Prioritizing Areas for King County Metro Transit's Feeder-to-Fixed Route Flexible Services

A Preliminary Approach for the Systematic Locational Prioritization of Future Services

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This thesis is the result of a collaborative effort of Morgan Cowick and Daniel Munkel by the authority of the Graduate School. All work was done under the direction of Professor Qing Shen from the Department of Urban Design and Planning, and Associate Professor Joaquín Herranz, Jr. from the Evans School of Public Policy and Governance.

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Abstract

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This work presents an approach for systematically prioritizing areas in King County, Washington for future feeder-to-fixed route (F2FR) flexible service. This approach is meant to inform service planning processes for King County Metro Transit (Metro) by providing a framework for the analytical process as well as for the policy considerations that underpin the inputs to the analysis. These analytical inputs are informed by Metro's Mobility Framework, Metro staff expertise, and academic and practice literature. The analysis identifies specific criteria and methods for Metro to prioritize areas within the county for future F2FR flexible transit services, and then employs spatial analysis to develop a ranked list of priority areas based on

these components. The authors are particularly interested in highlighting the policy priorities embedded in the weighted criteria that make up this analysis, and how varying the analytical inputs alters the prioritized ranking of areas throughout the county. Ultimately, this work seeks to present an analytical framework for planning for F2FR flexible services that is closely tied to a robust set of policy and service priorities.

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Table of Contents

List of Figures

List of Tables

Executive Summary

Like many other public transportation agencies, King County Metro Transit must continuously navigate the balance between different and often conflicting transportation needs. Over the past three years King County has increased its investment in demand-responsive flexible transit service options as a way to broaden the way it is able to address these needs, and to more nimbly meet demand that is inefficiently served by traditional fixed-route transit. Since October of 2018, Metro's Innovative Mobility team has piloted demand-responsive feeder-to-fixed route (F2FR) shuttles in three geographical areas of the county (King County Metro Transit Department, 2019c). This service model targets closing first-last mile transit gaps, using on-demand ride hailing and dynamic routing to feed people into the existing fixed-route transit network. These types of innovative flexible services present one tool to alleviate tensions around service prioritization, but because they are so new, few transit agencies have developed criteria for deciding where to put them. Furthermore, there is limited guidance in the academic and professional literature on how to systematically prioritize locations for this type of service. As Metro continues to embrace its role as the manager of a menu of mobility options, it is crucial that its innovative F2FR flexible services become more integrated into the systematized service planning processes.

For Metro, being more systematic with its demand-responsive flexible services planning aligns with its shift away from being a transit agency, and toward becoming a mobility agency. Metro envisions itself as a manager of services that fit into a larger mobility network reliant on interagency and public-private partnerships. It is this vision that is expressed in the Mobility Framework and which directly calls for increased innovation and equity in the way in which the need for service is met. One of Metro's new guiding documents, the Mobility Framework, was released in October of 2019 and charts a path for Metro to prioritize new transit service in the county, including how to provide innovative services like F2FR flexible transit. The recommendations in the framework specifically call for prioritizing service in areas and times of day with “unmet need,” or areas that have low public transit accessibility and have high concentrations of low- and no-income people, people of color and indigenous people, immigrants and refugees, people with disabilities, and limited- English speaking communities (King County Metro Transit Department, 2019b). King County Council has now directed Metro to update its policy documents in order to reflect the recommendations in the Mobility Framework. As Metro begins to align its broader service planning processes with the Mobility Framework, it is critical that planning for F2FR flexible services also align with the new framework.

This work aims to explicitly align with the service provision paradigm expressed in the Mobility Framework. Fortunately, the Mobility Framework includes a set of recommendations for how to prioritize service, including a set of initial criteria that will be used in this work. However, while the Mobility Framework offers a robust roadmap for Metro’s future service priorities, it does not provide guidance that is specific to each flexible service model. Given important distinctions in the goals that inform different flexible service models, this work evaluates and selects the criteria that are most applicable to one of these models: feeder-to-fixed route flexible service. This is the type of service model being pursued currently by the Innovative Mobility team, and one that increasingly overlaps with the work of the Service Planning team.

Fundamentally, the intention of this work is to model an approach for Metro to prioritize areas in the county for future F2FR flexible services. Through this work we: 1) identify locations throughout the county where transit service converges near clusters of jobs and important community assets, 2) refine sets of weighted criteria to prioritize new service locations, 3) develop base and alternate models for spatial analysis to identify areas that score highest based on these criteria, and 4) consider the policy implications of selecting certain criteria and designating thresholds or weights. The value of this work to Metro and other transit agencies pursuing similar work includes: the output of the analysis, including ranked prioritization of areas for future F2FR flexible service; the adaptable methodology that produced the analysis; and the policy framing that is crucial to guiding decisions around inputs to future analyses. This will enable greater alignment between policy goals, locational suitability analysis, and implementation of F2FR and other flexible services moving forward.

List of Terms

Alternative Service	Public transit services that differ from traditional fixed-route, fixed-schedule transit services. These include, but are not limited to, the following demand-responsive transit services: feeder-to-fixed-route services, paratransit, “Dial-A-Ride” services, door-to-door flexible transit services, and microtransit. Also often referred to as flexible services.
Community Assets	Facilities and service locations that provide public benefits to the surrounding community. For the purposes of this research, this includes educational facilities, job training centers, community centers, libraries, emergency shelters, Federally Qualified Health Centers, assisted living facilities, residential treatment centers, nursing homes, senior centers, hospitals, Tribal Health Centers, WIC clinics, WIC vendors, ORCA LIFT (regional subsidized public transit program) enrollment centers, ORCA (regional public transit payment system) fare outlets, food banks, farmers markets, grocery stores, shopping centers, subsidized housing facilities, and places of worship.
Demand Responsive Transit	Transit that operates in response to calls or requests from riders. A reservationist or automated system receives the request and then dispatches a vehicle to pick up riders and take them to their destinations. These vehicles do not operate on a fixed route or fixed schedule and typically pick up several passengers at different locations before taking them to their respective destinations. (Volinski, 2019)
Feeder-to-Fixed Route Service	Local transit service that provides users with connections to main-line principal arterial service, with the intention of feeding the existing fixed-route network. (Volinski, 2019)
First-Mile Last-Mile	Refers to the first and last segment of a trip where the mode of travel for the majority of the trip is public transit. The “first and last mile” of public transit trips are traditionally covered by personal means of transportation, such as a personal automobile or bicycle (or other human or battery-powered personal transportation vehicle) for public transit trips to or from park & ride facilities, or walking for shorter first-last mile trip segments.

Fixed-Route Service	Transit services that travel along a predetermined pathway and allow onboarding and off-boarding at predetermined stops along the route.
Flexible Service	A broad category of hybrid services that combine pure demand responsive services and fixed-route services. They often have established stop locations and/or established schedules, as well as elements of demand responsive operation. (Li & Quadrifoglio, 2010)
Microtransit	Shared public or private sector transportation services that offer fixed or dynamically allocated routes and schedules in response to individual or aggregate consumer demand, using smaller vehicles and capitalizing on widespread mobile GPS and internet connectivity. Because they provide transit-like service but on a smaller, more flexible scale, these new services have been referred to as “microtransit.” Also referred to as dynamic shuttles, or private flexible transit. (Feigon & Murphy, 2016; Volinski, 2019). Per discussions with Metro advisors, the variants on the term flexible services were used for the purposes of this analysis rather than microtransit.
Service Cannibalization	Induced changes in travel mode patterns from fixed-route public transit services to an alternative public or private mode of shared travel (e.g. private rideshare or public flexible on-demand transit).
Transit Accessibility	The ease of reaching goods, services, and destinations. The Transit Accessibility score measures— in relative terms and on average—how poor the accessibility is to jobs and community assets in the area surrounding each transit connection location (TCL). For this analysis, a high Transit Accessibility score indicates high need and low accessibility.
Transit Trip	The one-way travel of a public transit vehicle in revenue service between an origin and a destination.
Unmet Need	“Areas with high density, a high proportion of low-income people, people of color, people with disabilities, and members of limited-English speaking communities; and limited mid-day and evening service” ((King County Metro Transit Department, 2019b). This definition was adapted for this analysis to focus on the components of priority populations and low transit accessibility.

1. Introduction

A timeless challenge for public transit agencies is balancing service coverage (the overall area that can be accessed via public transit) with ridership. Traditionally, fixed-route transit services, such as traditional bus service, light rail, and heavy rail trains, have been operated on a hub and spoke model that is designed to primarily serve the areas with the highest population and commercial density. Transit agencies tend to invest in higher service frequency and reliability along high ridership transit corridors in order to maximize ridership and accumulate the highest return on their investment. As these services extend into areas with less population density, their operational efficiency significantly decreases, which lead to a higher cost-per-mile-traveled and often mark these portions of routes as the first to be eliminated in budget decreases (King County Metro Transit Department, 2015). This financial incentive competes with public transit agencies' charge to provide transportation to all who need it. The goal of providing high transit coverage places an emphasis on the socioeconomic benefits that public transportation provides: accessibility to community resources and places of employment (Walker, 2008). However, transportation investment is a zero-sum game, and investing in transit network coverage has traditionally been difficult to financially justify due to the desire to invest in speed and reliability improvements along the highest-ridership routes.

Decisions about how to distribute resources according to these goals has no clear technical answer, but is a question of competing values, and one with which transportation officials often struggle. Like many other public transportation agencies, King County Metro Transit (Metro) must also continuously navigate the balance between different and often conflicting transportation needs. Over the past three years King County has become increasingly interested in employing "flexible transit" service options as a way to fill gaps in the fixed-route network, provide new mobility options, and better meet coverage goals. Unlike traditional fixed-route transit, flexible transit include hybrid services that can offer variations of two operational models: 1) fixed route, fixed schedule, and 2) flexible route with on-demand scheduling (Shaheen et al., 2015). Although flexible services have existed for decades, innovations in technology and service delivery models have enabled the rise of more nimble public mobility options that closely resemble the ride-hailing services provided by private companies like Uber and Lyft. Because these flexible services can be tailored to meet various mobility needs, transit agencies are deploying these services in various forms to alleviate tensions around service prioritization. However, the relative novelty of these service models in the United States has left public transit agencies—including King County Metro—struggling to develop standard planning criteria to guide decisions on service deployment locations.

Currently, Metro's flexible services are managed by the Innovative Mobility, Contracted Services, and the Service Planning teams. Between October of 2018 and March of 2020, the Innovative Mobility team has piloted on-demand feeder-to-fixed route shuttles in three geographical areas of the county (King County Metro Transit Department, 2019c). These pilots involve user-requested shared vehicles that operate with dynamic routing that stop somewhere within walking distance of the rider, and takes them either to or from a transit hub (King County Metro Transit Department, 2019c). This work focuses on flexible transit service that has dynamically determined routes and schedules based on consumer demand and follows a feeder-to-fixed route (F2FR) service model. Although there are other flexible service models, the work herein focuses on the feeder-to-fixed route (F2FR) flexible service being piloted by the Innovative Mobility team, which uses on-demand dynamic routing to feed people into the existing fixed route transit network. While Metro provides other flexible transit services, the Innovative Mobility team is specifically tasked with developing strategic recommendations and integration frameworks to advance mobility solutions that can be used by other teams at Metro. Given this positionality, the Innovative Mobility team and its F2FR flexible services are well-suited for adopting new analytical frameworks, both in the value it can add to its own services and for its potential to serve as a model for other Metro flexible services.

One of Metro's new guiding documents, the Mobility Framework, was released in October of 2019 and charts a path for Metro to prioritize new transit service in the county, including how to provide more emerging services like F2FR flexible service. Notably, one of the Mobility Framework's top recommendations is to "invest in and measure the outcomes of public transportation services and improvements in geographic areas and at times of day in which there is unmet need, particularly as experienced by low- and no-income people, people of color and indigenous people, immigrants and refugees, people with disabilities, and limited- English speaking communities" (King County Metro Transit Department, 2019b). Recently King County Council directed Metro to update its policy documents in order to reflect these and other recommendations in the Mobility Framework. Although there is a clear drive and directive to prioritize service to those who would benefit most from it, Metro's flexible service planning process haven't yet incorporated a systematic approach to ensure that these aims are being pursued. Closing this gap is critical to ensuring that Metro prioritizes service in a way that aligns with stated policy priorities.

The Mobility Framework presents a set of recommendations for how to prioritize flexible service, including a set of initial prioritization criteria that will be used in this work. The base spatial analysis model produced in this work represents an approach to operationalizing the Mobility Framework recommendations for a specific flexible service type. The policy questions considered also create space to directly consider the implications of selecting certain criteria and designating thresholds or weights, in order to guide future adaptations of this work and application to other flexible services.

Ultimately, this work is guided by the following central questions:

1. What criteria should Metro use to identify future areas for piloting F2FR flexible services, using Metro's Mobility Framework as a guide?
2. Which areas of the county meet these criteria?

1.1 Fixed-Route Transit

It's important to discuss F2FR flexible transit relative to other forms of public transit, in order to contextualize its role in the overall transportation system. Public transit has historically taken the form of fixed route service, such as fixed bus routes, commuter rail infrastructure, and ferries (Shaheen et al., 2016). Fixed-route transit is the workhorse of any public transportation network, and will likely remain the primary mode of travel offered by public transit agencies. The "fixed" nature of fixed-route transit provides a certainty in destination, in operation timetables, and at least partially in operational costs for the agency. High capacity vehicles used for fixed-route transit also provide a significant benefit to public rights of way; by having the capacity to fit upwards of 50 people (who would otherwise have likely traveled solo in an automobile) into a single bus, buses are a powerful tool to combat roadway congestion and air pollution. However, fixed-route transit services are limited by high up-front capital costs, relatively static infrastructure installations, and significant labor costs. Therefore, the financial sustainability of fixed-route services usually requires the service network to be limited to high density urban centers and corridors (Walker, 2008). Transit agencies aim to maximize a transit network's capacity, versatility, and coverage by building hub and spoke systems where transfers between multiple routes and modes can occur at transit hubs, placed in the highest density urban centers within a transit network's coverage zone. The goal then is to feed routes--and riders--through these transit hubs. For transit hubs located in more suburban areas, the primary barrier to entry into the transit network is traveling to and from the transit hub. The accessibility to these hubs has traditionally been wholly reliant on riders' personal travel abilities, whether walking or cycling to a subway stop or driving a personal vehicle to a park & ride lot next to a bus rapid transit (BRT) station.

Attracting sufficient ridership in suburban areas has been problematic because suburban residential areas usually do not meet the initial density threshold necessary to financially justify any significant number of “spoke” bus routes feeding into the main transit hubs (Boarnet et al., 2017). Transit agencies have been trying to circumvent this problem by constructing suburban park & ride infrastructure at high capacity transit hubs to attract more public transit ridership along transportation corridors. However, in areas like King County where urban and even suburban property values are at a premium and undeveloped lots are scarce or nonexistent along key travel corridors, the financial and physical capacity for increasing park & ride capacity is very limited (Ong, 2019). Access to transit is also more challenging for people living in areas with geographic or topographic obstacles, or with a lack of pedestrian infrastructure and bike lanes (King County Metro Transit Department, 2019b).

Recently, new options have emerged to connect people to the existing transit network that aim to gain efficiency over more rigid service types. Among other advantages, flexible transit services can be implemented and retooled faster than fixed-route services, they circumvent issues of poor pedestrian infrastructure and insufficient parking at park & rides, and they leverage private sector technology and business models. Public transit agencies and private mobility enterprises have begun harnessing emerging technologies (namely, the mass spread of mobile phones equipped with GPS, service apps, and dynamic algorithms to match supply and demand for trips) to experiment with these new flexible strategies (Shaheen et al., 2015). These demand-responsive rideshare and public transit options can be used to bridge the “first mile and last mile” gap between people’s homes, workplaces, and trip destinations and the existing fixed-route transit network.

1.2 Flexible Demand-Responsive Transit

Over the past fifteen years, public transit agencies and private transit innovators alike have become increasingly interested and invested in flexible transit services to complement traditional fixed-route public transit services. These investments in flexible transit services are part of a growing movement to bring about the realization of the concept of "Mobility-as-a-Service" (MaaS), which is the concept of a fully integrated system of transportation services through which people can seamlessly onboard, travel, switch service modes, and then off-board at their desired locations (Kanda & Taylor, 2019). In many ways, the rise of the gig economy fomented the transformation of urban transportation. Rideshare, carshare, bikeshare, and other sharing economy companies that have invested in the transportation industry have filled temporal and spatial gaps left by public transit agencies.

Demand-responsive flexible service—an emerging transit service often operating within a set geofenced area that offers dynamic routing and scheduling— has emerged as a possible solution to the limitations of fixed-route transit. These public rideshare services can supplement fixed-route transit service by increasing a network's overall coverage areas without the up-front cost of infrastructure investments (Feigon & Murphy, 2016; Westervelt et al., 2018). The dynamic nature of these services also allows transit agencies to make rapid alterations to these services' operating areas, span of service, and pathway orientation (focusing on only peak commute direction or inbound/outbound service) (Alonso-González et al., 2018).

Transit agencies have implemented demand-responsive flexible services in one of two ways. Some services are oriented to provide feeder-to-fixed route (F2FR) service to transit hubs where "spoke" fixed-route service is insufficient or nonexistent (Hernandez, 2018). Other agencies have replaced underperforming fixed transit routes with demand-responsive flexible service areas (Westervelt et al., 2018). Recent technological advances and proliferation in GPS systems, cellular technology, and dynamic algorithmic modeling have made the expansion of different models of demand-responsive flexible service all the more feasible (Shaheen et al., 2015). However, locational decisions and performance evaluation of these types of services has not yet been standardized or optimized, and implementation has been ad-hoc and largely based on individual services capabilities and the contracted company's performance (Ong, 2019; Walker, 2008).

1.2.1 Flexible Demand-Responsive Transit Models

F2FR transit is one of many flexible demand-responsive transit models that exist in the United States, and one of a few different models employed by King County Metro Transit. Service models differ primarily in their flexibility in trip scheduling and their flexibility in routing, but a common theme is that these types of services are most often deployed to meet public transit coverage goals as opposed to transit ridership goals. Trip schedule flexibility varies primarily along a spectrum of responsiveness to customer demand. Flexible transit services that are less able to dynamically respond to customer demand, like King County Metro's Access Transportation paratransit service, require riders to book a trip at least 24 hours in advance (King County Metro Transit Department, 2020a). On the most flexible end of the spectrum are real-time demand-responsive flexible services like Via to Transit (Via) and Ride2 that generally pick up a customer within 15 minutes of the trip request and closely resemble the models of private rideshare services like Uber and Lyft.

Route flexibility varies in dynamism, ranging from a fully fixed route all the way to "fully dynamic routes that adjust in real time based on traffic and demand," (Shaheen et al., 2015). A key component of route flexibility is stop location flexibility. Flexible services like AC Transit's "Flex" operate at fixed bus stops for the origin and destination of trips, but the routing has real-time flexibility based on customer demand (AC Transit, 2020). Other services, like King County Metro's Via to Transit services, only allow one end of a trip to be flexible while requiring the trip to begin or end at a set transit hub within the service area (Via Transportation Inc., 2020).

Another goal-driven service design element would be to designate multiple access points within a service area—these could be key community assets like schools, grocery stores, medical facilities and social service centers—and, similar to Metro's current Via to Transit services, require trips to begin or end at one of these specified locations while allowing complete flexibility for the other stop in the trip within a designated service area. On the most flexible end of the stop location flexibility spectrum are services like King County Metro's Community Ride that allow complete stop location flexibility for a trip's origin and destination within a designated service area (King County Metro Transit Department, 2020b). The other key component of route flexibility is the set service area. While this component's variability does not readily fall along a linear spectrum, it should be noted that service area design can greatly influence a service's flexibility in routing and in trip scheduling.

The first publicly planned and operated flexible demand-responsive transit services were created as a solution to meet Title II of the Americans with Disabilities Act of 1990, which prohibits disability discrimination by all public entities at the local, state, and federal level. This led to U.S. transportation agencies deploying the first flexible demand-responsive services to people with disabilities who were unable to use the fixed-route transit system near them. In practice, transit agencies are required to provide paratransit service within ¾ of a mile of an existing fixed public transit route (King County Metro Transit Department, 2020a). While these services are demand-responsive, they are one of the least request-responsive demand-responsive transit service models; King County Access paratransit service requires customers to request a trip at least a day in advance, and service delivery time is variable (King County Metro Transit Department, 2020a).

"Dial-A-Ride" (DART) transit routes have some limited route flexibility, while maintaining fully fixed schedules (King County Metro Transit, 2020c). These hybrid flexible-fixed transit services are offered by King County Metro Transit. DART services are primarily located in suburban areas with lower population densities, greater distances between points of interest, and fewer public transportation options than surrounding, denser-populated areas. While primarily a low-capacity fixed-route service, these services—operated by a third-party contractor—have limited route deviation abilities in designated areas in order to respond to scheduled customer requests. While DART routes have some limited route flexibility, these services have fully fixed schedules (King County Metro Transit Department, 2020c).

King County Metro's Community Ride flexible transit service allows the most route flexibility out of any of Metro's flexible transit services; Community Ride provides door-to-door service for any combination of origins and destinations throughout a specified service area. It also operates more responsively than Access Transportation and DART (King County Metro Transit, 2020b). The four Community Ride service areas were developed through the Community Connections outreach process that is managed by the Service Planning team. Each Community Ride service varies in span of service and service area size according to localized demand and the service's intended utility for the given community, but all service areas require a customer to book their trip at least two hours in advance. Via to Transit is the most schedule-flexible (and the second-most route flexible) transit service provided by Metro. It is a pilot flexible on-demand public transit service that operates as a public-private partnership between Via Transportation, Inc. and King County Metro's Innovative Mobility team. This service is classified as a F2FR transit service, and the five service areas are oriented around transporting riders to and from Sound Transit Link light rail stations. The wait time between a customer requesting a trip and the vehicle picking up the customer is on average under 10 minutes, which puts the service in direct competition with private ridesharing services like Uber and Lyft. Much like the Community Ride services, trip pathways for this service are continuously optimized to respond to real-time demand.

