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Exploring the Shared Use Pathway: A Review of the Design and Demand Estimation Approaches

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ABSTRACT

Shared-use paths (SUPs) are rapidly growing in popularity worldwide as dedicated off-street paths that are shared by non-motorists. SUPS are becoming popular for pedestrians, inline skaters, roller skaters, skateboarders, wheelchair users, and electric bicycle riders, among others. SUPs can be built alongside or far from the roadway, with the former typically separated from vehicular traffic by a buffer. SUPs built off of roadways pose a lower risk of conflict with vehicular traffic. Given the crucial role of safety in SUP utilization, this study provides a targeted review of the existing literature and state of practice focusing on the implementation of the SUPs and design guidelines as well as factors, data, and approaches to estimate SUP user volume. The findings of this study will be helpful for transportation planners and policymakers with the planning, design, implementation, and evaluation of SUPs. Ultimately, this review aims to encourage the development of safer and more accessible SUPs, enabling a broader range of non-motorists to benefit from these essential infrastructure investments.

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KEYWORDS
Shared use path (SUP); non-motorists; demand; design

1. Introduction

Shared-use paths (SUPs) have gained significant popularity globally as dedicated off-street paths shared by non-motorists. SUPs are becoming popular for pedestrians, inline skaters, roller skaters, skateboarders, wheelchair users, electric bicycle riders, and scooters, among others (Allen et al., 1998; Hummer et al., 2006; TxDOT, 2021). SUPs may follow the roadway alignment or be built off-roadway, with the former being separated from vehicular traffic by a buffer. Safety, as with other non-motorist facilities, is a crucial factor in the utilization of SUPs. There have been reports indicating conflicts between cyclists or e-bikes against pedestrians, which led some SUP users to feel unsafe (Chen et al., 2010; H. Delaney, 2016). Further, the safe system approach aspires to separate the movements of road users at different speeds. However, the scarcity of funds to construct separate facilities for travel modes with varying speed characteristics calls for the

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adoption of SUPs. Given their growing popularity, understanding the factors that impact the safety and effectiveness of SUPs is critical for transportation planners and policymakers.

Although SUPs are becoming popular in the United States, less is known about their applicability, including demand estimation, design elements, use characteristics, and key factors that drive their utilization to their full potential. This is especially critical as few States have developed guidelines to install SUPs compared to other facilities for pedestrians and bicyclists (see, for instance, FDOT, 2018; TXDOT, 2022; WSDOT, 2022). However, the installation of SUPs greatly depends on the non-motorist's volume, and estimating demand can be a challenge, especially in areas where pedestrian and bicycle facilities are lacking. For instance, for new facilities, according to the TXDOT's updated manual, pedestrian and bicycle counts should be taken during the anticipated peak-hour period on the existing roadway and/or an analogous parallel facility that may provide a component of latent demand for the new SUP (TXDOT, 2022). This approach may not be feasible in the planning stages when bicycle and/or pedestrian facilities are lacking in or near the project area. Thus, it is important to understand available demand estimation tools that are easy to use and that provide anticipated user volumes for SUPs.

This study is based on a targeted review of the existing literature and state of the practice focusing on the implementation of SUPs and design guidelines as well as factors, data, and approaches to estimate SUP user volume. This study takes an inclusive approach by considering all potential types of SUPs, including paved trails in urban locations and unpaved trails in rural areas and parks. The specific focus of this study is to examine the interplay between design and demand estimation approaches within the context of SUPs. Although design and demand estimation may seem like separate aspects, they are closely intertwined and mutually dependent when it comes to planning and managing SUPs. The design of a SUP should take into account the projected demand for the facility to ensure that it meets the needs and preferences of the users. On the other hand, accurate estimation of demand requires a thorough understanding of the design characteristics that attract users and make the facility functional and appealing.

In pursuit of the research objectives, a broad overview of the relevant literature was conducted through computerized searches, which involved a meticulous search process to identify relevant studies. The approach to the literature review, detailed under Section 2, underscores the rigor and reliability of the findings, which have important implications for policymakers and practitioners in the field.

2. Literature search methodological approach and the study outline

Figure 1 presents the PRISMA flowchart employed in this study to guide the data collection and reduction process to obtain pertinent articles for this study. A set of keywords (shared use path, shared bicycle path, separated bicycle path, pedestrian trail, bicycle path, greenways, and park trail) was chosen based on the various ways that SUPs are referred to in different locations. The keywords reflect different terminology used to identify these paths. To ensure the inclusion of a broad range of studies, numerous state-based, national, and international databases were accessed, such as the Transport Research International Documentation (TRID), Web of Science, Scopus, and Google Scholar database, among others. This study did not utilize Scopus as a data source due to

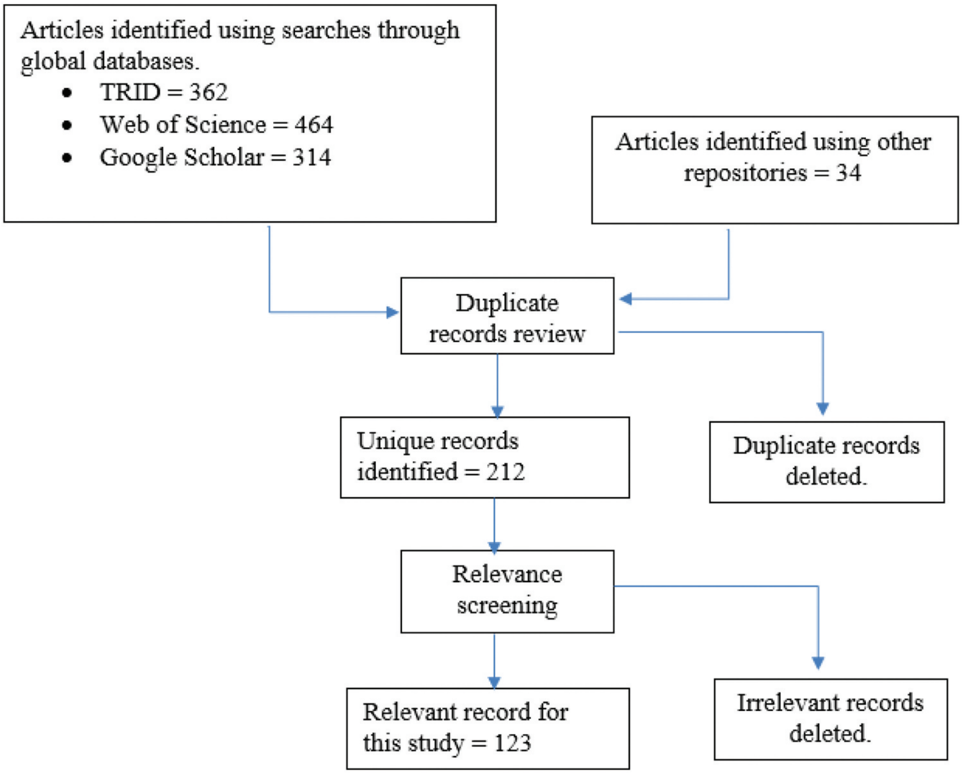

Figure 1. PRISMA Flowchart for Study Methodology.

accessibility limitations and since the research team's institution does not have a subscription. Access to Scopus is typically short-term and granted only upon agreement from the Scopus support center.

