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Movilidad Sostenible en Metro-Detroit: Una Propuesta de BRT

Sustainable Mobility in
Metro-Detroit:
A BRT Proposal

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I would like to start by expressing deep gratitude for the opportunity to study smart cities and sustainability at such a holistic matrix of environmental, social, political, and economic influences. To me, this program packaged the emotional energy reasonably surging from a generation thrown into an alarming tipping point of anthropogenic climate change, transforming it into a tactical skill set of strategic GIS modeling, creative orchestration of smart city drivers, and deepened curiosity for pushing new boundaries, all aimed to bolster resilience, inclusivity, and sustainability. The concept of sustainability always has and always will occupy my time, space, and energy; yet, only now, am I armed and equipped with these actionable, measurable, and scalable tools to serve this space.

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May we all find joy, purpose, strength, and community in playing an authentic role to serve and align with our environment. I'm thankful, excited, and committed in a journey to realize mine.

ABSTRACT

City infrastructure and mobility culture in the U.S. have been heavily influenced by the invention of the automobile, a clear case in the city of Detroit. Once considered the 'Motor City Capital', its own paradoxical rise and demise can both be attributed to the stronghold the automobile industry had on government, the economy, and U.S. culture, and whose interests spurred the decentralization of cities, a deeply rooted and lasting car culture, and the elimination of public transportation in Detroit and across U.S.

As such, the following study introduces a contextually relevant review of mobility in the U.S., mobility in Detroit, and current public transit in Detroit, serving to make a case for, as well as inform and guide, its objectives and methodology. Elaborating on the consequential lack of public transit infrastructure, the analysis suggests the introduction of transit oriented development (TOD) and smart mobility strategies for public transportation in the form of a proposed Bus Rapid Transit (BRT) system in Metro Detroit.

Using a GIS-based approach with *ArcGIS Pro*, the methodology includes: building a network dataset from which to simulate mobility in Metro Detroit, determining and weighing various influences of demand for public transit to inform placement of BRT routes and stops, and running *Location-Allocation* and *Service Area* modeling across various proposed BRT scenarios. Then, comparing resulting scenarios via metrics of weighted demand, weighted distance, and accessibility, an optimal BRT scenario is suggested. The study then concludes by commenting on the broader implications of BRT implementation, the matrixed approach to BRT decision-making, the role of transit-oriented development in satisfying BRT criteria, as well as additional limitations and areas for further analysis.

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INTRODUCTION

Smart and sustainable mobility is complex and personalized to the transportation infrastructure and influences of each city. For riders it likely means accessible, equitable, affordable, environmental, efficient, reliable, safe, and attractive transit options. For a city it may mean agile urban planning, carbon reduction goals, communication and information technology systems, economic stimulation, and an attractive quality of life. While critics cite high costs of investment in smart mobility infrastructure, they fail to capture the higher price not to do so, as well as the outweighing environmental, economic, and social benefits.

In setting the stage and making a case for the following BRT proposal, it is worth understanding some contextual background around the state of mobility in the U.S., mobility in Detroit, and public transit in Detroit, which together serve to inform and guide the direction of this analysis.

MOBILITY IN THE U.S.

The current U.S. landscape can be characterized by dynamic environmental, social, and economic challenges, many of which are drawing eyes towards its mobility infrastructure, questioning the nature of its future as well as who this infrastructure is set up to serve. During an accelerated age of information, it has become easy to compare data and behavior across countries, unfortunately revealing a regressive U.S. mobility infrastructure that does not appear to be sustainable. Namely, three dynamic factors challenging the current state of mobility in the U.S. include the introduction of federal climate goals, the diminishing affordability of private vehicles, and the increasing population density of cities.

Amid international pressures for emissions reductions, the U.S. has surfaced as a key player in the production, and therefore in the alleged reduction, of carbon emissions. The federal government has set a goal of net-zero emissions by 2050, with a milestone of 65% reduction of Federal operational emissions by 2030, under which public transportation is classified (The

White House, 2021). According to a 2020 study by the EQP, transportation accounts for almost a third (27%) of total U.S. greenhouse gas emissions, and furthermore generates the largest share of emissions compared to other economic sectors; commercial transportation, including passenger cars, medium and heavy-duty trucks, accounts for the largest source (over 50%) of transportation-related greenhouse gas emissions (United States Environmental Protection Agency, 2022). That said, transportation-related emissions are considered a high-impact area to be targeted in emissions reduction efforts. Detroit, specifically, the later-defined area of study for this analysis, has been called out as a particularly high contributor of transportation-related energy consumption relative to its low urban density, as seen in *Figure 1* below.