Where a given flexible service falls along each of the spectra of schedule and route flexibility determines its general typology. It's important to note that multiple typologies can exist within one flexible service program, especially for flexible services that are tailored to localized community needs. These can be generalized into three main types:

a) Point to a Hub – characteristic of feeder-to-fixed route services, anchored to single or multiple points of origin or destination.

b) Hub to Hub – not only characteristic of feeder-to-fixed route, but inclusive of intra-community mobility connections, with a limited set of origins and/or destinations.

c) Point to Point – the most flexible, with unlimited origins and destinations within a defined service area.

The flexible services managed by King County Metro Transit vary in other ways besides their typologies; service planning processes for flexible services can fundamentally shape service characteristics. At Metro, the Community Connections outreach process that has produced flexible service pilots managed by the Service Planning team differs from the planning process used by the Innovative Mobility team, and these differences stem from each team's service mandate and planning framework. While flexible and fixed-route service planning have historically been done separately, the flexible services managed by the Service Planning team have more recently shifted to approach flexible service planning in a manner closely resembling that used for fixed-route service planning initiatives at King County Metro. Data-driven initial findings are combined with associated planning work for related fixed-route service planning projects. This foundation directs the extensive community engagement which is a primary input for locating, designing, and right-sizing the Community Connections outreach process that guides flexible service projects. Alternatively, Innovative Mobility service projects have historically focused on iteration, evaluation, internal and external project collaboration, and “failing fast” in order to achieve continuous improvement. In practice, this means that the services planned and managed by the Innovative Mobility team are more quantitatively driven and less focused on community engagement during the initial service planning process. Moving forward, the two teams intend to align planning processes to more efficiently implement flexible services in order to best address needs for service. In the meantime, the Innovative Mobility team and its F2FR flexible services are well-suited for adopting new analytical frameworks, both in the value it can add to its own services and for its potential to serve as a model for other Metro flexible services.

1.2.2 Feeder-to-Fixed Route Service

Current practice in King County and most other metropolitan areas across the US is to implement flexible transit services as first-last mile— or feeder-to-fixed-route— solutions in areas where providing frequent, all-day fixed route service is not financially or physically feasible (Hernandez, 2018; King County Metro Transit Department, 2019c). In other areas, F2FR flexible service has completely replaced underperforming bus routes or has been implemented to provide public transit in areas that historically have had very minimal access to public transit (Westervelt et al., 2018). Selecting which application to implement has meaningful implications for the role that innovative and flexible services play in a city’s transportation system.

While F2FR and complete replacement models are sometimes used in tandem to meet different needs within a jurisdiction, F2FR tends to be the application most often chosen by transit agencies (Li & Quadrifoglio, 2010). In the United States, Pinellas Suncoast Transit Authority (PSTA) in Florida was the first to provide service using the F2FR model, and other transit agencies have since piloted similar programs, including King County Metro, Pierce Transit in Pierce County, Tri-Met in Portland, LA Metro, RTD in Denver, and VTA in Santa Clara (Murphy et al., 2019; Ong, 2019). It’s important to note that the analysis conducted here is catered specifically to the F2FR model— the type of flexible service that the Innovative Mobility team has piloted thus far. As discussed in Section 1.1: Fixed-Route Transit, the intent of this model is to close gaps in transit service, and feed riders into the existing fixed-route system without "cannibalizing transit." Transit cannibalization in this case refers to the *unintentional* shift of riders from fixed-route services to a flexible demand-responsive service, likely due to the appeal of a faster and more convenient commute option. This contrasts with the complete replacement models that *intentionally* aim to replace a poor performing fixed-route service.

While there is limited published work using predictive analysis or analyzing the measurable impacts of transit cannibalization by a public agency's flexible services— there have been studies on the impact of service provided by private ridehailing companies. Some studies suggest that the services provided by Transportation Network Companies (TNCs) directly compete with public transit trips (Erhardt et al., 2019). However, these studies do not consider services that are provided through partnerships with public agencies or the specific service models like F2FR that aim to minimize this impact. In looking at Metro's F2FR flexible services themselves, there is some limited indication that transit cannibalization may be occurring. Preliminary survey data from Via riders indicate that after Via became available in South Seattle and Tukwila there was a 7% shift away from using fixed-route public transit as a mode to get to and from Link stations.[1] However, this same data indicates that 22% of Via survey respondents did not previously use light rail for their typical travel trip and were new users. While self-reported survey data on mode shift behavior alone is insufficient to make conclusive determinations about transit cannibalization, these results suggest that Metro F2FR flexible services may be replacing some previous fixed-route trips, but that this may be offset by new transit users. Additional analysis is needed to identify the prevalence of transit

[1] Survey data was collected in September of 2019, with 731 responses collected.

cannibalization among flexible services, especially F2FR services, and the specific criteria for locating service that may prevent it from occurring.

In the absence of conclusive research on transit cannibalization, Metro must use the takeaways from its Innovative Mobility pilots to date to optimize future services that feed people to fixed-route services. Some of these findings have informed or confirmed the criteria selected for this work. For example, the Innovative Mobility team's pilots show that services provide the most value when they significantly improve access to jobs compared to existing fixed-route services (King County Metro Transit Department, 2019a). It's important to note that all of Metro's flexible service variations lean towards addressing coverage goals rather that ridership goals, and are primarily framed as a mobility option meant to increase transit accessibility. The key component of this is connecting people to very frequent service such as light rail or areas with concentrations of bus routes. Pilot data during its initial six months of service shows that 25% of all Via rides began outside a 0.5 mile buffer of the frequent network. This suggest that a significant proportion of people are benefitting from the service who don't live within an easy walking distance of fixed route service and may not normally be able to access it. Similarly, as stated above, preliminary survey data indicates that a significant proportion of Via survey respondents were new users of the light rail station. These findings reinforce the understanding of F2FR flexible services as providing the most benefit specifically where and when local transit service is poor, and where gaining access to frequent fixed route transit is needed. In this way, it can fill a gap in the transit network without threatening existing public transit. Additional descriptions of the criteria that align with these findings can be found in Section 3.1: Base Model and Section 3.3: Alternative Models.

2. Relevance of the Work

2.1 King County Metro

This work is geared towards specific applications for King County Metro's Innovative Mobility and Service Planning teams. It is important therefore to discuss the relevance of this work to those teams.

2.1.1 Service Planning

The Service Planning team at King County Metro is primarily tasked with planning updates to regional transit services and the policies guiding service provision. The most extensive service updates are Mobility Projects, which can involve a year of iterative planning, community engagement, and evaluative processes before the final package of service updates is brought to King County Council for approval. The scope of a Mobility Project typically encompasses all fixed-route and flexible transit services within a given geographic region of King County. For example, the Renton-Kent-Auburn Mobility Project updated service for most of South King County, which encompasses around 200 square miles of King County. These updates can include, but are not limited to: introduction of new routes, removal of underperforming routes, alteration to existing route pathways, changes in span of service, changes in service frequency, identification of priority areas for future flexible mobility services, and planning of capital improvements to accompany these service changes. Prior to 2018, the planning processes for flexible service options were conducted entirely independent of fixed-route network planning. The planning for flexible services took place in a work group called Alternative Services, which was located outside of Service Planning. Since then, the Service Planning team has absorbed the Community Connections outreach process and associated staff in order to better integrate these processes. While this move effectively positioned some flexible service planning and fixed route planning processes to occur within the same team, the planning processes still operate separately from the flexible services managed by the Innovative Mobility team. As King County Metro continues its shift towards operating as a “Mobility Agency” with a broader mandate of integrated service, the Service Planning team has expressed interest in improving the network-wide service planning process by uniting the planning processes for all fixed-route and flexible-route transit services.

The Service Planning team’s policy work centers on updating Metro’s key service policy documents, such as Metro Connects, the Strategic Plan, and the Service Guidelines. The Strategic Plan highlights challenges and opportunities facing the region and presents a 10-year plan for addressing these challenges and opportunities. This planning document was originally adopted in 2011 and was updated in 2016 (King County Metro Transit Department, 2016b). Metro Connects is King County Metro’s long-range, 25-year, planning document that builds upon the Strategic Plan and contains details on the long-term capital investment plans to improve speed and reliability, innovation and technology, passenger facilities, access to transit, demand management, and transit-oriented development (King County Metro Transit Department, 2016a). The Service Guidelines contain specific technical guidance for implementing the broader Strategic Plan and Metro Connects policies on fixed-route and flexible transit planning and operating processes. These policies span everything from criteria used to determine geographic levels of service to the levels of community engagement required during service revision planning (King County Metro Transit Department, 2015). The Service Planning team also manages the transit network in a number of other ways, including performance monitoring and capital project restructures.

2.1.2 Innovative Mobility

King County Metro's Innovative Mobility team is responsible for planning, managing, and evaluating pilot programs that provide demand-responsive flexible connections to transit, among other pilot programs. While demand-responsive flexible services are a shared transportation system that can have either fixed or flexible routes and schedules, Innovative Mobility's pilots have fully flexible routing and scheduling (King County Metro Transit Department, 2019c; Westervelt et al., 2018). These pilots involve user-requested shared vehicles that operate with dynamic routing that stop somewhere within walking distance of the rider, and takes them either to or from a transit hub. Because these pilots connect people to transit hubs, the specific model that the Innovative Mobility team employs for these flexible services is "feeder-to-fixed route."

Between October of 2018 and March of 2020, the Innovative Mobility team has piloted feeder-to-fixed route flexible services in seven geofenced services within three geographic areas: West Seattle, Eastgate, and Southeast Seattle and Tukwila (King County Metro Transit Department, 2019c). The two Ride2 pilots in West Seattle and Eastgate have since been ended after the one-year pilot concluded in December of 2019. The Via to Transit pilot in Southeast Seattle and Tukwila was suspended in March of 2020 as part of the COVID-19-induced Metro service reductions. The pilot service was subsequently reinstated and extended for a second year in June of 2020 for three of the service areas: Tukwila, Rainier Beach, and Othello (King County Metro Transit Department, 2019c). Metro's Innovative Mobility team has continued to apply for funding grants for new F2FR flexible services for King County, as well as consider new ways to leverage flexible on-demand services in other service reduction scenarios and using other models besides F2FR. The applicability of this work will be further addressed in the Section 5.3.2: Applications to Service Reduction Scenarios.

While the high-level locational decisions for these pilots have been kept within the agency, the contracted service companies have been granted some authority to identify and test the performance of specific service areas. When initiating the Via to Transit pilot, Via's proprietary modeling did not consider one of the service areas within Southeast Seattle as a viable service area (King County Metro Transit Department & Via Transportation Inc., 2020). Metro later decided to include this area as part of the pilot, and it became the area with the highest ridership. This oversight has led to increased discussion about the goals and priorities underlying selection of service areas for F2FR flexible service pilots, and the drive to systematize this process. While operation of flexible services will most likely remain with contracted service providers, King County Metro's preference is to assume responsibility for the service planning, modeling, and evaluation of its F2FR flexible services and perform these tasks in-house. Based on conversations with service planners at King County Metro, there is a push to create a more systematic, integrated approach to planning the wide array of transit services provided by Metro.

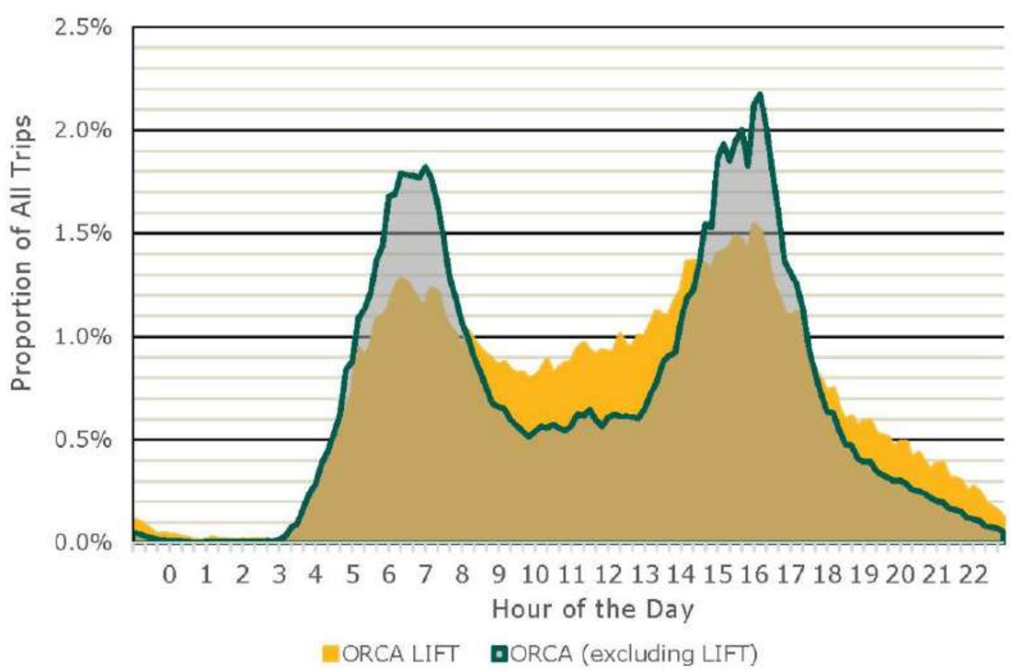
For Metro, better aligning policy goals, locational suitability analysis, and implementation of F2FR flexible services is crucial to its shift toward becoming a mobility agency. Metro intends to simultaneously be a "provider of fixed-route public transit and community-based mobility services; an employer and contractor; a partner to jurisdictions around the region; a co-provider of services with private mobility companies; and part of a local government that prioritizes equity and sustainability" (King County Metro Transit Department, 2019b). In order to balance this complex array of duties, Metro envisions itself as a manager of services that fit into a larger mobility network that is reliant on partnerships with other agencies and private companies. It is this vision that is expressed in the Mobility Framework which directly calls for increased innovation in the way in which need is met.

2.1.3 Mobility Framework

The King County Metro Transit Department is in the process of applying a new framework to guide future service provision of flexible public transit and other mobility options. This new vision begins with the recently published Mobility Framework, which was released in October 2019 (King County Metro Transit Department, 2019b). The Framework was community-led and co-created by the King County Mobility Equity Cabinet, which was a group of 23 community leaders tasked with helping Metro imagine its role amidst the rise of new technology and mobility options (King County Metro Transit Department, 2019b).

The work in the Mobility Framework is grounded in the belief that “mobility is a basic human right that allows communities and individuals to access the opportunities needed to thrive” (King County Metro Transit Department, 2019b). It contends that striving for mobility equity is inextricable from other efforts to respond to trends of government investments that have resulted in disproportionate negative health and economic impacts for certain communities (King County Metro Transit Department, 2019b). Indeed, the Framework begins by explicitly acknowledging that low- and no-income people, people of color and indigenous people, immigrants and refugees, people with disabilities, and limited- English speaking communities have benefited the least—and in many cases have been harmed—from the rapid changes in employment, housing, and transportation infrastructure in the Puget Sound region (King County Metro, 2019a). As a result, as the cost of living has risen more rapidly than wages, many of these people have been forced to spend greater proportions of their income on housing and transportation, which are two of the three top drivers of wealth (King County Metro Transit Department, 2019b). In particular, rising costs have led to the economic displacement of low-income households from more expensive areas to less-dense neighborhoods that have less access to frequent, fixed-route transit service. This means that people must travel longer and farther to access the jobs, schools, or other services they need. Transit inequities are further compounded given that low-wage jobs often require employees to travel for shifts during off-peak transit hours, and are often not located in employment centers that are well-served by transit (King County Metro Transit Department, 2019b). Travel patterns for lower income households differ from the County as a whole, with higher demand for transit during the midday and evening periods, as shown by the comparisons of ORCA bus trips in Figure 1. To clarify, ORCA LIFT fares are reduced public transit fares available to those whose annual income is below 200% of the federal poverty level (King County Metro Transit Department, 2020d). Accessibility to jobs and services during these time periods is not as extensive as during the traditional peak periods, as shown Figure 7 and Figure 8 in Appendix A. Figure 7. Given the need to address the multi-faceted issues surrounding mobility equity, a new agency-wide approach to prioritizing transit service has emerged, to focus in particular on serving priority populations in the areas and during the times of day where there is the most unmet need.

Figure 1: ORCA Bus Trips by Hour of the Day



Source: (King County Metro Transit Department, 2019b)

The Framework also acknowledges that the current regional transit network is primarily oriented towards serving commuters along established transit corridors. In a region like King County—where human-powered travel is significantly limited in many areas by quality of pedestrian infrastructure, wheelchair-accessible infrastructure, safety infrastructure, and geographical features—institutional spending patterns have caused inequities in accessibility to transportation, especially for first-last mile connections. As one of its recommendations, the Mobility Framework calls for investments in safety improvements that specifically add first-mile last-mile mobility services that benefit marginalized groups (King County Metro Transit Department, 2019b).

In light of these inequities, the Mobility Framework provides a new paradigm for service provision and expanding the transit network. Indeed, in order to accommodate projected regional growth, Metro anticipates expanding its transportation network by 70 percent, or by 2.5 million service hours, between 2017 and 2040 (King County Metro Transit Department, 2016a). The Framework recommends a focus on more equitable allocation of this projected service increase, and specifically on serving areas with the most 'unmet need.' It considers unmet need as the intersection of areas with both high concentrations of priority populations and with low off-peak transit accessibility to jobs and community assets. Areas with low levels of midday and evening transit service and accessibility are considered as time periods with the most unmet need. Priority populations are identified as the communities that are disproportionately experiencing the inequities of growth, including "low- and no-income people, people of color and indigenous people, immigrants and refugees, people with disabilities, and limited-English speaking communities" (King County Metro Transit Department, 2019b). Consistent with goals in Metro Connects to expand opportunities for people to access jobs, education, and other destinations through frequent all-day transit options, the Mobility Framework specifies that unmet need also includes low transit accessibility to jobs, schools, medical services, and social services.

As one strategy to address the inequities of this growth, Metro intends to foster partnerships with public and private entities to create one interconnected system that provides all-day mobility (King County Metro Transit Department, 2016a). By offering a menu of mobility options, the network would cater to many different needs and travel patterns. The Framework calls for investment in innovation and for the expansion of the region's portfolio of flexible demand-responsive services like F2FR (King County Metro Transit Department, 2019b). It recommends that the broad array of services focus in particular on serving unmet need. The framework includes preliminary criteria and spatial analysis to guide flexible service provision. Figure 7: Alternative Services Opportunities Composite: High Concentrations of Priority Populations, Low Off-Peak Access, Population Density between 4 and 15 people per acre in Appendix A shows the priority areas that were identified within the county.

King County Council has mandated that Metro use the Mobility Framework to direct the updates of many of its guiding documents. These include its Service Guidelines, its long-range plan: Metro Connects, and its Strategic Plan. It is important that any recommendations for updates to the Service Guidelines align with the Mobility Framework. Given that our work directly aims to inform planning processes as well as updates to the 2020 Service Guidelines, we aim to explicitly align with the vision and service provision paradigm expressed in the Mobility Framework. However, while the Mobility Framework offers a robust roadmap for Metro's future service priorities, it does not provide guidance that is specific to each flexible service model. Given important distinctions in the goals across demand-responsive flexible services and among service models, this work evaluates and selects the criteria that are most applicable to feeder-to-fixed route flexible transit.

2.2 Serving Those with the Greatest Need

The Mobility Framework's prioritization of those with the most "unmet need" is rooted in equity and justice theory dating back to the 1970s. Although not first among theorizers of social equity and distributive justice, John Rawls' work was foundational to modern theoretical underpinnings of equity with his conceptions of how market-based benefits and burdens are distributed among members of society. In his landmark work, *A Theory of Justice*, John Rawls directs public institutions to plan and provide services first to those with the most need in order to maximize public benefit (Rawls, 1971). He directly refuted prevalent utilitarian theories of the time and developed a moral theory that institutions that are built to combat the "accidents of natural endowment and the contingencies of social circumstance" (Rawls, 1971), which is to say the differences in people's starting places in life. Timothy Beatley expands on Rawls' work by calling out the need to tease out the intricacies of what it means to have need and who falls into the group of people with the greatest need (Beatley, 1988). Though the limitations of these works have since been raised and debated (Blanchard, 1986; Hayek, 1976; Lister, 2013; Nozick, 1974), adaptations of Rawls' foundational principles can be found in more modern equity-based theories across fields, including the field of transportation (Pereira et al., 2017). Applicable theories are discussed in greater detail in Section 2.3: Transit Accessibility.

It is important to be precise about what is meant by equity, and how these discussions of need relate to the vision represented in the Mobility Framework. As discussed in Section 2.1.3, the Mobility Framework conceives of mobility as a human right, with mobility equity positioned to respond to the disproportionate negative health and economic impacts wrought by public institutions on low-income communities of color. In this way equity, or vertical equity, is distinguished from equality, or horizontal equity, in which all individuals are treated equally and are expected to equally share benefits and burdens. In contrast to equality, equitable policies typically strive to acknowledge the existence of positionality among different identities, particularly as applied to race/ethnicity. As Litman summarizes, “policies are equitable if they favor economically and socially disadvantaged groups in order to [compensate] for overall inequities” (Litman, 2020). In line with this understanding of equity, the Mobility Framework explicitly identifies groups that are considered to have historically been inequitably served, and that should be actively prioritized moving forward.

For the practical purposes of this project, King County Metro’s definition of those with the greatest need has already been set forth by the creators of the Mobility Framework; those with the greatest (or unmet need) in King County have low transit accessibility to jobs and community assets and are the priority populations identified above. The Mobility Framework has also enabled easier identification of areas in which these communities are concentrated by including block group level census data analysis, in order to better plan for future service provision (King County Metro Transit Department, 2019b). This work has taken the abstract notion of serving those with unmet need into the realm of quantifiable analysis, which can now be used in tangible analyses like the one herein.

2.3 Transit Accessibility

Although not addressed at length in the Mobility Framework, transit accessibility underpins its vision for mobility equity, as well as much of the current work being done at King County Metro within the Service Planning and Innovative Mobility teams. As discussed, the Mobility Framework analysis identifies areas with low transit accessibility to jobs and community assets as one of the two components of unmet need. The use of transit accessibility analyses as an approach for modern transportation planning is now fairly widespread, and as Todd Litman puts it, “the ultimate goal of most transport activity is accessibility, which refers to people’s ability to reach desired services and activities” (Litman, 2020). Though this end goal may seem implicit, using accessibility as a success metric for a transportation system contrasts with traditional models of transportation planning, which have tended to measure the operations of the system (speed, level of service, frequency, road capacity). In contrast, accessibility measures shift attention to the users of the service, and relate more to the distributive questions of transportation (Martens & Golub, 2012). Working to increase transportation accessibility can therefore help address the gaps in service created by the mobility inequities summarized here and highlighted in the Mobility Framework.

