model to grasp the effects of climate change, particularly in the following areas:
        - Density Enhancement Impacts (92%)
        - Alignment with Land Use Models (85%)
        - Climate-resilient Urban Development Strategies (85%)
        - Adapting to Travel Pattern Changes (77%)
        - Infrastructure Vulnerability Assessments (69%)
        - Climate Impact Visualization Tools (69%)
        - Sync with Economic Models (69%)
        - Carbon Footprint Reduction (62%)
        - Shifting to Lower-emission Modes (54%)

- Advisory Committees
    - Only 38% of the MPOs have a Bicycle and Pedestrian Advisory Committee in place.
    - No Wisconsin MPO is using a Citizen's Advisory Committee to help synchronize land development, transportation infrastructure, and economic growth within their regions.
- Sustainable Transportation Planning
    - Almost all MPOs (85%) stated they will promote sustainable transportation modes and reduced reliance on automobiles in their next long-range transportation plan update.
    - Over half of the MPOs stated they currently have a moderate to significant focus on the following sustainability themes in their long-range transportation plans:
        - Expanding Mobility Choices (92%)
        - Environmental Equity and Justice (85%)
        - Enhancing Quality of Life (77%)
        - Environmental Consciousness (62%)
        - Infrastructure Resiliency and Sustainability (54%)
    - Over half the MPOs indicated that they only minimally address improving air quality in their current plan and do not foresee emphasizing it more in their next long- range transportation plan update.
- Staffing
    - Over half of Wisconsin's MPOs operate with a small staff, having only one to two individuals available to fulfill their MPO obligations.

4.5. Latent Thematic Comparisons

Chapter 2 provided an in-depth exploration into how Natural Language Processing (NLP) algorithms decipher latent themes, particularly in relation to climate change awareness within long-range transportation plans. In Chapter 4, a comparison is made between the outcomes of the NLP analysis and interpretation of the same content inclusion by human evaluators. The evaluators were the respective MPO transportation planners; well-acquainted with the nuances and intricacies of their adopted long-range transportation plans.

Specifically, survey Question 10 asked MPO planners to indicate which of the twelve latent climate change themes identified using NLP were present in their current plan and if so, to what extent. Given the expertise of the human evaluators and their deep-rooted understanding of their transportation plan content, their interpretations were considered the benchmark for NLP theme comparisons. When a respondent indicated a latent theme was "significant" in their plans, it received 3 points. Similarly, "moderate" was assigned a score of 2, and "minimal" received a score of 1. A perfect score was assumed to equal 3 points for each latent theme the planners identified as being included. Table 4.6 provides an example of the results for Oshkosh:

Table 4.6

Example of Computer vs Human Accuracy Rating

MPO	Computer ID'd Latent Theme	Planner ID'd Latent Theme	Points Received	Points Available	Accuracy Rate
Oshkosh	Mobility Options	Moderate	2	3	
	Quality of Life	Significant	3	3	
	Air Quality	Minimum	1	3	
	Environmental Justice	Minimum	1	3	
			7	12	58.3%

Examining all individual MPO scores yields the following results:

Table 4.7

MPO Latent Theme Accuracy Scores

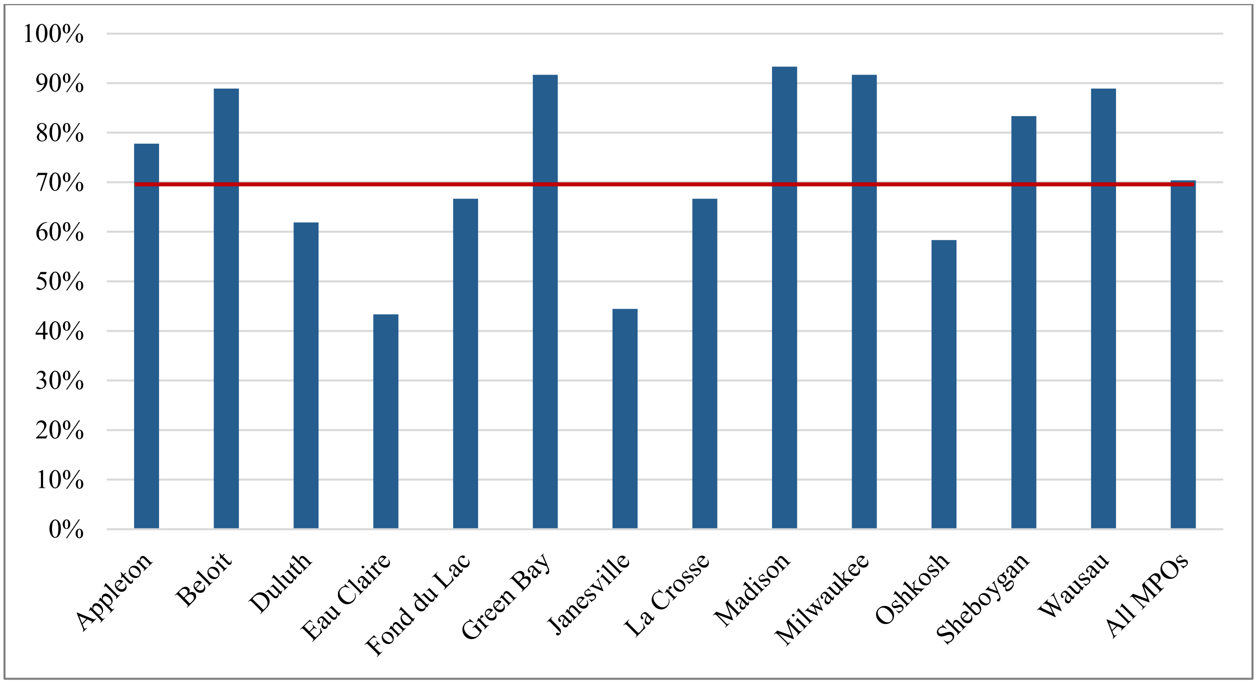
MPO	Accuracy Score
Appleton	61.1%
Beloit	88.9%
Duluth	42.9%
Eau Claire	43.3%
Fond du Lac	72.2%
Green Bay	91.7%
Janesville	44.4%
La Crosse	66.7%
Madison	93.3%
Milwaukee	91.7%
Oshkosh	58.3%
Sheboygan	83.3%
Wausau	88.9%
All MPOs[24]	70.4%

The data is comprised of rates ranging from 43.3% to 93.3%. A range of 50.0% indicates a wide variability in the accuracy scoring across the MPOs. While some MPOs achieved exceptionally high accuracy rates, others lagged significantly. Figure 4.9 graphically illustrates the respective latent theme identification accuracy results.

[24] While it's possible to take an average of averages, it's more appropriate to combine all the data and compute an overall average. The averages (means) being combined come from samples of different sizes. Each mean does not account for the number of data points it represents. Larger samples should have more weight in the overall average than smaller samples.

Figure 4.9

Computer vs Planner Latent Theme Accuracy Rates by MPO



4.6. Latent Thematic Analysis Takeaways

The findings highlight that while there have been significant strides in the NLP domain, especially in discerning latent themes like those of climate change in transportation plans, there remains a significant difference in outcomes when juxtaposed against interpretations by experts in transportation planning. The wide range in accuracy rates, coupled with a substantial standard deviation, emphasizes the diversity of outcomes from different MPOs. This finding hints at the impact of varied methodologies, tools, and intrinsic complexities found within the respective documents and agencies. Future research opportunities might focus on better understanding the depth and accuracy of the human evaluators.

CHAPTER 5: CONCLUSION

Chapter 2 underscored the increasing recognition of climate change as a central challenge within the domain of transportation planning. MPOs across six states were investigated for their evolving consciousness and commitment to integrating environmental sustainability, resilience, and equity within their long-range strategies. Divergent themes identified unique regional priorities, setting the stage for a diverse approach towards climate-responsive transportation planning. The utility of NLP and LDA in this manner provided an analytical framework capable of monitoring future shifts in the public narrative around transportation and climate change, thereby guiding the evolution of policy, informing best practices, and facilitating benchmarking. In the face of increasing climate-related challenges, employing advanced methodologies in transportation planning becomes crucial. A deep understanding of the intricate mix of themes, perspectives, and priorities in long-term transportation plans is key to enhancing the decision-making process. Sustainably integrating technology, regional transportation planning, and climate-focused policies holds great promise for the future.

Chapter 3 addressed the substantial challenges of mathematically representing the complexities inherent in contemporary transportation systems and human behavior within travel demand forecasting models. This ongoing process necessitates a continual reevaluation and refinement of the foundational assumptions that have shaped our understanding of the relationship between autonomous vehicles and urban planning, transportation systems, and sustainable development. As research in this field progresses, it is essential to recognize the Madison MPO travel demand model, as well as similar representations in other Midwest metropolitan areas, provides only a simplistic abstract view into a technologically advanced future. The practical consequences of autonomous vehicles will be substantially more complex and diverse, manifesting differently across different demographics, travel purposes, and situational factors.

In Chapter 4, the results of a Wisconsin MPO transportation planners' survey highlighted that while techniques such as Natural Language Processing have made significant strides in discerning latent or hidden themes like those of climate change in transportation plans, a significant difference in outcomes exist when juxtaposed against thematic interpretations by local experts in transportation system planning. The diversity of outcomes from different MPOs was underscored by a wide range in accuracy (i.e., agreement) rates. This implies the significant impact of varied methodologies, tools, and built-in complexities unique to each MPO document and agency.