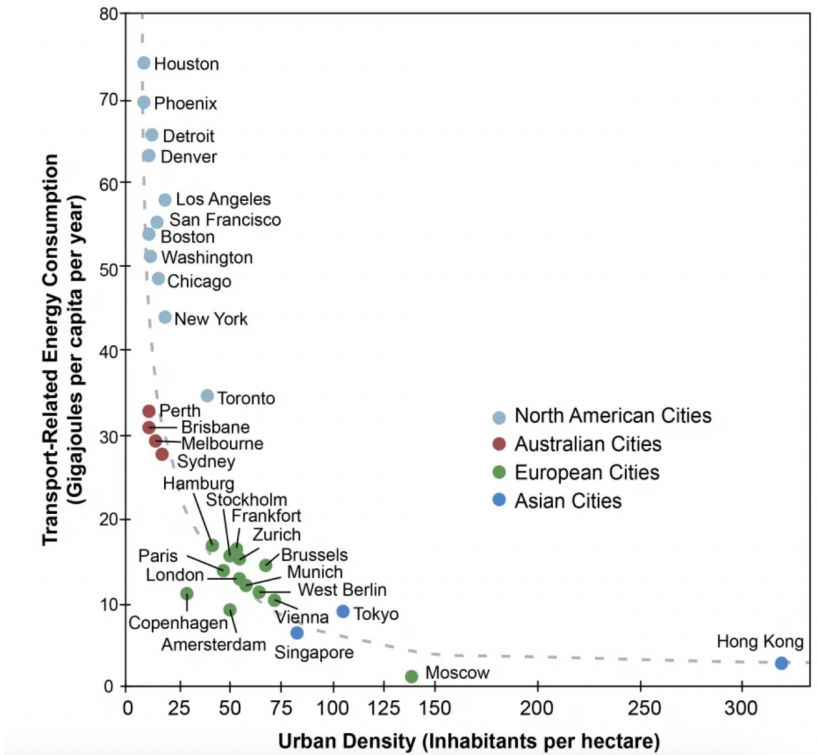


Figure 1 | Urban Density and Transportation-Related Energy Consumption

(United States Environmental Protection Agency, 2022)

Next, a perfect storm of supply chain backups and production delays has heavily flipped the U.S. automotive market to become a sellers' market, with demand far outweighing supply and near record low inventory levels, causing unprecedented surges in

car prices. Covid 19 shutdowns slowed automotive supply chains, like it did almost all industries. Yet, slowing production further, is an outpacing demand for semiconductor chips used in a growing number of vehicles with highly digitalized capabilities. This situation was magnified by Russia's invasion of Ukraine, the latter being a major supplier of neon gas, a required component of lasers used to carve silicon in the production of semiconductor chips; Ukraine also happens to be a key player in the production of wire harnesses used to bundle cables in automotive vehicles (Chernoff, 2022). This web of events has driven up the prices of new vehicles, electric vehicles, hybrid vehicles, and used vehicles some 13%, 15%, 18%, and 16% respectively from just one year ago (Chernoff, 2022).

Cities are also becoming more dense, and while in many ways cities provide benefits of shared resources, a strong U.S. car culture of individual and private car ownership, as opposed to public transit use, defeats the shared benefits of city density. As a result, U.S. cities are facing increasingly unfavorable mobility-related communal conditions like traffic congestion, increased travel times, and concentrated air and noise pollution. A study published by the University of Michigan estimates the trajectory of the U.S. population living in urban areas, citing 64% in 1950, 83% in 2021, and a projected 89% in 2050 (Center for Sustainable Systems, 2021). This is a call to action for cities to adapt land use and infrastructure planning, including mobility, to support a growing population density. The U.S. government and private sector tend to lean towards electric vehicles as a means of net-zero transportation planning, however, this tactic fails to address congestion problems. A traffic jam of electric cars is better than a traffic jam of fuel-run cars in that it generates less emissions, however it is the same in terms of stifled congested road infrastructure and inflated transportation times.

While public transportation in the U.S. has historically been brushed to the side in favor of car culture, an increasing collective consciousness of lack of accessible public transportation, as well as the consequential respective

unfavorable city conditions mentioned above, are increasing pressure on the need for restructured U.S. public transportation priorities. Detailing faults in the current public transportation models as well as emphasizing how the future of U.S. public transit will have to evolve, the Journal of Public Transportation published a paper commenting on the current and future state of ridership composition and system efficiency (Polzin, 2018). For one, the paper notes that in the current model of transit, ridership is dominated by low-income groups who do not have other viable mobility options. While transit as a public service, providing subsidized mobility access to those who do not have the privilege of mobility alternatives, is essential and must be continued in future models, public transit models also need to be more holistic in their objectives. This is especially the case as private vehicles are becoming less affordable for more of the population, redistributing and increasing the initially targeted base for public transit planning. Further, the efficiency of shared resources should be considered, in terms of finite resources such as fuel, carbon neutralization, infrastructure, labor, and urban space. In this way, while a holistic and inclusive model with sufficient ridership tackles an efficient use of resources, operating a public transit system without sufficient ridership is not necessarily more efficient than private vehicle use. On this note, metrics such as cost per various units of mobility and resource usage should be incorporated into mobility analysis, which is noted in this study as an area of continued analysis.

MOBILITY IN DETROIT

The city of Detroit presents a particularly interesting study of mobility, carrying a rich history of political, cultural, and corporate orchestrated efforts against the existence of public transportation. For that reason, it is worth understanding these forces in Detroit which have led to a lack of public transit planning and infrastructure, as well as a deeply rooted stigma against it.

Analysis of mobility in Detroit is a paradox, being a city, whose own rise and demise can be traced to the same thing: the

auto industry. The auto industry made Detroit the most successful modernist city in the early 20th century. During the Motor City reign, every element of the city, from the economy, to politics, to urban planning, to infrastructure, to culture, to patriotism, to culture, to class lines, to family ideals, and more, was rebranded around the success of a single product, the automobile (Resnick, 2017). Yet, this tactic was successful only at the elimination of any force that contradicted or competed with its existence, surfacing agendas for: a decentralized urban population connected by a network of highways, a car culture aligning political, legislative, and economic interests, and of course, the elimination of public transportation (Resnick, 2017).

While revolutionary in its time and industry, methods of mass production from the auto industry emphasized a low-density sprawl, influencing the decentralization of the urban population and characterizing the industrial modernism of urban planning and highway mobility infrastructure in the U.S., especially in the Motor City capital of Detroit. As the automobile grew in popularity in the 1920s, the industry sought methods to scale production to meet growing demand, which gave rise to 'Fordism', a mass-production methodology, coined due to its origins in Detroit's Henry Ford automotive factories. Fordism's most recognized contribution-to-date, the assembly line, altered the structure and function of automotive organizations, abandoning multi-story factory spaces in favor of linking single-story buildings to support multi-building assembly lines. Naturally, this restructure was easier to realize in the more spatially open suburbs, hence accelerating suburban growth, sprouting and anchoring a plethora of suburban communities around said factories. Importantly, these new pop-up suburban 'Fordist' hubs, and broader development of suburbia, were typically only accessible by private vehicles vs. public transit, again favoring car ownership.