Transportation accessibility analyses can be a powerful tool to apply a social equity lens to transportation system planning. As discussed in Section 2.1.3, transportation disadvantages, or inequities, impact vulnerable communities most, and in multi-dimensional ways. People who are transport disadvantaged can be understood as those who need transit but who cannot access it (Murray & Davis, 2001). In modern transportation equity studies, transportation disadvantage has been linked to social inequality and poverty, and can be traced to mobility barriers that limit accessibility to opportunity and relevant amenities (including jobs, education, healthcare, and other services) (Delbosc & Currie, 2011; Lucas, 2012). Mitigating these disadvantages by increasing accessibility to opportunities is the very place where accessibility analyses can be leveraged.

Accessibility can be conceived of as a measure of how the benefits of transportation plans and investments are distributed (Martens & Golub, 2012). Measuring these benefits is the role of public agencies like Metro because as discussed, public institutions have played a direct role in creating the inequitable distribution of burdens like mobility barriers. John Tomasi's work on economic liberty can be applied to the argument for government's role in addressing these impacts. Tomasi argues that each individual has the right to set out life plans for themselves, but that that "the very status of people as responsible self-authors may be threatened by conditions of extreme need" (Tomasi, 2012). The conditions of extreme need he refers to can be understand as the product of what Rawls termed the accidents of natural and social circumstance. This inequity is what Rawls aims to combat with his theory, and what Tomasi suggests falls to government to address.

Transportation disadvantage and its associated accessibility barriers can be addressed by public entities with appropriate policy frameworks in place. The Mobility Framework serves this role for Metro, and dictates the steps and approach that Metro should take moving forward. Part of that approach includes guidance for prioritizing how to distribute the benefits of new service by using tools like accessibility analyses. This is an analytical approach that has become indispensable to the research and practice work within the transportation field, and also closely aligns with the work in the Mobility Framework and guides the approach taken here.

2.4 Policy Gaps

This work is consistent with the guidance in the Mobility Framework to prioritize future service provision for those with unmet need. In spite of the direction provided in the Mobility Framework, there are still policy questions that need to be clarified around the role of flexible on-demand service given that the technology, partnerships, and service models that are crucial to providing these services are still in their nascent stages in the United States. Answering these policy questions is not the intention of this work, but rather the intent is to provide models and a framework for considering the relevant questions that can help clarify priorities and the applicability of service models. The underlying elements of these questions are discussed throughout this work, and summarized succinctly below. Ultimately, the primary questions around flexible on-demand service provision for King County Metro and other transit agencies are about its intended beneficiaries and its specific place in the greater regional transit network. In summary:

1. Who should be prioritized for service?
2. What types of destinations should be prioritized?

3. When should service be provided?
4. Which service model is most appropriate?

The first question considers who the intended beneficiaries of the service are. While the equity cabinet has called for prioritizing providing new service to groups with the most unmet need (priority populations), it's important to consider the relative weighting attributed to each group. For example, in the Mobility Framework's Alternative Services Opportunities Composite analysis, each of the five priority population sub-groups are weighted equally. However, additional work is explored here and is also being done within Metro in which this weighting is shifted to more closely align with King County's stated equity goals, as discussed in Section 3.3.2: Scenario 2: Priority Population Index Weighting Variation. Similarly, the second question of which destinations to prioritize has been addressed by the Mobility Framework's accessibility analysis, but warrants additional consideration about relative weighting. Though the Mobility Framework analysis prioritizes accessibility to jobs highest, schools second highest, and medical and social services third highest, it won't make sense for all flexible service models to prioritize access to destinations in this way. A hub-to-hub model for example may prioritize transporting riders to and from important community assets, and the given accessibility analysis inputs should reflect that. Alternate weighting models for accessibility analyses are discussed in Section 5.3.1.1: Altered Weighting of Transit Accessibility Components.

3. Methods

The purpose of this work is to prioritize new areas for F2FR flexible services by developing both base and alternate models for spatial analysis, and analyzing the values-based assumptions that underlie variations in the criteria. The intention is to create the framework for considering and applying the criteria identified herein, rather than developing a final list of ranked service area center points for King County Metro. This work is also intended to enable an iterative methods process that can be updated with new criteria, center points, and thresholds. This section describes the methods used to develop this base model and alternate models. The following section will discuss the implications of selecting certain criteria and designating thresholds or weights.

In summary, the steps to develop the spatial analysis model include:

1) Selecting possible F2FR flexible service area center points,
2) Developing a set of weighted criteria to evaluate possible new service areas, and
3) Incorporating possible service center points and the weighted criteria into a base model spatial analysis of King County to identify areas for possible F2FR flexible service projects based on the selected criteria.

These steps are further detailed in the following sections.

3.1 Base Model Overview

3.1.1 Criteria

The criteria inputs to the base model were primarily derived from the Mobility Framework, Metro documents and staff input, transportation practice-literature, and academic literature. As discussed, King County Council has mandated that Metro use the Mobility Framework to direct the updates of many of its guiding documents, including the Service Guidelines, Metro Connects, and the Strategic Plan. Therefore, the analysis and approach used in the Mobility Framework's analysis was the foundation that guided the base model analysis, which was then supplemented by the other resources where there were gaps and opportunity for deeper analysis.

First, we gathered information on the data and methods that the Mobility Framework used in evaluating future expansion of flexible services. Because the Mobility Framework provides criteria for flexible services broadly, we adapted the criteria to be directly relevant to F2FR flexible services. In order to validate the selection of criteria, we compared those in the Mobility Framework to those that have been used by the Innovative Mobility and Service Planning teams, as well as by the private mobility company Via, and to academic and practice literature. Given the limits on academic and practice-based documentation on criteria for F2FR flexible service, we filled any gaps with guidance from internal Metro resources and staff. This guidance was derived from meeting discussions with Service Planning and Innovative Mobility team staff, as well as from internal analyses of the Innovative Mobility F2FR flexible services to date, and from other Metro guiding documents, including Metro's Service Guidelines, Strategic Plan, and its long-range plan: Metro Connects. Table 9: Model Component Derivations in Appendix 7.2, identifies how determinations were made about using each of the selected criteria components and analytical methods.

The product of this research and deliberation was a set of base model criteria that at a high level can be considered to be addressing two primary service goals: unmet need and service feasibility. The selected base model criteria include the following:

Unmet Need

High Concentrations of Priority Populations, including:

- Low- and no-income people
- People of color and indigenous people
- Immigrants and refugees
- People with disabilities
- Limited- English speaking communities

Low All-Day Transit Accessibility to:

- Jobs
- Community Assets
    - Schools, Medical Services, Social Services

Service Feasibility

F2FR Flexible Service Specific:

- Transit Hub with a high number of daily transit trips
- Service area with a service model- appropriate average population density

The base model criteria for unmet need shown above reflect the same components that were identified in the Mobility Framework. As discussed in Section 2.1.3, the Mobility Framework identifies areas with concentrations of specific priority population sub-groups and low transit accessibility to jobs and community assets as the two components of the unmet need that should be prioritized for future Metro services (description of calculations included in Appendix).

As seen above, the transit accessibility analysis incorporates a job accessibility mapping analysis, an approach that has been used in both the Mobility Framework and by the Innovative Mobility team. However, while the Innovative Mobility team has used a job accessibility analysis to evaluate the increase in accessibility to jobs that is enabled by existing F2FR flexible services, the Mobility Framework used a variation on this analysis to identify where transit accessibility to jobs is low and could be improved county-wide (King County Metro Transit Department, 2019b; Ong, 2019). Jobs accessibility is a relevant element to include when planning for new service, and is consistent with Metro's guiding documents (discussed in

Section 3.1.1) as well as with work done by individual Metro teams. By using the jobs accessibility data used in the Mobility Framework and employing it proactively as a service planning tool, we have been able to better leverage existing approaches to guide future pilot locations.

The transit accessibility analysis also incorporated Metro's community assets GIS data, which includes the locations of important community social, educational, and medical services like libraries, cultural and religious institutions, and grocery stores. The Service Planning team, which is leading the full Service Guidelines update process, has used this data to show where important resources are for communities to access. The Mobility Framework also used this data for its analysis of transit accessibility to community assets. Using the community assets data is standard practice for certain Metro teams, and so by using it in the criteria we will enable it to become standard prerequisite for F2FR flexible service planning as well.

As discussed in Section 1.2.2: Feeder-to-Fixed Route Service, and below in Section 3.1.2: Model Approach, the inclusion of Service Feasibility goals in the criteria was relevant both because there must be enough trips at a hub to support ridership from the F2FR flexible service and because an inherent element of F2FR is to efficiently feed people into the network without shifting trips away from fixed-transit. Density restrictions served to filter out areas that have populations that are too dispersed to be appropriate for this type of service, and areas that would be more appropriately served by fixed route service.

Prior to the modeling process, consultation with demand-responsive flexible service providers was sought to ensure the model inputs aligned with emerging industry practices. Via, a service provider contracted to provide King County Metro's F2FR flexible service, operates similar projects for over 90 transit partners across over 20 countries (Via Transportation Inc., 2020). Through in-person correspondence, Via technical analysts confirmed that their service location predictive model considers population density, accessibility to jobs, and other trip generators such as grocery stores and social services (which are included in Metro's Community Assets database) (King County Metro Transit Department & Via Transportation Inc., 2020). Via analysts revealed that, based on their evaluation of current service performance in King County, the increased accessibility to amenities enabled by access to light rail seems to be the main factor for driving positive service performance. This finding reinforces the automatic inclusion of light rail stations in the transit connection location (TCL) list, and supports the model's focus on accessibility to community assets and jobs.

3.1.2 Model Approach

The base spatial analysis model provided a starting place for developing a process for ranking transit hubs throughout King County as potential areas for future F2FR flexible service. The base and alternative models utilize two primary units of analysis: the transit hub center point level and the county block group level. The transit hub center points are foundational to any F2FR flexible service analysis, as discussed in Section 1.2: Flexible Demand-Responsive Transit, and the block groups are the most granular level for which we have demographic and asset data. Analysis at the block group level gives us information about the value that a service can provide within a given area.

Metro's current practice for flexible feeder-to-fixed route service is to require a trip to start or end at a designated transit hub. The service area expands out from this point, and the selected point is key to the development of a F2FR flexible service. This service design identifies center points from which potential F2FR flexible service zones can be constructed. Given the importance of selecting center points that are both served by sufficient transit to be appealing hubs, and also connected to other areas of activity throughout the county, we deferred to Metro's Service Guidelines to identify points that have already been designated by Metro.

After identifying a base set of centerpoints, here termed Transit Connection Locations (TCLs), we filtered and scored these points according to how they perform according to the two main service goals: 1) serving unmet need and 2) service feasibility. For the first element, we ranked the TCLs by their Unmet Need composite scores, which is made up of the equally weighted all-day Transit Accessibility and Priority Population scores. For the second element, we filtered the initial list of TCLs with a feasibility analysis, which retained only the TCLs within the ideal population density range and that were above a designated threshold of daily transit trips. See Section 7.2 in Appendix B, for more details on this process.

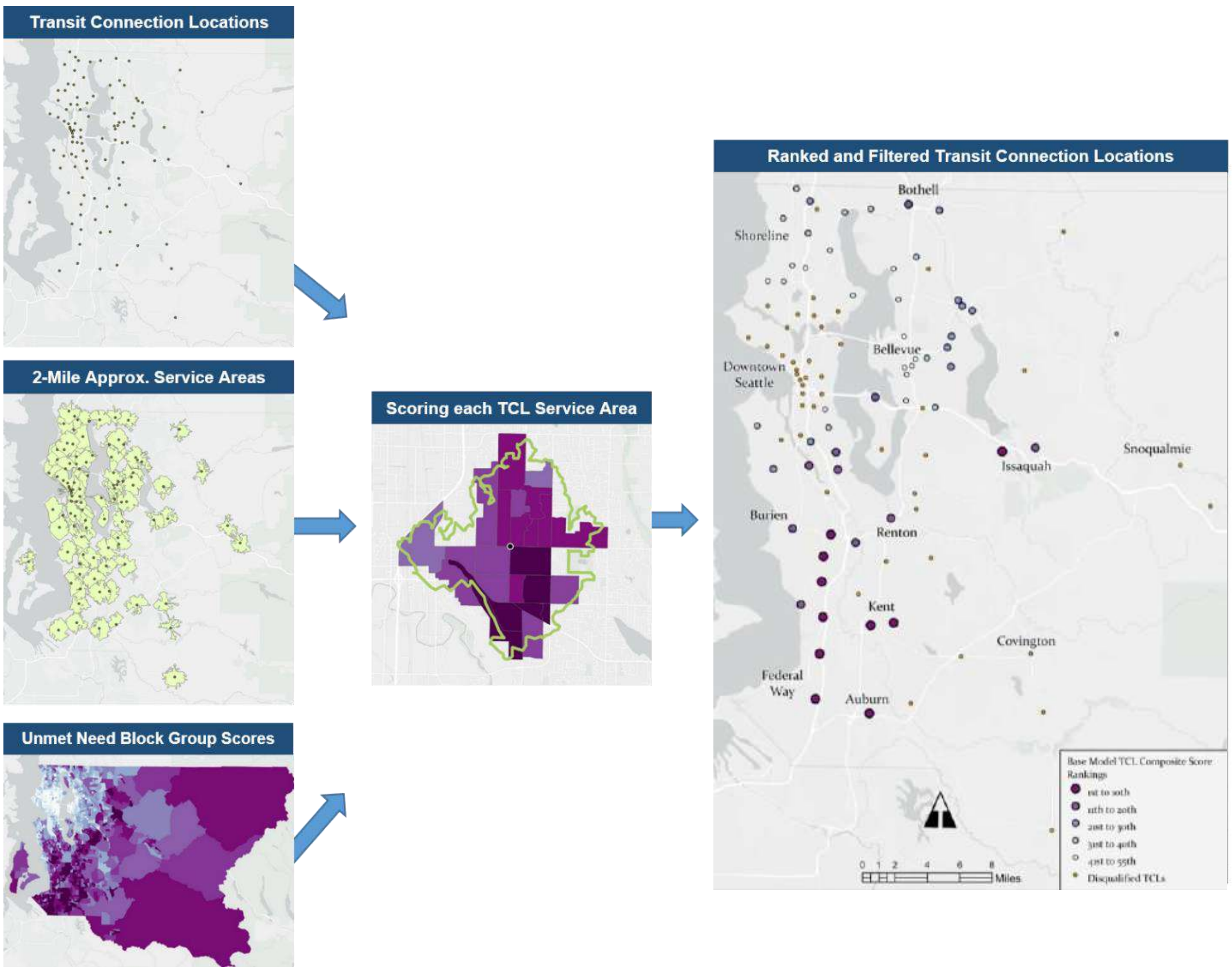
3.2 Base Model Scoring Methods

This section breaks down in more detail the methods used to:

1. Compile the list of TCLs,
2. Calculate Unmet Need block group scores,
3. Associate Unmet Need scores with each TCL service area approximation, and
4. Filter for service feasibility.

This process is illustrated at a high level in the diagram below.

Figure 2: Base Model Scoring Process



3.2.1 TCL List

King County Metro's Service Guidelines plans for its transit service to connect with a set of designated 'centers' in the county, which include the Puget Sound Regional Council's (PSRC) designated Regional Growth and Manufacturing/Industrial Centers, as well as a set of Metro identified Transit Activity Centers (King County Metro Transit Department, 2015). These 'centers' are collectively considered to be places that receive a large proportion of population and employment growth, include major institutions, are served by three or more all-day transit routes, or have concentrated housing, employment or commercial activity (King County Metro Transit Department, 2015). Therefore, the Transit Connection Locations (TCLs) used here are derived from each of the King County 'centers' combined with any existing or near-future Link Light Rail stations that will be constructed through 2024 (Table 1: Transit Connection Locations). Section 7.1.3 includes a detailed breakdown on the inputs to the list of TCLs. The intention is that this serves as an iterative list that can be modified for future analyses to include new locations that become relevant as new light rail stations are planned, new RapidRide or Sound Transit BRT stops are designated, or PSRC designations change.

Table 1: Transit Connection Locations Components

Inputs	Components
PSRC Regional Growth and Manufacturing / Industrial Centers	18 Regional Growth Centers in King County
	4 Manufacturing/ Industrial Centers in King County
Metro Transit Activity Centers	63 Transit Activity Centers
Link Light Rail Stations through 2024	36 current and planned Link light rail stations

Source: (King County Metro Transit Department, 2015)

3.2.2 Unmet Need Block Group Scores

King County Metro's Mobility Framework includes a set of criteria and a map to prioritize areas for future flexible transportation service: the Alternative Service Opportunities Composite, included as Figure 6 in Appendix A. The analysis highlights the county block groups that include high concentrations of priority populations, low off-peak public transit access, and population density between 4 and 15 people per acre (King County Metro Transit Department, 2019b). In order to gain a more granular picture of the demographics and transit accessibility to jobs and assets within King County we modified these elements for our analysis, and produced new composite Unmet Need scores for each block group in the county. The inputs to the Unmet Need score are identified in Table 2: Unmet Need Components, below.

Table 2: Unmet Need Components

Category	Components
Priority Populations	Population living 200% above the federal poverty line
	Population that is Non-white or Hispanic
	Population that is living with some type of disability
	Limited-English speaking households
	Population that is Foreign-born
Low-Transit Accessibility	Jobs accessibility (all-day, and for each time period)
	School accessibility (all-day, and for each time period)
	Social Services accessibility (all-day, and for each time period)
	Medical Services accessibility (all-day, and for each time period)

Source: (King County Metro Transit Department, 2019b)

Following discussions with Metro staff on takeaways from the Mobility Framework methods, our analysis recalculated the block group-level Transit Accessibility Index scores for ‘all-day’ and for each individual time period (rather than only separating scores by ‘peak’ and ‘off-peak’ hours) in order to tailor the analysis to our broader base model. We also chose to calculate the Transit Accessibility Index and Priority Population Index block group scores as percentiles instead of conducting a z-score or spatial clustering analysis. While the Mobility Framework analysis used this spatial clustering of block group z-scores (or “hot spots”) to smooth out results and more clearly display broader trends at a countywide level, our analysis specifically necessitated inclusion of all these block group variations in order to show more localized variation in demographic and accessibility trends. In other words, in order to accurately calculate average block group Unmet Need scores within the TCL service areas, the analysis required using the exact scores at the block group level. For the purposes of F2FR flexible service planning, this increase in scoring precision better reveals the differences in Unmet Need across the TCLs countywide.

3.2.2.1 Transit Accessibility and Priority Population Calculations

Transit accessibility to jobs and community assets was calculated for every block group within the county. This calculation was made using the number of jobs and community assets that an individual can reach within 60 minutes via public transit. Transit service varies throughout the day; so accessibility was calculated for each individual time period (AM, Midday, and Night) and for all-day, which was calculated as the average of the Transit Accessibility Index scores across each time period. The formula used to calculate all-day accessibility accounts for differing lengths of time between the AM, Midday, and Night periods of measurement. We aggregated the Transit Accessibility scores of the four variables by weighting each component variable according to the methods used in the Mobility Framework, which placed the most importance, or weight, on accessibility to jobs, followed by schools, and then medical and social services. This weighting was based on the values expressed by the Equity Cabinet. Ultimately the Transit Accessibility Index scores measure how poor the accessibility is to jobs and assets in each block group relative to the other county block groups; the higher the score the worse the transit accessibility.

Consistent with the Mobility Framework approach, the five sub-groups that compose the Priority Populations were given equal importance in the block group scoring. The Priority Population Index score measures the relative concentration of priority populations within each block group compared to county block groups; the higher the score the higher the relative concentration.

The final composite Unmet Need score for each block group was calculated to place equal importance on the scores for Priority Populations and low transit access. For more detailed descriptions of the accessibility analysis, and the weighting and scoring processes for Transit Accessibility and Priority Populations, see Appendix B, Sections 7.2.3 and 7.2.4.

3.2.3 Associating Unmet Need Scores with TCLs

After identifying TCLs and calculating Unmet Need scores for each block group in the county, we then attributed Unmet Need scores to their proximate TCLs. In order to do this we created a two-mile radius network buffer—that is, a buffer expanding out two miles from the center based on traveling the street network—for each TCL. This buffer size was chosen to reflect current conditions; the average max network radius extending from transit hubs in existing Metro's Via service areas is approximately 2.25 miles (King County Metro Transit Department, 2019c). Additionally, the selected 2-mile network radius service area coverage—encompassing 6.11 square miles on average—aligns with the average service areas in a recent study of six flexible service programs in the US. Of the six service areas that had calculations for coverage in square miles, the average coverage area was approximately 10.93 square miles, with a range of between approximately 3 and 25 square miles (KFH Group Inc., 2019).

The network buffers provide a rough estimate of a future service area that enables evaluation of how well each service area scores on average according to the Unmet Need criteria— in other words— how much value a future F2FR flexible service would provide to a given area, relative to other viable areas in the county. For more details on how the Unmet Need scores were aggregated for each TCL, see Appendix B, Section 7.2.5.

3.2.4 Refining for Service Feasibility

3.2.4.1 Trip Counts

After assigning an Unmet Need score to each TCL, we further filtered the list of TCLs based on their feasibility as center points for a F2FR flexible service. Given that this base list of TCLs included varying levels of transit activity (with routes offering headways anywhere between 8 minutes and 100 minutes), we filtered the list of TCLs to include only those that provide a significant number of transit trips. Transit types included in the filter consisted of all regional bus service and commuter rail that enters King County. TCLs were removed that had a daily transit trip count that fell below the 40th percentile of TCL trip counts.

All current and future Link Light Rail stations were retained given the high daily number of light rail trips serving these stations. Current Link Light Rail weekday service schedules provide 7-minute headways from 4:15 AM to 10:15 PM, with 15-minute headways being provided from 10:15 PM to 12:30 AM (Sound Transit, 2019). This equates to 163 daily light rail trips in each direction of travel (326 total trips per day). For reference, the threshold for TCL inclusion in the base model all-day composite score ranking process is 187 daily trips. Automatic inclusion of currently operating Link Light Rail stations in the finalized list of TCLs is meant to prevent the high light rail trip counts from crowing out TCLs with moderate daily bus trip counts that are not served by Link Light Rail. Inclusion of future light rail stations (all stations scheduled to enter into operation by 2024) regardless of current service levels is meant to acknowledge that—despite many future station’s current lack of bus service—King County Metro fixed-route transit service will be significantly reoriented to direct riders to these stations once they open. For more details on how service feasibility using trip counts was calculated, see Appendix 7.2.6: Service Feasibility.