APPENDIX A: NLP AND LDA PYTHON SCRIPTS

A.1 LDA Mallet Base Model and Coherence Tests

```
from datetime import datetime
startTime = datetime.now()

import pandas as pd
import io
import fitz    # imports PyMuPDF
doc = fitz.open('Combined.pdf')
text = ""
for page in doc:
   text+=page.get_text()

text = text.replace('\xa0', ' ')

import spacy
nlp = spacy.load('en_core_web_lg')
nlp.max_length = len(text) + 1000
doc = nlp(text)
names = set()
for ent in doc.ents:
    if ent.label_ == 'GPE':
        names.add(ent.text)
names = list(names)
for i in range(len(names)):
    names[i] = names[i].replace('\n', ' ')
geonames = [word.lower() for word in names]

df = pd.read_csv(io.StringIO(text), sep = "//r//n", engine = 'python')
df.to_csv('Combined.csv')
fulldata = pd.read_csv("Combined.csv", header=None)
data = fulldata.loc[:,1]
data = fulldata.values.tolist()

import gensim
from nltk.corpus import stopwords
from gensim.utils import simple_preprocess

for i in range(len(data)):
    for n in range(10):
        data[i] = str(data[i]).replace(str(n),'')
    for p in '[,.!?]:-()"%`;':
        data[i] = str(data[i]).replace(p,'')
        data[i] = str(data[i]).lower()
        data[i] = gensim.utils.simple_preprocess(data[i], deacc=True)
```

```
data = [[word for word in sublist if len(word) >= 3] for sublist in data]

stop_words = stopwords.words('english')

stop_words.extend( ) #Not showing several additional MPO plan-specific stopwords here for space
considerations

stop_words.extend(geonames)

def remove_stopwords(data):
    return [[word for word in simple_preprocess(str(doc)) if word not in stop_words] for doc in data]
data = remove_stopwords(data)

bigram = gensim.models.Phrases(data, min_count=5, threshold=10)
bigram_mod = gensim.models.phrases.Phraser(bigram)
def make_bigrams(texts):
    return [bigram_mod[doc] for doc in texts]
data = make_bigrams(data)

stop_words.extend([ #load several additional MPO plan-specific biwords from list file ])

def remove_stopwords_bi(data):
    return [[word for word in simple_preprocess(str(doc)) if word not in stop_words] for doc in data]
data = remove_stopwords_bi(data)

from collections import Counter
from nltk import FreqDist
words = Counter(c for clist in data for c in clist)
fdist1 = FreqDist(words)
print(fdist1, file=open('token_count.txt', 'w', errors = "ignore"))

import os
import gensim
import gensim.corpora as corpora

os.environ['MALLET_HOME'] = 'C:\\Users\\misci\\.mallet\\mallet-2.0.8'
mallet_path = 'C:\\Users\\misci\\.mallet\\\\mallet-2.0.8\\bin\\mallet'
id2word = corpora.Dictionary(data)
texts = data
corpus = [id2word.doc2bow(text) for text in texts]
print(corpus, file=open('corpus.txt', 'w', errors="ignore"))

from gensim.models.coherencemodel import CoherenceModel

def compute_coherence_values(dictionary, corpus, texts, limit, start=2, step=3):
   coherence_values = []
   model_list = []
   for num in range (1,41):
```

```
        model = gensim.models.wrappers.LdaMallet(mallet_path, corpus=corpus, num_topics=num,
id2word=id2word)
        model_list.append(model)
        coherencemodel = CoherenceModel(model=model, texts=texts, corpus=corpus, dictionary=id2word,
coherence='c_v')
        coherence_values.append(coherencemodel.get_coherence())
    return model_list, coherence_values

model_list, coherence_values = compute_coherence_values(dictionary=id2word, corpus=corpus,
texts=texts, start=1, limit=41, step=1)

print(coherence_values, file=open('coherence_values.csv', 'w', errors = 'ignore'))

import matplotlib.pyplot as plt

limit=41; start=1; step=1;
x = range(start, limit, step)
plt.plot(x, coherence_values)
plt.xlabel("Num Topics")
plt.ylabel("Coherence score")
plt.legend(("coherence_values"), loc='best')
#plt.show()
plt.savefig('Coherence.png', dpi = 300)

ldamallet =  gensim.models.wrappers.LdaMallet(mallet_path, corpus=corpus, num_topics=40,
optimize_interval = 10, id2word=id2word, random_seed=100)
ldamallet.save('optimized_model')

topics = ldamallet.show_topics(num_topics = 40, num_words=30)
with open('weighted_topics.txt', 'w', errors = 'ignore') as f:
    print(topics, stream=f)

import pyLDAvis.gensim_models

topics = [[(term, round(wt, 3)) for term, wt in ldamallet.show_topic(n, topn=40)] for n in range(0,
ldamallet.num_topics)]
topics_df = pd.DataFrame([[term for term, wt in topic] for topic in topics], columns = ['Term'+str(i)
for i in range(1, 41)], index=['Topic '+str(t) for t in range(1, ldamallet.num_topics+1)]).T
topics_df.head()

pd.set_option('display.max_colwidth', -1)
topics_df = pd.DataFrame([', '.join([term for term, wt in topic]) for topic in topics], columns =
['Terms per Topic'], index=['Topic'+str(t) for t in range(1, ldamallet.num_topics+1)] )
topics_df

print(topics_df)

import pyLDAvis
```

```
from gensim.models.ldamodel import LdaModel

def convertldaMalletToldaGen(mallet_model):
    model_gensim = LdaModel(id2word=mallet_model.id2word, num_topics=mallet_model.num_topics,
alpha=mallet_model.alpha)
    model_gensim.state.sstats[...] = mallet_model.wordtopics
    model_gensim.sync_state()
    return model_gensim

ldagensim = convertldaMalletToldaGen(ldamallet)
vis = pyLDAvis.gensim_models.prepare(ldagensim, corpus, id2word, sort_topics=False)

coherence_model = CoherenceModel(ldagensim, corpus=corpus, dictionary=id2word, texts=texts,
coherence='c_v')
coherence_score = coherence_model.get_coherence()

print(f"Coherence score: {coherence_score}")

pyLDAvis.save_html(vis, 'LDA_Visualization.html')
tm_results = ldamallet[corpus]
print(corpus)
print(tm_results)

df_weights = pd.DataFrame.from_records([{v: k for v, k in row} for row in tm_results])
pd.set_option('display.max_columns', None)
print(df_weights)

df_weights.columns = ['Topic ' + str(i) for i in range(1, 41)]
df_weights.to_csv(str(40)+'data.csv', index=False, header=True)

tm_results = ldamallet[corpus]
corpus_topics = [sorted(topics, key=lambda record: -record[1])[0] for topics in tm_results]
topics = [[(term, round(wt, 3)) for term, wt in ldamallet.show_topic(n, topn=40)] for n in range(0,
ldamallet.num_topics)]
topics_df = pd.DataFrame([[term for term, wt in topic] for topic in topics], columns = ['Term'+str(i)
for i in range(1, 41)], index=['Topic '+str(t) for t in range(1, ldamallet.num_topics+1)]).T
pd.set_option('display.max_colwidth', -1)
topics_df = pd.DataFrame([', '.join([term for term, wt in topic]) for topic in topics], columns =
['Terms per Topic'], index=['Topic'+str(t) for t in range(1, ldamallet.num_topics+1)] )
topics_df

from collections import Counter
from nltk import FreqDist

flat_list = [item for sublist in data for item in sublist]
c_counts = Counter(flat_list)
freq = Counter(flat_list).most_common()
```

```
import pandas

df = pandas.DataFrame(freq)
fdist900 = FreqDist(c_counts)
df = pandas.DataFrame(fdist900.most_common(900))
df.to_csv('900_most_comm.csv')

df = pandas.DataFrame(freq)
fdist5000 = FreqDist(c_counts)
df = pandas.DataFrame(fdist5000.most_common(5000))
df.to_csv('5000_most_comm.csv')

bow = []
for m in range(len(data)):
     for n in range (len(data[m])):
          bow.append(data[m][n])

from nltk import ngrams

words = ()
words = list(ngrams(bow,1))
word_count = Counter(words)
word_count.most_common(5)

bigrams = ()
bigrams = list(ngrams(bow,2))
bigram_count = Counter(bigrams)
bigram_count.most_common(5)

trigrams = ()
trigrams = list(ngrams(bow,3))
trigram_count = Counter(trigrams)
trigram_count.most_common(5)

quadgrams = ()
quadgrams = list(ngrams(bow,4))
quadgram_count = Counter(quadgrams)
quadgram_count.most_common(5)

import seaborn as sns

def word_frequency(ngrams):
    word_freq =
pd.DataFrame(word_count.items(),columns=['words','frequency']).sort_values(by='frequency',ascending=F
alse)
    word_pairs
=pd.DataFrame(bigram_count.items(),columns=['bigrams','frequency']).sort_values(by='frequency',ascend
ing=False)
```

```
    trigrams
=pd.DataFrame(trigram_count.items(),columns=['trigrams','frequency']).sort_values(by='frequency',asce
nding=False)
    return word_freq,word_pairs,trigrams

import matplotlib.pyplot as plt

data2,data3,data4 = word_frequency(ngrams)
data2, data3, data4
fig, axes = plt.subplots(3,1,figsize=(20,20))
sns.barplot(ax=axes[0],x='frequency',y='words',data=data2.head(30))
sns.barplot(ax=axes[1],x='frequency',y='bigrams',data=data3.head(30))
sns.barplot(ax=axes[2],x='frequency',y='trigrams',data=data4.head(30))
plt.savefig('Ngrams.png', bbox_inches = 'tight', dpi = 300)

from wordcloud import WordCloud

wc = WordCloud(background_color="white", colormap="Dark2", max_font_size=150, min_font_size = 15,
random_state=100)
plt.rcParams['figure.figsize'] = [15, 25]
plt.subplots_adjust(left=0.05, right=.95, top=.98, bottom=0.02)
for i in range(40):
    wc.generate(text=topics_df["Terms per Topic"][i])
    plt.subplot(10, 4, i + 1)
    plt.imshow(wc, interpolation="bilinear")
    plt.axis("off")
    plt.title(topics_df.index[i])
    plt.legend(fontsize=8)
plt.savefig('wordcloud.png', dpi = 300)

time = (datetime.now() - startTime)
print(time, file = open('run_time.txt', 'w', errors = 'ignore'))
```

A.2 Hyperparameter Optimization

```
# Set number of corpus topics to process for each LRTP (>= 20):

import re

df = pd.read_csv('coherence_values.csv', header=None)
df.index = df.index + 1
df.columns = df.columns + 1
df = df.T
df.iloc[0, 0] = float(re.sub('[^0-9.]', '', df.iloc[0, 0]))
df.iloc[-1, 0] = float(re.sub('[^0-9.]', '', df.iloc[-1, 0]))
df = df.iloc[20:, :]
max_index = ((df.values.argmax() + 1)+20)
max_value = df.values.max()

print('\n\nMaximum value in DataFrame:', max_value, file=open('Model output.txt', 'a',
errors="ignore"))
print('Index of maximum value in DataFrame:', max_index, file=open('Model output.txt', 'a',
errors="ignore"))
print('\n', file=open('Model output.txt', 'a', errors="ignore"))

num_topics= max_index

from gensim.models.coherencemodel import CoherenceModel

alpha_values = [0.01, 0.1, 0.2, 0.4, 0.6, 0.8, 1.0]
beta_values = [0.01, 0.1, 0.2, 0.4, 0.6, 0.8, 1.0]

best_alpha = None
best_beta = None
best_coherence = -1.0

for alpha in alpha_values:
    for beta in beta_values:
        lda_mallet = LdaMallet(mallet_path, corpus=corpus, num_topics=num_topics,
                     id2word=id2word, optimize_interval=10, iterations=40)
        lda_model = gensim.models.wrappers.ldamallet.malletmodel2ldamodel(lda_mallet)
        coherence_model = CoherenceModel(model=lda_model, texts=texts, dictionary=id2word,
coherence='c_v')
        coherence = coherence_model.get_coherence() # this returns a model with alpha =1 and beta = 1
        if coherence > best_coherence:
            best_alpha = alpha
            best_beta = beta
            best_coherence = coherence

print('Optimized hyperparameter results:', file=open('Model output.txt', 'a', errors="ignore"))
with open('Model output.txt', 'a') as f:
```

```
    f.write('Best Alpha = {}, Best Beta = {}, Best Coherence = {}\n'.format(best_alpha, best_beta,
best_coherence))

ldamallet =  gensim.models.wrappers.LdaMallet(mallet_path, corpus=corpus, num_topics=num_topics,
             optimize_interval = 10, id2word=id2word, random_seed=100, alpha = best_alpha)
ldamallet.save('Optimized_model')
```

A.3 Climate Change Keyword Counter

```
import csv

climate_change_keywords = [
    "climate", "climate_change", "greenhouse", "greenhouse_gas", "carbon", "carbon_monoxide",
    "oxides", "methane", "nitrous", "nitrogen", "fossil_fuels", "emissions", "air",
    "air_quality", "air_pollution", "pollution", "pollutants", "clean_air", "tailpipe",
    "resilience", "resiliency", "energy", "hybrid_electric", "electrification", "electrified",
    "electric", "electric_buses", "electric_bikes", "evs", "cng", "greening", "green",
    "green_design", "conservation", "natural", "habitat", "wetland", "watershed", "runoff",
    "extreme_weather", "environment", "environmental", "sustainability", "sustainable",
    "quality_life", ]

input_file = 'All words.csv'

counts = []

for keyword in climate_change_keywords:
    counts.append((keyword, 0))

with open(input_file, 'r', errors = 'ignore') as f:
    reader = csv.reader(f)
    next(reader)
    for row in reader:
        word = row[1]
        count = int(row[2])
        if word in climate_change_keywords:
            # If the word is in the list of keywords, add its count to the list of counts
            counts[keywords.index(word)] = (word, count)

with open('keyword_counts.csv', 'w', newline='') as f:
    writer = csv.writer(f)
    writer.writerow(['Keyword', 'Count'])
    for keyword, count in counts:
        writer.writerow([keyword, count])
```

A.4 Cosine Similarity Test (Corpora)

```
import PyPDF2
from sklearn.feature_extraction.text import TfidfVectorizer
from sklearn.metrics.pairwise import cosine_similarity
from nltk.corpus import stopwords
from nltk.tokenize import word_tokenize
from nltk.stem import WordNetLemmatizer
import string
import pandas as pd

# List of the pdf files
#pdf_files = ["Appleton.pdf", "Beloit.pdf", "Eau Claire.pdf", "Fond du Lac.pdf", "Green Bay.pdf",
#              "Janesville.pdf", "LaCrosse.pdf", "Madison.pdf", "Milwaukee.pdf", "Oshkosh.pdf",
#              "Sheboygan.pdf", "Wausau.pdf"]
#pdf_files = ["Bloomington.pdf", "Chicago.pdf", "Danville.pdf", "Decatur.pdf", "Kankakee.pdf",
#              "Marion.pdf", "Peoria.pdf",  "Rockford.pdf", "Springfield.pdf", "Urbana.pdf"]
#pdf_files = ["Bismarck.pdf", "Fargo.pdf", "Grand Forks.pdf", "Rapid City.pdf", "Sioux Falls.pdf"]
#pdf_files = ["Ames.pdf", "Cedar Rapids.pdf", "Davenport.pdf", "Des Moines.pdf", "Dubuque.pdf",
#              "Iowa City.pdf", "Omaha.pdf", "Sioux City.pdf", "Waterloo.pdf"]
#pdf_files = ["Duluth.pdf", "Mankato.pdf", "Minneapolis.pdf", "Rochester.pdf", "St Cloud.pdf"]
#pdf_files = ["IA.pdf", "IL.pdf", "MN.pdf", "ND.pdf", "SD.pdf", "WI.pdf"]
#pdf_files = ["Chicago.pdf", "Des Moines.pdf", "Madison.pdf", "Milwaukee.pdf", "Minneapolis.pdf",
#              "Omaha.pdf"]
pdf_files = ["Ames.pdf", "Bismarck.pdf", "Chicago.pdf", "Danville.pdf", "Fargo.pdf",
             "Iowa City.pdf", "Minneapolis.pdf", "Omaha.pdf", "Rapid City.pdf", "Rochester.pdf"]

def clean_text(text):
    stop_words = set(stopwords.words('english'))
    word_tokens = word_tokenize(text)
    filtered_text = [w for w in word_tokens if not w in stop_words]
    lemmatizer = WordNetLemmatizer()
    lemmas = [lemmatizer.lemmatize(w) for w in filtered_text if w not in string.punctuation]
    return lemmas

def read_pdf(file):
    pdf_file_obj = open(file, 'rb')
    pdf_reader = PyPDF2.PdfFileReader(pdf_file_obj)
    text = ''
    for page_num in range(pdf_reader.numPages):
        page = pdf_reader.getPage(page_num)
        text += page.extractText()
    pdf_file_obj.close()
    return text

documents = []
for file in pdf_files:
    text = read_pdf(file)
```

```
    clean = clean_text(text)
    documents.append(' '.join(clean))

vectorizer = TfidfVectorizer().fit_transform(documents)

cosine_similarities = cosine_similarity(vectorizer)

pdf_files_stripped = [file.replace('.pdf', '') for file in pdf_files]
df = pd.DataFrame(cosine_similarities, index=pdf_files_stripped, columns=pdf_files_stripped)

df.to_excel("cosine_similarities.xlsx")
```