Furthermore, the research team conducted searches in various other databases, including NCHRP reports, TRB meeting compendiums, FHWA reports, state DOT reports, national reports from organizations like the National Highway Traffic Safety Administration and National Traffic Safety Board, and peer-reviewed journals. After obtaining the articles, the presence of duplicate records was evaluated. A total of 962 records were found as duplicates, while 212 were unique articles. Next, an additional filter was performed to determine the articles relevant to this study. In this stage, several other keywords were used to refine the search, such as:

- Volume-related (i.e. volume, latent demand, direct demand, utilization, bicycle commuter rate, and demand estimation tools).
- Design-related (i.e. design, length, width, lanes, pavement markings, crosswalk, and intersection signalization).
- Demographic-related (i.e. population density, demographical factors, employment, household income, age, and gender).
- Roadway-related (i.e. posted speed limit, traffic control devices [stop signs, yield signs, etc.], and others).

A total of 123 articles were found to be more relevant to this study, and they were retained for further analysis. Accordingly, the following sections include reviews of four major areas that are critical in exploring the SUP: design elements and user characteristics, influencing factors, data needs, and methods and tools.

The following sections in this study provide a thorough examination of four key components that are central to understanding and analyzing SUPs. These components shed light on different aspects of SUPs and their utilization.

- The initial section (Section 3) focuses on the design elements of SUPs and user characteristics. It delves into the fundamental aspects that define SUPs as well as the expected user profiles. Understanding these design elements and user characteristics is essential for creating SUPs that cater to the needs of diverse users.
- Subsequently, the factors influencing SUP utilization are explored in Section 4. This section aims to comprehend the crucial determinants that impact the usage patterns and effectiveness of SUPs. These factors can range from infrastructure design and accessibility to surrounding land use and demographic considerations. By analyzing these influential factors, we can gain insights into the complex dynamics that shape the utilization of SUPs with different attributes.
- To effectively evaluate the identified influential factors, the next two sections, Section 5 and Section 6, provide a detailed overview of the necessary data sources and methodologies utilized for analyzing SUP usage. These sections establish a framework that enables the assessment of these factors using the available information, ensuring a robust and systematic analysis.

Together, these sections provide a comprehensive understanding of SUPs, their design elements, user characteristics, influential factors, and the methods used to assess them. This systematic approach enhances our knowledge of SUPs and facilitates informed decision-making in SUP planning and design.

3. Shared-use path design elements and user characteristics

SUPs and bicycle and pedestrian facilities share several features, as they cater to the same types of users, namely pedestrians and bicyclists, either concurrently or at different times and locations. However, there are notable differences between the two types of facilities. One difference lies in the provision of SUPs based on vehicular volume, as indicated by the Texas Road Design Manual (TXDOT, 2022). In areas with low to medium vehicular volume, options such as shared lanes or buffered bike lanes may be considered. In contrast, when the vehicular volume exceeds 7,000 vehicles per day, separate bike lanes or shared-use paths are more suitable. Additionally, discussions on shy distance, which refers to the lateral separation between path users and adjacent motorized traffic, are often more prominent in SUP designs compared to pedestrian facilities (AASHTO, 2012). This emphasis on shy distance recognizes the need for physical separation and safety measures between SUP users and motor vehicles.

Despite these differences, it is worth noting that due to the similarities between SUPs, pedestrian facilities, and bicycle facilities, the discussions and considerations presented in this study may overlap or resemble aspects of either pedestrian or bicycle facility design.

This acknowledgment highlights the interconnectedness and potential transferability of design principles and guidelines among these types of facilities. By acknowledging both the similarities and differences between SUPs and pedestrian or bicycle facilities, designers and planners can leverage existing knowledge and best practices to create effective and safe infrastructure for pedestrians, bicyclists, and SUP users.

SUP design elements play a great role in the safety and operations of SUPs. Unlike dedicated bicyclist or pedestrian facilities, SUPs are designed to accommodate other irregular non-motorists. A properly designed SUP can accommodate a range of users and is less likely to result in user conflicts. SUP design and characteristics cover various parameters. In addition to design elements, user characteristics play a vital role during the planning and operation stages. Understanding the expected user characteristics can inform planners of the proper designs to accommodate them.

3.1. Width, clearance, and number of lanes

The width and number of lanes both represent the lateral dimensions of SUPs. The width of a SUP is influenced by various factors, including the volume of users, user characteristics, the number of lanes, user interactions, the available right-of-way, the available project budget, and travel directions.

According to the AASHTO Bike Guide (AASHTO, 2012), under most conditions, a recommended paved width for a two-directional SUP is 10 feet (3.0 m). Further, pedestrian and bicyclist volumes play an important role in determining the size of the SUP. When pedestrian volume is low (up to 110 pedestrians per hour), a width of 8.2 ft (2.5 m) is recommended, even if there are no bicyclists using the path (Flower et al., 2010). As the bicyclist volume increases, the recommended SUP width also increases. At a high volume of pedestrians and bicyclists, separation of the two user groups is advised. Other situations that may lead to a narrower than 3 ft (1 m) SUP are occasional pedestrians, the presence of horizontal and vertical alignments that provide enough passing and resting opportunities, and if the expected presence of maintenance vehicle is relatively low (AASHTO, 2012).

As the AASHTO Bike Guide does not provide guidance for all conditions for SUPs, states have started developing their own guidelines. The Iowa Department of Transportation (IDOT) states that a bicyclist requires a minimum of 4 feet of essential operating space, with 5 feet preferred (IDOT, 2023). IDOT also recommends a typical path width of 10 feet to accommodate two-way traffic. In cases where path widths are reduced to 8 ft, low bicycle traffic and no pedestrian use are expected, and the path should provide well-designed passing and resting opportunities while not requiring regular maintenance. To segregate pedestrians and bicycle traffic, IDOT suggests a minimum width of 15 feet. According to the Washington State DOT (WSDOT) Design Manual, the desired width of a SUP is 12 feet, excluding the shoulders (WSDOT, 2023). The minimum paved width recommended by WSDOT is 10 feet. If the paved width exceeds 12 feet, it is suitable for both pedestrians and bicyclists to use simultaneously. The Hawaii Department of Transportation (HDOT) recommends a width of 12 feet for a SUP (HDOT, 2023). In restricted right-of-way areas, a 10-foot-wide path may be acceptable. A width of 14 feet indicates heavy use, while an 11 to 14 feet-wide path is recommended in areas with a higher volume of pedestrians.

In addition to width considerations, providing vertical and horizontal clearance is important for enhancing user comfort on SUPs. AASHTO (2012) recommends an 8-foot (2.5 m) vertical clearance for SUPs. However, when accommodating maintenance vehicles, a clearance of 10 feet (3 m) is recommended for undercrossings and tunnels. It is important to maintain 2 feet (0.6 m) shoulders on each side of the path, keeping them free from vertical elements or obstructions (Dickman et al., 2016). When crashworthy barriers are utilized, a lateral shy distance of 1 foot (0.3 m) is recommended for improved safety (TxDOT, 2021). For intersections, IDOT recommends a clear sight triangle extending at least 15 feet along the sidewalk, ensuring visibility for SUP users. They also suggest placing the SUP at the top of the fore slope near the roadway and adding a separation from the adjacent road. Barriers and railings can be used if needed. WSDOT emphasizes the need for clear right-of-way definitions and adequate sight distances at intersections with roadways. Hummer (2006) highlights that most safety concerns occur at intersections, underscoring the importance of maintaining low speeds.