3.2.4.2 Specifying the Appropriate Population Density

In refining the list of TCLs based on Service Feasibility, we also eliminated the TCLs that had average population densities outside of the range deemed most appropriate for F2FR flexible services. The Mobility Framework’s Alternative Services Opportunity Areas Map included areas with a population density of between 4 and 15 residents per acre. This upper range reflected the best industry understanding of where fixed route transit begins to be less feasible, and where flexible services become more appropriate. We selected a similar and slightly expanded density range relative to the one used in the Mobility Framework analysis because both case studies on F2FR flexible services and existing research on ideal corridor densities for fixed-route bus transit suggest that F2FR flexible service should target areas within a range of 4 to 18 residents per acre.[2] Average residents per acre was used for this filter rather than total population because the literature referenced largely uses this convention when discussing service feasibility and the associated thresholds. For a discussion of how this method impacts the analysis, see Section 4.2.3: Scenario 3: Altered Population Density Threshold.

As discussed, between October of 2018 and March of 2020, Innovative Mobility has contracted with Via to Transit and Ride2 to operate F2FR flexible services in seven geofenced services within three geographic areas: West Seattle, Eastgate, and Southeast Seattle and Tukwila (King County Metro Transit Department, 2019c). The average population densities for these seven service areas ranged between 6.7 and 17.2 residents per acre, with an overall average of just under 12 residents per acre. Beyond King County's services, a flexible transit planning guide published in 2019 discussed in detail three case studies of publicly regulated and privately operated demand-responsive flexible service programs and three publicly regulated e-hailing flex bus service programs. Three of these programs—AC Transit FLEX, City of Arlington Via & Rideshare, and City of West Sacramento Via On-Demand Rideshare—provided population density figures for their respective service areas; average population densities within these service areas range between 4.06 residents per acre and 14.53 residents per acre (KFH Group Inc., 2019). As a note, the AC FLEX service is not operating on a F2FR flexible service model, whereas the other two services are operating an approximation of F2FR service models. The population density ranges of flexible transit service areas around the

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[2] In extracting information from existing research on density ranges, all units of average population density were transformed to residents per acre using the average residents per household in King County—calculated in the 2013-2018 5-year estimate ACS dataset—as a conversion factor (United States Census Bureau, 2020).

country suggest that 4 to 18 residents per acre is an appropriate range for F2FR flexible services, based on existing best practices.

While existing conditions for such a novel type of transit service may not provide robust support for a target population density range for F2FR service areas alone, guidelines for fixed-route bus transit corridor designation provide additional context. The FTA guide for planning transit-supportive development finds that transit corridors for enhanced bus service—that is, high-frequency bus-service with enhanced physical and operational characteristics like signal priority—tend to range between 5 and 20 average dwelling units per acre (Santasieri, 2014). This equates to an average range of 12 to 49 residents per acre along established US bus corridors. The lower end of this density range would likely be found in suburban areas. While avoidance of service cannibalization is a priority, a properly functioning mobility system requires a certain level of service overlap between F2FR and fixed-route transit services in order to facilitate efficient customer transfers between transit modes. Following this line of logic, an overlap in the average population density ranges for these two service modes is expected.

3.2.5 Ranked List

The application of the Base Model criteria and methods resulted in a filtered and ranked list of TCLs that are good contenders for a future F2FR flexible service. To reiterate the process that produced this list, the Base Model included geospatial analysis of potential F2FR flexible service centerpoints (or, transit connection locations) that were scored according to two primary service goals, 1) serving unmet need and 2) service feasibility. The TCLs were scored based on the degree of unmet need of surrounding block groups, which took into account the concentration of priority populations and the relative need for better transit accessibility to jobs and community assets. The TCLs were then filtered for service feasibility, which retained only the TCLs within the ideal population density range and that were above a designated threshold of daily transit trips.

3.3 Alternative Models

The priority-ranked list of TCLs for the base model is the product of prioritized values represented by the chosen weighted criteria for the analysis, and these prioritized values are the reflection of the existing policy conditions at King County Metro. Alterations to the criteria's weighting or contents alter the resulting ranked list of priority TCLs for future F2FR service areas. In order to test the sensitivity of the base model to policy changes, a number of alternative policy scenarios were represented through changing weighted criteria and other inputs, and these scenarios were evaluated for alignment with the Mobility Framework's directives for future service provision, as well as those articulated by best practices in the literature. Alternative policy scenarios are based on the following alterations to the base model:

Alternative Scenarios

1. Transit Accessibility Fluctuation by Time of Day
    a. Accessibility by time period
    b. Change in accessibility from peak to off-peak
2. Priority Population Weighting Variation
    a. Non-equal weighting of Priority Population sub-groups
3. Altered Population Density Window
    a. Removing density window upper limit

3.3.1 Scenario 1: Transit Accessibility Fluctuation by Time of Day

The base model Transit Accessibility Index scores were calculated for the entire day, as it provides good base information about a TCLs accessibility relative to other areas of the county. However, a limitation of using all-day accessibility is that it also conceals valuable information about variations in accessibility throughout the day. As discussed in Section 2.1.3: Mobility Framework, serving unmet need means serving priority population sub-groups during times of day when transit service is less robust, which often includes off-peak hours when transit service is more important for people with low-wage jobs. The intention of this scenario was to provide a more temporally nuanced picture of how accessibility varies across the county, in order to better address the policy priorities expressed in the Mobility Framework. This scenario considered accessibility score rankings for all of the time periods, but of most interest is off-peak hours, here represented by the midday period.

For the first part of Scenario 1, Transit Accessibility scores were calculated for each time period. These time periods include the following hours, consistent with the periods used in the Mobility Framework analysis: the AM time period is assessed from 6:00 am to 9:00 am, the Midday time period is assessed from 11:00 am to 1:00 pm, and the Night time period is assessed from 6:00 pm to 9:00 pm. This analysis allowed for evaluation of how the relative accessibility scores vary based on time of day, so that future prioritization of F2FR flexible service provision can better address temporal gaps. The analysis also applied a TCL trip count filter to each of the time period accessibility scores, in order to act as an initial service feasibility check on any TCLs that seem to warrant new time-period specific F2FR flexible service but that may not have enough trips occurring at the TCL to support new riders. Because these rankings use accessibility scores and not composite Unmet Need scores, the TCLs that have a high Priority Population score are highlighted in table. This is included in order to ensure that both key components of Unmet Need are included in the analysis.

For the second portion of this scenario, the change in accessibility to jobs from peak to off-peak was assessed. This analysis involved calculating the percent change in jobs between the AM and the Midday periods that can be accessed for all block groups and then averaging this change within each TCL buffer. The range of hours within each of these periods serve as a proxy for peak and off-peak hours. The intention of this analysis was to gain a better understanding of the degree to which accessibility to jobs fluctuates between peak and off-peak periods within the same service area. For this analysis, the fluctuation in accessibility was assessed for TCLs that rank highly among the Midday Transit Accessibility (or, Midday Accessibility) scores, given that we are most interested in areas with poor off-peak accessibility. The TCLs that have a high Priority Population score are also highlighted in table.

The intention was that the two elements of this scenario could be used together to provide a more complete picture of the temporal gaps in transit accessibility. For example, given that midday service and accessibility are generally less robust than in the morning peak hours, the Accessibility score rankings by time of day indicate which TCLs in particular have the relatively worst midday accessibility, and the Percent Change calculation reveals the TCLs that could see the most dramatic increase in continuous all-day accessibility if service were targeted at the Midday period in particular. This is an analytical approach that could help Metro respond to policy directives like those that were proposed by the Mobility Framework to increase transit accessibility during off-peak periods.

For more detail on the methods for this scenario see Appendix C, Section 7.3.1.

3.3.2 Scenario 2: Priority Population Index Weighting Variation

In Scenario 2, the weighting for the Priority Population sub-groups was altered from the base model weighting, in which all five sub-groups were equally weighted. The intention was to test how an alteration in Priority Population Index weighting based on different policy goals changes the prioritized ranking of the TCLs. Although the Mobility Framework equally weights all Priority Population sub-groups in its analysis, King County has been explicit about its intention to lead with racial justice as it implements its Equity and Social Justice (ESJ) Strategic Plan, in an effort to address the disparities in health and economic opportunity that are greatest when considering data by race (Beatty, 2015; King County Office of Equity and Social Justice, 2016). The Mobility Framework itself also cites goals to lead with race, and calls out the inequities experienced especially by people of color and low-income households (King County Metro Transit Department, 2019b). Additionally, according to Metro staff, the census data that documents numbers of individuals with disabilities, limited English proficiency, and who are foreign-born, is especially unreliable and has a high margin of error. Given these data limitations and priorities, we felt it was important to produce an alternate weighting scenario for the Priority Population Index scores.

To simulate a priority of improving accessibility especially for low- and no-income households and households of color, these two sub-groups were weighted higher than the other three sub-groups. The weighting that was used for this scenario was: 40% households of color, 30% low- and no-income households, 10% individuals with disabilities, 10% individuals who are foreign-born, and 10% limited English proficiency. This type of re-prioritization has been tested by Metro staff related to the Mobility Framework inputs, and will be used for other Service Guidelines updates. See Appendix C, Section 7.3.2 for a table with the weighting for Scenario 2.

3.3.3 Scenario 3: Altered Population Density Threshold

For the base model, TCLs were removed from the scoring model if the population density was outside of the range of 4 and 18 residents per acre. Scenario 3 evaluated how removing the upper bounds of the threshold affects the number of TCLs that are included in the final rankings. Firstly, it is important to note that in the base model analysis the filter for population density is applied by averaging the population density of all block groups within a 2-mile network buffer of each TCL. These TCL buffers serve as a rough estimate of a service area, and an actual service area might end up looking quite different due to on the ground conditions. Therefore, calculating the average population density for a TCL 2-mile buffer area is only an estimate of the ultimate population density of the area. It is important to consider that some TCLs could be eliminated based on this filter due the method of calculating population density, but that would still be good contenders for F2FR flexible service. A formally designated service area could end up including different block groups and produce a lower average population density within the 4 to 18 residents per acre threshold, so this Scenario looks critically at the TCLs that are over the threshold for alignment with other indicators of feasibility.

In addition, although the range used for the base model represents the best industry and practice information about the ideal range for F2FR flexible services, the research around transit cannibalization is not conclusive when it comes to determining at which point raising the upper bound of the density range would result in inefficiencies or redundancy in transit service. Therefore, it is also worth considering TCLs above the currently selected population density window given the relative variability in ideal range in population density cited in the existing academic and practice literature.

4. Results

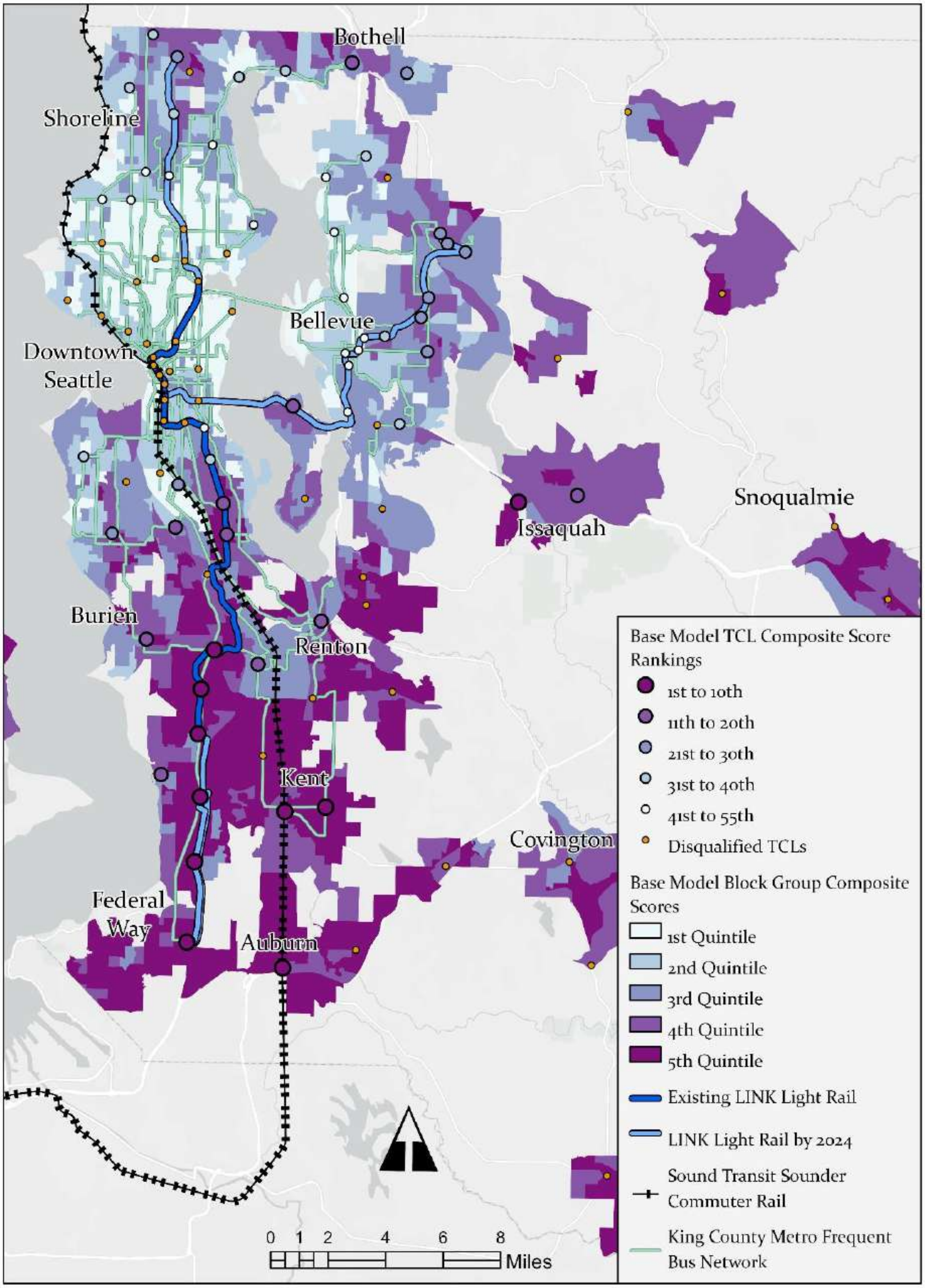
4.1 Base Model Results

The criteria described in Section 3.1 were applied in a geospatial analysis of the TCLs and their respective service area approximations. The results of this analysis indicate that geographically, the TCLs scoring highest in composite score are heavily concentrated in South King County, as seen in Figure 3: Base Model Map. Of the top-20-scoring TCLs, 16 are located in South King County. Issaquah Transit Center, located in East King County just south of Lake Sammamish, is the only top-20 King County TCL and it scored as the 18th-highest-scoring TCL in the base model. The two best-performing Via F2FR service areas in King County—Rainier Beach Station and Othello Station—also score within the top 20. Rainier Beach Station, Othello Station, and South Park Downtown are notably the only TCLs within Seattle City Limits to score within the top 20 TCLs for the base model. The top-20-scoring TCLs are listed in a ranked list in Table 3 below.

Table 3: Base Model TCL Scores

Composite Score Ranking	Transit Connection Location	Composite Score	All Day Transit Accessibility Score	Priority Population Index Score	Average Residents Per Acre	Count of Daily Transit Trips Serving TCL	LINK Station Completion Year
1	Kent East Hill 104th Ave SE/SE 240th St	0.732	0.718	0.746	13.78	216	NA
2	Auburn Transit Center	0.709	0.734	0.685	8.90	389	NA
3	Federal Way Transit Center Station	0.707	0.700	0.713	7.73	NA - LINK Station	2024
4	Kent Station	0.681	0.673	0.688	10.57	829	NA
5	Airport / SeaTac Station	0.673	0.572	0.775	9.21	NA - LINK Station	2009
6	Star Lake P&R / S 272nd St Station	0.666	0.684	0.649	11.40	NA - LINK Station	2024
7	Kent Des Moines Station	0.651	0.656	0.647	9.53	NA - LINK Station	2024
8	Angle Lake Station	0.640	0.618	0.662	9.77	NA - LINK Station	2016
9	Tukwila International Blvd Station	0.639	0.498	0.781	8.17	NA - LINK Station	2009
10	Issaquah Transit Center	0.638	0.765	0.511	6.56	288	NA
11	Renton Transit Center	0.628	0.532	0.724	9.27	1085	NA
12	Des Moines	0.626	0.686	0.566	8.84	187	NA
13	Issaquah Highlands P&R	0.595	0.741	0.448	5.05	266	NA
14	Rainier Beach Station	0.579	0.396	0.761	15.08	NA - LINK Station	2009
15	Southcenter Mall	0.578	0.481	0.675	8.32	466	NA
16	Burien Transit Center	0.553	0.472	0.633	9.83	832	NA
17	Othello Station	0.539	0.353	0.725	14.78	NA - LINK Station	2009
18	Bothell UW Cascadia	0.526	0.566	0.485	6.63	630	NA
19	South Park 14th Ave S/S Cloverdale	0.519	0.318	0.720	5.49	203	NA
20	Mercer Island Station	0.514	0.608	0.419	7.82	NA - LINK Station	2023

Figure 3: Base Model Map



Note: block groups shown in the above map are those that fall within the 2-mile buffer service area approximations.

The base model's dual service feasibility thresholds of population density and daily trip counts disqualified 48 of the 103 TCLs, or, about 47% of the TCLs that were either outside of the set average population density range of 4 to 18 residents or had daily trip counts below the 40th percentile of daily trip counts. Notably, the average population density window limited to 4 to 18 residents per acre disqualified two TCLs from the initial ranked list of top-20-scoring TCLs. The average population densities of the 2-mile service buffers around Carnation City Center and Snoqualmie City Center are 0.91 and 1.16 residents per acre, respectively—well below the lower density limit of four residents per acre. For comparison, when the TCLs are sorted by total estimated population with the 2-mile service area approximation, these two TCLs still rank very low, with the third and fourth lowest total population estimates of all of the TCLs (Appendix Section 7.2.6, Table 15: Service Feasibility Filter). This indicates that average population density is an appropriate measure for filtering out the TCLs that have insufficient population to support a F2FR flexible service.

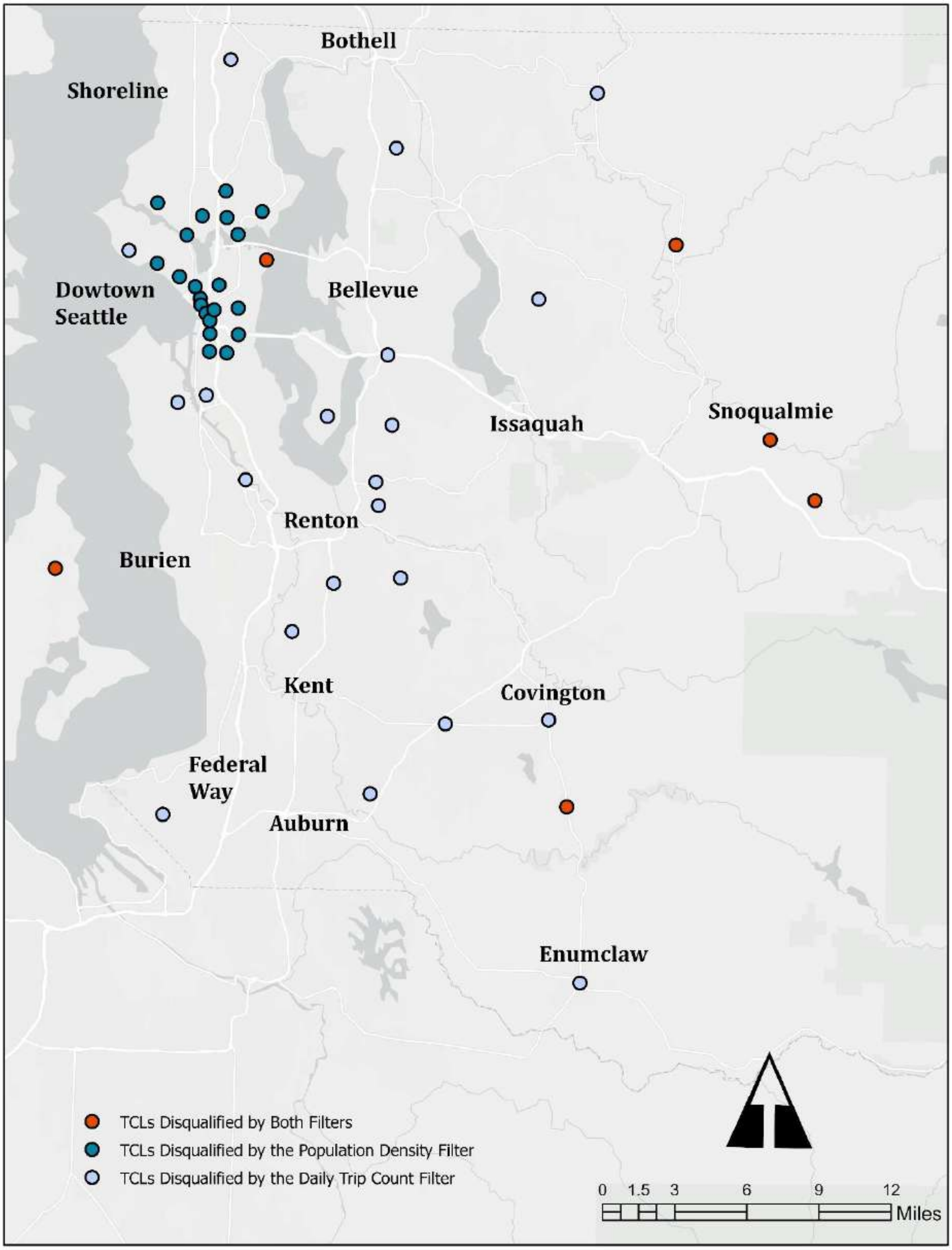
The trip count filter disqualified ten TCLs from the initial list of top-20-scoring TCLs, including the two TCLs that were also disqualified due to their average densities. It is worth noting that the two service feasibility filters did not evenly disqualify TCLs throughout the initial full ranked TCL list. In fact, as seen in Figure 4: Disqualified TCLs, 74% of the TCLs disqualified by the trip filter fall in the higher ranked half of the TCLs while 81% of the TCLs disqualified by the density filter fall in the lower ranked half of the TCLs.[3] This distribution makes sense given the inputs to the composite Unmet Need score. The Transit Accessibility score measures— in relative terms and on average—how poor the transit accessibility is to jobs and assets in the area surrounding each TCL; the higher the score the worse the accessibility. Given that this is one of the two inputs to the composite scores by which the TCLs are ranked, it follows that

[3] For the trip count filter this equates to 20 TCLs disqualified in the top 51 scoring TCLs and 7 TCLs disqualified in the bottom 52 scoring TCLs; for the density filter this equates to 5 TCLs disqualified in the top 51 scoring TCLs and 22 TCLs disqualified in the bottom 52 scoring TCLs.