A.5 Cosine Similarity Test (Climate Words)

```
import PyPDF2
import pandas as pd
from sklearn.feature_extraction.text import TfidfVectorizer
from sklearn.metrics.pairwise import cosine_similarity
from nltk.corpus import stopwords
from nltk.tokenize import word_tokenize
from nltk.stem import WordNetLemmatizer
import string

climate_change_keywords = [
    "climate", "climate_change", "greenhouse", "greenhouse_gas", "carbon", "carbon_monoxide",
    "oxides", "methane", "nitrous", "nitrogen", "fossil_fuels", "emissions", "air",
    "air_quality", "air_pollution", "pollution", "pollutants", "clean_air", "tailpipe",
    "resilience", "resiliency", "energy", "hybrid_electric", "electrification", "electrified",
    "electric", "electric_buses", "electric_bikes", "evs", "cng", "greening", "green",
    "green_design", "conservation", "natural", "habitat", "wetland", "watershed", "runoff",
    "extreme_weather", "environment", "environmental", "sustainability", "sustainable",
    "quality_life", ]

def clean_text(text):
    stop_words = set(stopwords.words('english'))
    word_tokens = word_tokenize(text)
    filtered_text = [w.lower() for w in word_tokens if w.lower() not in stop_words and w.lower()
not in string.punctuation]
    lemmatizer = WordNetLemmatizer()
    lemmas = [lemmatizer.lemmatize(w) for w in filtered_text]
    return ' '.join(lemmas)

def read_pdf(file):
    pdf_file_obj = open(file, 'rb')
    pdf_reader = PyPDF2.PdfFileReader(pdf_file_obj)
    text = ''
    for page_num in range(pdf_reader.numPages):
        page = pdf_reader.getPage(page_num)
        text += page.extractText()
    pdf_file_obj.close()
    return text

# List of the pdf files
#pdf_files = ["Appleton.pdf", "Beloit.pdf", "Eau Claire.pdf", "Fond du Lac.pdf", "Green Bay.pdf",
#              "Janesville.pdf", "LaCrosse.pdf", "Madison.pdf", "Milwaukee.pdf", "Oshkosh.pdf",
#              "Sheboygan.pdf", "Wausau.pdf"]
#pdf_files = ["Bloomington.pdf", "Chicago.pdf", "Danville.pdf", "Decatur.pdf", "Kankakee.pdf",
#              "Marion.pdf", "Peoria.pdf",  "Rockford.pdf", "Springfield.pdf", "Urbana.pdf"]
#pdf_files = ["Bismarck.pdf", "Fargo.pdf", "Grand Forks.pdf", "Rapid City.pdf", "Sioux Falls.pdf"]
#pdf_files = ["Ames.pdf", "Cedar Rapids.pdf", "Davenport.pdf", "Des Moines.pdf", "Dubuque.pdf",
```

```
#             "Iowa City.pdf", "Omaha.pdf", "Sioux City.pdf", "Waterloo.pdf"]
#pdf_files = ["Duluth.pdf", "Mankato.pdf", "Minneapolis.pdf", "Rochester.pdf", "St Cloud.pdf"]
#pdf_files = ["IA.pdf", "IL.pdf", "MN.pdf", "ND.pdf", "SD.pdf", "WI.pdf"]
#pdf_files = ["Chicago.pdf", "Des Moines.pdf", "Madison.pdf", "Milwaukee.pdf", "Minneapolis.pdf",
#             "Omaha.pdf"]
pdf_files = ["Ames.pdf", "Bismarck.pdf", "Chicago.pdf", "Danville.pdf", "Fargo.pdf",
             "Iowa City.pdf", "Minneapolis.pdf", "Omaha.pdf", "Rapid City.pdf", "Rochester.pdf"]

documents = []
for file in pdf_files:
    text = read_pdf(file)
    clean = clean_text(text)
    documents.append(clean)

vectorizer = TfidfVectorizer(vocabulary=climate_change_keywords)
dtm = vectorizer.fit_transform(documents)

cosine_similarities = cosine_similarity(dtm)

pdf_files_stripped = [file.replace('.pdf', '') for file in pdf_files]
df = pd.DataFrame(cosine_similarities, index=pdf_files_stripped, columns=pdf_files_stripped)

sklearn_cosine_sim = cosine_similarity(dtm)
my_cosine_sim = cosine_similarity(dtm)

print("Cosine Similarity (Scipy):")
print(sklearn_cosine_sim)
print("\nCosine Similarity (My code):")
print(my cosine_sim)

df = pd.DataFrame(cosine_similarities, index=pdf_files_stripped, columns=pdf_files_stripped)

print("Cosine Similarity:")
print(df)

df.to_excel("cosine_similarities_keys.xlsx", index=True, header=True)
```

A.6 K-means Clustering (Corpora)

```
from sklearn.cluster import KMeans

num_clusters = 5
kmeans = KMeans(n_clusters=num_clusters, random_state=100).fit(vectorizer.toarray())
cluster_assignments = kmeans.labels_
df_kmeans = pd.DataFrame(list(zip(pdf_files_stripped, cluster_assignments)), columns=["File",
"Cluster"])

df_kmeans.to_excel("kmeans_clusters.xlsx")plot_tsne_scatter(tsne_vectors, cluster_assignments,
num_clusters, pdf_files_stripped)
```

APPENDIX B: LATENT CLIMATE CHANGE TOPICS

Table B.1

Latent Topics - Illinois MPOs

Bloomington (39)	
Topic8	economic, community, transportation, sustainability, fiscal, support, management, address, concern, concerns, infrastructure, supported, sustainable, issues, process, baby, social, continuing, practices, institutional, public, trend, common, plans, environmental, financial, boomers, made, findings, environmentally **(SR)**
Topic20	transportation, funding, investment, fuel, sustainable, infrastructure, opportunities, technology, health, types, advocacy, alternative, vital, action, direct, sources, vehicles, levels, care, framework, private, continues, general, materials, multiple, seek, public, future, traditional, channels **(SR)**
Topic22	transportation, report, include, impacts, environmental, condition, system, data, document, outcomes, cooperation, review, stormwater, issues, network, practices, systems, facility, dashboard, monitor, construction, development, primary, highway, land, public, results, create, evaluate, mitigation **(EA)**
Topic24	transportation, system, existing, resources, future, service, functional, priorities, levels, expansion, feasible, preservation, limited, maintenance, improvements, gaps, determined, focused, keeping, exhibit, technically, permit, sustainable, continued, path, demands, conditions, partnerships, classification, private_sector **(SR)**
Topic26	section, costs, freight, promote, accessibility, focus, transportation, materials, mobility, information, energy, goal, quality_life, performance, communities, increase, people, improved, sustainable, riders, degree, health_safety, clean, level, improve_safety, conditions, relevant, truck, operations, relationship **(QL)**
Topic32	federal, incorporate, public, agencies, requirements, information, public_outreach, environmental, law, participating, protection, plan, civil_rights, regulations, legislation, discrimination, monitor, levels, access, required, congestion, government, review, local, activities, resources, agency, services, rules, enforcement **(EJ)**
Topic34	transportation, plan, regional, public, vision, system, technologies, local, policy, born, outreach, community, needed, priorities, sustainability, work, making, developed, actions, goals, projects, understanding, determine, support, focus, results, expected, information, emerging, based **(SR)**

Chicago (30)	
Topic5	plan, indicators, integer, description, benefits, plan_regionally, system, revisions, methodology, shop, indicator, residence, characters, billon, format, transportation, totaltime, plan_financial, building_type, hbw, contents, adoption, hov_distance, mobility, starthour, environment, report, evaluated, suite, process **(EA)**
Topic10	data, medium, light, heavy_trucks, trucks, daily, truck, nox, emissions, office, secretary, vehicles, effects, number, duty, region, provided, compounds, public, updated, control, traffic, nitrogen, clearance, restrictions, used_calculate, crash, oxides, emission, travel_survey **(AQ)**
Topic12	area, emissions, greenhouse_gas, region, zone, inventory, remainder, zones, urbanized_area, speed, central_area, planning, includes, mile, calculation, vehicle, subzones, data, change, additionally, coordinate, land, land_use, amount, toll, international, quarter, water, supply, buffer **(TE)**
Topic19	subzones, zones, census, areas, based, remaining, suburban, standards, air_quality, area, boundaries, fips, allocated, trip_generation, geography, considered, higher, document, levels, digits_equal, ozone, community, subzone, level, adjustment, airport, o_zone, processes, effort, locations **(AQ)**
Topic23	model, travel_demand, moves, emissions, data, input, based, vmt, analysis, results, travel, information, trip, transportation, conformity, estimates, emission, regional, run, updated, values, type, analyses, vehicle_type, daily, epa, runs, process, calculation, air_quality **(AQ)**

Danville (40)	
Topic4	route, corridor, major, connection, traffic, main, employers, interchange, district, improvements, programs, match, pass, regional, collector, arterial, serves, terminal, classification, primary, transportation, additionally, large, volumes, seeks, barriers, sustainability, measured, enhanced, result **(SR)**
Topic7	environment, safe, complete, convenient, shared, enhancing, natural, create, built, supports, negatively, adopt, sets, policy, path, balanced, growth, protecting, assist, balance, protection, nation, residential, coalition, identify, individuals, region, developing, overpass, framework **(EA)**
Topic10	improvements, support, projects, transportation, improve, potential, roadway, access, rail, operations, regional, construction, economic, area, corridor, identify, enhance, opportunities, development, intersection, improving, encourage, planned, impacts, airport, climate, connectivity, implementation, eliminate, analysis **(CC)**
Topic19	dats, lrtp, planning, transportation, process, goals, recommendations, national, vision, projects, local, measures, safety, developed, section, document, effort, future, selection, making, support, environmental, organization, updated, modal, objectives, fundamental, approach, bring, members **(EA)**
Topic32	transportation, safety, community, economic, increase, policies, address, land_use, plans, environmental, existing, programs, activities, projects, benefits, current, factors, security, planning, growth, include, quality_life, enhance, environment, conditions, development, operation, protect, coordinated, promote **(QL)**
Topic35	vehicle, riders, personal, transit, options, choice, variety, continue, types, passes, include, availability, captive, makes, wider, persons, serves, users, boomers, government, access, decide, sustainable, baby, cards, flexibility, independence, weekly, freedom, foundation **(SR)**

Decatur (34)	
Topic3	age, system, removal, older, card, reliability, senior, impacts, personal, snow, full, resiliency, approved, fare, ride, plant, end, free, site, pay, early, stormwater, monitored, disabled, ice, ages, high_school, place, individuals, evening **(SR)**
Topic4	traffic, air_quality, noise, local, program, connection, fhwa_fastact, urban, vmt, factsheets, access, roads, collectors, minor_arterials, per_million, standards, meeting, areas, serious_injury, impact, base_plus, high, mitigation, properties, provide, national, progress_toward, strategies, direct, rolling_average **(AQ)**
Topic5	environmental, impacts, federal, areas, minimize, natural, planning, efforts, legislation, national, procedures, species, effort, endangered, threatened, cooperation, local, coordinate, coordination, negative, provisions, avoid, bicycle, early, effects, listed, designated, activities, focus, harm **(EA)**
Topic21	freight, rail, reliability, truck, travel_time, faries, movement, index, trucks, distance, days, improve, emissions, goods, shippers, aviation, larger, highway, size, budget, measure, overpass, represents, safety, load, travel, designed, carries, include, mobile **(AQ)**
Topic30	lrtp, projects, transportation, project, development, analysis, process, plan, future, included, planning, significant, regional, public, areas, land_use, potential, environmental, local, agencies, identified, priorities, impacts, benefits, revenues, issues, address, stakeholders, improvements, identify **(EA)**

DeKalb (40)	
Topic2	health, water, trails, program, snowmobile, develop, center, resources, areas, public, services, fund, land, fields, quality, sports, boardwalk, complex, times, grants, grant, private, conservation, lands, open_space, athletic, assistance, response, security, improve **(EA)**
Topic5	image, design, entrance, safe, features, community, environment, friendly, unique, place, create, pedestrian, walk, area, location, comfortable, walkable, core, promote, designed, person, attractive, ages, walking, amenities, making, consistent, communities, accessible, elements **(MO)**
Topic8	areas, neighborhood, provide, core, open, open_space, commercial, landscaping, adjacent, density, building, area, development, play, space, green, neighborhoods, developers, action, design, natural, integrate, parking_lots, shade, land, trees, paths, control, add, follow **(NC)**
Topic29	persons, income, environmental, family, household, materials, housing, households, single, census, primarily, lower, standards, bridge, identified, population, material, ethnicity, hispanic, median, rating, structural, information, strategy, enhance, signs, protection, quality, curb, traditional **(EJ)**
Topic31	neighborhood, public, core, community, acres, center, spaces, historic, amenities, size, paved, site, access, residents, parking, construct, trails, green, recreational, space, cul, building, experience, facades, front, extend, obtain, adjacent, habitat, trees **(NC)**

Kankakee (36)	
Topic1	development, land, public, bicycle, acquisition, emergency, provide, facilities, right_way, design, engineering, open, conservation, engineer, enforcement, committee, community, opinion, response, pedestrian, developers, survey, professionals, recreation, cost, scenic, space, areas, input, education **(NC)**
Topic6	project, section, committee, included, procedures, coordination, environmental, required, manual, projects, information, points, planning, studies, water, provide, additional, wildlife, specific, meeting, process, habitat, impact, considerations, statement, member, approved, lands, mission, detailed **(EA)**
Topic9	sources_varying, levels_accuracy, existing, greenway, urban, minority, populations, upgrade, persons, trails, proposed, income, natural, traffic_signal, traffic, african, population, community, black, hispanic, system, group, completes, location, eligible, greenways, segment, information, latino, regulations **(EJ)**
Topic12	transportation, weather, impacts, historic, events, due, related, security, improve, national, resiliency, resources, snow, avoid, preservation, traffic_flow, reductions, effects, dollars, safety, analysis, mobility, covid, sites, properties, conditions, cultural, measures, adverse, climate_change **(SR)**
Topic17	intermodal, facility, bike_share, locations, users, located, increase, ages, matter, carbon, trains, dock, rail, logistics, particulate, center, monoxide, technologies, growing, region, network, major, bnsf, acre, facilities, create, site, ozone, anticipated, number **(AQ)**
Topic22	route, ridership, service, station, average, lowest, hour, school, length, highest, operates, daily, roadways, trip, speed, trains, reduction, peak_period, decreased, champaign, round, width, high, trips, miles, routes, emissions, agriculture, vehicle, limit **(AQ)**
Topic29	targets, performance, transportation, system, required, fast, freight, management, safety, federal, established, non_motorized, continued, air_quality, overview, conditions, process, statewide, plan, achieve, plans, law, establish, measures, reduction, transit_asset, support, report, develop, specific **(AQ)**
Topic33	area, long_range, planning, miles, provided, data_shown, area_uza, terrace, career_center, railroad, areas, transportation, power, boundary, intersection, overview, skyline, urbanized, overpass, air_quality, urban, study, segments, mile, standards, tier_projects, truck_routes, unincorporated, rank, organization **(AQ)**
Topic36	projects, areas, environmental, impacts, noise, construction, made, project, natural, significant, negative, require, development, developed, environment, detailed, costs, cost, contributor, expressway, threatened, data_collected, occurred, abatement, evaluate, data, assessment, national, reasonable, policy **(NC)**

Marion (36)	
Topic11	population, lrtp_objectives, support, employment, access, existing, trends, region, growth, healthcare, sustainable, assets, environmental, breakdown, forecasted, age, easy, change, providers, forecasts, level, patterns, economic, developed, effort, regional, groups, expand_improve, poverty, expansion **(SR)**
Topic15	transit, usage, increase, energy, existing, facility, require, current, station, spillertown, signal, lrtp_objectives, amtrak, administration, distance, produce, sight, lane, grid, facilitate, solar, photovoltaic, tied, installation, site, reducing, options, footprint, timing, estimated **(AF)**
Topic17	passenger_miles, vehicle_revenue, per_capita, hours, lane, passengers, air_quality, revenue, hour, congestion, traveled_per, miles, mitigation, mile, information, national, capita, mckinney, muddy, run, separate, delays, continue, carry, per_vehicle, standards, significant, peak, internet, impediment **(AQ)**
Topic19	data, locations, analysis, provided, national, based, crash, crash_data, historical, wildlife_refuge, flood, included, environmental, group, areas, identify, considerations, high, priority, land_use, identified, poole_economics, database, level, plain, conducted, determine, field, census, information **(EA)**
Topic29	transportation, system, safe, public, costs, operating, roadway, capital, region, projects, facilities, maintain, systems, include, strategies, boundary, rides_mass, existing, characteristics, maintaining, conditions, modes, assistance, legislation, reliability, biking, sustainable, users, walking, services **(SR)**