Amid changing mobility demands due to urban sprawl, the development of highway systems became the focus of urban planning, approved and lobbied for by the interests of the automobile industry, but paid for by public funds. Full circle, this expansion of highway systems only gave momentum to the

decentralization of cities, and as cars got faster, urban sprawl distances naturally grew. All the while, and non-coincidentally, as highways became more accessible, and urban sprawl expanded, automobile sales rose.

Suburban sprawl and highway infrastructure giving way to flight from city centers consequently meant the abandonment and disinvestment of industry and wealth from downtown Detroit. Downtown commercial businesses began to relocate from downtown to the suburbs, following the wealth, often relocating itself in factory 'hub' designs created by Fordist sprawl. This mass exodus, of industry, economy, and population, from Detroit to the suburbs, left the city boundaries isolated, depleted of resources and attractions, to be occupied by those who did not have the means to move to the suburbs (Resnick, 2017). It would be ignorant and biased to not also mention the large influence of racial tensions in the U.S. at this time, accelerating a racist-motivated exodus from downtown Detroit in the name of upholding racially segregated communities, coined 'white flight'. White flight as it relates to urban mobility, is a subject for further study, and should not be underestimated in its contribution to the decentralization of Detroit and other like-minded U.S. cities.

Next, Detroit's unique economic structure, completely dependent on one single product, aligned economic, legislative, and cultural interests to that of the auto industry, creating a powerful 'car culture' dynasty. This stronghold on economic activity essentially meant that "whatever legal, political, or urban planning decisions that were in the best long-term interests of the automobile industry always prevailed" (Resnick, 2017). Not to mention, during these years, the auto industry employed one in seven U.S. workers, giving a massive portion of the U.S. population the impression that their interests too were aligned to the success of the auto industry. Further encouraging public support, automotive campaigns were launched to convince consumers that automobiles were a necessary part of everyday life - in terms of function, leisure, and even so far as patriotism, with propaganda that what is good for the automobile industry is good for the country.

Finally, and most directly relevant to setting context for this study, the powers of the automobile industry saw public transit as a direct competitor to their interest in growing ownership of private vehicles for transit, therefore going to great extents to ensure its demise across Detroit, and generally across the U.S. Specifically, a lack of public transit served various agendas: first, backing campaigns to increase car sales and use, thus increasing profits; second, reducing tax dollars on maintenance and infrastructure of public transit, leaving more funds available for automotive transit infrastructure like highways; and third, maintaining communities racially and economically segregated, following racial tensions and 'white flight'. Succumb to powerful private automotive interests intertwined in public decision-making, Detroit began to see the disappearance of their public transit infrastructure. In 1922, the Detroit Street Railway (DSR) was the largest municipally owned transit system in the world, primarily made up of electric streetcars on rails (Resnick, 2017). The DSR Commission, the municipal board formed to drive operational and managerial decisions around the public rail system, was composed primarily of leaders of the largest and most powerful auto companies, including John Dodge (partner and founder at Dodge Brothers Motor Car Company) and James Couzens (Executive of Ford Motor Company), amongst other high-level executives. Unsurprisingly, and conveniently, the DSR Commission determined that "urban rail transportation was inherently inefficient, inflexible, and incapable of fulfilling the needs of the modern commuter" (Resnick, 2017). Consequently, in 1925, despite commuter and community preferences for rails and streetcars over buses, and despite the fact that 60% of public transit ridership at the time was on rails and streetcars, the DSR Commission decided that the only viable public transit option was via automobiles. Acting even more obviously in self-interest, the DSR Commission then launched the first permanent bus route operated exclusively by a fleet of Dodge Brothers buses. Then in 1946, the DSR Commission announced their plans to discontinue all rail lines in favor of modern motor bus systems, to be implemented across the growing infrastructure of paved roads and highways, again conveniently fronting public transit planning as a means to realize auto

industry gains. In turn, more public money was put towards paved roads and highway infrastructure, destroying rail lines in its path.

The influence of the auto industry rode a fine line between legitimate interest and criminal action. In fact, General Motors' (GM) influence in motor-bus transit has been accused of intentionally dismantling rail transit in Detroit and other U.S. cities. In 1951, GM released a transit survey report detailing inefficiencies in the DSR system and highlighting low ridership, furthermore solutioning that the DSR should purchase around 400 GM diesel buses to be deployed in public transit service. Given the deep political and financial ties between the DSR Commission and the auto industry, the Commission followed GM's advice and used public money to purchase GM's vehicle fleet to be used in public transit. Raising red flags, GM's interest and influence in motor-bus transportation later faced almost thirty years worth of Federal antitrust hearings. Starting in 1949, the automotive corporation was accused of intentionally eliminating competing modes of transit (rail, streetcar, and subway systems), then securing control over any rival bus transit systems, further substituting their automobiles for all competing modes of transportation. Moreover, they were accused of colluding with oil and tire companies, even going so far as forming holding companies to purchase and discard electric transit systems, then creating contracts prohibiting the purchase of any resources or fleets that do not operate on gas as fuel (Resnick, 2017).

Finally, and unsurprisingly, in 1956, the DSR Commission made a case for full rail abandonment and derailment, and despite large and loud public objection, the Detroit Street Railway, at one point the largest urban network of electric streetcars in the country, ran its last route. At the same time, the Commission fully converted Detroit's transit system to a fleet of diesel buses supplied of course by the auto industry. Amid public disappointment, as well as the regressive switch from the rail of electric streetcars to diesel buses, which were noisy, smelling, and polluting, ridership of public transit decreased further, deepening its stigma.