TCLs with worse accessibility (and a higher composite score) would also generally have fewer trips occurring, because transit trips are a prerequisite for being able to get to jobs and other assets. It also then follows that more TCLs in the higher ranked half of composite scores would be removed by the trip filter than in the lower half. Similarly, the vast majority of the TCLs that the density filter removes are in the lower ranked half of composite scores— all of these disqualified TCLs have an average density above the threshold of 18 residents per acre. This means that the areas with the greatest average densities largely have good transit accessibility. This aligns with historical trends in service prioritization because denser areas tend to have better transit service and accessibility to key destinations. It fits that the TCLs with high average densities also generally have good accessibility and were disqualified from the rankings— just as it fits that the TCLs with low trips counts generally have poor accessibility and were also disqualified. These disqualifications indicate that the base model criteria and filters did what they were intended to do. For a complete list of the ranked TCLs that identifies disqualifications due to each Service Feasibility filter, see Appendix Section 7.2.6, Table 15: Service Feasibility Filter.

The result of the base model design can also be seen in the geographic distribution of ranked TCLs. The lowest composite scores are found accompanying TCLs within Seattle City Limits. With the exception of Rainier Valley and the northern city limits around Shoreline, the City of Seattle enjoys a robust multimodal public transit network due to historical prioritization of transit investments within the city limits. This trends continues due to the Seattle Transportation Benefit District, which funds additional King County Metro bus service hours for routes that primarily service the city. With the exception of Rainier Beach Light Rail Station, Othello Light Rail Station, and South Park commercial center, all of the top 20 composite scores correspond to TCLs outside of Seattle City Limits.

Figure 4: Disqualified TCLs



4.2 Alternative Model Results

This section summarizes the results from the alternative model analyses. Collectively, the three alternative model scenarios did not produce substantially different prioritization rankings from the base model, but are useful in sensitivity testing the inputs and weightings used in the base model.

In Scenario 1, comparing accessibility score rankings by time of day indicates minimal variation in the list of top ranked TCLs, but does reveal some variation in the rank order for each time period. This confirms the value of using a time-period specific analysis for prioritization efforts that intend to align with the Mobility Framework's recommendation to serve people during times of day when unmet accessibility need is highest. For Scenario 2, altering the weighting of the priority population percentiles in the scoring process also changes the rank order of the top scoring TCLs, though only minimally. This scenario suggests that altering the weighting of any of the inputs may produce small changes in rank order that are nevertheless important to catalogue, especially as multiple inputs may be varied simultaneously in future analyses. For Scenario 3, removing the upper limit on the density filter doesn't alter the rank order of the top 20 TCL composite scores because all TCLs disqualified for having high population density also have low composite scores. This supports the finding that F2FR flexible services provide the most benefit in mid to low-density areas.

4.2.1 Scenario 1: Transit Accessibility Fluctuation by Time of Day

4.2.1.1 Accessibility by Time Period

For the base model, transit accessibility was assessed and aggregated in an all-day score. For the first part of Scenario 1, the Transit Accessibility scores for the TCLs and their service area approximations were assessed for each time period. Table 4: TCL Accessibility Score Rankings by Time Period compares the relative rankings of each of the TCLs accessibility scores for their individual time period to the base model all-day scores. The top 20 highest scoring TCLs for the Transit Accessibility score were selected as a reference point to visualize how the TCL rankings in the base model are differently distributed when considering time-period specific transit accessibility.

Additionally, Table 4 includes a F2FR flexible service feasibility trip count filter for each individual time period. "Low Trip Count" indicates that—for that particular period of time—the number of transit trips serving that particular TCL do not exceed the 40^{th} percentile for trip counts among all the included TCLs and is therefore excluded from the ranking process. The 40^{th} percentile threshold is the same benchmark used as the exclusion threshold for all-day base model filter. This threshold supplements the time period specific analysis with a service feasibility lens. In other words, if only considering the Transit Accessibility score rankings during the Midday period, the analysis could be used to justify new service during that time period for top ranking TCLs. The trip count filter provides an extra layer of analysis to verify that the given TCLs have sufficient trips occurring during the time period to support a potential F2FR flexible service. Ultimately, if it is a policy priority to increase accessibility for people during specific times of day like off-peak hours, it's important to ensure there is enough existing service to take people where they need to go.

It is important to note that both the all-day and the time period-specific Transit Accessibility scores are calculated as percentiles; the AM Transit Accessibility score for each block group represents a block group's relative accessibility at that particular period of time in comparison to the other block groups throughout the county during that same time period. Taken individually, the time period accessibility scores allow for comparison of one TCL service area's accessibility potential during a particular period of time to other TCL service areas at the same particular period of time, but comparison between TCL service areas across different periods of time should only be interpreted as performance relative to the rest of the service areas throughout the county.

Table 4: TCL Accessibility Score Rankings by Time Period

Base Model Accessibility Score Ranking	Transit Connection Location	AM Accessibility Score Ranking	Midday Accessibility Score Ranking	Night Accessibility Score Ranking
1	Issaquah Transit Center	2	3	1
2	Issaquah Highlands P&R	7	2	2
3	Auburn Transit Center	3	4	3
4	Kent East Hill - 104th Ave SE/SE 240th St	Low Trip Count	5	5
5	Federal Way Transit Center Station	4	6	4
6	Des Moines - Marine View Dr/S 223rd	8	Low Trip Count	Low Trip Count
7	Star Lake P&R / S 272nd St Station	6	7	6
8	Kent Station	5	10	8
9	Kent Des Moines Station	9	8	9
10	Angle Lake Station	10	11	10
11	Mercer Island Station	15	1	11
12	Woodinville P&R	12	Low Trip Count	12
13	Airport / SeaTac Station	11	15	15
14	Bothell UW Cascadia	13	12	14
15	Renton Transit Center	17	14	13
16	Tukwila International Blvd Station	14	24	21
17	Southcenter Mall	21	25	20
18	Lake Forest Park Town Center	23	16	16
19	Alaska Junction	20	20	24
20	Burien Transit Center	18	13	30

Note: dark blue-highlighted TCLs indicate Priority Population Index scores above the 60th percentile of scores.

The results of this alternative model— summarized in the table above— illustrate that there are notable differences between the all-day base model accessibility rankings and those of the individual time periods. This validates the selection of this model for analysis, by directly comparing how service prioritization could change when considering accessibility by individual time periods rather than across the whole day.

Table 4 also indicates that there is notable variation in the accessibility score rankings of the TCLs across time periods— this could be due to several factors. King County Metro service frequency and span of service varies significantly across the county, and very few places in the county have the same service quality during midday hours as they do during peak morning and evening commute hours. In most places, midday service quality is lower than peak commuting service quality. If this drop in service were consistent, the rankings would vary little across time periods, given that the scores calculate relative accessibility. However, the range in the difference of service quality between time periods is in some cases significant. This could be based on the specific characteristics of a given TCL service area; while some areas only see a drop in fixed-route service frequency from 15 minute headways to 30 minute headways, other areas lose midday transit service altogether.

This scenario provides Accessibility score ranking for all of the time periods, but of most interest is the Midday period. An example of a TCL with a dramatic drop in relative accessibility during the Midday period is the future Link Station on Mercer Island— while the AM and Night Accessibility Score rankings are similar, this TCL has the absolute highest Midday Accessibility ranking, which makes sense given that current transit service at this TCL location is limited and oriented to commuter service. In contrast, many of the *current* Link Stations, including Angle Lake Station, Airport / SeaTac Station, and Tukwila International Boulevard Station rank lower for Midday Accessibility; they have more relative transit accessibility than other TCLs during that period, which makes sense given that light rail provides fairly consistent all-day service.

It is also worth noting the TCLs that haven't been ranked for a given time period due to being disqualified by the trip filter. Kent East Hill, for example, has a high AM Accessibility score, and Des Moines and Woodinville P&R have high Midday Accessibility scores, but none of these TCLs met the trip count threshold for those respective periods. This additional filter provides key contextual information about the feasibility of implementing a F2FR flexible service at these TCLs that is lacking from the base model analysis. Given the interest in enhancing accessibility during times such as the Midday period, this filter offers an approach for confirming that a TCL has enough existing service during those particular hours to meet the demand that could be added due to a F2FR flexible service.

Also important to note is that this scenario focuses on the accessibility scores instead of the composite Unmet Need scores in order to better evaluate changes in temporal accessibility without being obscured by the averaging process that produces the composite score. However, the Priority Population Index scores are a crucial part of evaluating unmet need, in particular as related to the Midday Accessibility scores. The TCLs that are both in the top 20 ranked TCLs for the Midday Accessibility and are above the 60th percentile of Priority Population scores are highlighted in table. In other words, these TCLs have poor midday accessibility and a high concentration of priority populations. It’s noteworthy that these highlighted TCLs are located very close to one another in south King County, which is also where the highest Unmet Need composite scores are concentrated. If a policy goal is to improve off-peak service for priority populations, this list of TCLs provides a good starting point.

4.2.1.2 Change in Transit Accessibility from Peak to Off-Peak

As discussed in Section 3.3.1: Scenario 1: Transit Accessibility Fluctuation by Time of Day , the Accessibility Score rankings from the first part of this scenario represent relative accessibility during a given time period. The intention of the second part of the scenario was to produce additional information about the degree to which service fluctuates throughout the day for each TCL. To measure the fluctuation in accessibility between peak commuting hours and off-peak hours for the top-20 scoring TCLs for Midday Accessibility, the percent change in transit accessibility to jobs from AM to Midday time periods was calculated, as shown in Table 5:

Change in Accessibility Between AM and Midday Time Periods. The TCLs that have high Priority Population scores are highlighted in the table.

Table 5: Change in Accessibility Between AM and Midday Time Periods

Midday Accessibility Score Ranking	Transit Connection Location	Percent Change in Transit Accessibility from AM to Midday Ranking	Percent Change in Transit Accessibility from AM to Midday
1	Mercer Island Station	1	-96%
2	Issaquah Highlands P&R	6	-63%
3	Issaquah Transit Center	28	-42%
4	Auburn Transit Center	43	-27%
5	Kent East Hill 104th Ave SE/SE 240th St	57	-18%
6	Federal Way Transit Center Station	39	-29%
7	Star Lake P&R / S 272nd St Station	29	-40%
8	Kent Des Moines Station	33	-37%
9	Valley Medical Center	66	-14%
10	Kent Station	44	-26%
11	Angle Lake Station	36	-31%
12	Bothell UW Cascadia	14	-51%
13	Burien Transit Center	10	-55%
14	Renton Transit Center	31	-38%
15	Airport / SeaTac Station	52	-19%
16	Lake Forest Park Town Center	3	-67%
17	South Bellevue Station	7	-62%
18	Totem Lake Transit Center	5	-64%
19	Kenmore P&R	8	-62%
20	Alaska Junction	32	-38%

Note: dark blue-highlighted TCLs indicate Priority Population scores above the 60th percentile of scores.

As seen in Table 5, the TCLs that rank the highest for Midday Accessibility have variable rankings for the Percent Change in Accessibility between AM and Midday. The TCLs that are ranked in the top 20 for both scores include: Mercer Island Station, Issaquah Highlands P&R, Bothell UW Cascadia, Burien Transit Center, Lake Forest Park Town Center, South Bellevue Station, Totem Lake Transit Center, and Kenmore P&R. These are the TCLs that have low midday accessibility currently and also see a proportionally higher decrease in the jobs that can be accessed during the Midday period as compared to AM. Of these TCLs, only Burien Transit Center meets the threshold for a high Priority Population score. This is important to highlight if the focus of improving off-peak service is to benefit priority populations.

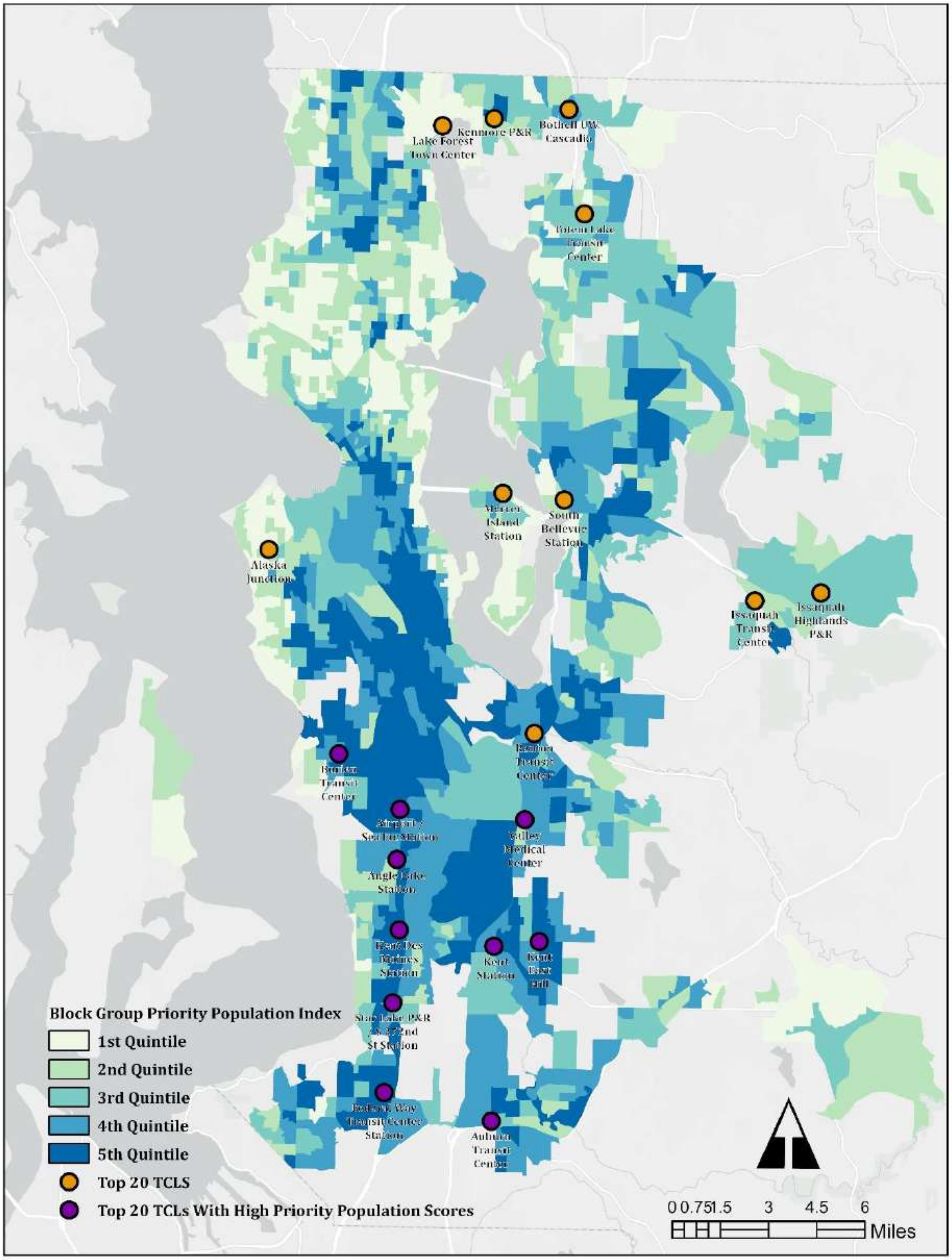
The percent change— or relative decrease— in accessibility between morning peak hours and midday is interesting to evaluate when considering where new services like F2FR flexible could have the most benefit. However, it's important to consider that while this calculation of percent change tells us how dramatically accessibility fluctuates, it doesn't explain the context specific factors that have produced that fluctuation, nor does it tell us directly what the needs are of the specific communities in the area. It's noteworthy that the top scoring TCL for both Midday Accessibility and Percent Change is Mercer Island Station, which is a future Link station; this accessibility gap will certainly change given the increase in all-day service that light rail will bring in 2023.[4] It's also worth noting that one scenario that produces high fluctuation in accessibility is TCLs with peak-only commuter service like park & rides, as seen by the high rankings of Issaquah Highlands P&R, South Bellevue Station, and Kenmore P&R. Indeed, these TCLs, like most of the TCLs that have a high fluctuations in accessibility from peak to off-peak are located on the east side of King County, which has a notoriously high peak commute market to office centers on the east side and in Seattle. While this information is still useful, it suggests that any type of service prioritization based on improving midday accessibility requires a good understanding of the demographics, on-the-ground conditions, and travel patterns of each area. It would not make sense to add a F2FR flexible service to a TCL that has been designed primarily for peak-service.

[4] Note that four of the TCLs ranked in the top 20 scores of the Midday accessibility scores are locations of future Link Stations, including: Mercer Island Station, Federal Way Transit Center Station, Kent/Des Moines Station, and South Bellevue Station. Accessibility scores will have to be recalculated when these stations become operational.

It’s interesting to pair the two elements of this scenario when considering temporal accessibility gaps at a transit connection location. However, it is also relevant to note that the rankings of the top 20 scores for each of these analyses do not closely align, and align even less when a Priority Population score threshold is applied. As stated, Burien Transit Center is the only TCL to meet both rankings and the threshold. Ultimately, evaluating the relative decrease in accessibility is worth continuing to explore, but may not provide direct guidance on how to prioritize new F2FR flexible service during midday given the many possibilities for the fluctuation. Given this, the TCLs with high Midday Accessibility scores and the high Priority Population scores that are highlighted in Table 5 provide an initial prioritization of where a F2FR flexible service could be located during midday. Figure 5: Prioritized TCLs for Midday Service shows where these TCLs are geographically located.

This analysis serves as a starting place for prioritizing F2FR flexible service using a time period specific analysis, and does not intend to be the final word. For a discussion of potential additional applications of this work, see Section 5.3.1.3.

Figure 5: Prioritized TCLs for Midday Service



4.2.2 Scenario 2: Altered Weighting for Priority Population Sub-Groups

As described in Section 3.3, Scenario 2 alters the weighting of the Priority Population sub-groups, in order to evaluate how such a modification changes the rankings of the TCLs. The results for this alternative scenario show only slight differences from the base model. The top-10-scoring TCLs in this model are the same as those for the base model, but the ranking for each TCL within the top 10 varies, though at most only by two positions. This trend applies to the ranking of TCLs throughout the list. While further investigation is needed, initial findings suggest that the goal of the alternative ranking system—centering on race and income—is achieved in the outcome—the rankings of the TCLs. That being said, the changes in ranking are minor.

Table 6: TCL Composite Scores and Rankings for Alternative Priority Population Weighting Scenario

Transit Connection Location	Alternative Weighting Scenario Composite Score	Alternative Weighting Scenario Composite Ranking	Base Model Composite Score Ranking
Kent East Hill - 104th Ave SE/SE 240th St	0.752	1	1
Federal Way Transit Center Station	0.724	2	3
Auburn Transit Center	0.713	3	2
Kent Station	0.709	4	4
Star Lake P&R / S 272nd St Station	0.697	5	6
Airport / SeaTac Station	0.685	6	5
Kent Des Moines Station	0.671	7	7
Angle Lake Station	0.668	8	8
Tukwila International Blvd Station	0.650	9	9
Des Moines - Marine View Dr. & S 223rd St	0.642	10	12
Renton Transit Center	0.637	11	11
Issaquah Transit Center	0.625	12	10
Southcenter Mall	0.604	13	15
Rainier Beach Station	0.600	14	14
Issaquah Highlands P&R	0.596	15	13
Burien Transit Center	0.563	16	16
Othello Station	0.557	17	17
South Park - 14th Ave S & S Cloverdale	0.540	18	19
Georgetown - 13th Ave S & S Bailey	0.527	19	22
Bothell UW Cascadia	0.515	20	18

4.2.3 Scenario 3: Altered Population Density Threshold

In the base model, TCLs were disqualified if the average population density was outside of the range of 4 and 18 residents per acre. For scenario 3, the upper threshold on this filter was removed. This was done in response to the lack of concrete guidance in the literature on prescribing an exact upper limit and given the method limitations discussed in Section 3.3.3: Scenario 3: Altered Population Density Threshold and Section 5.2.2.2: Population Density Filter. The intention of this scenario was to look critically at the TCLs that had been removed by the upper density limit for alignment with other indicators of feasibility and unmet need, given limitations of the density filter method. The below table identifies the TCLs that were disqualified by the upper density limit that might have otherwise been included using another method of filtering based on population.