While the width of a SUP is often used to measure its lateral span, it does not necessarily indicate the number of lanes that can be utilized to separate users by direction or type. Thus, the number of lanes has been used as an indicator of the lateral span of the SUP. Typically, SUPs can have two to four lanes (Flower et al., 2010). A two-lane SUP is typically 8.2 feet (2.5 m) wide, a three-lane SUP ranges from 9.8 feet (3.0 m) to 13.1 feet (4.0 m) wide, and a four-lane SUP is approximately 14.8 feet (4.5 m) wide.

3.2. Traffic control devices and signage

Some SUPs cross roadways, which increases the chance for non-motorists to interact with vehicular traffic. When either vehicular traffic or non-motorist traffic is significantly high, the safety of SUP users needs to increase. Traffic control devices (TCDs) and signage play a large role in these cases. TCDs include stop signs, rectangular rapid flashing beacons (RRFBs), signals, advance warning signs, stop signs with blinking light-emitting diode (LED) lights, yellow bollards, speed limit signs on the path, and wayfinding, among others. The selection of TCDs may depend on both the vehicular traffic conditions on the roadway and the nonmotorized volume along the SUPs (AASHTO, 2012; Beierle, 2015). The installation of 'YIELD' signs, 'STOP' signs, or traffic signals should be carefully considered to provide the least amount of restrictions to SUP users (AASHTO, 2012). Further, it should be noted that some TCDs such as bollards are meant to prevent motor vehicles from entering SUPs but can cause safety issues for bicyclists.

In their report, the Pioneer Valley Planning Commission (PVPC) (2019) examined the role of advanced warning signs along roadways near SUPs to alert motorists about the presence of vulnerable road users, such as pedestrians or bicyclists, crossing the road. It was recommended that these signs should depict both pedestrians and motorcyclists. PVPC further suggests that all locations lacking existing signs should install Manual on Uniform Traffic Control Devices (MUTCD) compliant warning signs. For warning signs aimed at SUP users, stop signs should be installed at locations where bicyclists are required to stop, while yield signs should be placed where bicyclists have sufficient visibility of conflicting traffic as they approach the sign. Additionally, appropriate turn or curve signs should be implemented in areas with unexpected changes to alert bicyclists, and warning signs indicating bicycle surface conditions should be used when the path conditions could potentially cause bicyclists to lose control. Intersection warning signs should indicate the presence of an intersection, but they should not be used when the SUP is already controlled by a stop sign, yield sign, or traffic control signal.

Interestingly, Silber et al. (2016) found that more bicyclists stopped at locations with yield signs than with stop signs, and bicyclists were more likely to stop at locations with adequate sight distances. These findings suggest that stopping behavior is primarily influenced by conflicting traffic rather than the presence or absence of a TCD. Therefore, the placement of warning signs should be carefully considered, taking into account the location's specific characteristics.

Additional TCDs, such as traffic control lights and pedestrian hybrid beacons (PHBs), can be beneficial at intersections involving SUPs. Lindsey et al. (2017) discovered that traffic controls are often required on weekends, with 25 percent of crossings meeting warrants for PHBs and 7% for traffic signals. Over 60 percent of crossings meeting these warrants already have controls, but approximately 9 percent of all crossings may necessitate additional traffic controls.

3.3. Pavement markings

Pavement markings help to communicate information to SUP users and are important to reduce conflict among SUP users and improve safety at the intersecting roadway by providing lateral separation, longitudinal separation, and the ability to pass (Dickman et al., 2016; Hummer et al., 2006; Zheng et al., 2019). However, a study by Dickman et al. (2016) suggests that centerlines are not necessary under most conditions, especially when the traffic volume is low, as path users would naturally keep right except to pass. Increased traffic volume necessitates the presence of a centerline to organize the traffic (Dickman et al., 2016). Specifically, the centerline intends to separate SUP users by direction. Like roadways, SUPs experience tidal flow, meaning the flow is affected by the location of the major traffic creators such as central business districts. That being the case, the higher the tidal nature of the path, the higher the proportion of passings to meetings in terms of total user interactions (Flower et al., 2010). The solid centerline can also be provided on tight or blind corners and on the approaches to roadway crossings (Dickman et al., 2016). The mark edges are only necessary when SUP usage is expected in the evening times (Dickman et al., 2016). Where the SUP intersects the roadway, SUPs can also have text markings, such as 'STOP AHEAD', that indicate the presence of a stop sign ahead (PVPC, 2019). Further, advanced stop or yield lines are provided on the roadway in accordance with state laws (AASHTO, 2012).

PVPC (2019) highlights the utilization of pavement markings to inform drivers about the potential requirement to decrease speed or come to a stop. Along SUPs, it is common to encounter pavement markings that serve as alerts for upcoming crossings, often featuring written markings such as 'Ahead Stop'. On SUPs, it is appropriate to use smaller-sized letters and symbols for these markings. Centerlines are not mandatory on SUPs unless the path is wide enough to accommodate two lanes of minimum width. In such cases, a solid or broken yellow line, or a solid white line, may be employed to distinguish the two paths of travel. Broken lines on SUPs should adhere to the typical 1-to-3 segment-to-gap ratio.

3.4. Horizontal and vertical alignments

Although they are not very commonly discussed, horizontal and vertical alignments are important design parameters of SUPs because they play a part in the safety and operation of SUPs. Sharp horizontal curves are likely to result in crashes or lowered visibility, while steep SUPs might discourage users who are not stable enough to climb hills. Horizontal alignment depends on the design speed. Considering normal site conditions, the recommended minimum radius of horizontal curves is 60 ft. However, many times this is not feasible. Thus, slower design speeds can be applied to allow sharper horizontal curves. AASHTO (2012) suggests that the minimum radius of the SUP should be 18 ft for a 10-mph design speed and 166 ft for a 30-mph design speed. Vertical curves depend on sight distance (see AASHTO, 2018). The maximum superelevation rate for the SUP is recommended to be 3 percent, while the design side friction should range between 0.31 at 12 mph (21 kph) to 0.21 at 30 mph (50 kph).

3.5. Vehicular volume and speed

Vehicular speed and volume can determine the nonmotorized facilities to be installed. A study on bikeway selection guidelines (Bill et al., 2019) showed that SUPs can be appropriate for moderate- to high-volume roadways. SUPs can be recommended for roadways with vehicular speeds of 30 mph or higher or volumes of 6,500 vehicles per day (vpd). However, in rural areas, an SUP is recommended along roads with higher speeds (45 mph or greater). Also, the recommended traffic volume is more than 6,000 or 7,000 vpd, depending on context (Bill et al., 2019; TXDOT, 2022). At a flat terrain, the recommended design speed for the SUP is 20 mph (30 kph), while at a grade greater than 4 percent, a 30 mph (50 kph) design speed is advisable (AASHTO, 2012).