Figure 2 follows Detroit's influence of the demise of public transit ridership across U.S. cities, revealing this substantial mid-century decline in ridership.

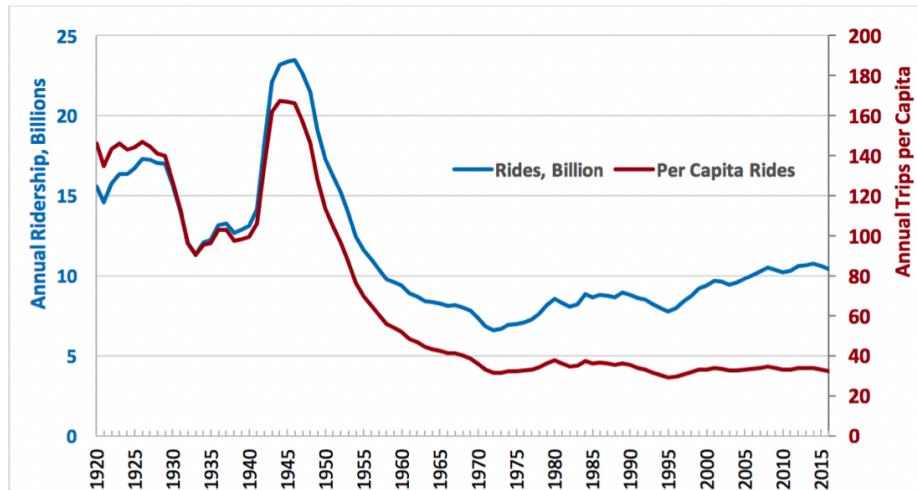


Figure 2 | U.S. Transit Ridership Trends
(Polzin, 2018)

All of this serves to introduce the orchestration behind the current lack of public transit in the city of Detroit, and the deeply ingrained political, cultural, and corporate biases that have challenged its existence.

Returning to the current state of mobility in Detroit, the University of Michigan published a study titled, *Detroiters' Views on Transportation and Mobility: Detroit remains a driving city, presenting challenges for non-car owners*, which reveals mobility challenges in Metro Detroit, giving a taste of the public opinion and looming car culture still at play (Smith, 2017). In the once 'Motor City', over one-third (34%) of respondents do not own or have access to a private vehicle. In a city where 98.34% of distance traveled is by private automobile, this is considered a transit-insecure population (Environmental Insights Explorer, 2021). To give an idea of how this may affect job opportunities, socioeconomic mobility, and standard of living, 43% of carless respondents report to have "missed appointments or work because they did not have a way to get there" (Smith, 2017).

The survey makes the preference for private vehicle transport

clear. In comparing responses around frequency of use of various modes of transportation, driving a car/truck/motorcycle is a clear first choice, with 80% ridership in terms of general use, and 60% ridership in terms of daily or almost daily use. Despite over a third of the city reportedly carless, only 45% of respondents report taking the bus ever, with a staggeringly low 7% taking the bus somewhat daily. Here, the stigma around public transportation begins to reveal itself, seeing that public transit, in this case the bus system, is used mainly out of necessity vs. a realistic and favorable alternative to mobility. And even so, while it would seem that those without a car rely on public transit, the carless population reported their most popular mode of transit as having someone drive them to their destination, at 85% ever and 12% daily, further indicating a strong preference for private vehicle use over public transit. Second most popular amongst the carless respondents is taking the bus, at 65% ever and 18% somewhat daily, seemingly here out of necessity. On the other hand, "new mobility" options such as ridesharing or car-sharing are very unpopular, with 2% reporting ever using, and 0% using somewhat daily (Smith, 2017).

Another interesting angle revealed through this same survey is the public perspective around improving mobility. In ranking the top proposals for transportation improvement in and around Detroit, the number one choice was "lowering the cost of auto insurance for Detroit residents", with a 55% majority amongst all respondents, 61% from respondents with a car, and 42% from respondents without a car (Smith, 2017). The fact that, for both populations, with and without a car, auto insurance accessibility was prioritized as the most important mobility improvement, again emphasizes the stigma against public transit. Moreover, this indicates that carless people hope to gain access to a car vs. remain carless by choice, or else this category would not affect them. It becomes clear that car culture is still deeply ingrained in the mobility of the city, and that there is the illusion that a private vehicle is a necessity vs. one mobility option. Second to lowering the cost of auto insurance is "adding more public transportation routes and services", far behind the first option, favored overall by only 29%, and by 27% with a car and 32% without a car (Smith,

2017). Naturally, this option is favored by more carless respondents, but only by 2%, and still behind auto insurance. Again, these are remnants upholding years of car culture.

PUBLIC TRANSIT IN DETROIT

Metro Detroit currently has a few public transit systems in operation: People Mover, QLINE, DDOT, and SMART.

The People Mover is an above-ground rail whose route is a single loop around the center of downtown Detroit. There are no connecting networks or lines, and the track is unidirectional. Needless to say, this is not a highly functional mode of mobility, but rather serves as an attractive ride around the city. While plans were originally laid for a futuristic form of urban travel back in the 1970s, amid the auto-industry dynasty, funding and politics did not align, and by the time of its implementation in 1987, Detroit's population had plummeted; average yearly ridership for the last decade has hovered around two million, a fraction of what planners intended (Bliss, 2018). The following analysis does not take into account the QLINE due to its narrow scope and function, but if anything, is complementary to its service.