Peoria (32)

Topic1	long_range, improvement, public_health, environment, threatened, endangered, items, goal, reconstruction, system_overview, project, innovation, location, new_roadway, action, data_review, agency_epa, envision_hoi, governments, focus_group, responsible, economy, topics, entity, discussed, fondulac, long, primary, stated, description **(EA)**
Topic6	construction, maintenance, bicyclists, costs, local, reconstruction, sedimentation, water, habitat, visual, recreation, center, reduce, weather, continued, critical, preventative, bridges, railroad, helps, native, sustainable, lane, decline, representation, sources, latino, elliptio, phrase, provide **(NC)**
Topic9	transportation, travel, region, lead, environmental, air, bicycling, improve, modes, provide, emissions, walking, public, projects, include, reduce, high, facilities, improving, automobile, efficiency, traffic, truck_air, freight, large, fuel, health, limited, improved, land_use **(AQ)**
Topic14	epa, retrieved, ozone, water, air_quality, system, standards, air, ppm, national, pollution, usace, standard, index, sulfur_dioxide, resources, designation, quality, monitoring, waterways, level, army, area, ambient_air, lower, pollutants, clean, basics, pollutant, sewer **(AQ)**
Topic18	tons, open, questionnaire, hour, open_house, time, black, central, transported, results_review, pollutants, distributed, week, ended, miles, data, values, ton, acronym, outbound, schedule, nonstop, full, commodities, passenger, readings, compiled, observed, yellow, high **(AQ)**
Topic25	stormwater, natural, erosion, management, wastewater, waste, infrastructure, green, runoff, construction, water, land, maintenance, sanitary, amount, scrap, resource, discharge, sediment, impacts, reduce, sewers, technology, surfaces, impervious, result, utility, dedicated, micrometers, carbon **(WQ)**
Topic29	rail, study, trails, future, corridors, funding, wayfinding, corridor, abandoned, service, effort, encourage, electric_buses, determine, lines, hybrid, actively, systems, acquiring, additionally, biking, commuter, vehicles, pursue, feasibility, studies, additional, recreational, perform, diesel **(AF)**

Rockford (39)

Topic6	department, bridge, energy, cooperative, data, dioxide, manual, nitrogen, agency, gas, operations, shown, epa, fuels, acres, measures, agriculture, tax, emissions, desired_trend, control, pollution, stone, current_results, sulfur, qualitative, highway, agreement, lead, sources **(AQ)**
Topic7	park, path, vehicles, main, buses, alpine, diesel, facilities, transit, college, university, fleet, number, texas, station, interchange, electric, windsor, extension, play, commuters, alternative, role, statewide, center, institute, hybrid_electric, fueled, medicine, price **(AF)**
Topic8	events, school, routes, due, weather, extreme, life, flooding, walk, bike, natural, cycles, periods, zones, areas, safe, work, recurring, greatly, manmade, region, increased, bell, assets, disasters, affect, climatic, rainfall, climate, recover **(CC)**
Topic15	vehicle, internal, vehicles, hybrid_electric, combustion, autonomous, power, mile, distance, direction, electric_motor, engine, fuel, quarters, category, driving, fees, technologies, living, batteries, registrations, gasoline, roadways, historically, plug, powered, energy, xvi, high, separate **(TE)**
Topic23	cargo, air, inbound, shared_use, freight, paths, outbound, path, nation, facilities, weight, percent, largest, growing, emissions, reduce, billion, rfd, ghg, million, passengers, particles, goods, greenhouse_gas, existing, tons, trucks, passenger, world, fastest **(AQ)**
Topic25	area, air_quality, areas, air, attainment, pollutants, transportation, identified, nonattainment, national, clean_air, region, pollution, regulations, epa, statistical, maintenance, issue, association, officials, geographic, carbon_monoxide, conformity, based, release, standard, core, status, criteria, previously **(AQ)**
Topic26	environment, transportation, economic, environmental, land_use, infrastructure, community, impacts, enhance, potential, development, quality_life, quality, policy, reduce, existing, promote, areas, consideration, design, sustainability, region, process, strategies, natural, physical, social, health, flooding, air_water **(EA)**
Topic29	condition, congestion, system, high, air_quality, traffic, roadway, percent, interstate, health, national, pavements, percentage, level, terms, degree, bridges, los, communities, received, medium, classified, social, emissions, improvement, cmaq, lane_miles, suitability, flow, space **(AQ)**
Topic30	transportation, system, safety, improve, network, mobility, congestion, freight, public, current, goods, region, projects, movement, efficiency, modes, security, designed, improving, health, issues, roadway, travel, increase, related, modal, reliability, resiliency, efficient, operating **(SR)**

Springfield (38)	
Topic12	plan, areas, planning, environmental, development, economic, organizations, health, transportation, public, made, impacts, groups, benefits, social, factors, geographic, workshop, floodplains, choose, due, impact, patterns, governmental, regional, provide, concerns, water, engagement, land **(EA)**

Urbana (28)	
Topic1	university, congestion, traffic, difficult, due, air, support, pollution, global, delay, normal, emissions, aquatic_life, crossing, systems, cars, signal, supporting, people, lead, natural, unique, makes, blind, consumption, crystal, environment, roundabouts, dioxide, hospital **(AQ)**
Topic3	water, economic, development, environment, region, design, growth, environmental, natural, project, sprawl, resources, include, urban, provide, water_quality, sustainability, site, efficiency, survey, guidelines, activities, fiscal, increase, surface, improved, areas, measures, historical, existing **(SR)**
Topic5	urbanized_area, area, lrtp, planning, population, region, air_quality, number, percent, annual, stations, level, standards, endangered, standard, land, miles, disability, threatened, poverty, levels, age, status, air, report_card, signals, employees, people, boundary, includes **(AQ)**
Topic6	health, obesity, variables, impact, factors, negative, population, volume, public_health, activity, environment, significant, diabetes, analysis, records, data, community, diseases, local, relationship, taz, risk, factor, social, type, correlation, studies, journal, related, predicted **(QL)**
Topic18	transportation, planning, future, area, development, local, plan, vision, land_use, lrtp, region, community, health, plans, safety, infrastructure, existing, goals, urbanized_area, policies, regional, projects, residents, sustainable, provide, analysis, order, highway, conditions, areas **(SR)**
Topic20	leam, projections, moves, model, emissions, based, growth, scalds, population, inputs, models, type, scenarios, change, data, output, input, drivers, provided, wide, development, user, employment, developed, land_use, vehicle, emission, growth_zones, motor_vehicle, instance **(AQ)**
Topic24	path, bike, trails, extension, pedestrian, miles, traffic, complete, prospect, shared_use, light, green, signal, armory, route, interchange, rails, walk, bike_paths, pipeline, fields, chief_shemauger, boneyard, hour, paths, upgrades, barber, project, parking, roadway **(MO)**

Table B.2

Latent Topics - Iowa MPOs

Ames (38)	
Topic1	program, turn_lanes, transportation, air, projects, funding, grade, safe, network, routes, school, congestion, grant, traffic_signal, route, improve, clean, separation, cyride, cmaq, left, frame, surface, quality, access, pollution, phase, water, area, impacts **(AQ)**
Topic2	vehicle, path, shared_use, electric, vehicles, battery, charging, hours, buses, create, infrastructure, scooters, policies, engine, traveled, vht, implement, ice, peak, bus, power, combustion, electricity, single, batteries, facility, approximately, additional, cost, internal **(AF)**
Topic10	transportation, system, statistics, integration, system_wide, connectivity, emissions, environmental, scenarios, enables, modes, constraints, outcomes, improvement, progress, tdm, techniques, capital, physical, existing, purpose, government, comparison, factors, gases, underlying, carbon, shift, tailpipe, human **(AQ)**
Topic24	areas, natural, area, waters, regulations, transportation, boundaries, subject, streams, rural, resource, bounded, projects, impacts, urbanized, built, defined, environment, usace, census_blocks, resources, statistical, data, miles, jurisdiction, determine, typically, roads, reduce, manmade **(EA)**
Topic33	vehicles, taxi, lyft, ride, uber, energy, conservation, mobility, duty, light, interested, environment, install, older, concerned, apcs, owned, bikes, motorcycle, dial, electrification, moped, private, hail, privately, alternate, operate, fleet, borrowed, excluding **(MO)**

Cedar Rapids (24)	
Topic14	vehicle_miles, traveled, emissions, social, vehicles, truck, trucks, health, public_health, related, per_million, individual, environmental, vehicle, connected, cars, economic, reducing, reduce, driver, patterns, air_quality, number, obesity, lead, includes, fuels, ghg, hmvmt, promoting **(AQ)**
Topic15	parking, bicycle, pedestrian, quality, traffic, areas, includes, facility, bike_lanes, stop, physical, lanes, facilities, improve_air, bike, include, sidepath, minimum_level, useful_life, sidewalks, environment, lights, ride, drivers, curb_offset, project_include, pedestrians, bike_share, provide, trans **(MO)**
Topic18	freight, system, traffic, region, rail, area, reliability, major, improve, truck, routes, connectivity, travel_time, travel, efficiency, route, highway, higher, average, time, resiliency, project, efficient, capacity, movement, modes, terms, work, center, goods **(SR)**
Topic20	roadway, points, sidewalk, project, based_factors, green_design, design_factors, safety_security, transit, add, school, capacity, features, include, car, facility, signage, school_district, maintenance, green, pierce, traffic, designed, involves, gibson, schools, markings, viola, safe_routes, crosswalk **(MO)**

Davenport (21)	
Topic4	area, region, community, plan, economy, opportunities, critical, program, high, travel, air_quality, services, service, transportation, benefits, industries, pandemic, covid, work, continue, attainment, people, impact, alternative, driver, emergency, movement_goods, global, local, technology **(AQ)**
Topic17	extreme_weather, resilience, areas, flooding, events, natural, transportation, event, hazards, snow, due, flood, water, system, travel, water_resources, sidewalks, income, increased, weather, affect, effects, groups, hazard, higher, vulnerability, lower, made, environment, related **(CC)**

Des Moines (36)	
Topic6	planning, regional, sustainability, communities, community, hud, partnership, develop, team, local, ideas, leaders, grant, residents, technical, phase, initiative, principles, effort, design, approach, stormwater, process, epa, livability, led, concept, experts, developed, forum **(SR)**
Topic7	electric, charging, vehicle, vehicles, scooters, power, equipment, fuel, shared, global, companies, fleet, railroad, parked, bikes, purchase, class, pev, fleets, level, devices, government, stay, publication, result, fully, workplace, electricity, grid, resulting **(AF)**
Topic11	land, development, conservation, water, open_space, areas, trails, natural, property, districts, greenways, overlay, recreation, acres, factors, private, lands, easements, node, public, resources, percent, population, zoning, minimum, land_use, regulations, boundaries, protect, current **(NC)**
Topic12	water, stormwater, systems, water_quality, runoff, control, quality, stream, streams, reduce, tree, natural, urban, green, flood, management, region, system, infrastructure, flooding, habitat, wildlife, provide, site, trees, buffers, events, include, manage, volume **(WQ)**
Topic27	health, environmental, food, economic, environment, local, energy, impacts, improve, impact, social, healthy, reduce, benefits, reducing, people, emissions, effects, public, locally, enhance, quality, physical, economy, efficiency, promote, farmers, improving, system, personal **(QL)**

Dubuque (33)	
Topic2	service, emissions, bus, rta, tons, services, epa_national, department, district, hours, workers, tiger, million, fixed_route, passenger_rail, addition, grant, data, green, project, provided, residents, fares, human, secured, door, university, living, agency, manage **(MO)**
Topic4	park, service, airport, industrial, include, center, public, information, unit, review, corridor, lrtp, adoption, ipl_boiler, chapters, mile, evs, international, sustainability, security, meeting, terminal, meetings, keer, surface, expand, charging, concept, hours, connects **(TE)**
Topic6	budget, vision, average_annual, natural_gas, health, reduce, spending, education, goals, due, generation, building, strong_regional, vehicles, healthy_air, risks, emissions, car, office, economy, black, duty, retail, rta, fuel, green, nepa_process, leadership, diesel, higher **(QL)**
Topic7	program, air_quality, emission, standards, attainment, sources, highest, emissions, diesel, public_health, region, air, local, improve, dera, clean_air, maintain, nepa, policy, national, public, community, communities, matter, reductions, reduce, programs, particulate, advance, works **(AQ)**
Topic11	alliant, energy, plant, small, located, increase, particles, coal_fired, size, place, air_quality, powerline, education, intersections, potential, power_plant, fenelon, micrometers, awareness, cease, completely, design, inflation, positions, index, specific, additional, ytisrevin, problems, adjusted **(AF)**
Topic14	reduce, emissions, university, congestion, roundabouts, impacts, traffic, safety, areas, environment, vehicle, complete, project, natural, corridor, capacity, improve, improvements, study, identify, significant, economic, traffic_flow, travel, los, health, avoid, region, improve_safety, minimize **(AQ)**
Topic15	area, trails, areas, provide, information, regional, community, system, businesses, existing, hiking, encourage, local, network, program, recreational, connections, facilities, complete, schools, people, designed, develop, national, routes, opportunities, signage, integrated, public, air_quality **(MO)**
Topic16	fuel_combustion, project, lrtp, study, recommendations, projects, include, sustainable, policy, committee, final, research, smarter_travel, order, working, complete, developed, citizen, section, electric_utlity, industrial, implement, encourage, requirements, resources, adopted, waste_disposal, plan, advisory, community **(AF)**
Topic19	employment, division, grant, health, community, water, advance, routes, conservation, engaging, opportunity, collaborations, vision, manager, administration, completion, experts, ridership, covid, plain, water_resource, expected, long, steadily, land, plans, facility, flood, sustainable, pandemic **(NC)**
Topic21	facilities, network, region, projects, existing, proposed, communities, planned, construction, long_term, plan, maintain, facility, major, destinations, development, trails, connections, enhance, roadway, resources, maintenance, sidewalks, infrastructure, bicycle, quality_life, provide, improving, condition, sidewalk **(MO)**
Topic31	education, air_quality, community, resources, efforts, environmental, grant, plan, air, partners, university, development, program, wide, engagement, local, epa, educational, technology, project, task_force, percentage, months, limited, proficiency, minority, identify, improvement, implement, stakeholder **(AQ)**

Iowa City (25)