Table 7: TCLs Removed by Upper Threshold of the Density Filter

Transit Connection Location	Composite Score Ranking	Composite Score	Average Residents per Acre	Count of Daily Transit Trips
Beacon Hill Station	65	0.406	19.31	N/A - Link Station
SODO Station	71	0.385	25.23	N/A - Link Station
Stadium Station	77	0.363	33.96	N/A - Link Station
Judkins Park Station	79	0.360	24.81	N/A - Link Station
International District Station	80	0.329	45.04	N/A - Link Station
Pioneer Square Station	83	0.310	45.56	N/A - Link Station
University Street Station	84	0.307	46.56	N/A - Link Station
Harborview Medical Center	85	0.306	43.30	412
Westlake Station	87	0.302	46.90	N/A - Link Station
Central District - 23rd Ave E/E Jefferson	89	0.296	33.01	370
South Lake Union	90	0.296	46.10	321
Ballard-Interbay - Galer Bridge	91	0.295	33.55	396
Childrens Hospital & Medical Center	92	0.292	24.52	255
Uptown Queen Anne	93	0.287	45.69	810
Capitol Hill Station	95	0.277	42.26	N/A - Link Station
Roosevelt Station	96	0.276	23.90	N/A - Link Station
Ballard - Ballard Ave NW/NW Market St	98	0.273	19.11	464
Wallingford Center	99	0.251	27.00	370
U District Station	100	0.251	25.96	N/A - Link Station
Fremont - Fremont Ave N/N34th St	101	0.245	24.18	511
University of Washington Station	102	0.245	25.96	N/A - Link Station
Madison Park - 42nd Ave E/E Madison St	103	0.211	21.37	136

Eliminating the upper threshold of the density filter did not change the overall composite score ranking of TCLs significantly, and added no new additional TCLs to the list of top 20 ranked TCLs. Indeed the highest ranked TCL that is added is Beacon Hill Station, which is ranked 65th with a composite score of 0.406. In looking at the components of the Unmet Need composite scores, none of the disqualified TCLs have Transit Accessibility scores above 0.30, which aligns with trends of greater accessibility (and a lower Transit Accessibility score) in denser, more populated areas. All of the TCLs are either future or current Link stations, or have daily transit trip counts above the 40th percentile threshold, with the exception of Madison Park which has a low trip count and the lowest composite score of all TCLs. This suggest that these TCLs are already served well by traditional fixed-route transit. This also aligns with what we'd expect for TCLs that have such high densities, and relatively high accessibility already. Although almost all of the TCLs largely score well for trip count feasibility, their composite scores are too low to indicate high levels of unmet need. Given this, it doesn't make sense to consider any of the TCLs as good contenders for F2FR flexible service at this point.

4.3 Applying the Base Model Analysis to Metro's Via to Transit Pilots

It's informative to evaluate how the F2FR flexible services that Metro has implemented so far perform using the base model, as a way to ground-truth this analytical approach. The *existing* service areas for each of the seven F2FR Via services were used for these calculations, in order to compare their relative scoring using actual service areas. Table 8: Metro's Implemented F2FR Flexible Service Pilot Scores includes the relative composite score ranking of each of Metro's F2FR flexible services, with the first and second highest scores shown in dark and light grey, respectively, for the component elements.

Table 8: Metro's Implemented F2FR Flexible Service Pilot Scores

Name	Composite Score Ranking	Composite Score	All-Day Transit Accessibility Score	Priority Population Score	Average Residents Per Acre
TIBS Station	1	0.606	0.417	0.796	8.3
Rainier Beach Station	2	0.593	0.490	0.695	10.0
Othello Station	3	0.569	0.349	0.790	17.1
Ride2 Eastgate	4	0.491	0.426	0.556	6.7
Columbia City Station	5	0.449	0.295	0.603	12.6
Ride 2 West Seattle	6	0.431	0.482	0.379	14.0
Mt. Baker Station	7	0.370	0.180	0.559	13.0

As seen by the relative rankings, Tukwila International Boulevard (TIBS) Station and Rainier Beach scored the highest for composite scores. However, Rainier Beach Station had the highest or second highest ranked scores for *both* all-day Transit Accessibility and Priority Population Index scores. It's relevant to note that—in terms of ridership and thus cost per vehicle-hour—Rainier Beach Station service area performed the best out of the F2FR flexible services that Metro has piloted, and indeed of all Via services in the country. While our base model focuses primarily on elements of unmet need, it inherently gets at elements of service potential by prioritizing areas where there may be latent demand for service. In other words, the focus of the analysis is not to predict where ridership or specific performance metrics would be highest, but it does filter TCLs by where service would likely be infeasible, and prioritize areas where needs are greatest. The fact that Rainier Beach scored among the highest using the base model analysis has positive implications for the performance of future service areas that may be identified based on our model. As discussed in Section 1.2.1: Flexible Demand-Responsive Transit Models, although flexible services like F2FR align more closely with goals focused on coverage than on ridership, some consideration of relative performance among F2FR flexible services is warranted.

It should be noted that the inclusion or exclusion of block groups based on service area size and shape produces notable changes on the averaged components of the Unmet Need scores within a service area buffer. For a discussion of the impact and limitations of this method, see Section 5.2.2.1: Unmet Need Scoring.

5. Discussion

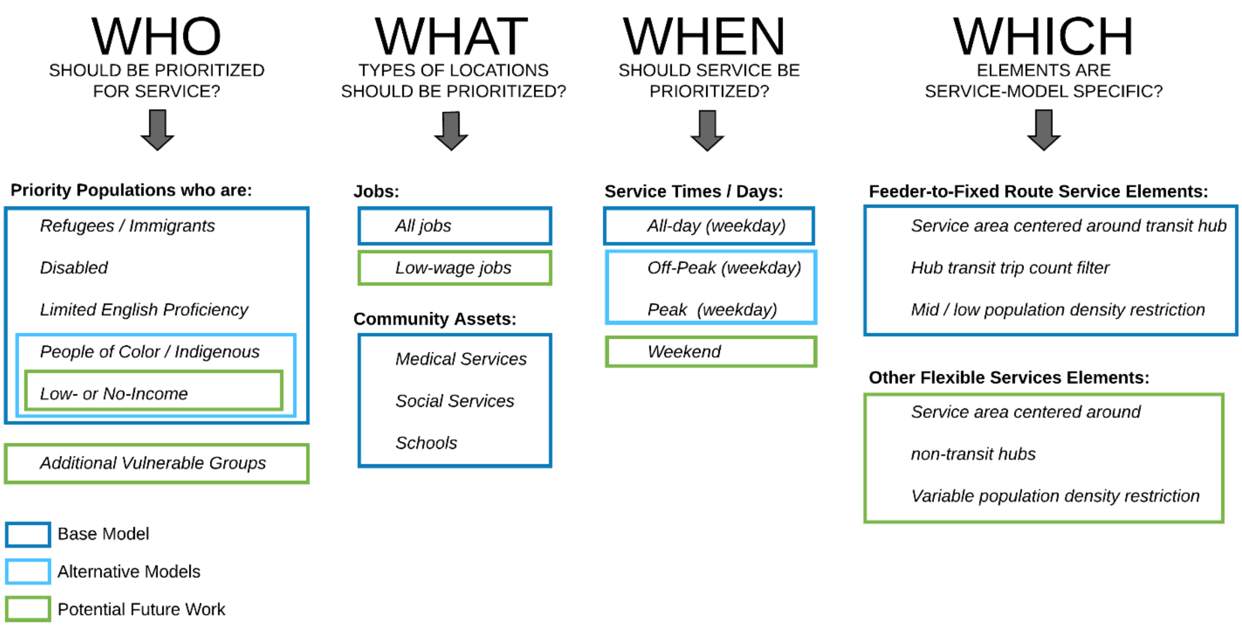
Fundamentally, the intention of this work was to develop a systematic approach for Metro to prioritize areas in the county to pilot F2FR flexible services. The end goal was not simply to develop a ranked list, but to develop and refine the systematic process itself, which can then be re-tooled for different purposes and goals moving forward. As part of this effort, this section identifies key policy questions that Metro and other transit agencies will have to answer as they plan for flexible services like F2FR. These questions provide a framework for aligning the goals of a service with the inputs included in an analysis. This analysis should be considered a first step in systematizing a complex process that merits iteration and continuous improvement, so limitations and future work are detailed in this section as well.

5.1 Key Policy Questions

For Metro, better aligning policy goals, locational suitability analysis, and implementation of F2FR flexible services is crucial to its shift toward becoming a mobility agency. Metro envisions itself as a manager of services that fit into a larger mobility network reliant on interagency and public-private partnerships. This vision is expressed in the Mobility Framework, which directly calls for increased innovation and equity in meeting community needs for transit service. As the transportation industry continues to incorporate flexible mobility services like F2FR services, agencies like King County Metro Transit should systematically evaluate new service locations based on professed goals and policy priorities. Metro's Mobility Framework provides guidelines for these priorities for Metro, and other policy documents should align with it moving forward. As discussed, the Mobility Framework's analysis and recommendations still warrant consideration of the relevant application to a given transportation service and policy goal.

There are important distinctions in the goals served by different flexible service models. This work focused on evaluating and selecting the criteria most applicable to feeder-to-fixed route transit services. It also analyzed different scenarios that represent how varying the inputs and priorities that make up the criteria alter the prioritization of areas for service. It's important to recognize that specific policy goals lend themselves to certain selection criteria for service provision of F2FR flexible services, and that alterations to those criteria can produce different results, as seen in Section 4.2: Alternative Model Results. The figure below, Figure 6, maps out some of the primary policy questions that transit agencies like Metro must strategically weigh when prioritizing service. The elements of the analysis included here are highlighted and categorized by the policy question they are associated with. Areas that could be considered for future work but that were beyond the scope of this work are also highlighted. The intention is that this framework can guide future analysis by matching policy priorities with analytical inputs.

Figure 6: Policy Questions Guiding Flexible On-Demand Service Planning Analysis



It should be noted that this framework was developed in the context of planning for F2FR flexible services for Metro, but that it could be adapted to other flexible service models. The spatial analysis models developed and the framework laid out above approach service planning through an equity-centered lens that is informed by the Mobility Framework, academic theory, and practice literature. These elements produce a robust lens of analysis that is applicable to a multitude of transportation services, and especially other flexible services. The service-specific elements differ, however, depending on the model that is being used for service delivery, and represents a vast array of options that go far beyond the scope of this work. Other applications are further discussed in Section 5.3.2: Applications to Service Reduction Scenarios.

5.2 Limitations

As with any social science research, the optimal analysis is often limited by certain data and methodological limitations. These limitations are identified in this section, and potential solutions are suggested, where applicable.

5.2.1 Data Limitations and Potential Solutions

Due to capacity limitations, block group Transit Accessibility Index scores were gathered from previous analytical work conducted for the Mobility Framework Report. These scores were calculated prior to our work, and the time periods of analysis (6:00 am to 9:00 am for Morning, 11:00 am to 1:00 pm for Midday, and 6:00 pm to 9:00 pm for Night) are not optimized for matching access to Metro’s service scheduling periods. While the Morning time period closely approximates Metro’s AM service period and the Midday period captures half of Metro’s midday service period, the Night time period used for the Mobility Framework work spans two of Metro’s service periods. This makes it difficult to draw conclusions about afternoon and evening service quality in areas. This also prevented analysis of all off-peak periods, which was why—for this analysis—the midday period was used as a stand-in for off-peak. Ideally, the Transit Accessibility scores would be calculated for each of Metro’s time periods. To address the accessibility score time period compatibilities, Transit Accessibility scores should be calculated for each population-weighted block group centroid for each hour of the day so that custom service analysis periods can be created according to the intended analysis purpose. Though more time intensive, it will allow for more flexibility in research design and more precision in analysis results.

Another limitation is that the Transit Accessibility scores for community assets were calculated using a dataset from 2017. An updated version of the file was recently completed, and accessibility scores should incorporate the updated Community Assets dataset into its analysis in order to utilize the most recent data.

Finally, the Priority Population Index data—drawn from the 2013-2018 ACS rolling estimate dataset—contains significant margins of error for the block group population estimates for people with disabilities, people with limited English proficiency, and foreign-born persons. For this reason and others, the alternative Priority Population Index weighting scenario significantly lowers the weights for these three datasets. Overcoming the ACS data limitations is not straightforward. In order to gain a better understanding of the existing conditions for these demographic groups, targeted community engagement and research efforts should be conducted in areas that received high scores in this work’s ranking analysis. Qualitative data and lessons learned through community outreach and further research should be incorporated into the model to further refine the rankings of the top scoring proposed service areas.

5.2.2 Methods Limitations and Potential Solutions

While many elements of the criteria for this analysis were adapted from the Mobility Framework, much of the methods were developed by the authors based on the limited literature available and through collaboration with Metro staff. As such, it’s important to discuss the tradeoffs that were made given the choice of methods.

5.2.2.1 Unmet Need Scoring

It is critical to keep in mind that the process that produced the final ranked list of TCLs is based on block group averages. Each block group was scored for the components of unmet need and population density, and these calculations were averaged within each of the TCL's service area approximations. It was determined with Metro staff that the method of score aggregation by averaging was preferred for the purpose of replicability of analysis. However, it is important to note that because this method was used, a shift in the inclusion or exclusion of block groups based on service area size and shape produces notable changes on the averaged components within a service area buffer. These buffers serve as a rough estimate of a service area, so an actual service area might end up looking quite different given the actual existing conditions of a specific area. This could alter the scoring of a given TCL, and by extension the degree to which unmet need is being served.

These score variations can be seen by comparing Metro's existing Via service areas to the service areas created around the existing Via service areas' hubs as approximations for this analysis. For example, the Transit Accessibility score for the Rainier Beach Station—using the 2-mile service area approximation for our base model—was 0.284. In comparison, when calculating the average block group score using the officially designated pilot service area, Rainier Beach had a Transit Accessibility score of 0.490, indicating a higher average need for increased transit accessibility. Although the two service areas contain comparable amounts of total area, Rainier Beach Station is located at the northernmost point of the official georeferenced area while the service area approximation produced a network buffer that expands equidistantly from the TCL point. Because the elements of unmet need generally increase as you move further south in King County, the official Rainier Beach service area ends up serving more people with unmet need because it includes more block groups to the south.

When considering the TCL rankings, it’s critical to keep the fluctuation-readiness of the scores in mind and the potential for certain TCLs to rise or fall in the rankings depending on the service area construction. Ultimately, the differences in scores between the top ranked TCLs is minor, and can be made negligible if certain block groups are included or excluded. It’s important to look at the top scoring TCLs holistically and limit the focus on the numerical rankings themselves. In addition, these service area approximations should be replaced with individually-refined service area proposals once a narrowed list of TCLs is developed for a specific project. A manually-designed service area for each TCL should be created and should account for specific existing conditions of each area. These manually-created service areas should look to include more high-scoring Unmet Need block groups, add any important local assets that may have been omitted in the initial street-network-created 2-mile buffer, and incorporate any other relevant components highlighted through local outreach and engagement.

As another potential mitigation to the shortcomings of the TCL scoring method, an alternative method is to weight the block group Unmet Need scores by the total population of a given block group. This method could avoid a situation where the composite score of a TCL with populous and high scoring block groups was brought down by a similar number of low scoring and unpopulous block groups. If the averaging of these scores produced a middling Unmet Need score, then a TCL with overall high need could be overlooked. The intention of using unmet need in the criteria was to determine where the most benefit from transit service could be provided, so considering the net population of people with unmet need within a service area should be considered for future analyses.

5.2.2.2 Population Density Filter

Similar to the calculation of Unmet Need scores, the population density filter is applied by averaging the population density of all block groups within a 2-mile network buffer of each

TCL. Because an officially designated service area could end up including different block groups and produce a different average population density, the utility of this filter is limited by the method of creating a service area approximation. Unfortunately, manually constructing a service area buffer for each TCL would have been immensely time-consuming, and—given the intention that findings from this work would be an intermediate product to inform final analysis—the 2-mile network radius approach was sufficient for the purposes of this analysis.

Another methodological tradeoff worth considering is the use of average population density for the Service Feasibility filter rather than estimating total population within the service area approximation. As stated previously, average residents per acre was the selected population density measurement rather than total population because the referenced academic literature and literature of practice largely uses this convention when discussing service feasibility and the associated thresholds. However, it's worth comparing how each of these methods alter the analysis. As shown in Table 15: Service Feasibility Filter in Appendix Section 7.2.6, 27 TCLs were removed by the density filter in the base model. It's noteworthy that the five TCLs with the lowest average population densities (below 4 residents per acre) also have the lowest total population estimates. However, there is much more variation in the distribution of TCLs that were disqualified for having population densities over 18 residents per acre when they are sorted by total estimated population. Eight TCLs that have average population densities over the inclusion threshold of 18 residents per acre were excluded from the final ranking process despite having lower total population estimates within their given service areas than other TCLs that were included in the final ranking process. For example, the Judkins Park Station TCL service area and the Crown Hill TCL service area have average population densities of about 25 and 18 residents per acre, respectively, but the Crown Hill service area has an estimated total population of about 1,000 more residents than the Judkins Park Station service area. This indicates that averaging population density may remove TCLs from the analysis that could otherwise be included if a different method of filtration were used. Partly for this reason, Alternative Model: Scenario 3 was included to identify the TCLs that were above the upper density limit and considers if they would have otherwise been good contenders for F2FR flexible service.

5.2.2.3 Trip Count Aggregator and Filter

The trip count aggregator and filter captures unique transit trips serving transit stops within 660 feet (an eighth of a mile) of a TCL point for a given time period and then filters out TCLs whose trip counts fall below the 40^{th} percentile of trips measured at each TCL for the given time period. Consistent with the goals of the feeder-to-fixed route model, the trip capture area of 660 feet was intentionally chosen to target the immediate area around potential transit connection location points, or, the area where riders could connect with the most concentrated grouping of fixed-route trips. Expanding the buffer radius much further than an eighth of a mile would lead to less-interpretable trip count comparisons between TCLs located near each other. However, it’s important to note that the limited trip capture area has a disproportionate impact on the inclusion or exclusion of counts for TCLs that are not designated transit centers or light rail stations. Many of the TCLs that were identified in PSRC regional growth areas are located in mid- and lower-density areas of the county where East-West transit service and North-South transit service do not directly connect at a bus stop, and bus stops are often spread further apart due to the density characteristics of the areas. The relatively small trip count buffer captures a smaller proportion of transit trips in these mid-density areas that do not have a transit center or light rail station as a main transit transfer point.

Kent Des Moines Station illustrates the TCL locational dilemma seen in certain areas of the county. Kent Des Moines Station is a King County Metro-designated Activity Center, which indicates that this point has generally high levels of transit service. There aren’t any nearby transit centers and the nearby light rail station is not scheduled to open until 2024, but the surrounding area includes a shopping center served by a north-south BRT route and a low-frequency local collector bus route, a public community college served by four bus routes, and a park & ride facility served by five peak-only commuter bus routes and one low-frequency local bus route (the same route serving the shopping center). While all three areas are within one mile from each other, the transit stops are not concentrated enough to be captured by the 660 foot buffer. Ultimately, the authors decided to locate the TCL next to the shopping center in order to capture the BRT line’s high-frequency all-day transit service, but an argument could be made that the true levels of transit service for this area were not captured using the current methods. The case of Kent Des Moines also reinforces the logic behind the decision to exclude current and future light rail stations from the trip count filter. While transit service at the Kent Des Moines TCL is somewhat disparate and unconducive to quick transfers between transit routes, the transit service in the area will soon be reoriented to concentrate transit transfers at the light rail station once it opens.

5.3 Future Work

Given the novelty of F2FR flexible service planning, the findings contained in this report should be used as guidance for narrowing the focus of further location selection research in King County. The results from this location prioritization model should be used to direct targeted qualitative research and community engagement efforts that help further refine the TCL priority rankings. The TCL rankings for the base model and in the alternative scenarios should be viewed as a starting point; while the quantitative model may point to an area as a high priority area, conditions on the ground may lead decision-makers to reevaluate the feasibility of locating F2FR flexible service at a given location.

5.3.1 Additional Scenario Models

In addition to making improvements to the inputs and methods used in this analysis, future analyses should also consider modeling additional scenarios. These additional models would supplement and enhance the analysis included here, which was limited by scope. While these are by no means the only relevant models to consider, they are the ones that were identified through the course of this analysis. It is assumed that— similar to the Via model that initially did not identify Rainier Beach station as a viable centerpoint for a service area— these types of models are in flux and will continue to be influenced by new theories that are developed over time.

5.3.1.1 Altered Weighting of Transit Accessibility Components

An additional scenario that would be relevant to model is to alter the weighting of the component elements of the Transit Accessibility score, which includes jobs, schools, medical services, and social services. This type of alteration would represent a change in policy towards the comparative importance placed on accessing certain community features. Currently, the accessibility score is calculated such that, for a weighting index of 1, accessibility to jobs is weighted at 0.500, accessibility to schools is weighted at 0.250, and accessibility to social services and medical services are each weighted at 0.125. In an alternative policy scenario, all component elements could be equally weighted, or modified according to the different policy goal. Such an alteration could be especially relevant to other types of flexible services that may not prioritize improving accessibility for commuters, as was prioritized by the weighting in the Mobility Framework and for the F2FR flexible service here. Figure 6 asks this specific policy question, “What types of destinations should be prioritized.”

5.3.1.2 Altered Weighting of Composite Unmet Need Scores

The weighting for the Priority Population Index score and the Transit Accessibility Index score could be altered to variably influence the final composite TCL Score. Currently, these two component scores are weighted equally. An increase or decrease in either of these component scores could represent a number of different alternative policy priorities. For example, increasing the Transit Accessibility component score weighting could represent a policy priority of expanding network potential ridership capture over targeting specific demographic equity goals.

5.3.1.3 Transit Accessibility for Low-Income Priority Populations

As discussed in Section 4.2.1: Scenario 1: Transit Accessibility Fluctuation by Time of Day, the two elements of this scenario provide a starting place for prioritizing new service to address temporal accessibility gaps at identified TCLs. However, addressing these gaps for priority population groups in particular warrants additional analysis. As stated in the Mobility Framework, the purpose of focusing on increasing off-peak accessibility is to serve people who may lack continuous all-day transit accessibility, and who may specifically rely on accessibility during off-peak hours to access employment. Therefore, an additional analysis could focus specifically on increasing accessibility to the employment destinations that may be more frequently accessed by low-income priority populations.

In the base and alternative models, the accessibility scores are calculated based on the same weighting and the same elements included in the Mobility Framework: jobs, schools, medical services, and social services. This provides a general picture of accessibility in a given area, but it does not look at how accessibility scores change if the analysis is specific to the destinations that low-income people may travel to more frequently. In future analyses it could be informative to calculate Accessibility scores with low-wage jobs weighted highest, and see how the TCL rankings differ in Midday Accessibility. Aligning accessibility to low-income jobs during midday with high Priority Population Index scores could help to focus the analysis on a specific subset of the intended beneficiaries. It should be noted that although this type of analysis aims to get at the more specific needs of priority groups, in practice it could have the effect of generalizing the accessibility needs of people who may qualify as low-income. A limitation of this analysis is that the more nuance one tries to capture, the greater the possibility for error and for attaching too much weight to the findings.