The QLINE, previously the M1 Rail, is an above-ground rail line with service spanning only 3.3 miles. This line was originally a result of interest from the federal government in a light rail transit system to move people in and out of Detroit to the local suburbs. However, in recent years, this line has become controversial for various reasons. This line is "not necessarily to move people - the city doesn't have a congestion problem - but this is a way to boost economic development and real estate development", specifically raising real estate values along this particular QLINE strip downtown (Soergel, 2016). Despite its unprecedented narrow service area, it took \$30 million of public service funds to develop (Tobin, 2022). This begs the question, who owns this line and who is it meant to serve. Originally named the M-1 Rail after a historic nearby highway, it was renamed the QLINE after the business Quicken Loans, the largest private donor, and owned by Dan Gilbert (Tobin, 2022). Dan Gilbert also happens to own 79 properties

along the suspiciously short QLINE strip. Critics rightfully cite Detroiters' taxpayer money once again being used as a private investment tool, benefiting a small number of wealthy individuals vs. being reinvested to serve its own Detroit community. The following analysis does not take into account the QLINE due to its narrow scope and function, but if anything, is complementary to its service.

The Detroit Department of Transportation, or DDOT, is a bus system operating within Detroit city limits, and is funded by the City of Detroit. The following analysis is complementary to the DDOT system.

The Suburban Mobility Authority for Regional Transportation, or SMART, is a bus system with service across Metro Detroit, for inbound and outbound commuters during rush hour times, and is funded by opted-in suburban municipalities. Critics of SMART, however, complain that this system exclusively serves commuters during rush hour, and in this way is not inclusive nor functional for the majority of the population (Lawrence, 2022). The following study specifically draws on criticisms of the SMART system, looking to make mobility between downtown Detroit and its suburbs more inclusive, accessible, and reliable.

STATE OF THE ART

The surge in popularity of Smart Cities, in a way, is in response to growing challenges in city living amid a wave of new communication and information technology capabilities. A key component of smart cities is smart mobility. Research suggests that BRT systems can serve as an effort to encourage transportation sectors of cities towards smart mobility models and networks (Kusumawardani et al., 2021). Rapid transit typically refers to urban mobility means of carrying a high volume of passengers short to mid distances with high mobility frequency. BRT specifically constitutes a regional cooperation to address real needs and challenges of a lacking transit system, to elevate the city and its surrounding communities, as well as transform undesired levels of congestion and air pollution.

STATE OF GIS MODELS FOR BRT ANALYSIS

BRT systems deliver unique value and criteria compared to other mobility options (ITDP, 2022):

- Fast and frequent operations and service
- Dedicated lanes for faster commutes; preferably center lanes to avoid human and vehicle curbside activity and parked vehicles
- Straightaway routes for avoiding turns and turn delays/congestion
- Platform-level boarding, accessible for disabled passengers, strollers, carts, etc. without delays in service
- Off-board fare collection for faster boarding, with tech-enabled options to pay at stop or via user-friendly personal device applications prior to boarding
- Intersection treatment with signal priority and smart traffic light coordination, ensuring right-of-way passage and more rapid transit

On the technical side, the use of GIS to drive transit-oriented analysis and execution has surfaced in various studies, improving scope, efficiency, and levels of specificity with spatial data.

One relevant use of GIS for BRT analysis claims that the integration and effectiveness of a BRT system in a city depends largely on the location of its stops, and in this way, GIS supports the process of spatial data analysis quickly and accurately (Phan-Hien et al., 2016). This study claims that BRT stop locations should be determined by natural (topography, land use), socio-economic (population density), and traffic infrastructure factors. Further, in determining optimal locations for stops, this same study focuses on travel demands, public transit, and road network as indicators of stop locations, then assigns a weighted factor of influence to compare across standard units. Once again, this study stresses the importance in attracting a large number of riders in order for the system to be effective and efficient.

Another relevant study models a geospatial analysis approach in determining effective BRT routing and BRT route selection in finding locations that meet determined criteria (Jamalul Shamsudin et al., 2019). This study considers that proper public transport carries the rider from origin to destination without the burden of traffic congestion, with the general goal to increase connectivity to rural areas, hence boosting commercial activities through improved mobility, in alignment with BRT model criteria.

STATE OF INFLUENCES OF PUBLIC TRANSIT RIDERSHIP

While this analysis does not provide metrics nor estimations of ridership on a micro-level, its methodology does measure demand for public transit with the intention to maximize ridership in order to ensure efficiency and accessibility of a proposed BRT system.

Accessibility is a major component of public transport effectiveness, and as such its metrics should become an important indicator in the study and proposal of public transit. Unlike European cities, more inspired by walking landscapes and public transit inclination, North American cities tend to face further decentralization and sprawl not conducive to transit oriented development (TOD) (Nivola, 1999).

TOD refers to the promotion of urban planning for compact, walkable, bicycle-friendly, mixed-use, high-density development, and importantly high accessibility to public transit.

On this note, distance plays an important role in public transit use, especially in these North American cities where public transit is less normalized and does not have as much public support or use, but hopefully which will change with the introduction of TOD and smart mobility models. In a study conducted by the *Journal of the American Planning Association*, on the elasticity of public transit demand in terms of accessibility by distance, it is proposed that increasing distance to transit by 10% will decrease ridership by 3% (Ewing & Cervero, 2010). On the same note, another study conducted by the *Journal of the Transportation Research Board* suggests an exponential decrease in demand and ridership for public transit as distance of accessibility increases (Zhao et al., 2003). More specifically, another study conducted in a North American city in California revealed that people residing within 0.5 miles of a transit station were four times more likely to ride public transit in comparison with those residing 0.5 - 3 miles from a transit stop (Cervero, 2007). One TOD-based study by *HN Transit* predicts a 139% increase of households in the U.S. looking to buy or rent within 0.5 miles of a transit stop, between 2000 and 2025 (HN Transit, 2004). Various other studies confirm a 0.5 mile threshold as a reasonably agreed upon distance in studying public transit access and coverage (Hsiao et al., 1997; Kimpel et al., 2007; Larsen et al., 2010). For this purpose, the following study employs a 0.5 distance threshold in the weighted analysis of transit demand.