Topic5	routes, access, safety, safe, transit, system, provide, improve, bicycle, transportation, school, enhance, people, users, principle, travel, accessible, route, quality_life, public, opportunity, efficiency, alternative, essential, designed, options, healthy, active, increase, direct **(QL)**
Topic16	opportunities, times, program, air, emissions, fuel, environment, reduce_travel, consumption, natural, riders, people, resources, impacts, young, demand, ride, learn, gas, fuels, provide, popular, climate_change, pollution, social, delay, vehicles, clean, long, role **(AQ)**

Omaha (35)

Topic10	air, home, base, accessed, lanes, air_quality, lane, impact, levels, truck, air_force, little_steps, cargo, strategy, images, photo, real, pictometry, round_responses, ozone, aux, emissions, lead, estate, cleaner, insurance, basic, finance, sign, full **(AQ)**
Topic17	access, safety, accessibility, reliability, travel, travel_time, measure, intersections, improve, pedestrian, design, mobility, safe, issues, neighborhood, quality, freight, intersection, reduce, truck, level, traffic, corridors, connectivity, equitable, environment, standards, movement, ways, enhance **(EA)**
Topic24	accessible, comfortable, pedestrian, intersections, routes, safe, walking, sidewalks, bike, engaging, environment, safety, national, people, designed, accommodations, park, users, cyclists, average, pedestrians, provide, environments, trails, sidewalk, confident, feel, comfort, citizens, signed **(MO)**
Topic25	people, transportation, residents, transit, walking, options, cycling, region, quality_life, cost, investments, trips, driving, infrastructure, move, survey, individual, services, roads, improve, frontage, life, focusing, moving, walking_biking, living, vehicles, means, reasons, ability **(QL)**

Sioux City (35)

Topic2	gateway_airport, airport, flights, service, vehicles, airlines, commercial, kansas, area, electric, large, continue, frontier, communities, market, airports, daily, route, airline, energy, federal, number, order, battery, benefit, operate, services, electric_buses, early, connections **(AF)**
Topic13	water, highest, flood, approach, rails, historic, waste, flooding, control, runoff, reached, numbers, repair, avoid, cyclone, mitigate, impacts, storm, improved, stormwater, lowest, strategies, bomb, level, recorded, surface, run, amount, result, implementing **(WQ)**
Topic15	charging, electric, locations, drivers, navigation, businesses, serve, stations, station, wheelchair, video, older, administrator, partners, laid, visitors, walkability, atokad, steps, uber, lyft, conference, telephone, implementation, department, confluence, fueling, young, discussion, installed **(MO)**
Topic22	income, environmental, air_quality, populations, area, lower, natural, areas, improve, mobility, agency, mode, disabilities, energy, federal, capacity, reliability, human, quality, elderly, efficiency, department, attainment, individuals, effects, disabled, committee, increased, determine, reduce **(AQ)**
Topic29	flooding, water, high, engineers, basin, record, due, conditions, army, weather, runoff, events, corps, historic, barge, levels, remained, led, experienced, traffic, cold, wet, soils, keeping, flooded, impossible, streams, amounts, levee, remainder **(WQ)**
Topic31	fuel, natural, cng, gas, diesel, fueling, multiple, potential, system, budget, technology, change, systems, alternative, units, based, automated, compressed, increase, impacts, busses, driving, sands, seals, epoxy, chip, actual, viable, economically, ride **(AF)**

Waterloo (26)

Topic11	transportation, project, environmental, federal, policy, projects, planning, local, fhwa, potential, fast, document, process, safety, resources, included, public, agencies, updated, natural, lrtp, development, environment, department, impact, national, land_use, region, required, historic **(EA)**
Topic22	miles, locations, candidate, company, railroad, location, ethanol, pipeline, active, corn, shipments, grains, large, vehicle, materials, railway, plants, hazardous, sicl, billion, cereal, conservation, intersections, priority, primary, message, directly, farmland, agriculture, dynamic **(AF)**

Table B.3

Latent Topics - Minnesota MPOs

Duluth (24)

Topic1	lrtp, information, share, overview, meetings, public, data, included, stakeholder, survey, purpose, vision_goals, feedback, sustainable, transportation, lrtp_committee, final, plan, input, provided, aspects, moving_people, opportunity, presented, primary, screen, time, discussed, project, consultations **(SR)**
Topic2	multimodal, system, transportation, safe, pedestrian, bus, efficient, transit, options, creating, community, school, people, network, design, place, infrastructure, region, provide, routes, alternatives, sustainable, transport, supports, rail, investment, integrated, means, manner, encourage **(MO)**
Topic5	people, travel, survey, health, environment, responses, choices, priorities, goal, participants, mode, look_like, public, freight, transportation, asked, support, selected, options, primary, acs, identified, provide, community, results, neighborhoods, open, modes, factors, barriers **(MO)**
Topic8	trip, trips, lanes, home_based, model, work, attractions, reduce, walk, home, school, lane, trip_generation, pollution, number, attraction, trip_purposes, auto, vehicle, ends, end, production, shopping, single, geo_id, trip_purpose, length, left_turn, air_emissions, average **(AQ)**
Topic15	transportation, projects, options, plans, area, choices, public, system, jurisdictions, related, improve, issues, safety, additional, issues_impacted, ensure, planning, include, provide, community, incomes, environment, agencies, future, pedestrians, modal, related_access, local, people_ages, security **(EA)**
Topic20	looking_ahead, existing_area, employment, area, product, type, economic, gross_regional, data, public_health, tourism, health, environmental, housing, cultural, school, efficiency, suburban, college, travel, historical, office, representative, education, promote, enrollment, neighborhood, preservation, productivity, decisions **(QL)**
Topic21	major, projects, planning, transportation, cost, future, bridge, project, address, past, plan, time, addressed, sustainable, study, development, ports, issue, change, high, identified, timeframe, factor, travel, car, scope, happen, bong_bridge, due, approaches **(SR)**

Mankato (37)

Topic6	project, ensure, impacts, federal, local, ada, community, ramps, transportation, stakeholders, species, policies, consideration, environmental, pedestrians, opportunities, threatened, endangered, next_steps, laws, mitigate, partners, pedestrian, potential, public, executive, communities, sidewalk_gaps, push, processes **(NE)**
Topic15	transit, balance, urban, areas, rural, provide, regional, safety, region, access, traffic, vehicles, service, options, routes, users, due, public, airport, bus, bus_stops, land, connectivity, air, mobility, network, limited, ridership, existing, freight **(MO)**
Topic16	projects, environmental, local, development, preservation, growth, plan, project, agencies, roadway, improvements, timeframe, maintenance, estimated, policy, review, row, planned, future, meetings, planning, illustrative, operating, center, patterns, risk, economic, forecasted, documentation, transit **(EA)**
Topic33	plan, transportation, implementation, future, projects, project, identified, planning, targets, transit, regional, vision, area, goals, safety, system, performance, freight, improve, investments, life, environmental, long_term, multimodal, public, development, conservation, guidelines, health, promote **(NC)**

Minneapolis (36)

Topic1 emissions, transportation, impacts, reduce, air, related, greenhouse_gas, mitigation, health, construction, benefits, environmental, climate, reducing, natural, energy, noise, climate_change, communities, operations, sustainability, avoid, quality, regional, potential, environment, impact, mitigate, protect, cost **(CC)**

Topic8 federal, area, region, requirements, transportation, guidance, maintenance, standards, program, environmental, adopted, agency, administration, planning, epa, air_quality, compliance, policy, requires, authority, implemented, legislation, carbon_monoxide, regulatory, fhwa, thrive, government, designated, quality, attainment **(AQ)**

Topic16 plan, highway, strategies, overview, preservation, investment, outcomes, system, transportation, goals, equity, objectives, transit, includes, aviation, thrive, investments, freight, long_range, performance, bike_ped, region, plan_amendment, identifies, actions, discussed, air_quality, specific, environment, strategy **(EJ)**

Topic24 projects, plan, transportation, required, project, regional, analysis, air_quality, information, implementation, process, emissions, included, exempt, completed, listed, federal, evaluation, conformity_rule, federal_law, fast, improvement, modeling, law, performance, applicable, area, prepare, section, annual **(AQ)**

Topic26 air, freight, service, region, federal, corridors, airlines, commercial, time, pounds, goods, international, nitrogen, cargo, critical_urban, ppb, infrastructure, passenger, long, providers, airports, ozone, hour, operational, precision, aircraft, hub, shipped, companies, critical_rural **(AQ)**

Topic35 pedestrian, units_per, acre, features, environment, design, provide, parking, safe, accessibility, bicycle, connections, facilities, experience, accessible, transit, create, information, pedestrians, creating, communities, users, friendly, improve, shared, providing, active, include, shelter, secure **(MO)**

Rochester (34)

Topic7 technology, vehicles, systems, infrastructure, future_trends, signal, vehicle, information, avs, cavs, communications, data, control, connected, traffic, needed, installation, emergency, benefits, engineering, operations, place, electric, country, applications, communication, automated, replacement, cav, hardware **(TE)**

Topic10 bike, lanes, parking, pedestrians, users, bicyclists, sidewalks, bikes, cross, center, ride, cyclists, shared, space, facilities, traffic, scooters, downtown, roadway, ped_bike, add, people, trails, travel, bicycle, shoulder, electric, riding, route, safe **(MO)**

Topic19 project, environmental, resources, development, resource, impact, natural, corridor, environment, protection, regulatory, features, areas, early, work, preservation, planning, federal, design, assessment, agencies, impacts, minimize, risk, agency, management, consideration, review, phase, built **(NC)**

Topic21 safety, education, enforcement, issues, efforts, reduce, concerns, related, driving, community, environmental, events, representative, local, initiatives, solutions, traffic, targeted, awareness, encouragement, measures, address, carbon, natural, response, safe, bicyclists, flooding, funding, creating **(EA)**

Topic23 system, transportation, improve, safety, users, efficiency, reliability, existing, improving, impacts, addresses, travel, enhance, economic, emerging, performance, technologies, promote, environment, accessibility, time, modes, reliable, efficient, potential, security, outcomes, travel_options, mobility, connectivity **(MO)**

St. Cloud (21)

Topic2 number, percent, vehicles, miles, vehicle, average, vehicle_miles, tax, vehicle_revenue, annual, traveled, service, range, level, evs, electric, car, revenue, spent, divided, fuel, cng, miles_traveled, gas, income, single, charging, roads, trips, person **(AF)**

Topic4 water_quality, water, standards, construction, resources, reduce, stormwater, pollution, air, watershed, drinking_water, air_quality, environment, agency, program, floodplain, impacts, wetland, epa, requirements, practices, percent, management, surface_water, protection, control, groundwater, include, pollutants, areas **(EA)**

Topic5 safety, goal_maintain, based_tdm, build_corridor, transportation, living, museum, fema_history, increase, cost, basin, communities, encourage, active, capacity, opportunities, health, healthy, central, residents, promote, free, benefits, driving, wetland, issues, users, feedback, older, high **(QL)**

Topic12 conservation, goal_promote, environment, communities, impacts, environmental, opportunity, species, health, natural, native, intersection, native_plant, wetland, rare, populations, include, resources, definition, types, promote_energy, asian, complaint, activities, rural, areas, designed, impact, mitigation, economic **(NC)**

Topic16 development, water, goal_support, areas, sources, systems, rural, waters, public, resources, drainage, bridge, projects, section, fix, roads, due, highway, water_quality, urban, factors, high, permit, community, resource, designed, runoff, natural, pavement, habitat **(WQ)**

Table B.4

Latent Topics - North Dakota MPOs

Bismarck (35)	
Topic7	system, transportation, freight, safety, reliability, transit, goal, security, increase, maintain, enhance, safe, efficient, environment, current, area, targets, mobility, goals, modes_people, efficiency, department, connected, non_interstate, motorized, people_freight, goods, autonomous, route, modes **(MO)**
Topic15	transportation, performance, objectives, plan, areas, projects, targets, arrive, system, identified, range, impacts, vision_goals, future, investments, address, systems, development, funding, based, goals, security, environmental, network, support, critical, local, strategies, evaluate, scenarios **(EA)**
Topic21	shown, analysis, impacts_average, daily_traffic, transportation, life, improvements, promote, factor, conservation, consistency, improve_quality, planning, ultimately, creates, services, human, require, engineering, effectively, asset, promote_energy, bypass, natural, vehicles, additional, attracting, technology, programming, caused **(NC)**

Fargo (37)	
Topic8	vehicle, technology, vehicles, driving, connected, infrastructure, level, cavs, require, users, smart, driver, cav, drivers, buses, trucks, freight, collision, automated, communication, resilient, autonomous, communicate, natural, environment, enabled, automobiles, mobile, full, called **(TE)**
Topic10	electric, parking, cost, study, access, vehicles, scooters, vehicle, space, operating, car, apply, curb, dockless, price, mobility, prepare, multiple, reuse, commercial, powered, transport, programs, battery, larger, micro, purposes, establishing, owning, conversion **(AF)**
Topic13	development, corridors, land_use, parking, transit, urban, areas, density, access, land, intersection, traffic, residential, neighborhoods, work, environment, promote, reduce, corridor, supportive, locations, mobility, growth, create, types, cavs, starting, commercial, reduced, demand **(MO)**
Topic18	study_area, historic, resources, species, section, cultural, listed, areas, habitat, construction, environmental, required, coordination, historical, present, potential, occurring, wetland, intended, regulated, long, properties, endangered, skipper, identifies, eared, resource, include, wildlife, esa **(NE)**
Topic29	network, improve, travel, enhance, grid, transportation, promote, bicyclists, smart, land, pedestrians, people, rights, data, connectivity, conservation, fund, limitations, energy, environment, civil, regulation, amenities, destinations, complete, pattern, companies, assist, tier, arterials **(QL)**

Grand Forks (27)	
Topic10	goal, transportation, safety, quality_life, reliability, objective, area, system, motorized_non, motorized, travel_time, targets, increase, center, performance, security, meeting, results, entrance, tourism, index, motorized_uses, environment, enhance, health, mobility, desired, livability, prior, plan **(QL)**
Topic17	freight, percent, urban, rail, population, traveled, local, region, transportation, system, vehicle_miles, traffic, highways, regional, access, critical, commercial, vmt, emissions, movement, truck, movements, routes, centers, vehicle, rural, railroad, heavy, spacing, trucks **(AQ)**
Topic25	pedestrian, transportation, network, barriers, bicycle, system, communities, activities, users, user, travel, modes, bicyclist, access, mobility, children, directness, direct, perceived, factors, gaps, reasons, pedestrians, safety, environment, trips, facilities, security, people, ability **(MO)**