3.6. User characteristics

SUPs are designed to accommodate users with diverse characteristics. These users can be characterized by their mode of travel. Each mode has its unique characteristics, which can vary significantly and be influenced by demographic factors. For instance, bicyclists are likely to move fast and maintain speed, whereas pedestrians are the slowest users. Further, people with disabilities tend to be slow to react. Such varying characteristics are important for SUP designers to know in order to effectively design SUPs.

The percentage composition of SUP users may vary significantly depending on several factors, including contextual factors such as the location of the SUP. However, the most dominant users are walkers/pedestrians and bicyclists (Aultman-Hall & LaMondia, 2005). In three surveyed trails in Connecticut, the percentage composition of walkers varied between 22 and 45 percent, and bicyclists varied between 37 and 56 percent. Two of the trails had more bicyclists than pedestrians. Other users with a significant percentage composition were runners and skaters (Aultman-Hall & LaMondia, 2005).

Understanding the demographic characteristics of users provides insights into design requirements. However, for design purposes, the space occupied by each user at a given time is usually a more important criterion than demographic characteristics. Understanding user-space characteristics is the first step toward a better design. For instance, adult male pedestrians cover more area than female pedestrians, whereas female pedestrians exhibit a higher level of hip movements (pelvic rotation) for a given distance (Hummer et al., 2006).

This section introduced a range of design elements relevant to SUPs. These design elements are essential for creating well-designed SUPs. However, it is important to recognize that the actual utilization of SUPs can be influenced by numerous factors beyond design alone. These factors play a significant role in determining the usage patterns and effectiveness of SUPs. The subsequent section will delve into a comprehensive exploration of the influential factors of SUP utilization.

4. Influencing factors of shared-use path utilization

To account for a return on investment, it is important to maximize the usage of SUPs. Several factors can impact the maximum utilization of SUPs. This section reviews the literature on influential factors that contribute to the utilization of SUPs, with a focus on facility design characteristics, the built environment and access management characteristics, environmental and meteorological factors, demographic and socioeconomic characteristics, and other contextual factors.

4.1. Facility design characteristics

Facility design characteristics may be the key factors for SUP utilization from an operator's perspective. Compared to other factors, operators have more control over design elements. The term 'utilization of a SUP' refers to the assessment of user volumes, indicating that there is an adequate amount of traffic on the path. However, SUP utilization is influenced by factors beyond user volumes. These facility design characteristics encompass factors such as the number of lanes, SUP width, barriers, pavement types, and markings, as well as the location of the SUP within the street in relation to traffic flow. Pavement markings, such as the centerline, facilitate safety for SUP users. For instance, the presence of a centerline is associated with a decrease in bicyclist speed (Hatfield & Prabhakharan, 2016). Also, narrow SUPs were among the factors associated with bicyclists crossing the centerline to use the lane in the opposite direction. Other factors were the presence of pedestrians in the same direction and bicyclists in the same or opposite directions (Zheng et al., 2019).

4.2. Built environment and access management characteristics

The built environment and access management characteristics include area type (rural, suburban, and urban), land use (commercial, agricultural, residential, etc.), driveway access and density, minor public street access density, types of commercial delivery and delivery techniques, and the connectivity of the bicycle facility to the surrounding network. Most SUPs are constructed in urban environments, but some have been constructed in rural areas in recent years (TXDOT, 2022).

Network density (facility miles of pedestrian links per square mile), intersection density (automobile-oriented intersections per square mile), and the percentage of industry jobs accessed by a 20-minute walk are among the built environment factors associated with trail utilization in Minneapolis, MN, and Columbus, OH (Wang et al., 2016). The magnitude of impact varies significantly. Network density has the largest positive impact, whereas the percentage of industry has a negative impact, except for in Columbus, OH (Wang et al., 2016). Conversely, network density was associated with fewer users in a multi-city study (Ermagun et al., 2018a). This variable had a greater negative impact for bicyclists than pedestrians. Additionally, the facility features such as bike-related infrastructure designation and zones can be used to forecast the number of trips on the SUP (Gehrke & Reardon, 2020).

4.3. Environmental and meteorological factors

Since SUPs involve outdoor activities, such as walking and biking, environmental and meteorological factors may dictate SUPs' usability. The key environmental and meteorological factors include the time of day, day of the week, season, weather conditions, precipitation, number of days with snow coverage, and lighting condition, among others (Ermagun et al., 2018b).

Weather variation was a key factor for 32 multiuse trails located in 14 cities in the United States, with temperature having a greater impact than precipitation (Ermagun et al., 2018b). Studies have revealed that bicyclists and pedestrians respond differently to variations in weather, both within and across regions (Ermagun et al., 2018b). Snow, dewpoint, and wind speed were also found to be associated with lower use of multiuse trails (Ermagun et al., 2018b; Gobster et al., 2017). High temperatures and clear visibility were associated with an increase in the utilization of the elevated pedestrian and bicycle trails constructed in 2013 in Chicago, IL (Gobster et al., 2017). However, high temperature is a relative term, which may vary per geographical location. Thus, this finding may not be applicable globally.

Most of the studies indicated that weekends have more SUP users than weekdays, but the number of users may also be influenced by the location of the SUP. On average, more than 70,000 SUP users used the elevated pedestrian and bicycle trail during summer weekends compared to about 30,000 on weekdays in Chicago, IL (Gobster et al., 2017). Similarly, the peak utilization of the trails in six cities in Indiana was on a weekend afternoon (Lindsey & Nguyen, 2004). The non-motorist count was greater during the daytime than during the nighttime (Lindsey & Nguyen, 2004). This observation can be attributed to lighting conditions. SUP utilization during weekends also varied significantly with weather conditions, with the largest number of users observed in hot humid regions (Ermagun et al., 2018b).

4.4. Demographic and socioeconomic characteristics

The demographic characteristics of people living within a given spatial distance from the facility play a significant role in the utilization of SUPs. Among demographic factors, population density, employment, household income, bike commuter rate, age, gender, and vulnerable user groups (elderly, children, and people with disabilities) have been extensively explored (Gehrke & Reardon, 2020; Gobster et al., 2017; NCTCOG, 2022; Wang et al., 2016).

SUP utilization varies by the ethnicity of the people living close to the SUP. The non-White population in Minneapolis, MN, and Columbus, OH, was associated with lower utilization of trails (Wang et al., 2016). Further, African Americans were less likely to use trails in central Ohio than in Minneapolis (Wang et al., 2016). An increase in the percentage of people with high school education levels and below degrees was associated with lower numbers of SUP users (Wang et al., 2016). SUPs are most likely to be used by middle-aged people, but the definite range of age is unclear. The 20- to 30-year-old and 30- to 60-year-old age groups were the most common ages for trail users in Wisconsin, with very few users over 60 years (Noyce & Dutta, 2005). Although the group of users aged 30 to 60 years was the most dominant, the users aged 20 to 30 years had a higher equivalent frequency. For the other age groups, SUP users above 45 years had the largest portion, with female SUP users being slightly more common than male SUP users (Aultman-Hall & LaMondia, 2005).