Recent urban planning practices encourage European-influenced city design, highlighting and favoring population density and mixed land use as determinants and target areas for high-impact urban development (Litman, 2022; Miralles & Marquet, 2012). Another study specifically cites the built environment influence of demand for transit in terms of density, diversity, and design (Cervero & Kockelman, 1997). The importance of density stems from its relationship with proximity, in that the more people living and/or going to spaces in close proximity to

transit increases ridership (Murray et al., 1998). This relationship between density and ridership is well justified as positively correlated at the station level (Seskin & Cervero, 1996). Next, the influence of land use and diversification of land use is less documented than that of density, but still has been studied and determined to generate demand for transit, concluding that suburban areas with diversified land use result in higher transit use (Filion, 2001). Mixed land use also supports equilibrating peak-periods of travel like rush hour, in both direction and flow, lending itself to reduced capacity restraints (Cervero, 2004).

As such, in the following study, origin points of demand are classified by population density, and destination points of demand are classified as favorable mixed land use.

OBJECTIVES

GENERAL GUIDING PRINCIPLES

The purpose of this study is to adopt a holistic approach to studying mobility in Detroit, first evaluating in context the history that has set the context for current state mobility of the city, then further proposing a methodology in designing and developing a smart mobility BRT system with optimized routes and stops, backed by Geographic Information System (GIS) analysis, processing, and tools.

The goal is to create a competitive mobility alternative to private vehicles, chosen not only by transit-insecure populations as an only option, but rather as the most efficient and affordable, accessible and inclusive, safe and reliable, and environmental option, despite deeply ingrained stigmas around public transit in the U.S. and in Detroit. That said, the design and criteria of a BRT system should be informed by the following guiding principles:

Efficiency & Affordability

In order for public transit to be a viable and competitive mobility option, it should be an efficient and affordable form of travel. BRT as a form of public transit can lower travel times through dedicated lanes amid traffic, eliminate time and money on parking and tickets, reduce the cost of transportation, and offer leisure time experienced as a rider vs. driver while commuting.

Accessibility & Inclusivity

The proposed BRT system should prioritize inclusivity through accessibility to mobility. It should satisfy transit demand needs for as many people as possible, driving equal access to mobility. This analysis does not favor any particular population, rather it favors maximizing accessibility for all populations. As such, over time, increased ridership from all populations will support the continued maintenance and prioritized development of the system, as well as destigmatize public transit as the 'last-resort' option.

Security & Reliability

Public transit and BRT should offer a more secure and reliable form of transit. For the community, public transit can reduce traffic incidents and congestion due to less vehicles on the road. Additionally, properly designed BRT transit stops can support Jane Jacobs' 'eyes on the street' concept, drawing on a form of community-based vigilance of its streets (Jacobs, 1961). On the other hand, the timeliness and reliability of posted schedules add another element of security, in that riders should be able to rely on transit schedules for personal planning. Hence, vehicles and schedules need to feel safe and reliable in order to encourage ridership.

Emissions Reduction

Given the global and local urgency of carbon emission reduction efforts, a major benefit of public transportation is reduced emissions, if done efficiently and effectively. Increasing ridership of public transit should be aligned with a reduced dependency on individual vehicles, a major mobility factor in the city of Detroit. For this reason, as well as inclusivity purposes, demand for transit is not confined to transit-insecure populations, rather it is inclusive of car reliant populations in order to provide an adequate and competitive alternative to transit, that subsequently improves air quality, reduces emissions, and supports carbon neutrality goals. Additionally, while not included in this study, further emissions reduction measures may be taken in BRT systems such as deploying electric and/or hybrid vehicles.

SPECIFIC OBJECTIVES

Backed by the aforementioned guiding principles, the following study aims to realize the following specific BRT and methodology-based objectives:

BRT OBJECTIVES

BRT Methodology

Using a GIS-based methodology, select and locate optimal BRT routes and stops within the defined Metro Detroit area of study, informed by current indicators of transit demand data, to be used for transit between Metro Detroit and downtown Detroit, complementary to the current DDOT bus system designed for inner-Detroit travel.

BRT Criteria

In addition to the use of transit demand data, follow criteria classifying transit as BRT in the selection of routes and stops, seeking main roads with 2+ lanes available for dedicated busway alignment and dedicated bus right of way lanes, as well as routes conducive to minimal turns and long stretches of straight paths.

Agile Model

Inevitable changes and uncertainty in mobility demand, climate conditions, and technology capabilities should be considered in BRT models, using an agile approach capable of adoption to changing transit demand and conditions.

METHODOLOGY OBJECTIVES**Gather Data**

- Develop a holistic and broad background understanding around mobility in the U.S., mobility in Detroit, public transit in Detroit, and a state of the art for GIS modeling with BRT analysis and ridership influences, together making a case for and guiding the direction and criteria of the resulting objectives and methodology
- Define inputs of transit demand and use in BRT route selection and BRT stop placement
- Gather corresponding data and cartography based on determined variables of interest necessary to realize the objectives of the study

Network Dataset

- Define, create, and build a network dataset using GIS toolsets and GTFS data to model transportation

networks on which to simulate the BRT system

Analysis of Demand

- Evaluate demand using a weighted overlay approach, creating one weighted output model to inform selection and location of BRT routes, and a second weighted model to determine demand points informing the placement of BRT stops along determined routes

Location-Allocation Network Analysis

- Apply localization optimization techniques integrated in the GIS environment, specifically making use of the *Maximize Coverage* model within *Location-Allocation Network Analysis* capabilities, to determine optimal placement for BRT stops along determined routes
- Elaborate the model for various scenarios in order to evaluate the optimal number of BRT stops

Results

- Observe and evaluate resulting BRT scenarios, characterizing notable differences across scenarios, and highlighting relevant destinations for reference
- Apply and visualize metrics to compare BRT stops scenarios, including weighted demand, weighted distance, and *Service Area Network Analysis* accessibility coverage, indicating various angles of effectiveness and optimization of proposed models

Conclusions

- Make final recommendations and conclusions based on results of BRT scenarios
- Comment on limitations of analysis preventing further and/or more in-depth realization of the current analysis
- Comment on notable areas of future research that would expand upon and bolster the current analysis

CASE STUDY & DATA

SYSTEM

The following analysis is carried out with *ArcGIS Pro*, a GIS-based enterprise tool capable of loading, processing, and analyzing spatially-located data in order to realize the determined methodology. The analysis further uses the *ArcGIS Pro* extension *Network Analyst* to model realistic mobility movement in the defined area of study.