Table B.5

Latent Topics - South Dakota MPOs

Rapid City (34)	
Topic14	bicyclists, ride, riding, cyclists, traffic, areas, pedestrians, people, motorists, bicycling, safe, riders, experience, safety, bicycle, walking, air, income, potential, sidewalk, increase, difficult, education, lack, sidewalks, wrong_way, awareness, types, path, environment **(MO)**
Topic17	trips, bicycle, pedestrian, future, results, demand_model, benefits, daily, existing, increase, current, area, cost, vehicle_trips, air_quality, estimate, analysis, purpose, potential, weekday, period, based, number, vmt_reduction, assumptions, model, hour, acs, mode_split, demand **(AQ)**

Sioux Falls (30)	
Topic2	vehicles, shared_use, people, devices, transportation, bicycles, modes, center, bike, freight, drivers, services, information, resources, mobility, cars, bikes, existing, powered, vehicle_fleet, shared, route, environment, citizens, commercial, users, project, motorists, senses, portion **(MO)**
Topic10	tax, transportation, transit, system, electric, role, automated, public, work, future, play, national_gas, case_vehicles, money, areas, ride, people, space, ride_sourcing, demand, revenue, bus, school, minor, trips, shared, revenues, establish, travel, support **(MO)**
Topic16	vehicle, connected, devices, infrastructure, communicate, traffic, signals, monitor, equipped, technologies, network, poles, smart_light, fuel, technology, energy, sensors, activity, taxes, smart_traffic, parking, emissions, electric, signal, intersections, sales, real_time, phase, conditions **(TE)**
Topic25	funding, transportation, maturity_level, grant, agency, opportunities, challenges, projects, options, future, corridors, category, current, federal, national, preparedness, environment, major, signed, build, recommended, america, surface, direct, driven, identify, specific, identified, goals, rails_trails **(EA)**

Table B.6

Latent Topics - Wisconsin MPOs

Appleton (35)	
Topic15	improve, health, healthy, access, opportunities, communities, residents, strategy, community, transportation, support, adults, food, obesity, environment, physical, built, social, recreation, levels, mental, active_living, safe, goal, related, priority, wellness, obese, reducing, days **(QL)**
Topic20	transportation, system, highway, transit, safety, land_use, national, freight, federal, administration, existing, environmental, preservation, motorized, network, policy, develop, department, motorized_non, fta, database, fhwa, identify, monitor, public, trucks, rail, systems, data, security **(EA)**
Topic22	transportation, public, planning, health, process, environmental, fast, include, input, air_pollution, data, surface, system, particulate, review, users, matter, fixing, plan, long_range, premature, equity, provide, mitigation, death, emphasis, factors, impacts, federal, institutional **(AQ)**
Topic23	traffic, crashes, fatalities, bicyclists, pedestrians, non_motorized, lights, design, injuries, number, complete, public, include, transportation, users, motor_vehicle, motorized, improve, increase, infrastructure, facilities, air_quality, related, long, roadways, laws, motorist, health, roadway, intersections **(MO)**
Topic28	program, planning, income, per_less, minority, workers_earning, lost, displays, age, environmental, life, limited, schools, population, participation, populations, choices, event, percent, continues, fast, executive, potential, answer, time, chart, justice, factor, horizon, economic **(EJ)**
Topic32	transportation, system, promote, network, improve, performance, strategies, safety, management, modes, efficient, preserve, safe, enhance, policies, active, congestion, reduce, lrtp, energy, investment, efficiency, people, quality_life, recommendations, region, future, conservation, provide, reliability **(QL)**

Beloit (33)	
Topic6	fast, injuries, reduce, environment, number, fatalities, travel_speeds, observed, serious_minor, resiliency, natural, improve, result, system, impact, quality, preserve, crashes, reducing, area, resources, protect, includes, non_motorized, question, infrastructure, protecting, serious_injury, concept, stormwater **(SR)**
Topic13	future, vehicles, region, service, development, plan, technologies, respondents, technology, term, focus, vehicle, connected, decisions, scooters, promote, describe, cranston, current, vision, investments, desire, compact, additional, change, includes, electric, existing, passenger_rail, urban **(TE)**
Topic14	bike_lane, improve_extend, impacts, covid, pandemic, significant, useful_life, potential, region, populations, environmental, significantly, travel_patterns, minimum, long_term, created, reflects, follow, tables, fta, due, engineering, potentially, conditions, face, effects, utilities, house, facility, determine **(EA)**

Eau Claire (40)

Topic1	bicycle, travel, improvements, safety, system, pedestrian, improve, safe, trails, include, route, network, lanes, recommendations, facilities, quality_life, bicyclists, barriers, improving, enhance, bike_lanes, rural, ramp, modes, provide, proposed, bicycling, constructed, shared, roads **(MO)**
Topic7	large, survey, results, areas, lower, avoid, wetland, significant, human, minimize, direction, increases, daily, health, adverse, commuting, close, wages, average_annual, scientific, proximity, distance, sustainable, patterns, presence, groups, closer, joan, commutes, ear **(QL)**
Topic8	crashes, reduce, brackett, intersections, due, crash, analysis, number_crashes, traffic, research, techniques, number, data, frontage, air_pollution, corridor, modeling, severity, combined, noise, zone, application, covid, capabilities, period, helped, hastings, combination, extremely, impact **(AQ)**
Topic13	economic, development, area, environmental, communities, community, social, resources, impact, impacts, additional, gas, considered, financial, protection, global, urban, director, change, greenhouse, negative, term, long_term, effects, environment, downtown, populations, support, tax, emissions **(CC)**
Topic15	areas, area, natural, modes, transportation, respondents, asked, resources, endangered, questions, include, open, resource, identified, specifically, valuable, wildlife, mapped, recreation, spaces, public_survey, historic, projects, participants, communities, cultural, designated, survey, recreational, applicable **(NE)**
Topic22	characteristics, socio_economic, facility, measures, standards, intermodal, traffic_control, making, decision, modal, rule, consistent, control, ordinance, operational, air_quality, drivers, national, approaches, roundabouts, approved, zoning, rail_lines, establishes, referred, type, recipients, home, changing, slope **(AQ)**
Topic23	areas, water, identified, stream, development, flood, include, features, groundwater, capacity, limiting, actions, provide, shorelands, reduction, steep_slopes, amendments, reduce, floodplain, surface, physical, sewered, pollution, identification, floodplains, soils, recharge, result, quality, definition **(WQ)**
Topic26	planning, project, environmental, level, policy, mitigation, regulations, nepa, process, agencies, system, analysis, design, issues, municipalities, factors, assistance, federal, project_level, high, national, section, priority, preservation, programming, required, approach, stage, protection, efforts **(NE)**
Topic28	area, number, emissions, options, reducing, businesses, rail, professionals, companies, major, young, environment, factor, create, retain, noise_pollution, automotive, parts, type, jobs, engine, corridors, direct, separation, slowing, campaigns, recommends, management, bottom, joles **(EA)**
Topic36	impact, implementation, policies, environmental, actions, potential, programs, impacts, effects, ensure, communities, activities, developed, airport, engineers, mitigation, mitigate, mission, drivers, maintain, potentially, hope, minimizing, carpooling, negative, tenets, ridesharing, promote, negatively, discussion **(MO)**

Fond du Lac (33)

Topic7	environmental, monitor, mitigation, srts, regional, infrastructure, design, participation, school, activities, ratings, justice, local, data, trails, rail, productivity, quality, system, innovative, database, installation, identify, enhancing, capabilities, events, residents, programs, natural, principles **(EA)**
Topic10	vehicle, miles, access, households, employed, mile, living, facility, area, communities, selection, healthcare, facilities, rural, areas, national, environment, traveled, equitable, destinations, average, community, providing, medicine, walking, planned, funds, affected, fatalities, exercise **(EJ)**
Topic19	transportation, planning, projects, system, process, public, improve, plan, services, reliable, local, recommendations, health, conservation, include, implement, illustrative, candidate, future, providing, urbanized_area, environmental, regional, provide, individual, implementation, efforts, confidence, developing, enhance **(NC)**
Topic24	transportation, long_range, system, plan_conditions, freight, motorized, modes, mobility, increase, motorized_non, users, planning, safety, tourism, movement, statistics, research, plan, plan_priorities, spooner, factors, medford, accessibility, enhance, million, people, network, integration, carbon, capabilities **(MO)**
Topic26	health, health_rankings, system, data, transportation, factors, goal, social, populations, improve, policy, effects, long, advisory, committee, technical, rankings, income, reduce, reliability, provide, shaping, displays, increase, health_outcomes, environment, recommendations, environmental, natural, mitigate **(QL)**
Topic31	number, transportation, crashes, motorized, long, tip_project, commute, travel, workers, mode_share, work, area, displays, days, average, active, utilities, open, infrastructure, recreation, planning, fatalities, health, chip, industry_class, air_quality, reported, vehicles, amount, increase **(AQ)**

Green Bay (39)	
Topic4	pedestrian, path, crosswalks, crossings, driveway, intersections, access, employment, exist, drivers, sidepath, traffic, curb_cuts, environmental, points, analysis, training, close_parallel, constraints, opportunities, physical, yield, social, education, segment, paths, visible, intersecting, pedestrians, close **(EA)**
Topic16	purposes, projects, offices_used, populations, minority_income, major, impacts, highway, ladders, transportation, built, affect, approach, effects, negatively, addition, identify, tip, opportunity, project, significant, committee, tcc, environmental, human, mitigation, determine, protected, policies, studied **(EJ)**
Topic21	features, parking, general_budget, environmentally, hyperloop, routine, summarized, significant, trees, avoid, alternative, amount, situations, air, minimal, setbacks, friendly, cargo, costs, buildings, passenger, direct, sections, employee, tubes, visibility, distances, approaches, freight, completion **(TE)**
Topic31	transportation, system, area, disabilities, enhance, air, facilities, mobility, water, improve, quality, future, program, expand, rail, increase, seniors_people, options, travel, maintain, existing, services, cars, access, security, green, enhanced, impact, tourism, opportunities **(MO)**

Janesville (30)	
Topic12	areas, area, development, land, recreational, industrial, transit, land_uses, residential, access, public, activity, outdoor, urban, transportation, community, facilities, growth, family, commercial, provide, agricultural, historical, density, recreation, social, objective, natural, housing, variety **(NC)**
Topic22	transportation, system, safety, infrastructure, improvements, environment, improve, existing, users, systems, network, multimodal, increase, develop, strategies, design, promote, security, transit, climate_change, impacts, speeds, health, pedestrian, facility, roadways, mph, identify, recommendations, limits **(MO)**
Topic28	data, events, precipitation, climate, increase, frequency, annual, water, flood, increased, census, days, gage_height, streamflow, survey, temperature, amount, daily, fhwa, average, climate_change, national, household, rain, fifty, wicci, heavy, travel_survey, nhts, number_days **(CC)**

La Crosse (39)	
Topic1	vehicles, electric, bus, service, include, feasible, alternative, curb, purchase, resulting, diesel, buses, fleet, transitioning, engineers, fuel, significant, schedule, army, needed, policies, limited, green, modifications, older, ward, infrastructure, corps, rider, wheelchair **(MO)**
Topic6	bridge, travel, main, route, salem, highway, incidents, improve, sidewalk, rail_accidents, environment, wide, path, long, quality_life, corridor, black, bridges, pedestrian, wheel, rehabilitation, connecting, conservation, green, promote, paths, coulee, railroad, enhance, shoulder **(QL)**
Topic13	planning, area, strategies, committee, identify, areas, corridors, community, natural, expansion, organization, effective, corridor, jurisdiction, urbanized_area, existing, amtrak, tac, wildlife, include, considers, works, advisory, roadways, thing, locally, habitat, long_distance, competitiveness, change **(NC)**
Topic28	agencies, finances_report, environmental, department, protection, citation, resource, service, consultation, land, federal, responsible, gas, contacts, emissions, management, compliance, wildlife, agriculture, regulatory, local, deadline, revenue, natural, levels, agency, district, separation, employers, waterways **(EA)**

Madison (40)	
Topic1	recommendations, needs_analysis, project_policy, security, health, personal, sense, region, time, financial, community, due, future, life, lack, expanded, ladder, factors, personally, places, fare, steve, linked, quality_life, implemented, representing, schedule, social, air_quality, access_nature **(QL)**
Topic33	impacts, environmental, resources, project, areas, potential, features, roadway, screening, information, natural, projects, conducted, inventory, analysis, open, resource, provide, system, corridor, study, impact, significant, location, considered, locations, design, water, minimize, nepa **(NE)**
Topic37	environmental, lands, sites, agricultural, land, areas, soils, site, happy, adjacent, department, protection, historic, conservation, based, historical, database, ratings, resources, developed, resource, created, water, system, assessment, land_evaluation, steep_slopes, preservation, rec, agriculture **(NC)**
Topic38	people, community, work, number, region, living, bicycle, trips, residents, quality_life, school, options, workers, walking, population, programs, communities, increasing, users, bike, commuting, direction, transportation, continue, live, children, things, improve_equity, percentage, area **(MO)**
Topic39	roadway, regional, system, address, potential, due, bottlenecks, scores, technology, physical, capacity, issues, active_living, index, time, transit, solve, attributes, autonomous, benefits, delivery, difficult, expand, region, vehicle, consistent, process, critical, quality_life, corridors **(TE)**

Milwaukee (28)	
Topic1	bicycle, bike, stations, neighborhood, scooters, sidewalks, electric, large_lot, paths, pilot, pedestrian, plan, impacted, completed, designated, standard, showing_lots, study, transition, major, accessibility, freeway_system, ada, primarily, connections, dockless, provide, reconstruction, vehicle, hour_ozone **(MO)**
Topic3	transportation, impacts, cost, related, potential, areas, truck, revenue, drivers, stormwater, resources, impact, environmental, rail, requirements, major, water, negatively, higher, development, due, future, recommendation, result, emissions, region, study, reduce, vehicles, businesses **(AQ)**
Topic10	reduce, transit, services, shared, encourage, access, transportation, alternatives, vehicles, alternative, car, users, energy, region, facilities, provide, medical, green, objective, modes, routes, support, automobiles, residents, fuel, sharing, economy, safe, flexible, buses **(AF)**
Topic20	equity, related, public_health, greatest, safety, identified, transportation, benefits, concerns, impacts, access, region, extension, strategies, quality, questions, concern, water, planning, health, question, mobility, sustainability, food, impact, responses, risks, effects, education, respondents **(EJ)**