4.5. Contextual factors

In some cases, the utilization of SUPs may be affected by contextual factors, which are factors that are specific to the prevailing circumstances at a given time. Such factors may include land use, surveys, trends, sales, recreation, campaigns, promotions, prohibitions, bike share, etc. SUP utilization due to sales, campaigns, or promotions is less likely to be sustainable and cannot be used for design/planning purposes since sales, campaigns, or promotions are designed for a special purpose. For example, the distribution and characteristics of land use surrounding a SUP can have a significant impact on its planning and usage. If the path passes through predominantly residential areas, considerations may need to be made regarding privacy, noise control, and ensuring safe interactions with local traffic. On the other hand, if the path traverses commercial or industrial zones, addressing issues such as accessibility for workers or potential conflicts with vehicular movements may be necessary.

Prohibition of certain types of users/bicycles on the SUPs may hinder the utilization of SUPs. A typical example in this context is Toronto, which does not allow e-bikes to use SUPs (Hasnine et al., 2020). The main reason for prohibition was the speed differences between regular bikes and e-bikes. Thus, in such cities, e-bikes cannot influence the utilization of SUPs. Recreational trips are likely to influence SUP utilization. According to a study performed in Los Angeles County, CA (Stinson et al., 2014), the presence of bicycle trails is associated with increased recreational trips. The study added that bicycle facilities are key access-and-egress components of commuter bicycle routes that use nearby trails. The presence of bike-sharing systems also affects the utilization of SUPs. Buck et al. (2012) found that the length of multiuse trails is negatively associated with bike-sharing utilization because the multiuse trails are located on the outskirts of the city or on the National Park Service property, away from Capital Bikeshare stations.

This section elucidated several factors that are anticipated to have an impact on the utilization of SUPs. Accurately measuring the extent of the influence exerted by each factor necessitates the use of a diverse range of datasets. The following sections provide an extensive compilation of data sources that can be leveraged to assess the influence of each specific factor.

5. Data needs for SUP demand estimation

The first two data sources (under the category of primary data sources representing the *count* data) are related to the non-motorist activity determination, providing either the number of SUP users or the level of activities of non-motorists who are likely to use the SUPs. The remaining data sources (under the category of secondary data sources) help to explain the variability in the estimated/counted number of SUP users.

5.1. Primary data sources

5.1.1. Observed counts

Unlike vehicular traffic, a relatively small number of jurisdictions collect and store non-motorist traffic counts. Even for the available non-motorist counts, the spatial coverage is normally relatively small. Further, pedestrian and bicyclist data vary significantly in response to external factors such as weather and season (Ermagun et al., 2018a). Traditionally, SUP demand analysis has used count data where researchers collect sample data and extend the analysis to generate insights (Ermagun et al., 2018a; Gehrke & Reardon, 2020; Ryus et al., 2014).

The counting techniques may include manual counts (in the field and from video) and automated counts from video, pneumatic tubes, inductive loop detectors, and passive infrared (Ryus et al., 2014). Other approaches are active infrared, piezoelectric strips, radio beams, thermal sensors, laser scanners, pressure and acoustic pads, magnetometers, and fiber-optic pressure sensors (Ryus et al., 2014). The type of approach and the amount of data to be collected depends on the objective of the study. Infrared (active and passive), inductive loops, and magnetometers are among the technologies that have been widely used to collect SUP utilization data and facilitate demand evaluation (Louch et al., 2016).

5.1.2. Crowdsourced Counts

Crowdsourced data are data collected by a large group of people performing various activities that are stored in cloud storage. The data collection tools may include Google Maps, GPS-tracked sports tools such as running watches, and phone applications. Among the crowdsourced data sources, Strava (Strava, 2022) and StreetLight (Streetlight, 2022) are the most frequently used for estimating nonmotorized demand in the absence of observed count data (Lee & Sener, 2021). While the utilization of crowdsourced data for SUPs is limited, a notable study was performed by Creany et al. (2021) in Orange County, California. According to their results, the StreetLight, Inc., dataset provided relatively similar SUP demand estimates as the automatic trail counting and GPS-based monitoring methods (Creany et al., 2021). The study also emphasized the need for more research to determine the availability and quality of such data sources in undeveloped recreation areas or areas with limited cellular coverage.

5.2. Secondary data sources

Due to the limited availability of studies specifically focused on the demand for SUPs, the literature reviewed in this section encompasses demand studies related to SUPs, pedestrian facilities, and bicycle facilities. It is assumed that pedestrians and bicyclists constitute a significant portion of SUP users, and therefore, secondary data relevant to pedestrian and bicycle facilities can be applicable to SUPs as well.

5.2.1. Built environment data

Built environment data, which are collected from numerous sources, consist of land use, land cover, street networks, and urban form. Such sources include various agencies in the local governments, state-level agencies, and national data sources. Such data may be sourced from OpenStreetMap (OSM, 2022) and the Smart Location Database (SLD) (EPA, 2021). The SLD contains details related to housing density, diversity of land use, intersection density, employment, and other social vulnerability measures. Land use data have been a key dataset for various previous studies/projects (Hochmair et al., 2019; Kwigizile et al., 2019; Liu et al., 2021; Orvin et al., 2021).

5.2.2. Roadway features and active transportation infrastructure data

Roadway features and active transportation infrastructure data, such as network measures (corridors with sharrows, bike lanes, trails, road class, and intersection type), were among the data used to predict bicycle volume in Miami-Dade County (Hochmair et al., 2019). The road segment length, number of through lanes, bicycling on a suggested bike route, greenways, U.S. routes, and one-way roads were used to predict the bicycle ridership in Charlotte, NC (Z. Lin & W. D. Fan, 2020). In the same city, Z. Lin and Fan (2020) used the speed limit, segment length, number of through lanes, slope, bike lane (signed and suggested), greenways, and off-street path data to predict bicycle volume using crowdsourced data. The built environment and roadway features data can be used to develop measures to assess walkability and bikeability (Mekuria et al., 2012; Munira et al., 2021). Such measures can be used to develop a GIS-based SUP network and exposure maps to determine potential design characteristics for installing new facilities.

5.2.3. Transit infrastructure data

The Bureau of Transportation Statistics (BTS) hosts the National Transit Map (NTM), which includes the details of fixed-guideway and fixed-route transit services across the United States and is available publicly for research and other purposes (BTS, 2022). The NTM database also includes the geospatial details of the transit agencies' stops, routes, and schedules. The database is updated biannually in the spring and fall, and there are plans for it to be updated quarterly. Additional transit data can be obtained from GTFS which offers transit data, including schedule, fare, route, and stops (GTFS, 2022). Such data have already been used in multiple studies, including one study in Seattle, WA (Sanders et al., 2017).

5.2.4. Demographic and socioeconomic data

Demographic and social-economic data have been predominantly used in pedestrian and bicycle facility demand (Burmester & LaMondia, 2018; Frank et al., 2021; NCTCOG, 2022; Zheng et al., 2019). Various sources of demographic data are available, but the decennial census (USCB, 2022b), American Community Survey (USCB, 2022a), National Household Travel Survey, and Longitudinal Employer-Household Dynamics are among the major sources. Sources such as American Community Survey are available in one-year, one-year supplemental, three-year, and five-year estimates.