Given the imperative to align all future work with the Mobility Framework, this type of prioritization should be considered in analyses moving forward. A similar approach could also be used to analyze accessibility needs specific to other Priority Population sub-groups. A more granular analysis could include a selection of the facilities, services, or cultural institutions that are specifically relevant other Priority Population sub-groups. However, the level of specificity involved in the inputs to this type of analysis would strongly recommend itself to robust community engagement. Engagement would be important for both informing the inputs to the analysis as well as verifying if actual travel patterns and needs match the quantitative analysis.

5.3.2 Applications to Service Reduction Scenarios

While most of the work described here assumed a service expansion scenario, flexible service locational analysis will differ slightly for a budget-induced service reduction scenario. In this type of scenario, the areas considered for new flexible services will be determined (at least in the short-term) by fixed-route service planning processes. As a result, a flexible service may be implemented as a way to maintain accessibility amidst fixed-route service reductions in areas that have the highest unmet need. Service reductions could result in greater variability in accessibility throughout the day if service is reduced primarily outside of commute hours. Future expansion of this work should prioritize incorporating time-period specific transit trip count analysis for areas that are being considered for F2FR flexible services. This should be done to verify if there are enough trips occurring to support the service. Alternatively, service reductions during the midday period could warrant a different type of flexible service that is not based on transporting people to and from transit focal points.

In general, service reduction may increase the applicability of other types of flexible services beyond feeder-to-fixed route. Given that F2FR flexible services provide the most accessibility benefit when they feed people to an established point of high-frequency transit, a scenario of reduced transit service for lower density areas warrants a rethinking of the value of TCLs and of the applicability of F2FR flexible services. For lower density areas with limited existing fixed-route transit and a primary transit need for local service, localized flexible on-demand transit services that provide door-to-door service or door-to-community-asset trips would be better suited to meet customer needs than a F2FR service that limits trip purpose to accessing regional public transit hubs. The TCLs identified in Section 0 may be largely irrelevant in a locational suitability analysis for these non-F2FR flexible services that aim to prioritize localized accessibility. Instead, a locational suitability analysis for these types of flexible services in a reduction scenario should first identify areas where the accessibility need is primarily for local trips and where this overlaps with high concentrations of Priority Populations. Concentration of community-identified assets should also be considered as well as level of trip generation for different assets. Localized flexible on-demand services will perform best in areas that attract a lot of trips, minimize trip time and provide opportunities for service vehicles to link multiple customer trips.

An additional consideration is how flexible service locational analysis interfaces with the service reduction process dictated by the Service Guidelines. If the order of operations in the short-term is to have flexible service planning follow fixed-route planning, we should consider how the Service Guidelines incorporates the recommendations from the Mobility Framework. Service Planning is working on applying an unmet need lens to its Service Guidelines updates and planning moving forward, which has implications for how locations for flexible service are subsequently prioritized. If reductions are done equitably, this will minimize the decrease in accessibility to areas with highest unmet need. This analysis then is relevant as a way to prioritize service in areas that may not have high unmet need, but that still aims to target areas with the highest relative need.

In the long-term, the planning for fixed-route service reduction should be done in tandem with—and be shaped by—the locational suitability analysis for localized flexible on-demand transit services. Regardless of the given service or scenario, it will be important to be consistent with agency service priorities and continue to work to meet Metro’s mandate of prioritizing service where there is the most need.

6. Conclusion

In an environment where public transit agencies strive to innovate and adapt to changing travel patterns and to address inequities in regional growth, it's more important than ever to leverage all the mobility tools at an agency's disposal in order to deploy resources in a manner that optimally balances public benefit with efficient use of public resources. While F2FR flexible services are generally employed to address coverage goals and are unlikely to be the deciding factor in meeting public transit ridership goals, thoughtful deployment of F2FR services enables fixed-route transit services to be deployed in a more efficient manner that can contribute to both ridership and coverage goals.

The purpose of this work was to provide an analytical framework for identifying and prioritizing areas for F2FR flexible services, so that agencies like Metro can be more systematic in operationalizing its policy priorities moving forward. While the analysis has already informed prioritization of additional potential F2FR flexible service areas within the Innovative Mobility team at Metro, the work provides value beyond the direct output of the analysis. The broader value of this work to Metro and other transit agencies pursuing similar work is that it models county-wide service planning analysis that is adaptable for other flexible services, through modeling the selection of relevant criteria inputs, an adaptable analytical methodology, and the policy framing that is crucial to guiding decisions around inputs to future analyses. The intention is that this work enables greater alignment between policy goals, locational suitability analysis, and implementation of F2FR and other flexible services moving forward.

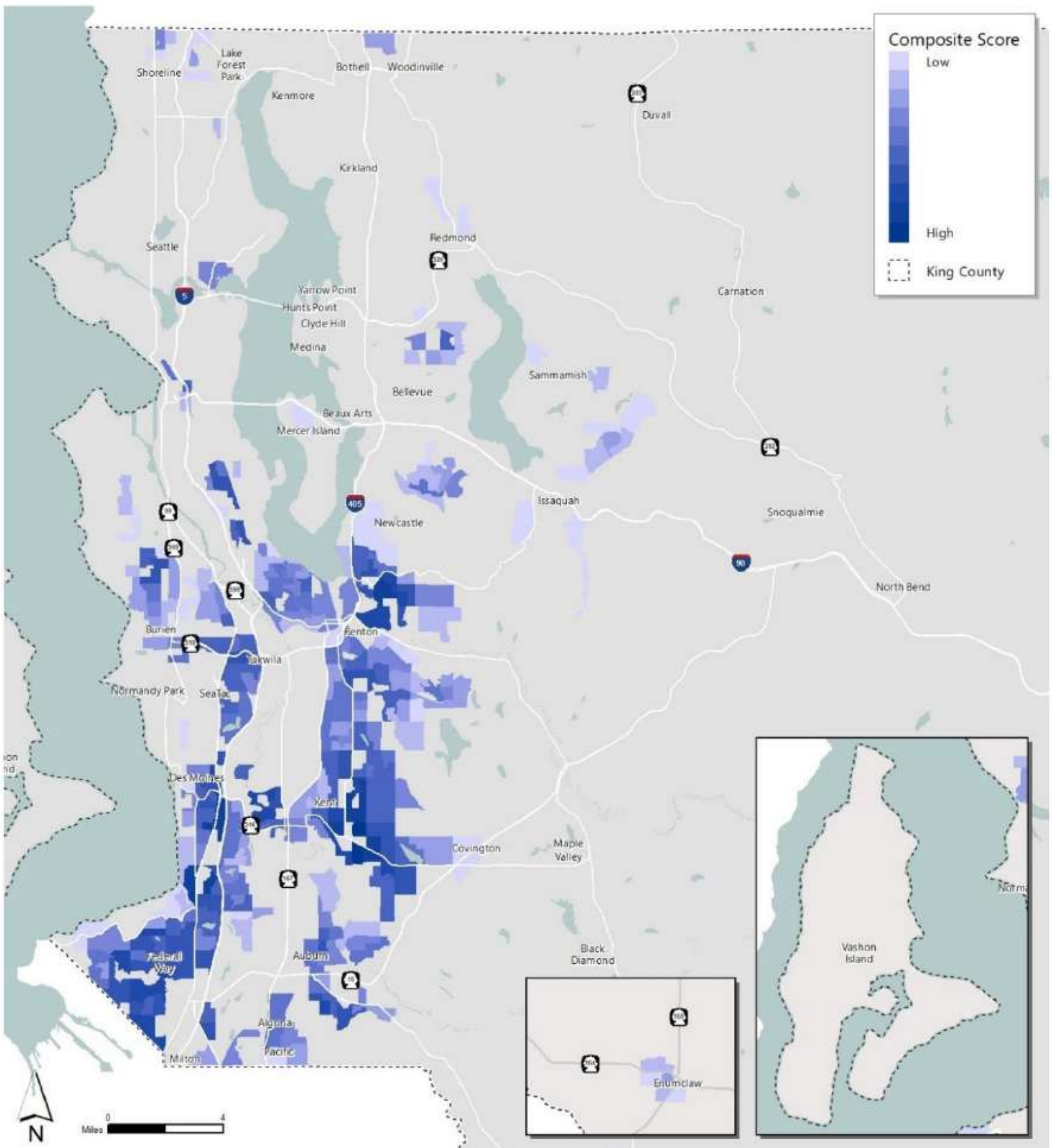
While the findings contained in this work should not be the final analytical step in a locational decision-making process, this work has been developed to meet the goal of providing a foundation for future analysis and relevant policy considerations. All work that leverages these methods or inputs should take into account the limitations discussed herein, and keep in mind that any work that is adapted for other applications or types of services should be firmly grounded in service-specific policy goals. That being said, this type of analysis should be incorporated into regional service planning projects, as applicable. Moving forward, the goals and planning processes for both fixed-route and flexible services will need to align with a single cohesive mobility policy framework. Aligning Metro’s existing policy goals with the locational suitability analysis for F2FR flexible services is one step toward enabling this transportation system integration and facilitating its shift toward becoming a mobility agency.

7. Appendices

7.1 Appendix A

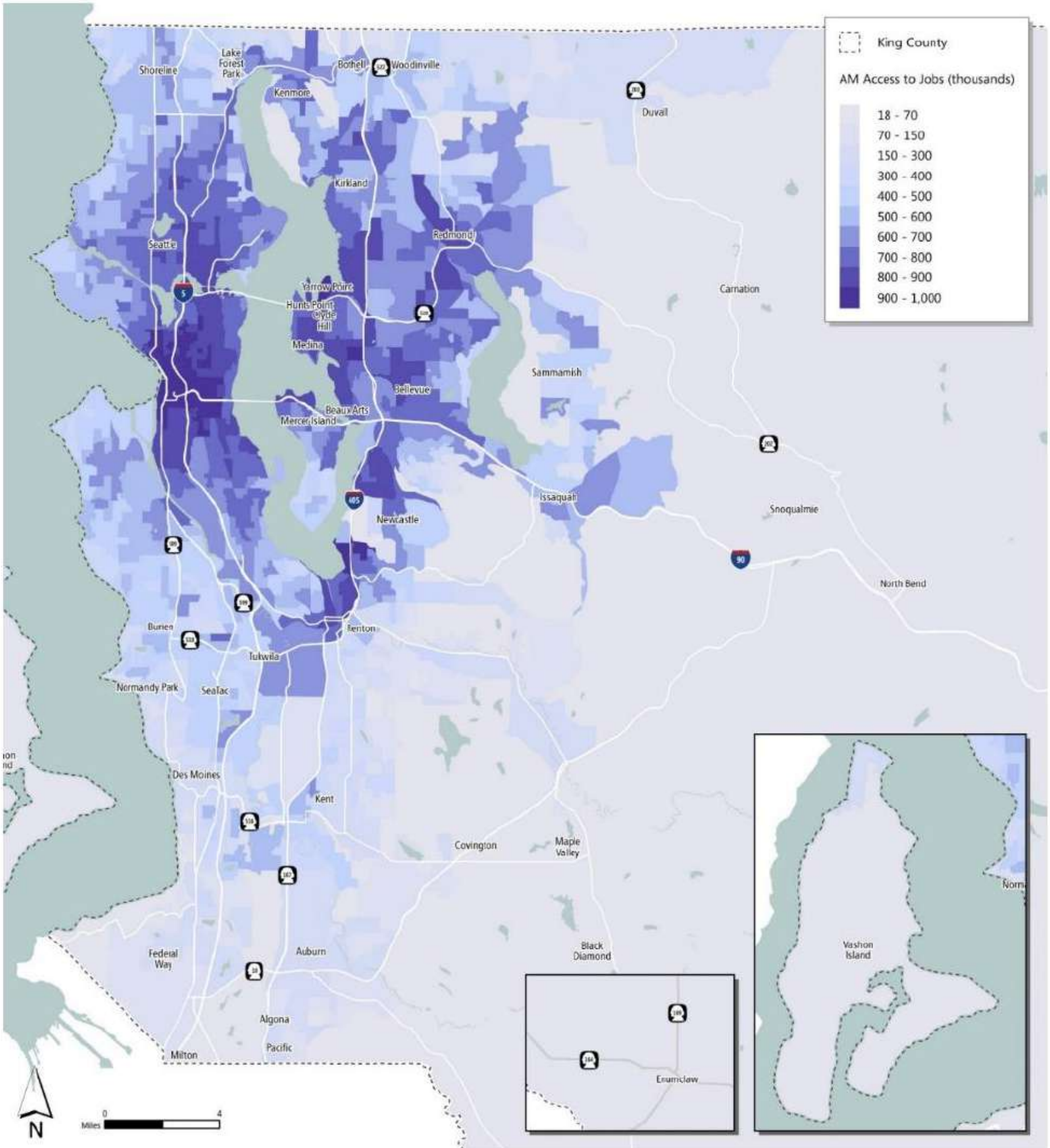
7.1.1 Mobility Framework Figures

Figure 7: Alternative Services Opportunities Composite: High Concentrations of Priority Populations, Low Off-Peak Access, Population Density between 4 and 15 people per acre



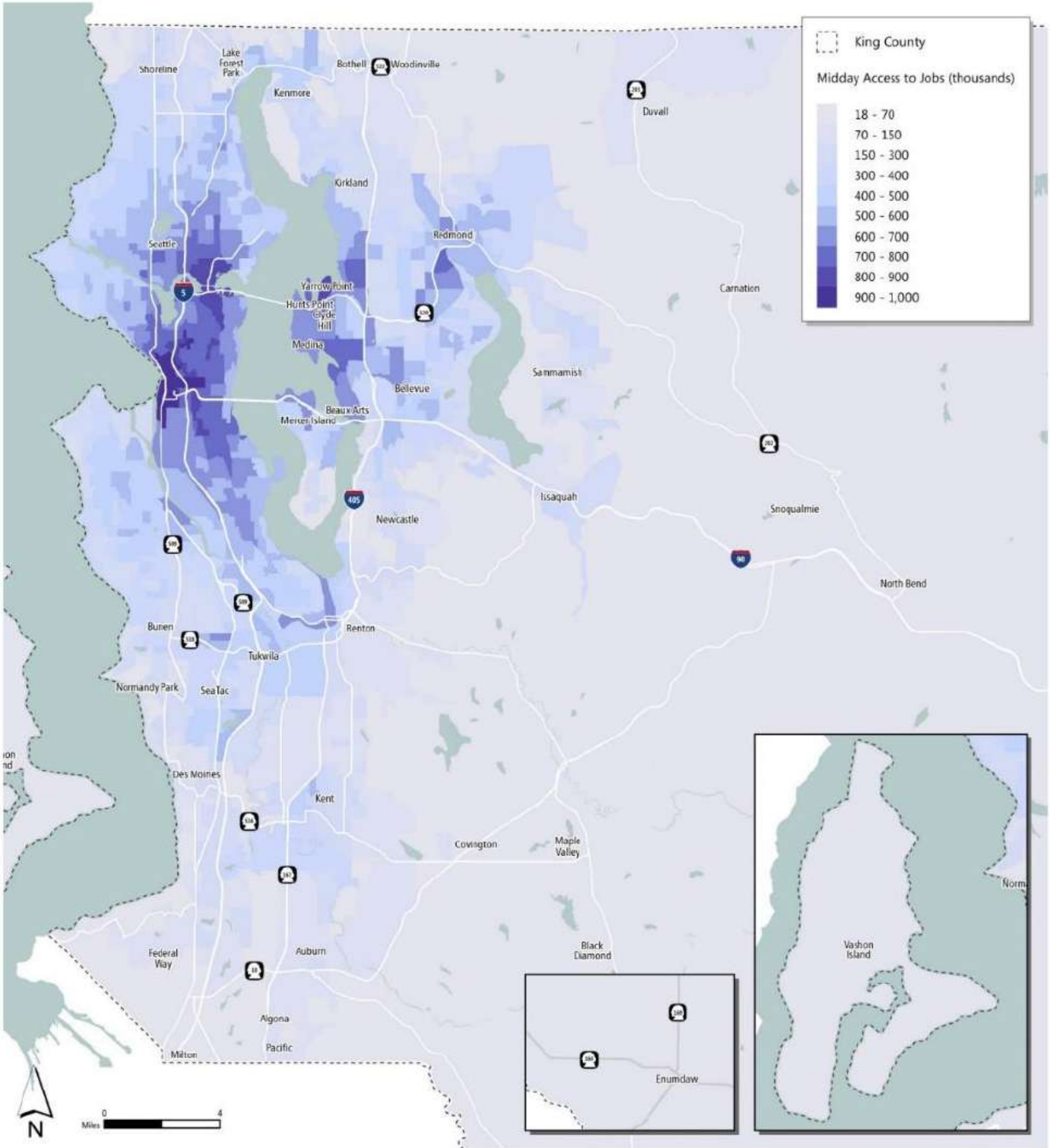
Source: American Community Survey (ACS) 2017 5-Year Estimate, (King County Metro Transit Department, 2019b)

Figure 8: AM Peak Period Job Access by Transit (2015)



Source: US Census Longitudinal Employer Household Dynamics (LEHD) 2015, Puget Sound Regional Transit Feed Specification (GTFS) (King County Metro Transit Department, 2019b)

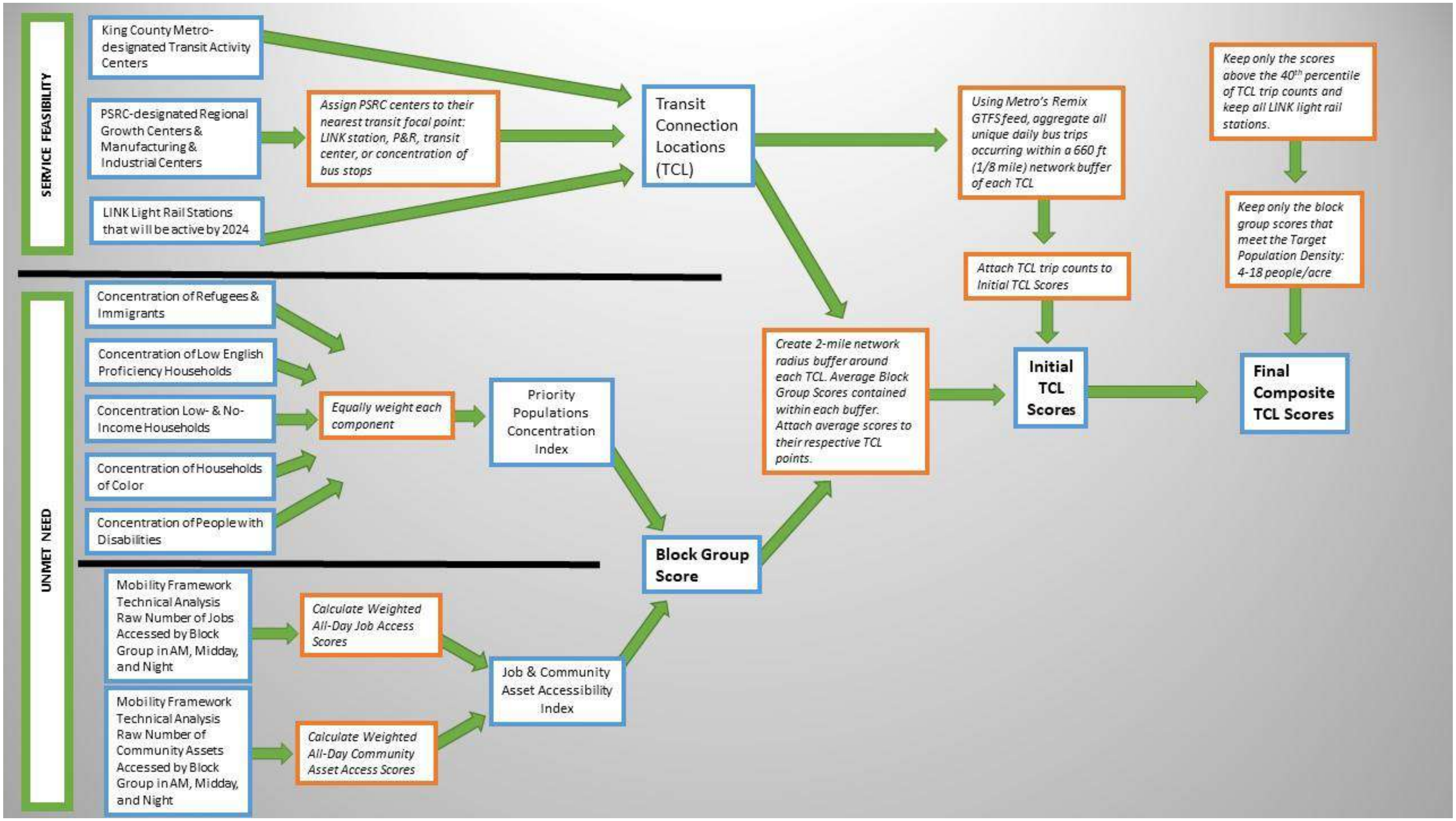
Figure 9: Midday Peak Period Job Access by Transit (2015)



Source: US Census Longitudinal Employer Household Dynamics (LEHD) 2015, Puget Sound Regional Transit Feed Specification (GTFS) (King County Metro Transit Department, 2019b)

7.1.2 Methods Diagram

Figure 10: Base Model Methods Diagram



7.1.3 Base and Alternative Model Components

Table 9: Model Component Derivations

	Criteria	Components	Criteria / Component Determination	Source Data	Weighting Determination	Methods Determination	Analysis Components	Analysis Execution
Unmet Need Block Groups	High Priority Population Score	Concentration of low- and no- income people, people of color and indigenous people, immigrants and refugees, people with disabilities, and limited-English speaking communities	Mobility Framework	U.S. Census Bureau's ACS 2013-2018 rolling block group level data	Mobility Framework	Mobility Framework	Calculating percentages of population and weighted percentile scores by block group	DM-MC
					Scenario 2: deliberations with Metro staff / Metro agency documents			
	Low Transit Accessibility Score	All-day transit accessibility to jobs and community assets	Mobility Framework / existing academic literature	Mobility Framework	Mobility Framework	Mobility Framework	Travel trends analysis	Mobility Framework Consultant
						DM-MC	Weighted percentile scores by time of day, AM/MID % change, Scenario 1: transit accessibility scores by time period	DM-MC
Service Feasibility Filter	Near hub (TCL) w/ high trip count	Transit Connection Locations	DM-MC / deliberations with Metro staff	Metro Service Guidelines / Sound Transit / PSRC	N/A	DM-MC	Locating all points at transit stops	DM-MC
		Approximate service area (2-mile) surrounding TCL	DM-MC / deliberations with Metro staff	TCL points created by DM-MC	N/A	DM-MC / evaluation of Metro F2FR flexible services to date	GIS network analysis	DM-MC
		Trip counts	DM-MC / practice literature / deliberations with Metro staff	GTFS feed—generated via Remix--of King County Metro, Sound Transit, Community Transit, and Pierce Transit	N/A	DM-MC	Aggregate trip counts within buffer, filter for repeats with R script, filter out TCLs with low trip count	DM-MC
	Mid/low population density	Service area average density	Mobility Framework / existing academic and practice literature	Mobility Framework / U.S. Census Bureau's ACS 2013-2018 rolling block group level data	N/A	DM-MC	Filter out TCLs outside of density range	DM-MC

7.2 Appendix B: Base Model

This Appendix includes additional detail the inputs and analysis that went into the Base Model, including definitions and sources.