Oshkosh (22)	
Topic6	transportation, system, public, green, management, complete, people, plan, participation, policy, efficient, motorized, users, provide, promote, active, freight, safe, process, opportunities, motorized_non, acres, safety, committee, increase, means, space, region, movement, modes **(MO)**
Topic16	land_use, area, policies, economic, infrastructure, future, transportation, workers, promote, development, support, enhance, tourism, living, industry_class, age, proposed, travel, employed, selection, patterns, utilities, remain, environmental, mode_share, demands, quality_life, mixed, commute, improve **(QL)**
Topic21	traffic, crashes, motor_vehicle, safety, public, fatalities, non_motorized, highway, prevention, health, lights, air_quality, injury, disease, number, national, related, bicyclists, reduce, air_pollution, death, chronic, improve, injuries, increase, premature, improves, reducing, center, schedule **(AQ)**
Topic22	access, income, population, vehicle, food, limited, household, households, urbanized_area, projections, minority, populations, housing, displays, environmental, residents, matter, average, national, healthcare, miles, increase, connected, individuals, data, farmers, expected, car, transportation, justice **(EJ)**

Sheboygan (21)	
Topic1	area, diesel, gasoline, objective, network, truck, planning_area, ethanol, passenger_car, passenger_truck, transit_bus, refuse_truck, motor_home, school_bus, mph, municipality, auto, type, miles, motorcycle, cng, railroad, per_vehicle, hydrology, passenger, intercity_bus, highway_lower, boundary, highway, revenue **(AF)**
Topic3	plan, projects, transportation, impacts, environmental, project, major, area, approved, level, impact, recommended, planning, natural, resources, analysis, planning_area, potential, species, included, original, elements, process, reviewed, updated, include, joint_meeting, recommendations, tip, proposed **(EA)**
Topic8	information, emissions, data, hour_ozone, attainment_plan, air_management, transportation, railroad, percent_workers, national, system, database, worked, budgets, resources, established, commodity_flow, implementation, conformity, lived, range, plan, census, motor_vehicle, forecast, compounds, budget, latest, model, ihs_transearch **(AQ)**
Topic21	plan, development, transportation, planning_area, transit, projects, future, implementation, planning, air_quality, travel_demand, model, process, tip, long_range, analysis, conformity, forecast_model, land_use, data, performance, range, forecast, horizon, included, made, federal, tazs, trends, scenarios **(AQ)**

Wausau (39)	
Topic15	national, information, provide, environmental, policy, reasonable, providing, resources, participation, complete, include, limited, assistance, basis, social, discrimination, receiving, ensure, origin, impacts, adult, timely, access, opportunities, services, local, stakeholders, consultation, adopting, college **(EJ)**
Topic17	bicyclists, users, traffic, children, motorists, safely, education, enforcement, drivers, interact, skills, rules, continue, safety, disabled, knowledge, environment, role, disabilities, car, elderly, share, typically, driver, neighborhood, people, teaching, adults, transportation, properly **(MO)**
Topic19	federal, level, planning, requirements, environmental, strategies, federal_highway, mitigation, place, regulations, administration, document, advisory, transit, strategy, legislation, project, required, livability, agency, analysis, review, purpose, consultation, plan, related, organizations, developing, highway, develop **(EA)**

APPENDIX C: COSINE SIMILARITY TEST RESULTS

Table C.1

Cosine Similarity - All States

	IA	IL	MN	ND	SD	WI
IA	1.00	0.88	0.82	0.71	0.81	0.83
IL	0.88	1.00	0.80	0.67	0.77	0.84
MN	0.82	0.80	1.00	0.60	0.68	0.78
ND	0.71	0.67	0.60	1.00	0.67	0.64
SD	0.81	0.77	0.68	0.67	1.00	0.72
WI	0.83	0.84	0.78	0.64	0.72	1.00

Table C.2

Cosine Similarity - Dakotas

	Bismarck	Fargo	Grand Forks	Rapid City	Sioux Falls
Bismarck	1.00	0.59	0.45	0.48	0.54
Fargo	0.59	1.00	0.42	0.51	0.54
Grand Forks	0.45	0.42	1.00	0.52	0.43
Rapid City	0.48	0.51	0.52	1.00	0.54
Sioux Falls	0.54	0.54	0.43	0.54	1.00

Table C.3

Cosine Similarity - Illinois

	Bloomington	Chicago	Danville	Decatur	Kankakee	Marion	Peoria	Rockford	Springfield	Urbana
Bloomington	1.00	0.46	0.65	0.50	0.54	0.60	0.56	0.68	0.47	0.43
Chicago	0.46	1.00	0.47	0.43	0.44	0.47	0.43	0.57	0.39	0.40
Danville	0.65	0.47	1.00	0.55	0.54	0.62	0.55	0.68	0.49	0.45
Decatur	0.50	0.43	0.55	1.00	0.49	0.54	0.46	0.53	0.45	0.39
Kankakee	0.54	0.44	0.54	0.49	1.00	0.55	0.50	0.56	0.46	0.40
Marion	0.60	0.47	0.62	0.54	0.55	1.00	0.54	0.63	0.49	0.41
Peoria	0.56	0.43	0.55	0.46	0.50	0.54	1.00	0.58	0.49	0.41
Rockford	0.68	0.57	0.68	0.53	0.56	0.63	0.58	1.00	0.46	0.43
Springfield	0.47	0.39	0.49	0.45	0.46	0.49	0.49	0.46	1.00	0.45
Urbana	0.43	0.40	0.45	0.39	0.40	0.41	0.41	0.43	0.45	1.00

Table C.4

Cosine Similarity - Iowa

	Ames	Cedar Rapids	Davenport	Des Moines	Dubuque	Iowa City	Omaha	Sioux City	Waterloo
Ames	1.00	0.60	0.50	0.58	0.52	0.39	0.52	0.51	0.66
Cedar Rapids	0.60	1.00	0.53	0.61	0.66	0.46	0.56	0.49	0.68
Davenport	0.50	0.53	1.00	0.57	0.48	0.39	0.54	0.44	0.62
Des Moines	0.58	0.61	0.57	1.00	0.53	0.54	0.65	0.50	0.68
Dubuque	0.52	0.66	0.48	0.53	1.00	0.39	0.51	0.45	0.59
Iowa City	0.39	0.46	0.39	0.54	0.39	1.00	0.44	0.36	0.48
Omaha	0.52	0.56	0.54	0.65	0.51	0.44	1.00	0.45	0.59
Sioux City	0.51	0.49	0.44	0.50	0.45	0.36	0.45	1.00	0.60
Waterloo	0.66	0.68	0.62	0.68	0.59	0.48	0.59	0.60	1.00

Table C.5

Cosine Similarity - Minnesota

	Duluth	Mankato	Minneapolis	Rochester	St Cloud
Duluth	1.00	0.36	0.52	0.55	0.50
Mankato	0.36	1.00	0.40	0.43	0.40
Minneapolis	0.52	0.40	1.00	0.72	0.57
Rochester	0.55	0.43	0.72	1.00	0.58
St Cloud	0.50	0.40	0.57	0.58	1.00

Table C.6

Cosine Similarity - Wisconsin

	Appleton	Beloit	Eau Claire	Fond du Lac	Green Bay	Janesville	La Crosse	Madison	Milwaukee	Oshkosh	Sheboygan	Wausau
Appleton	1.00	0.44	0.38	0.74	0.47	0.44	0.47	0.38	0.33	0.81	0.44	0.45
Beloit	0.44	1.00	0.44	0.44	0.47	0.56	0.48	0.44	0.33	0.48	0.47	0.55
Eau Claire	0.38	0.44	1.00	0.38	0.44	0.44	0.43	0.39	0.26	0.42	0.39	0.48
Fond du Lac	0.74	0.44	0.38	1.00	0.46	0.42	0.47	0.38	0.32	0.80	0.44	0.44
Green Bay	0.47	0.47	0.44	0.46	1.00	0.51	0.48	0.44	0.39	0.50	0.50	0.56
Janesville	0.44	0.56	0.44	0.42	0.51	1.00	0.51	0.46	0.36	0.47	0.47	0.63
La Crosse	0.47	0.48	0.43	0.47	0.48	0.51	1.00	0.42	0.37	0.52	0.47	0.48
Madison	0.38	0.44	0.39	0.38	0.44	0.46	0.42	1.00	0.32	0.41	0.40	0.48
Milwaukee	0.33	0.33	0.26	0.32	0.39	0.36	0.37	0.32	1.00	0.35	0.31	0.33
Oshkosh	0.81	0.48	0.42	0.80	0.50	0.47	0.52	0.41	0.35	1.00	0.49	0.49
Sheboygan	0.44	0.47	0.39	0.44	0.50	0.47	0.47	0.40	0.31	0.49	1.00	0.48
Wausau	0.45	0.55	0.48	0.44	0.56	0.63	0.48	0.48	0.33	0.49	0.48	1.00

Table C.7

Cosine Similarity - Hi-Lo Density

	Ames	Bismarck	Chicago	Danville	Fargo	Iowa City	Madison	Omaha	Rapid City	Rochester
Ames	1.00	0.52	0.41	0.53	0.56	0.36	0.41	0.48	0.47	0.53
Bismarck	0.52	1.00	0.38	0.43	0.48	0.32	0.36	0.46	0.43	0.44
Chicago	0.41	0.38	1.00	0.42	0.40	0.27	0.37	0.52	0.42	0.45
Danville	0.53	0.43	0.42	1.00	0.47	0.37	0.44	0.51	0.45	0.53
Fargo	0.56	0.48	0.40	0.47	1.00	0.33	0.40	0.47	0.43	0.48
Iowa City	0.36	0.32	0.27	0.37	0.33	1.00	0.34	0.41	0.46	0.38
Madison	0.41	0.36	0.37	0.44	0.40	0.34	1.00	0.44	0.44	0.46
Omaha	0.48	0.46	0.52	0.51	0.47	0.41	0.44	1.00	0.56	0.52
Rapid City	0.47	0.43	0.42	0.45	0.43	0.46	0.44	0.56	1.00	0.49
Rochester	0.53	0.44	0.45	0.53	0.48	0.38	0.46	0.52	0.49	1.00

Table C.8

Cosine Similarity - Most Sustainable Cities

	Chicago	Des Moines	Madison	Milwaukee	Minneapolis	Omaha
Chicago	1.00	0.55	0.44	0.43	0.59	0.57
Des Moines	0.55	1.00	0.54	0.39	0.66	0.64
Madison	0.44	0.54	1.00	0.37	0.56	0.50
Milwaukee	0.43	0.39	0.37	1.00	0.44	0.39
Minneapolis	0.59	0.66	0.56	0.44	1.00	0.62
Omaha	0.57	0.64	0.50	0.39	0.62	1.00

APPENDIX D: AGREEMENT TO UTILIZE DANE COUNTY MODEL

AGREEMENT FOR AND RESTRICTIONS ON USE OF WisDOT TRAVEL DEMAND MODELS
Wisconsin Department of Transportation
DT1599 10/2022

WisDOT Traffic Forecasting
4822 Madison Yards Way, 6th Floor South
Madison, WI 53705
DOTTrafficForecasting@dot.wi.gov

DEREK HUNGNESS (GRADUATE STUDY at NDSU)

RESEARCH PROJECT NOT UNDER CONTRACT. Independent effort and data will not be used for official WisDOT forecasts, but rather for academic excercises.

I, **Derek Hungness** understand that the travel demand model and associated data supplied by the Wisconsin Department of Transportation (WisDOT), Bureau of Planning and Economic Development (BPED), Travel Forecasting Section are subject to the following restrictions as to the use of that travel demand model and associated data.

1. Under no circumstance shall the **Dane County** Travel Demand Model and associated data be redistributed unless prior approval is granted from the WisDOT/BPED/Travel Forecasting Section. This restriction includes, but is not limited to, the distribution of the entire or partial amount of the travel demand model and associated data to:
   - Wisconsin public agencies,
   - Public agencies outside of Wisconsin,
   - National associations,
   - Private industry organizations,
   - Research firms,
   - Consultants,
   - Or any other person.
2. Please attach a "Scope of Modeling Work" to the completed DT 1599. The scope should include a summary of intended changes to the requested TDM during work on the above-referenced project. The summary should be of sufficient detail to give TFS staff a clear understanding of the changes to be made, and include a timeline for completion of the work.
3. Any changes or revisions to the **Dane County** Travel Demand Model and associated data and results must be fully documented, and submitted to the WisDOT/BPED/Travel Forecasting Section at the conclusion of the modeling work for the above-referenced project. Specifically for network edits, please record any network edits as CUBE .log files, document the edits associated with each .log file, and include these items with the submittal.
4. The **Dane County** Travel Demand Model and associated data must be stored in a secure place.
5. Use of the **Dane County** Travel Demand Model and associated data is approved only for working with the **Research Project NOT** under contract to **Derek Hungness**. All **Dane County** Travel Demand Model files and associated data files shall be purged from any device following completion of the project.

The limitations on promulgation of the **Dane County** Travel Demand Model and associated data, as described above, are acceptable and agreed upon.

Name (First, MI, Last – Print) Derek J. Hungness	Name (First, MI, Last – Print) Miao Zhang
Title NA	Title Traffic Forecaster
Organization Graduate Study at NDSU	Organization WisDOT
X Derek Hungness (Signature) 11/23/22 (Date – mm/dd/yyyy)	X Miao Zhang (Signature) 04/21/2023 (Date – mm/dd/yyyy)

APPENDIX E: NOTES FROM WISDOT AND MPO REVIEW MEETINGS

The results of the AV model scenario work described in detail in Chapter 3 were presented to the Wisconsin Department of Transportation on August 31, 2023. The Department staff provided the following comments during the review:

- The regional travel demand model was applied correctly, and the AV scenario results appeared reasonable.
- Wisconsin's MPOs have not yet expressed a desire to model AVs, however, the Department has had one of its consultants investigate the requirements for such an application as part of a transportation facility planning study in Dane County.
- WisDOT provides model support for all MPOs except Southeastern Wisconsin Regional Planning Commission (Milwaukee). Future metrics of land development impact are based on Level of Service and Volume to Capacity ratios. Madison is the only MPO that has a bicycle and pedestrian network in their travel demand model.
- Budget limitations preclude additional analyses, however, with new census and household travel survey data arriving in the next couple years, the Department is considering options for additional model uses.
- The University of Wisconsin's Traffic Operations and Safety Laboratory is doing research work with CAVs, which might be helpful in updating the regional travel demand model's ability to forecast new mobility technology impacts.