AREA OF STUDY

Given the objective to model a BRT system encouraging transit between Detroit's suburbs and downtown areas, complementary rather than competing with the existing inner-city DDOT bus system, the area of study is determined to be Metro Detroit, defined in terms of regional planning by the South East Michigan Council of Governments (SEMCOG). Based on the data used in this analysis, Metro Detroit counts on a total population of 4,830,489 inhabitants across 4,500 square miles.

DATA

To begin the following analysis, it's necessary to collect and standardize spatially-located data as relevant inputs to the proposed BRT system. Given the natural curvature of Earth's surface, it is important to define and standardize a coordinate system as a reference framework to define the position and projection of data features on the same spatial reference. As determined by SEMCOG for Metro Detroit GIS analysis, the coordinate system for the following analysis is projected as *NAD_1983_HARN_StatePlane_Michigan_South_FIPS_2113_Feet_Intl*.

The following sources provide raw data to be used as inputs in the construction of a network dataset and to form indicators of transit demand in the Metro Detroit area of study:

Census Population

The U.S. Census is a national survey that accounts for every resident by location. From the SEMCOG GIS Open Data

Portal, this feature layer of polygons provides geolocated total population data, as well as information on household composition and housing units, publicly available to visualize the distribution of people and housing in the region. (SEMCOG_GIS, 2020a)

Land Use

From the SEMCOG GIS Open Data Portal, this feature layer of polygons provides geolocated data classified by 20 land use categories present in the SEMCOG communities. This data is derived and consolidated from master plans across neighborhoods. The land use categories are as follows: Single-Family Housing, Attached Condo Housing, Multi-Family Housing, Mobile Home, Agricultural / Rural Res, Mixed Use, Retail, Office, Hospitality, Medical, Institutional, Industrial, Recreation / Open Space, Cemetery, Golf Course, Parking, Extractive, TCU, Vacant, and Water.¹ (SEMCOG_GIS, 2020b)

Roads

From the SEMCOG GIS Open Data Portal, this feature layer of lines provides geolocated data on all roads in the SEMCOG area, publicly available for regional planning and spatial analysis. (SEMCOG_GIS, 2020c)

Traffic

From the SEMCOG GIS Open Data Portal, this feature layer of lines provides traffic-related data, including daily traffic, number of lanes, speed limit, and more, all assigned to roads in Metro Detroit classified under federal funding. (SEMCOG_GIS, 2020d)

GTFS DDOT Bus

From the City of Detroit Open Data Portal, this General Transit Feed Specification (GTFS) file includes a package

¹ 1. Agricultural / Rural Res includes any residential parcel containing 1 or more homes where the parcel is 3 acres or larger.
 2. Mixed Use includes those parcels containing buildings with Hospitality, Retail, or Office square footage and housing units.
 3. Parcels that do not have a structure assigned to the parcel are considered vacant unless otherwise indicated, even if the parcel is part of a larger development such as a factory, school, or other developed series of lots.

of the entire schedule and stop data for DDOT bus system.
(City of Detroit Open Data Portal, 2019)

Upon collecting the data, it is noted that the roads and traffic datasets need to be cleaned and consolidated. First, given that the modeling of roads will be a function of traffic data, yet the two feature classes contain independent data, the two layers are combined using a *Spatial Join*, joining traffic volume features to road target features. Second, roads without an assigned posted speed are observed to be low-usage inner-residential roads, and are therefore assumed to have a speed limit of 25 miles per hour.

METHODOLOGY

NETWORK DATASET

The study of mobility and public transit in Metro Detroit requires modeling the flow of movement in the area of study. This form of simulation can be modeled through a network dataset, which is a GIS-dataset designed to support network analysis, with capabilities to classify line segments as routes, set topology features, define impedances and modes of transport, among a broad spectrum of network settings.

The feature layer that combines road and traffic data for Metro Detroit becomes the reference for streets in the network dataset, and a topology is created to ensure all roads are topologically correct. It is established that there is connectivity across intersections and road segments, no road segments intersect at different elevations, and dangle segments are correctly represented. It is confirmed that there are no further topological network errors.

The DDOT GTFS file then facilitates the creation of stops, lines, and schedules for transportation within the network dataset. These generated feature layers are then connected back to the streets data, assigning DDOT bus stops to their corresponding streets, and the network dataset is created.

Next, the source settings and travel attributes of the network dataset are defined. In terms of source settings, connectivity is established across three groups, defining how each feature class of edges and junctions fit together. In terms of travel attributes, the modeling of the BRT system is supported by two modes of travel: walking and driving. Walking, being the assumed mode of transit to arrive at a BRT stop, and driving, being the mode of transit riding the bus. That said, there are two cost attributes, or impedances to be established accordingly: time walking and time driving. Time data is not predetermined, it is determined as a function of speed and distance for both modes of transit.