5.2.5. Meteorological data

Meteorological data include temperature, precipitation, snowfall, and other information. The National Oceanic and Atmospheric Administration's (NOAA's) Online Weather Data website maintains a database for use by researchers and the public (NOWData, 2022). The database covers the entire United States, and any interested person can search for and access past weather and climate data by station name, ZIP code, city, county, state, or country. The data can be retrieved in hourly, daily, and monthly granulation.

5.2.6. Point-of-interest data

Crowdsourced data sources provide opportunities to obtain supplementary data. As an emerging source of location-based services (LBS) data, SafeGraph provides point-of-interest (POI) data based on business listings and location information (SafeGraph, n.d.). These data provide the locations of various POIs with detailed attributes (brand affiliation, advanced category tagging, open hours, number of visitors, etc.). The POI may be a park, restaurant, or stadium, among others. SafeGraph data have been utilized for various tasks, such as monitoring park visitors, spatial and temporal visitations, fast-food area visitations, and cross-border travel (Gurbuz et al., 2022; Juhasz et al., 2020; Liang et al., 2021; Zhou et al., 2022).

The data sources discussed in this section demonstrate the abundant availability and diversity of data for SUP demand analysis. Leveraging these data sources, a range of analytical methodologies can be employed to effectively analyze SUP demand. The subsequent section delves into a comprehensive exploration of these methodologies, providing insights into their applicability and potential for assessing SUP demand.

6. Methods and tools for active transportation demand forecasting: adaptation for SUP

Methodologies and tools for demand forecasting are usually used interchangeably. In general, methodologies are considered to present the entire approach used to estimate demand. This may include the developed statistical models and the step-by-step approach used to develop a model. A tool is considered the result of the statistical model. Typically, the tools are Excel sheets, GIS-based applications, web-based applications (e.g. R Shiny apps), etc. Using such tools, practitioners can input various parameters/variables and estimate bicycle and/or pedestrian volumes.

As discussed in an FHWA study (Turner et al., 2017), various models and methods are available to measure or estimate demand at different geographic scales. It is noteworthy to add here that at the regional planning level, the state of practice mainly consists of regional travel demand models that are based on traditional trip-based forecasting models. These regional models might be dedicated to only motorized travel or are limited in estimating non-motorized travel due to their coarse level of spatial analysis structure. Some enhancements are underway to go over such limitations and increase the sensitivity of the regional models to bicycle and pedestrian trips. Emerging tour- or activity-based models also provide superior alternatives to traditional trip-based models. However, these models generally require extensive data and efforts to develop, which are not practical in most cases due to the limited resources (budget, time, etc.) available to agencies to estimate bicycle and pedestrian demand, and thus falls outside the scope of the current study.

The limited number of studies specifically focused on SUPs poses a challenge when it comes to developing dedicated methods for estimating SUP user demand. However, considering that a significant portion of SUP users is expected to be pedestrians and bicyclists, it is reasonable to assume that similar approaches used for data collection and demand estimation in pedestrian and bicyclist facilities can be applied to SUPs. While SUPs possess unique characteristics due to their shared use by various active transportation modes, it is essential to adopt a differentiated approach to demand estimation methods that can account for these distinct features. By synthesizing the existing literature, our study aims to provide valuable insights for practitioners and policymakers involved in enhancing SUP design and planning. Moreover, acknowledging that SUPs are likely to be utilized by both pedestrians and bicyclists, we anticipate that modified forecasting methodologies originally developed for pedestrian and bicyclist demand estimation can be adapted and applied to SUPs. By leveraging insights from the broader field of active transportation demand forecasting, we can gain valuable knowledge and recommendations to enhance SUP design and planning. The subsequent sections will delve into the methods and tools employed in bicycle and pedestrian demand forecasting, highlighting their potential adaptation for SUPs and emphasizing their relevance in addressing the unique challenges and requirements of SUP user demand estimation.

6.1. Sketch planning methods

Sketch-planning methods generally estimate demand by collecting mode-choice information from the U.S. Census data or by applying locality-specific rules or weights to relate non-motorist demand to existing or new populations or activity levels. For non-motorist demand estimation, these approaches can be defined as a series of calculations or statistical analyses to estimate the number of non-motorists using a particular facility in a particular locality or area (Turner et al., 2017, 2019).

Turner et al. (1998) developed the sketch-planning method for bicycle and pedestrian travel demand forecasting. The study used trip generation rates from an Institute of Transportation Engineers manual and collected sample data from eight urban locations in Texas to validate the developed sketch-planning method. The developed methodology follows seven steps:

(1) Define the study corridor and analysis sub-sections.
(2) Define the influence area along the study corridor.
(3) Identify and quantify land uses in the influence area.
(4) Apply trip generation rates to the analysis sub-sections.
(5) Sum trip estimates for each sub-section.
(6) Sum the trips for the entire study corridor.
(7) Apply reasonableness checks and adjust trip estimates if necessary.

Further, Jacobs (2022) developed a methodology to estimate the I-20 SUP demand. Basically, this study followed six main steps:

(1) Identify count locations within the study area.
(2) Identify representative permanent count locations that fit the SUP characteristics.
(3) Identify the recent growth rate (2018–2020) and future growth rates (for less than 20 years and more than 20 years) and apply seasonal adjustment factors.
(4) Identify the peak-hour factor and the trail user mode split for the short-duration count.
(5) Forecast for existing and future-year demand.
(6) Analyze pedestrian and bicycle level of service for the SUP.

A study by the Houston Parks and Recreation Department (HPRD, 2018) developed an Excel sheet tool for estimating bicycle demand for the Little White Oak Bayou Regional Greenway project. The inputs for the tool were the mode share from census data, the percentage of adult bike riders, recreational mode share, and commuter mode share. Additionally, the tool considered commuters within 2,400 m of the SUP. The developed tool, however, was specific to bicycles only, making it difficult to apply to SUPs that include bicycles, pedestrians, and other nonmotorized traffic.

A study by Griffin (2009) reviewed simple techniques to estimate bicycle and pedestrian demands for bicycle lanes, sidewalks, and SUPs and adopted the techniques to estimate a relatively simple (though experimental) method using GIS and data readily available in most areas to forecast demand for an entire roadway network. The developed technique follows five key steps:

(1) Identify the mode share and roadway network data. The mode share can easily be obtained from the ACS under 'S0801 Commuting Characteristics by Sex'. The roadway network is usually available in the geospatial repositories of the respective cities.
(2) Estimate the total trips by mode whereby the percentage of adult bicyclists and adult bicycle commuters and commute share are used.
(3) Estimate the mode shares by area type and apply bicycle/pedestrian rates to roadway geometry.
(4) If necessary, review reasonableness and adjust trip rates.

6.2. Spatial-focused methods

Spatial-focused methods use spatial analysis to generate demand for a given region. Some of these tools could also be considered advanced sketch-planning tools, with a specific focus on spatial data. In most cases, GIS is applied to determine either the number of non-motorists or their activity levels. These methods can be particularly beneficial when applied at the corridor and sub-area planning levels. For example, scenario planning tools, which heavily depend on the usage of GIS-based modeling and/or methodologies, are used to estimate nonmotorized travel under alternative land use and transportation investment scenarios. A typical example is the GIS-based method for trail alignment planning which was developed by Xiang (1996). The method uses the physical, ecological, and land use conditions of the area to determine the connecting path that links a future trail's origin and destination. The method was tested using a North Carolina state park and proved to be useful.