The travel demand model results from Chapter 3 were presented to the Madison MPO staff on October 2, 2023. Based on the findings presented, four pivotal areas of continued research were collaboratively identified:

- As AVs emerge in the commercial market, it will be essential to use the Madison travel demand model to assess both small-scale and large-scale impacts of new technologies. Relying on "external stations" is not adequate for evaluating the appeal of driverless vehicles by commuters residing outside of Dane County. It stands to reason that as journeys become longer, the value of time spent inside a car might further shift, making these long-distance trips even more attractive.
- A significant limitation encountered was the absence of a mechanism to measure shifts in land development pressures with the advent of AVs. The MPO agreed this makes it challenging to comprehensively address one of Chapter 3's core research questions and warrants further consideration.
- The current model's inability to isolate and quantify effects based solely on AV user behavior hinders a deeper understanding of autonomous vehicle use patterns. Given this limitation, the MPO is contemplating creating AV specific trip parameters and adding them as a distinct mode within the model, like Bus Rapid Transit is included.
- A widely recognized limitation, not just by the Madison MPO but also by other modelers, is the lack of empirical data to quantify induced demand, making it very difficult to measure things like zero-person AV trips.

APPENDIX F: MPO SURVEY DOCUMENT

WISCONSIN LONG RANGE TRANSPORTATION PLANNING & CLIMATE ACTION SURVEY

Greetings Wisconsin MPO transportation planners!

I am conducting research as part of my Ph.D. program in Transportation Infrastructure and Capacity Planning regarding the connection between long range plans, travel demand modeling, and climate action. I am requesting your assistance by completing this short survey.

The purpose of the survey is to identify the key long-range transportation planning themes and methods related to climate action that are included in Wisconsin MPO transportation plans. The feedback obtained from this survey will provide crucial benchmarking data and promote knowledge sharing among the MPOs operating within the state.

Duration: Approximately 20-30 minutes
Confidentiality: Data will be aggregated and individual responses will not be identified.
Return Requested By: Friday, September 29, 2023

If you have any questions or desire further information about the survey and its use, please don't hesitate to reach out to me at xxxxx.xxxxxxxx@xxxx.xxx or at ###.###.####.

Name of Respondent:

Title:

Email:

Phone Number:

Question 1.

Does your MPO have an established policy to address climate change as it relates to the transportation system and its use? If yes, please briefly describe it in the comment area below.

Yes ☐

No ☐

Comments

1

Question 2.

Does your MPO use a long-range travel demand model (or related data) to specifically assess the impacts of climate change in your region? If yes, please briefly describe how in the comment area below.

Yes ☐

No ☐

Comments

Question 3.

What additional insights or applications would you like to have from your regional transportation demand model? Please select all that apply.

- ☐ Impacts of micromobility use (small-scale personal electric vehicles like scooters)
- ☐ Impacts of electric vehicle use
- ☐ Impacts of autonomous vehicle use
- ☐ Impacts of active transportation modes
- ☐ Other (please specify below)

Comments

Question 4.

What advisory structures does your MPO regularly use to synchronize land development, transportation infrastructure, and economic growth? Please select all that apply.

- ☐ Ad hoc task forces, subcommittees, or working groups
- ☐ MPO Bike and Pedestrian Advisory Committee
- ☐ MPO Technical Advisory Committee (TAC)
- ☐ MPO Citizens Advisory Committee (CAC)
- ☐ MPO Policy or Executive Board
- ☐ Regional Planning Commission (RPC) collaboration
- ☐ State agencies
- ☐ Direct engagement with municipal or county officials
- ☐ Grass roots advocacy groups
- ☐ Other (please specify below)

Comments

Question 5.

In your next LRTP update, which elements related to regional transportation sustainability will be emphasized? Please select all that apply.

- ☐ Promoting sustainable transportation modes and reduced reliance on automobiles
- ☐ Endorsing and adopting stronger sustainable regional transportation policies
- ☐ Creating new or improved sustainable infrastructure analysis and monitoring tools
- ☐ Other (please specify below)

Comments

Question 6.

How many full-time equivalent staff does your MPO employ?

☐ 1-2 ☐ 3-4 ☐ 5-6 ☐ 7-8 ☐ 9-10 ☐ More than 10

Question 7.

What is your current Long Range Transportation Plan base year?

Question 8.

What is your current Long Range Transportation Plan future or horizon year?

Question 9.

When is your next Long Range Transportation Plan update due?

Additional comments on Questions 6-9

4

Question 10.

Twelve themes are identified below which have been associated with land use, transportation system sustainability, and resiliency in Long Range Transportation Plans. For each theme, please indicate if it is present in your current Long Range Transportation Plan and to what extent. If not currently included, please indicate if you are considering it for inclusion in your next Plan update.

	Minimally included	Moderately included	Significantly included	Considering for future inclusion
Air Quality Improvement	☐	☐	☐	☐
Expanding Mobility Choices	☐	☐	☐	☐
Environmental Consciousness	☐	☐	☐	☐
Enhancing Quality of Life and Health	☐	☐	☐	☐
Infrastructure Resiliency & Sustainability	☐	☐	☐	☐
Natural Habitat Preservation	☐	☐	☐	☐
Adoption of Alternative Energies & Fuels	☐	☐	☐	☐
Environmental Equity & Justice	☐	☐	☐	☐
Technological Evolution in Transportation	☐	☐	☐	☐
Climate Change Mitigation & Adaptation	☐	☐	☐	☐
Water Quality & Runoff Management	☐	☐	☐	☐
Considerations Specific to NEPA	☐	☐	☐	☐

Comments

Question 11.

The list below outlines planning activities from various regions utilizing travel demand models to better understand the impacts of climate change. Imagining a future where you have the opportunity to enhance your regional travel demand model, please indicate the importance of the following potential model improvements to address climate impacts within your region.
(See the last page for some application examples.)

	1 Not Important	2	3	4	5 Highly Important
1. Emissions Analysis					
Carbon Footprint Reduction	☐	☐	☐	☐	☐
Air Quality Monitoring	☐	☐	☐	☐	☐
2. Climate Resilience and Adaption					
Infrastructure Vulnerability Assessments	☐	☐	☐	☐	☐
Mitigation Strategy Development	☐	☐	☐	☐	☐
3. Transition to Sustainable Mobility					
Shifting to Lower-Emission Modes	☐	☐	☐	☐	☐
Electrification of Transport	☐	☐	☐	☐	☐
4. Sustainable Urban Planning					
Density Enhancement Impacts	☐	☐	☐	☐	☐
Climate-Resilient Urban Development Strategies	☐	☐	☐	☐	☐
5. Travel Behavior Feedback Mechanisms					
Adapting to Travel Pattern Changes	☐	☐	☐	☐	☐
6. Public Policy and Stakeholder Engagement					
Climate Impact Visualization Tools	☐	☐	☐	☐	☐
Cost-Benefit Analysis for Climate Initiatives	☐	☐	☐	☐	☐
7. Model Integration					
Synchronization with Economic Models	☐	☐	☐	☐	☐
Alignment with Land Use Models	☐	☐	☐	☐	☐
Incorporation with Energy Consumption Models	☐	☐	☐	☐	☐

6

Question 12.

Please add any additional comments or questions you may have about the survey, my research interests, or long-range transportation planning and climate impact mitigation, in general.

Please save the PDF form and return it to xxxxx.xxxxxxxx@xxxx.xxx when completed.

Thank you for your time, sharing your expertise in transportation planning, and interest in creating a more sustainable future for generations to come.

Respectfully,

Derek Hungness, PE, PTOE, AICP
Ph.D. Candidate, Transportation and Logistics
Transportation Infrastructure and Capacity Planning
North Dakota State University

Examples of Future Potential Climate/Transportation Model Applications (Question 11)

Carbon Footprint Reduction	A travel demand model can evaluate transportation choices and their emissions, informing strategies to minimize the sector's carbon footprint.
Air Quality Monitoring	By simulating transport activities and their emissions, the model can predict areas of potential air quality degradation.
Infrastructure Vulnerability Assessment	Travel demand insights highlight infrastructure areas most at risk from climate change-induced transport pattern shifts.
Mitigation Strategy Development	Using the model's predictions, planners can develop strategies to mitigate negative environmental and social impacts of transportation.
Shift to Low-Emission Modes	The model can inform on potential transportation shifts, guiding initiatives to promote greener travel alternatives.
Electrification of Transport	Travel demand models can project the growth and spatial distribution of electric vehicle use, informing where infrastructure like charging stations should be prioritized.
Density Enhancement Initiatives	The model can demonstrate the relationship between urban density and travel behaviors, helping urban planners target areas for density enhancement.
Climate-Resilient Urban Development Strategies	By highlighting transportation needs under different climate scenarios, the model can inform resilient urban planning decisions.
Adapting to Travel Pattern Changes	Travel demand models can capture shifts in transportation behaviors, ensuring infrastructure and policies remain relevant.
Climate Impact Visualization Tools	Leveraging model outputs, visualization tools can depict transportation's role in climate impacts, making the data more accessible and actionable.
Cost-Benefit Analysis for Climate Initiatives	The model can provide data on the potential impacts of transportation-related climate initiatives, aiding in a comprehensive economic evaluation.
Synchronization with Economic Models	The travel demand model can be harmonized with economic projections to understand the intertwined effects on transportation and the economy.
Alignment with Land Use Models	Integrating with land use models allows the travel demand model to predict how transportation needs change with different land use patterns. Feedback loops allow residential location preference shifts with new technologies such as Connected and Autonomous Vehicle travel.
Incorporation of Energy Consumption Models	Travel demand models can project energy use based on transportation behaviors, guiding energy policy and sustainable energy sourcing decisions.

APPENDIX G: 2023 WI MPO/RPC CONFERENCE AGENDA

MPO/RPC Conference
October 10-11, 2023
(as of 10/03/23)

Monday, October 9

3:15pm Team Building – We will gather at the Heartwood Resort Main Lodge for a group 5K hike through the woods along the property ski trail system. It's October in the Northwoods and the weather is forecast to be sunny with temps in the low 60s. Join us for a casual hike and conversation.

6:00pm	Dinner	

Tuesday, October 10

8:00 - 9:00	Breakfast	
9:00 - 9:15	**Welcome**	**Sheldon Johnson/Ron Chicka**
9:15 - 10:00	**Blatnik Bridge Reconstruction**	**Duane Hill, District Engineer, MnDOT District 1**
10:00 - 10:30	**AMPO**	**TBD**
10:30 - 11:00	**Urban Planning & Boundary Discussion**	**Alex Gramovot, Planning Section Chief- WisDOT**
11:00 - 11:45	**EV Planning State**	**Jeremy Kloss, Program & Policy Supervisor, Electric Vehicle Unit, WisDOT**
12:00 - 1:15	Lunch	
1:15 - 1:45	**State Rail Plan**	**Alex Gramovot, Planning Section Chief- WisDOT**
1:45 - 2:15	**WATCO**	**Ken Lucht, Assistant VP-Government & Industry Relations, WATCO**
2:15 - 3:00	**Northwoods Rail Transit Commission & Lacrosse Freight Study**	**Darryl Landeau, Senior Planner, NCWRPC and Ken Harwood, Planner, MRRPC**
3:00- 3:20	Break	
3:20 - 3:45	**Tower Ave Road Diet Study**	**Todd Janigo, City Engineer, City of Superior, and Derek Salomonsen, TITLE, AECOM**

3:45 - 4:15	**Superior Port Activities**	**Jason Serck, Planning-Economic Development & Port Director, City of Superior**
4:15 - 4:45	**Culvert Inventory of Four Coastal Counties**	**Clem Larson, GIS Specialist, NWRPC**
4:45	**Adjourn**	
6:00	Dinner	

Wednesday, October 11

8:00 - 9:00	Breakfast	
9:00 - 9:15	**Welcome**	**Ron Chicka/Sheldon Johnson**
9:15 - 9:45	**SRTS Panel**	**Melissa Kraemer Batke, Executive Director, ECWRPC Kim Biederman, Principle Planner, Regional Bicycle & Pedestrian Coordinator, ECWRPC Darryl Landeau, Senior Planner, WCWRPC**
9:45 - 10:15	**Transportation Planning & Climate Action Survey WI MPO Results**	**Derek Hungness Ph.D. Candidate, Transportation & Logistics, Transportation Infrastructure & Capacity Planning- NDSU**
10:15 - 10:30	Break	
10:30 - 11:00	**Equitable Engagement Guidebook and Toolkit**	**Melissa Kraemer Batke, Executive Director, ECWRPC Kim Biederman, Principle Planner, Regional Bicycle & Pedestrian Coordinator, ECWRPC**
11:00 - 12:00	**Regional/State/Federal Go (*Jump*) Around**	**During the conference, a comment board will be available to put up discussion topics.**
12:00	**Adjourn** Lunch available for sit-down or to go	

APPENDIX H: 2023 WI MPO/RPC CONFERENCE ATTENDEE COMMENTS

On October 11, 2023, the results of the MPO climate change and transportation planning survey were presented at the annual WisDOT/MPO/RPC conference in Trego, Wisconsin. Attendee comments that followed the presentation included:

- The Milwaukee MPO added a significant limitation of 4-step models is the way the model initially generates trips which are not adjusted after that initial step. That makes it challenging to test changes in AV accessibility and its impact on trip making.
- The Madison MPO added that the survey seemed to be mostly about travel demand modeling, so it was left to their modeler to complete. He wasn't fully aware of the the climate change action details in the plan.
- The Duluth-Superior MPO asked where additional data could be found, and discussion ensued regarding stated preference surveys and problems with the data collected from them. Agency endorsed AV transferable model parameters are non-existent.
- The Milwaukee MPO said not having an Executive Committee or Board to do land use, transportation, and economic coordination may be specific to their MPO, as the Southeast Wisconsin RPC/Milwaukee MPO has a complex organization structure with several subcommittees charged to conduct those specific activities, which do not reach the level of the RPC/MPO commissioners to directly address.
- The Wausau MPO agreed that MPOs of different sizes would respond to the survey in different ways. How should that be taken into consideration?
- The Madison MPO asked if differences in MPO make-up were addressed in the report.

- The Milwaukee MPO recounted how their MPO "burns electrons" and that the MPOs travel demand modeler ran ~130 scenarios for a single transportation infrastructure analysis study. Too much data can be as bad as too little, in some cases.
- The Milwaukee MPO underscored the importance of doing model parameter sensitivity testing.
- The conference organizers asked for an update on the research, if available, during the 2024 annual MPO/RPC/WisDOT conference in Wausau, Wisconsin.