7.2.1 Transit Connection Location Components

Table 10: Transit Connection Location Inputs

Input	Description	Components	Data Source
PSRC Regional Growth and Manufacturing / Industrial Centers	Places that will receive a significant proportion of population and employment growth compared to the rest of the urban area.	18 Regional Growth Centers in King County 4 Manufacturing/ Industrial Centers in King County	Puget Sound Regional Council, Regional Centers Framework Update, 2018
Transit Activity Centers	Each transit activity center identified meets one or more of the following criteria: • Is located in an area of mixed-use development that includes concentrated housing, employment, and commercial activity • Includes a major regional hospital, medical center or institution of higher education located outside of a designated regional growth centers • Is located outside other designated regional growth centers at a transit hub served by three or more all-day routes.	63 Transit Activity Centers	King County Metro, Metro Connects, 2016
Link Light Rail Stations through 2024	Current and planned Link light rail stations up to 2024	36 current and planned Link light rail stations	Sound Transit, 2020

Source: (King County Metro Transit Department, 2015)

7.2.2 Priority Population Index

The raw numbers of people that make up the five sub-groups of the Priority Population Index (PPI) were generated by Metro staff using the United States Census Bureau's 2013-2018 American Community Survey (ACS) rolling estimate Block Group Level data. These variables are further described in the table below, including the census variable calculations that comprise each variable.

Table 11: Priority Population Sub-Group Definitions

Sub-Group	**Definition**	**Census Variable Calculation**[5]
Household Poverty	200% of Federal Poverty Line	C17002e1 - C17002e8
Foreign Born Individuals	Anyone who is not a U.S. citizen at birth. This includes naturalized U.S. citizens, lawful permanent residents (immigrants), temporary migrants (such as foreign students), humanitarian migrants (such as refugees and asylees), and unauthorized migrants.	B99051e5
Households of Color	All ethnicities excluding Non-Hispanic White	B03002e1 - B03002e3
Limited English-Speaking Households	A household in which no member 14 years and over speaks only English or speaks a non-English language and speaks English "very well."	C16002e4 + C16002e7 + C16002e10 + C16002e13
Individuals with Disabilities	The Census Bureau reports six disability types: hearing difficulty, vision difficulty, cognitive difficulty, ambulatory difficulty, self-care difficulty, and independent living difficulty. An individual who reports any of these six disability types is considered to have a disability.	B23024e3 +B23024e18

Source: (King County Metro Transit Department, 2019b)

Consistent with the Mobility Framework analysis, for this analysis each set of raw numbers was converted into a percentage of population by census block group. All fields were normalized by total population as defined by census estimates (defined by field B01001e1). The exception to this was Limited English-speaking households, which was normalized by an

[5] Census data source: block-group level ACS data, 2018.

estimate of households as defined by field C16002e1. The percentages were then scored on a percentile basis (from 0 to 1) by comparing every block group against other block groups within King County. Each percentile score was combined into an equally weighted index using the five variables with each variable given 20% weighting.

7.2.3 Transit Accessibility Index

The raw numbers of jobs and community assets that are accessible by transit were generated for the Mobility Framework analysis by a consultant, Fehr & Peers. The component elements of community assets variables are detailed in Table 12: Community Assets Variables, below. In order to generate these numbers, the consultant conducted a travel trends analysis that included a travel shed analysis based on certain time periods, a 60-minute travel window, and the number of jobs and assets that could be reached. Specifically, transit accessibility was measured using an UrbanAccess network with Pandana, which is a tool for computing networks for accessibility analysis. Travel time was estimated using the UrbanAccess coding for various transit service and travel time characteristics based on schedules from General Transit Feed Specification (GTFS) data. Travel time estimates considered the sum of the trip attributes and input sources shown in Table 13: Factors Used in the Accessibility Analysis.

Table 12: Community Assets Variables

Community Assets Variables	**Components**
Educational Facilities	Elementary School Middle or High School Other School College
Social Services	Library Senior Center Community Center Farmers Markets Grocery Stores Shopping Centers Places of worship Food Banks Emergency Shelters WIC Vendors Work Source Site
Medical Services	Hospitals Residential Treatment Centers Nursing homes Federally Qualified Health Clinics Assisted Living Facilities WIC Clinics

Source: King County Metro Community Assets Geodatabase, 2019

Table 13: Factors Used in the Accessibility Analysis

Factor	Description
Origin points	Census block group centroids that were spatially adjusted to place the centroid near bus stops within and adjacent to the block group
Destination points	Jobs from Longitudinal Employer-Household Dynamics (LEHD) and community assets from the May 2019 version of the Metro-based Community Asset database
Transit network	GTFS for the Spring 2019 service period
Walk speed/time	3 mph, network-based
Wait time	Half of the headway
In-vehicle transit time	Based on GTFS speeds during time period of analysis
Transfer time	If required, based on walk time to connecting service, and half-headway wait times
Time periods of analysis	• Morning (6:00 – 9:00 a.m.) • Midday (11:00 a.m. – 1:00 p.m.) • Evening (6:00 – 9:00 p.m.)
Travel shed time	60-minutes, including walk/wait/in-vehicle
Accessibility metrics	Cumulative jobs and community assets within the travel shed[6]

Using the raw numbers of jobs and community assets that were generated for each time period, this analysis generated an all-day Transit Accessibility score. Transit service varies throughout the day; so to get the all-day Transit Accessibility score we took the average of the Transit Accessibility scores across each time period (AM, Midday, PM, and evening) for each block group weighted by the number of hours in each period. The equation is included below.

$$All\ Day\ Access\ Score = \frac{(AM\ Access\ Score\ \times Hours\ in\ AM\ Period) + (Midday\ Access\ Score\ \times Hours\ in\ Midday\ Period) + (PM\ Access\ Score\ \times Hours\ in\ PM\ Period)}{Sum\ of\ Hours\ in\ AM,\ Midday,\ and\ PM\ Study\ Periods}$$

This all-day weighted average was then converted into the corresponding percentile distributions across block groups. We took the inverse of this percentile score so that high scores represent the lowest transit access. We then aggregated the Transit Accessibility scores

[6] No distance decay was applied to the results. All opportunities within the 60-minute shed were equally scored, regardless of distance from the origin.

of the four variables by weighting each component variable according to the approach used in the Mobility Framework, which put the most importance on accessibility to jobs, followed by schools, and then medical and social services. See Table 14: Unmet Need Variable Weighting for the specific weighting of each variable.

7.2.4 Unmet Need Composite

The base model Unmet Need composite score for each block group was averaged to equally weight the Priority Population Index score and low transit access. The weighting for each component of Priority Populations and Transit Accessibility is detailed below.

Table 14: Unmet Need Variable Weighting

Broad Category	Variable	Broad Factor Weight	Sub Components
Priority Populations	Population living 200% above the federal poverty line	50%	20%
	Population that is Non-white or Hispanic		20%
	Population that is living with some type of disability		20%
	Limited-English speaking households		20%
	Population that is Foreign-born		20%
Transit Access	Jobs accessibility (all-day)	50%	50%
	School accessibility (all-day)		25%
	Social Services accessibility (all-day)		12.5%
	Medical Services accessibility (all-day)		12.5%

7.2.5 Associating Unmet Need Scores with TCLs

After identifying TCLs and calculating Unmet Need scores for each block group in the county, we then attributed Unmet Need scores to their proximate TCLs. In order to do this we created a two-mile radius network buffer for each TCL that could be used to approximate a service area. We then averaged all block group scores whose population weighted centroid fell within each network buffer. The population weighted centroid corresponds to the area within the block group that has the highest population density, as determined at the parcel level. This approach allowed us to more precisely include or exclude block groups based on whether or not the block group point with the highest population density was included within the buffer. Finally, the aggregated block group scores were associated with each TCL point. It was determined with Metro staff that the method of score aggregation by averaging was preferred for the purpose of replicability of analysis.

7.2.6 Service Feasibility

After assigning an Unmet Need score to each TCL, the list of TCLs was filtered based on their feasibility as center points for a F2FR service. A buffer was created for each TCL with a network radius of 660 ft. (⅛ mile) and the unique transit trips were aggregated within each TCL buffer for the AM, Midday, Night, and All-Day time periods of measurement using ArcGIS and R. This method prevented double counting of unique trips that serve multiple transit stops within a given TCL's 660-foot radius buffer. Daily weekday trip counts and weekday trip counts for each time period were gathered using the most up-to-date GTFS data from King County Metro Transit, Sound Transit, Pierce Transit, and Community Transit agencies. The city of Seattle's Monorail, Streetcar, and Water Taxi were not included in the trip counts, nor was Sound Transit's Link Light Rail. TCLs that were locations of current or future Link Light Rail service (up to 2024) were not subject to the trip filter. To create the final list of TCLs for the base model and for Scenario 2: Priority Population Weighting Variation, all TCLs with an associated daily trip count that fell below the 40th percentile of TCL trip counts were removed as a way to filter for financial infeasibility of F2FR flexible service. This filtering process was also conducted for the individual time periods for Scenario 1: Transit Accessibility Fluctuation by Time of Day.

The list of TCLs was also simultaneously filtered to remove TCLs that had average population densities outside of the range of 4 to 18 residents per acre. This was calculated by averaging the population densities of the block groups within each TCL 2-mile buffer.

The complete ranked list of 103 TCLs is included in the table below, indicating the TCLs that were disqualified based on the each of the two Service Feasibility filters. The TCLs that were disqualified due to the trip count filter are shown in light yellow, those that were disqualified due to the density filter are shown in light orange, and those that were disqualified due to both filters are shown in dark orange.

Table 15: Service Feasibility Filter

Transit Connection Location	Composite Score Ranking	Composite Score	Total Population Estimate within 2-Mile Buffer	Average Residents per Acre	Count of Daily Transit Trips
Kent East Hill - 104th Ave SE/SE 240th	1	0.732	42,666	13.78	216
Auburn Transit Center	2	0.709	20,751	8.90	389
Federal Way Transit Center Station	3	0.707	23,779	7.73	N/A - Link Station
Twin Lakes - 21st Ave SW/SW 336th	4	0.696	36,175	10.83	155
Kent	5	0.683	8,743	5.97	135
Kent Downtown	6	0.681	33,339	10.57	829
Green River Community College	7	0.674	14,222	6.44	147
Airport / SeaTac Station	8	0.673	20,923	9.21	N/A - Link Station
Valley Medical Center	9	0.671	19,621	9.12	141
Fairwood Shopping Center	10	0.667	28,394	8.99	110
S 272nd St Station	11	0.666	31,345	11.40	N/A - Link Station
Renton Tech College	12	0.663	44,585	10.95	90
Carnation	13	0.663	2,576	0.91	18
Enumclaw	14	0.660	11,427	5.00	36
Kent / Des Moines Station	15	0.651	31,311	9.53	N/A - Link Station
Snoqualmie City Center	16	0.643	2,285	1.16	47
Angle Lake Station	17	0.640	24,484	9.77	N/A - Link Station
Tukwila International Blvd Station	18	0.639	28,970	8.17	N/A - Link Station
Covington - 172nd Ave SE/SE 272	19	0.638	16,353	8.78	74
Issaquah Transit Center	20	0.638	9,282	6.56	288
Renton Highlands - NE Sunset/NE 12th	21	0.638	35,007	11.33	180
Vashon	22	0.632	1,718	0.52	56
Renton Transit Center	23	0.628	29,877	9.27	1085
Des Moines - Marine View Dr/S 223rd	24	0.626	24,593	8.84	187
North Tukwila	25	0.609	19,784	5.58	138
North Bend Downtown	26	0.600	6,066	2.17	47
Issaquah Highlands P&R	27	0.595	23,822	5.05	266
Black Diamond	28	0.588	1,224	0.27	32
Rainier Beach Station	29	0.579	43,986	15.08	N/A - Link Station
Tukwila - Southcenter Mall	30	0.578	11,314	8.32	466
Maple Valley - SR 169/Kent-Kangley	31	0.564	20,214	6.67	97
Burien Transit Center	32	0.553	32,403	9.83	832
Sammamish City Center	33	0.548	18,177	6.69	90
Duvall	34	0.542	8,237	4.21	52
Othello Station	35	0.539	56,608	14.78	N/A - Link Station
Bothell UW Cascadia	36	0.526	10,076	6.63	630
South Park - 14th Ave S/S Cloverdale	37	0.519	10,203	5.49	203
Mercer Island Station	38	0.514	14,521	7.82	N/A - Link Station
SE Redmond Station	39	0.512	21,492	9.02	N/A - Link Station
Mercer Village Shopping Center	40	0.509	9,795	4.88	49
Georgetown 13th Ave S/S Bailey	41	0.508	25,033	11.79	350
Downtown Redmond Station	42	0.507	32,333	10.58	N/A - Link Station
Westwood Village	43	0.499	51,054	11.51	236
Shoreline North / 185h St Station	44	0.495	36,641	9.46	N/A - Link Station
North City 15th Ave NE/NE 175th	45	0.489	34,665	9.01	147
Overlake Village Station	46	0.489	42,333	13.36	N/A - Link Station
Woodinville P&R	47	0.485	11,953	4.91	200
Redmond Technology Station	48	0.483	38,146	12.00	N/A - Link Station
Crossroads	49	0.482	44,215	12.68	420
Redmond Transit Center	50	0.481	31,322	9.60	763
Aurora Village Transit Center	51	0.480	23,914	8.99	604

South Seattle Community College	52	0.473	26,536	13.24	78
Columbia City Station	53	0.469	59,964	14.12	N/A - Link Station
Kenmore P&R	54	0.459	20,554	6.29	358
Newcastle Commercial Center	55	0.451	16,715	5.88	106
Bel-Red/130th Station	56	0.451	33,599	16.07	N/A - Link Station
Shoreline Community College	57	0.449	27,927	10.27	320
Shoreline South / 145th St Station	58	0.448	48,702	13.14	N/A - Link Station
Factoria - Factoria Blvd SE/SE Eastgate Wy	59	0.446	21,999	5.71	108
Eastgate P&R	60	0.436	25,711	6.85	747
Lake Forest Park Town Center	61	0.435	26,205	10.53	242
Lake Washington Institute of Technology	62	0.429	22,749	8.38	61
Duwamish Industrial Area	63	0.425	9,631	7.97	158
Totem Lake Transit Center	64	0.413	37,570	10.62	349
Beacon Hill Station	65	0.406	51,302	19.31	N/A - Link Station
Alaska Junction	66	0.406	54,038	14.37	503
Mount Baker Station	67	0.404	51,753	16.18	N/A - Link Station
South Bellevue Station	68	0.397	15,407	6.56	N/A - Link Station
Spring District/120th Station	69	0.394	32,566	14.73	N/A - Link Station
Wilburton Station	70	0.391	33,157	15.56	N/A - Link Station
SODO Station	71	0.385	23,368	25.23	N/A - Link Station
Lake City	72	0.383	53,045	14.38	870
East Main Station	73	0.378	32,082	13.70	N/A - Link Station
Juanita - 98th Ave NE/NE 116th	74	0.371	27,118	10.34	282
Oak Tree - Aurora Ave N/N105th	75	0.365	71,706	15.11	429
Northgate Station	76	0.363	61,280	14.40	N/A - Link Station
Stadium Station	77	0.363	60,901	33.96	N/A - Link Station
Bellevue Downtown Station	78	0.362	32,999	13.08	N/A - Link Station
Judkins Park Station	79	0.360	74,808	24.81	N/A - Link Station
International District Station	80	0.329	113,099	45.04	N/A - Link Station
Magnolia - 34th Ave W/W McGraw	81	0.319	23,407	13.01	129
Kirkland Transit Center	82	0.312	26,989	8.30	636
Pioneer Square Station	83	0.310	121,322	45.56	N/A - Link Station
University Street Station	84	0.307	128,646	46.56	N/A - Link Station
Harborview Medical Center	85	0.306	130,838	43.30	412
Crown Hill - 15th Ave NW/NW 85th St	86	0.305	75,802	17.48	617
Westlake Station	87	0.302	128,861	46.90	N/A - Link Station
Greenwood - Greenwood Ave N/N85th	88	0.300	79,342	16.90	370
Central District - 23rd Ave E/E Jefferson	89	0.296	104,729	33.01	370
South Lake Union	90	0.296	132,323	46.10	321
Ballard-Interbay - Galer Bridge	91	0.295	72,376	33.55	396
Childrens Hospital & Medical Center	92	0.292	62,263	24.52	255
Uptown Queen Anne	93	0.287	96,213	45.69	810
South Kirkland P&R	94	0.281	21,905	9.26	424
Capitol Hill Station	95	0.277	137,166	42.26	N/A - Link Station
Roosevelt Station	96	0.276	98,110	23.90	N/A - Link Station
Sand Point - Seattle Children's Hospital	97	0.274	32,756	11.95	343
Ballard - Ballard Ave NW/NW Market St	98	0.273	84,259	19.11	464
Wallingford Center	99	0.251	91,687	27.00	370
U District Station	100	0.251	93,270	25.96	N/A - Link Station
Fremont - Fremont Ave N/N34th St	101	0.245	88,978	24.18	511
University of Washington Station	102	0.245	70,725	25.96	N/A - Link Station
Madison Park - 42nd Ave E/E Madison St	103	0.211	25,382	21.37	136

7.3 Appendix C: Alternative Models

This Appendix includes additional detail on the calculations and methods that are used for the alternative models.

7.3.1 Scenario 1: Transit Accessibility Fluctuation by Time of Day

For the first part of Scenario 1, Transit Accessibility scores were calculated across each time period and then new accessibility scores were calculated for each TCL based on the individual time periods. Additionally, Table 4: TCL Accessibility Score Rankings by Time Period includes a F2FR flexible service feasibility trip count filter for each individual time period. “Low Trip Count” indicates that—for that particular period of time—the number of transit trips serving that particular TCL do not exceed the 40th percentile for trip counts among all the included TCLs and is therefore excluded from the ranking process. The 40th percentile threshold is the same benchmark used as the exclusion threshold for all-day base model filter. Note that this time-period specific trip filter was applied in lieu of the all-day trip filter, but the density filter was applied the same as for the base model. This threshold supplements the time period specific analysis with a service feasibility lens. In other words, if only considering the Accessibility score rankings during the Midday period, the analysis could be used to justify new service during that time period for top ranking TCLs. The trip count filter provides an extra layer of analysis to verify that the given TCLs have sufficient trips occurring during the time period to support a potential F2FR flexible service. Ultimately, if a policy priority is to increase accessibility for people during specific times of day like off-peak hours, it’s important to ensure there is enough existing service to take people where they need to go.

The second part of scenario 1 involved calculating the average percent change in transit accessibility to jobs from the AM to the Midday period for all block groups. The AM/Midday Percent Change calculations were averaged for all block groups within the two-mile TCL buffers and attributed to each respective TCL. The TCLs that did not meet the midday trip count threshold of being above the 40th percentile of trip counts were removed from the rankings. The percent change in transit accessibility was calculated only for jobs and not for community assets, because of the drastic difference in scale between number of jobs and numbers of other assets that can be accessed by each block group. Because the calculation used the raw numbers of jobs that could be accessed within a block group based on the travel trends analysis, a change in the number of jobs would have watered down any change in community assets. Furthermore, because this calculation considered percent change, the change in accessibility to jobs would likely be comparable to that of community assets. Focusing on jobs is also consistent with the current goals of F2FR flexible services and with the priorities expressed by the Mobility Framework through its higher weighting of jobs among the transit accessibility elements.

Both elements of this scenario included a final filter to the TCLs for Priority Population scores that were over the 60th percentile of scores. This percentile calculation included all TCLs.

Equations

% Change between AM and Midday Accessibility to Jobs:

$$\%\,Change\ in\ Transit\ Accessibility\ to\ Jobs = \frac{jobs\ accessible\ via\ transit\ during\ midday -\ jobs\ accessible\ during\ AM}{Mean\ value\ of\ jobs\ accessible\ via\ transit\ during\ the\ AM\ and\ Midday\ time\ periods} \times 100$$

All-Day Access Score (same equation used for all-day access to jobs and to community assets):

$$All\ Day\ Access\ Score = \frac{(AM\ Access\ Score\ \times Hours\ in\ AM\ Period) + (Midday\ Access\ Score\ \times Hours\ in\ Midday\ Period) + (PM\ Access\ Score\ \times Hours\ in\ PM\ Period)}{Sum\ of\ Hours\ in\ AM,\ Midday,\ and\ PM\ Study\ Periods}$$

7.3.2 Scenario 2: Altered Weighting for Priority Population Sub-Groups

The alternate weighting that was used for the Priority Population Index score in Scenario 1 is compared to the base model weighting in Table 16: Unmet Need Variables Alternate Weighting, below.

Table 16: Unmet Need Variables Alternate Weighting

Broad Category	**Variable**	**Broad Factor Weight**	**Base Model Sub-Components**	**Scenario 1 Sub-Components**
Priority Populations	Population living 200% above the federal poverty line	50%	20%	*30%*
	Population that is Non-white or Hispanic		20%	*40%*
	Population that is living with some type of disability		20%	*10%*
	Limited-English speaking households		20%	*10%*
	Population that is Foreign-born		20%	*10%*
Transit Access	Jobs accessibility (all-day)	50%	50%	
	School accessibility (all-day)		25%	
	Social Services accessibility (all-day)		12.5%	
	Medical Services accessibility (all-day)		12.5%	

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