Vernez Moudon et al. (2002) developed GIS tools to identify suburban areas with potentially high latent demand for pedestrian travel. One of the developed tools takes advantage of parcel-level data with specified land use attributes. A second tool uses commonly available census block data and aerial photography. The second tool is labor intensive and requires familiarity with reading urban form and development patterns. However, this study did not focus on bicyclists and other nonmotorized traffic that are likely to use SUPs. Further, a GIS-based tool developed by Kuzmyak et al. (2014) is among the tools that are capable of estimating pedestrian trip tables using a walk-accessibility index. The tool creates walk trip tables by purpose from computed measures of accessibility to and from any point using all modes of transportation. While providing more realistic results (compared to traffic-analysis-zone-based results), the tool is limited to pedestrians and does not capture bicyclists' activities. Another web-based GIS bike/pedestrian demand tool was developed by Manning (2021) for the South-Central Planning and Development District Region in Louisiana. The input to the tool includes the overall population, population aged 14 and under, population aged 65 and over, car ownership, job density, specific landmarks, intersection density, historical crash data, and public comments per each census block. The output is the demand score per census block. NCTCOG (2022) developed GIS-based bicycling and walking demand zones to calculate demand at a zonal level in the Dallas – Fort Worth region. The focus was on five criteria including high population and employment density, high density of short trips, density of low-income population, density of zero-car households, and areas of high vehicle congestion. Such criteria are likely to create walking and biking trips. The project produced a GIS-based map that can be used to prioritize future investments in walking and bicycling infrastructure.

The bikeability index developed by Arellana et al. (2020) for Barranquilla, Colombia, is another spatial-focused methodology that produces a GIS-based map, which shows a pattern of generated and attracted trips for each link. Based on the developed bikeability index, the study estimated the bicycle infrastructure investment prioritization, which city officials can use to select the key areas to install bicycle infrastructures.

6.3. Direct demand models

With advancements in data collection, methodologies used to estimate nonmotorized demand have improved. Direct demand models have become some of the most widely used approaches for pedestrian and bicyclist volume estimation modeling due to their simplicity and convenience in development and application, and because they are generally based on available data.

Direct demand models are statistical models that use various explanatory variables to predict the number of users for a given facility, including SUPs. These models are particularly useful for screening and preliminary analyses, especially when resources are limited, and a more comprehensive (and relatively expensive) model is not available or not possible to develop. Furthermore, such models can be used by transportation planners in monitoring facility usage and identifying opportunities to enhance safety (Bhowmick et al., 2022).

Although direct demand models have been used extensively, they are limited in terms of capturing behavioral structure. In addition, they are usually not transferable due to their strong linkage to the local context, activity levels, and the characteristics that the models are built on. Direct demand models have thus been primarily used to develop facility-specific demand estimations for the local level of community, project, and facility planning and to evaluate and prioritize projects (Kuzmyak et al., 2014). The potential usages of direct demand models are to:

- Answer questions about facility use or needs that could not be addressed with traditional trip-based regional models because of limitations related to scale and ad hoc treatment of nonmotorized modes.
- Address the need for estimates of walk activity on links and at intersections for safety analysis and design.
- Address the need for estimates of bicycle activity to support questions on bicycle network design and to support decisions about facility needs.
- Provide a better connection between the context of the given built environment and nonmotorized travel behavior and demand.

6.3.1. Direct demand models for pedestrian and bicycle facilities

While existing demand models have largely focused on estimating demand for general pedestrian and bicyclist facilities, the need for specific demand models for SUPs has become increasingly apparent. Despite this, the approach to modeling demand for SUPs remains similar to those used for other types of pedestrian and bicyclist facilities.

Because the direct demand models intend to determine the number of users, count models, such as Poisson regression and negative binomial, are the most common direct demand models (Dhanani et al., 2017; Fagnant & Kockelman, 2015; Kwigizile et al., 2019; Liu et al., 2021; Munira et al., 2021; Tabeshian & Kattan, 2014). The ability to predict non-negative numbers is one of the key reasons for them being given high priority. Further, log-linear models that transform bicycle and pedestrian counts into logarithmic values of the same in order to avoid negative values prediction have also been used (Miranda-Moreno & Fernandes, 2011; R. Schneider et al., 2012). Additionally, multiple regression analysis, ordinary least squares (OLS) regressions, and stepwise regression models have also been used (Arellana et al., 2020; Fan & Lin, 2019; Hankey et al., 2012, 2021; Hochmair et al., 2019; Jones et al., 2010; Lu et al., 2018; R. J. Schneider et al., 2009; Tabeshian & Kattan, 2014). While most of the models to date are based on actual volume counts, crowdsourced data have also been used in estimating statistical models of bicyclist and pedestrian demand when a study wants to cover a large geographical area. Various research and modeling efforts were conducted, especially using Strava through Strava Metro (e.g. Dadashova & Griffin, 2020; Lee & Sener, 2019; Roll & Proulx, 2018).

In addition to traditional statistical models, machine learning algorithms have been used for demand estimation. Hankey et al. (2021) compared random forest and gradient boosting models for predicting walking and bicycle trips using data from 20 cities across the United States. Their study utilized street view imagery and destination data to determine pedestrian and bicycle trips. Further, Miah et al. (2022) compared eight machine learning algorithms to estimate daily bicycle traffic in Portland, OR. The comparative analysis between models showed that the deep neural network and shallow neural network machine learning techniques produced higher accuracies in estimating daily bicycle volumes. Although these studies did not focus on SUPs, they provided inputs that can be used in SUP studies, such as machine learning tools and features.

6.3.2. Direct demand models for SUPs

Though relatively limited, direct demand models have also been developed for pedestrians and bicyclists for shared paths and trails. Ermagun et al. (2018a) developed and compared three separate models for pedestrians, bicyclists, and mixed-mode trail traffic. The study used data that were collected from 50 locations on trails in 13 urban areas across the United States. The developed models used network density, education level, job access, water density, and percentage of legally working people, among other variables. Additionally, Ermagun et al. (2018b) applied negative binomial regression to estimate pedestrian and bicyclist use of trails across the United States.

6.4. Latent demand models

A latent demand model is simply the 'current desired demand' for travel and activities 'that is not fulfilled due to a wide range of restrictions' (Clifton & Moura, 2017). According to Clifton and Moura, latent demand can be met by either redistributing already occurring travel or meeting generative demand. The distribution of latent demand may not be uniform across a community, with disadvantaged population groups such as the poor, the elderly, people with physical and mental disabilities, and communities of color being the most likely to bear the greatest costs of repressed demand. Logically, inquiries into latent demand should also consider inequities given that latent demand is likely to be allocated unevenly and in a way that may perpetuate other inequities. The SUP-related latent demand estimation methods can be divided into four categories (see also, Beetham et al. (2021)), which include pragmatic approaches, demand typology techniques, stated-preference-based models, and revealed-preference-based models.

6.5. Pragmatic approaches

A pragmatic approach is the method that asks 'what works?' and incorporates techniques that are less organized, ad hoc, or generally generic in nature for the sake of the activity. When more structured or locally relevant methods or models are not accessible or are deemed unsuitable or insufficient for the intended objective, pragmatic approaches are frequently used.

Pragmatic approaches to latent demand forecasting can use one or a combination of methods, including informed expert estimation, sketch planning, and comparison approaches.

In Informed Expert Estimation, SUP-related informed expert estimation can contribute to forecasting in three main ways: (1) as the basis of a forecast, (2) as choices and assumptions about components of a method or model, and (3) as a way to adjust a forecasted model using other methods. Although this approach engaged the community and can result in a better network design and latent demand, it is more feasible for a small geographical area. Sketch planning methods, on the other hand, are generally rudimentary and based on generic formulas or factoring. Although sketch-planning methods had been viewed as being low in accuracy, these methods were also frequently perceived as being quick, simple, and inexpensive (Beetham et al., 2021).

Lastly, the comparison approaches look at levels of activity or changes in activity owing to interventions in specific locations and use this knowledge to estimate latent demand in other locations of a similar nature. According to a survey/interview study by Beetham et al. (2021), survey participants from different agencies who used comparison approaches usually performed quality checks of the estimates from sketch-planning methods and revised forecasts from other methods as necessary.

6.6. Demand typologies

Roadway users interested in increasing their walking and/or cycling because of investments that promote these modes have a latent demand for these activities. Demand typology techniques can be useful to quantify the proportions of a population that exhibit specific demand traits as well as qualitatively evaluate the preferences of individuals who have latent demand.

Several types of demand typologies exist but many of these have relied on surveys and current behavior with limited information related to general use to help attract new people (Dill & McNeil, 2013). Geller (2006) proposed a typology that would also help examine latent demand: (1) the strong and the fearless, who can cycle almost anywhere; (2) the enthused and the confident, who prefer dedicated cycling facilities; (3) the interested but concerned, who are cautious about safety but enjoy riding a bike occasionally, and (4) the no way no how, who have no current interest in cycling. Based on a recent study by Hosford et al. (2020), the typologies are still intuitive but may not necessarily match the perception of bicyclists, and it would be important to ask the current bicyclists to self-identify their category. Another example is the Transtheoretical Model of Intentional Behavior Change, which has been applied to ped-bike demand forecasting (Gatersleben & Appleton, 2007; Mutrie et al., 2002; Pettit & Dodge, 2014). This method explores an individual's preparation and willingness in changing a particular behavior so that interventions can be appropriately targeted.

6.7. Stated-preference-based models

Some methods for predicting latent demand for walking and cycling use stated-preference-based models. Other methods also use stated-preference data as part of their demand assessments. For example, Wardman et al. (2007) stated-preference methods are especially useful for identifying how people with latent demand for walking and biking might feel and what they might do about it (such as changing their travel mode). Furthermore, stated-preference-based models may help explore how roadway users react to infrastructure that is very different from previous ones or completely new, even when no data is available to understand potential users' reactions. Most of the time, stated-preference data are collected through a survey in which people answer questions by naming a hypothetical choice or behavior response or a preference to a proposed situation (Brown, 2003; Kroes & Sheldon, 1988).

6.8. Revealed preference-based models

By relying on real-world data and techniques, revealed preference-based models enable researchers to gain a more accurate and dependable understanding of human behavior and decision-making processes. Compared to stated-preference models, which rely on hypothetical scenarios or self-reported data, revealed-preference models provide a more reliable and robust foundation for decision-making and policy development. Given that SUPs are implemented across different jurisdictions and their usage is assessed through various studies (Aultman-Hall & LaMondia, 2005; Beiler et al., 2015; H. Delaney, 2016; H. B. Delaney et al., 2017), the development of revealed preference-based models are critical for analyzing actual utilization data. This approach has played a significant role in advancing our understanding of activity-travel behavior and is expected to continue to play an important role in the future, including SUP demand estimation. Continued investment in this approach and exploring new methodologies will unlock valuable insights and drive progress in accurately estimating SUP user demand.

7. Conclusions

This study provides a detailed overview of various aspects related to SUP design and utilization, highlighting the importance of considering key design elements and user characteristics such as the width and number of lanes, traffic control devices, pavement markings, vertical and horizontal alignment, vehicular volume, and speed, as well as user attributes. Further, the study explored the influencing factors for SUP utilization, such as design characteristics, built environment, meteorological factors, demographic factors, and contextual factors. Next, a specific focus was placed on the data needs for SUP demand analysis, and various data sources were explored, including observed counts and crowdsourced counts, built environment data, transit data, demographic data, and roadway infrastructure data, among others. This study concluded with a detailed examination of the methods used for demand estimation, including sketch planning methods, spatial-focused methods, direct demand models, latent demand models, and various pragmatic approaches. By providing a broad overview of the ongoing practices and challenges associated with the planning, design, implementation, and evaluation of SUPs, this study aims to encourage the development of safer and more accessible SUPs, enabling a broader range of non-motorists to benefit from these essential infrastructure investments.

The review findings provide valuable insights. Although previous studies have focused primarily on SUP design elements, user characteristics, and safety and operational impacts, there is a dearth of research on demand estimation, which is a crucial aspect of transportation planning and management. Considering that SUP users are likely to include pedestrians and bicyclists, who have been the focus of previous demand forecasting research, it is logical to leverage the methodologies developed for these active transportation modes. By adapting current existing methods, transportation planners can effectively utilize established approaches for demand estimation in SUP planning and design. This allows for the incorporation of valuable insights and experiences from related fields such as bicycle and pedestrian demand forecasting. This is particularly valuable when resources, such as time, budget, and expertise, are limited. However, as the understanding of SUPs and their unique characteristics deepens, it becomes increasingly important to develop new methods specifically tailored to SUP demand estimation. The evolving research in this area necessitates innovative approaches that capture the complexities of SUP usage patterns and user preferences. By combining the adaptation of existing methods with the development of new approaches, transportation planners can ensure the accuracy and relevance of demand estimation methodologies, ultimately leading to well-informed decision-making, user-centered facility design, and sustainable SUP infrastructure. In addition, the absence of centralized databases for SUP utilization data is a shared challenge observed in demand estimation for bicycle and pedestrian facilities as well. However, existing data can be fused with the influx of new and crowdsourced data sources or data vendors (e.g. Strava, Wejo) to generate surrogate information. The current gap presents an opportunity for researchers to explore the potential application of methodologies and data used for bicycle and pedestrian facilities in SUP demand estimation.

There are some limitations that need to be acknowledged. First, the decision to exclude Scopus from the literature search was made due to accessibility challenges, which may have resulted in some relevant publications being omitted from the study. To address this limitation, future research could explore alternative means of accessing Scopus or include additional databases with broader coverage. Furthermore, the review was confined to English language publications, which may have overlooked research published in non-English publications, presenting a unique opportunity for future studies to utilize tools to access relevant research in other languages.

The review findings also provide a foundation for future research in this field. First, more research is necessary to explore the demand for SUPs in different contexts, including urban and rural areas. Additionally, research on user characteristics, such as age, gender, and income, is critical to understand SUP user preferences and behavior. Furthermore, the development of new analytical methodologies and tools for demand estimation should consider the unique features of SUPs. Future research should also explore the potential of using advanced technologies, such as artificial intelligence and machine learning, to improve the accuracy of demand estimation.

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