The analysis assumes an average walking speed of 3mph, or 0.05 miles/minute. Therefore, for each line segment, time walking is calculated as follows:

$$\text{time walking (minutes)} = (\text{segment length (miles)} / 0.05 \text{ (miles/minute)})$$

The geometry of each line segment is calculated in miles, and then time driving is calculated as follows:

$$\text{time driving (minutes)} = (\text{segment length (miles)} / \text{posted speed (mph)}) * 60 \text{ (minutes/hour)}$$

The network dataset is then built upon the defined topology, connectivity, and attributes, setting the foundation to model mobility in Metro Detroit.

ANALYSIS OF DEMAND

Defining and classifying inputs of demand for transit is key to aligning with the objectives of this analysis and for setting up a successful execution of the proposed BRT system. Following the stated objectives for an all-inclusive target ridership, referencing the *State of the Art* ridership influences with holistic transit demand across all demographics, the determinants of demand are classified across the following origin points of demand, destination points of demand, and route trajectories of demand.

Table 1 | Variables of Demand

Demand Type	Demand Variable	Data	Determinant of BRT:	
			Route Locations	Stop Locations
Origin	Favor high density population	Population Density	✓	✓
Destination	Favorable land use	Land Use Type	✓	✓

Route	Favor roads with high-volume traffic	Annual Average Daily Traffic (AADT)	✓	
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Origin Demand

Origin points of demand as population density assumes transit to and from the home, determined by census population data. Density vs. total population is considered given that population data is broken down and assigned to neighborhoods and districts of unequal sizes. Thus, density considers population as a function of space, making for a standard unit of measure across the area of study.

Destination Demand

Destination points of demand as favorable land use assumes riders are more likely to travel to certain locations over others, classified by differences in land use.

Route Demand

Unlike origin and destination demand determinants, route demand is used to inform the location of BRT routes but not the location of BRT stops. The selection and location of BRT routes includes traffic volume data assuming that areas with current high volume of traffic indicate a demand for movement through a determined area between origin and demand points, as well as informing where there is an infrastructure ready to support mobility volume. The location of BRT stops excludes traffic volume data because BRT stops should be located where there is high origin and/or destination demand, but not necessarily where there is high traffic volume. Further, it's important to note that, given the objective of inclusivity of this analysis, and given the high levels of transportation insecurity in Detroit, the almost third of the population who do not have access to a private vehicle are essentially excluded from this traffic volume data, regardless of their transportation needs, further reinforcing its exclusion in determining BRT stops locations. For these reasons, the

selection and location of BRT stops relies exclusively on determinants of origin and destination demand.

These determinants of demand define the data to be used in the selection and location of routes and stops of the BRT system. While it's a bit of a chicken or egg situation, that of choosing routes or stops first, the inclusion of traffic data as an indicator of BRT route demand favors the initial selection of routes and the later selection of stops along determined routes.

Next, these determinants of demand are weighed spatially in two distinct models, in order to standardize the scale of their respective influences in locating BRT routes and stops.

WEIGHTED DEMAND

In conducting a weighted overlay of demand, the aim is to spatially classify and weigh data on a standardized scale according to prioritization and importance of influence. In order to adequately visualize an overlay of the three inputs of demand, it's important to note that origin and destination demand data are located alongside streets, while route data is located over streets. That said, route data needs to be prepared to spatially overlap origin and destination data. Taking this opportunity to also downsize the data, in line with BRT criteria encouraging designated bus-only lanes, roads and traffic data is downsized to exclude road segments with only one lane, effectively removing segments not suitable for BRT routes. Then, a 0.5-mile buffer is generated around road segments (*Buffer*), extending their influence to create spatial overlap with the origin and destination data. The buffer distance of 0.5 miles is discussed in *State of the Art* as an acceptable baseline distance threshold to public transit.

To prepare the weighted overlay, all feature classes must be converted to raster datasets (*Feature to Raster*), and then reclassified from vector data to raster classes (*Reclassify*). The reclassification of each input of demand is as follows, using eight degrees of classifications in order to create a sufficiently multi-tiered hierarchy of demand data influence. A

classification of 8 is deemed most attractive for transit demand, 1 as least attractive, and 0 as a restricted area.

The reclassification of origin demand, destination demand, and route demand are realized as follows:

Origin Demand: Population Density

In evaluating its distribution, it can be noted in *Figure 3* that population density is not normally distributed, rather it is heavily weighted towards its lower values. Hence, population density is best reclassified using a percentile approach, parting the data into eight reclassification groups according to distribution. Eight unique classifications create percentile multiples of 12.5%, which inform the classification ranges in *Table 2*.

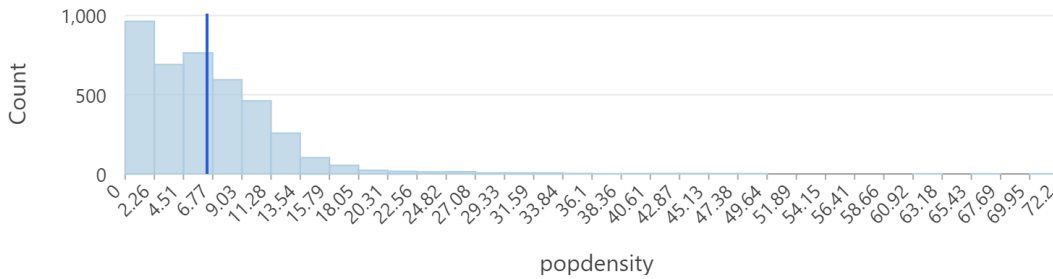


Figure 3 | Population Density Distribution

Table 2 | Population Density Reclassification

Classification Value	Percentile	Value Count	Upper Range Population Density (ppl/acre)
1	12.5	499	0.57
2	25	998	2.40
3	37.5	1,497	4.01
4	50	1,996	5.50
5	62.5	2,495	7.09
6	75	2,994	8.97
7	87.5	3,493	11.45

8	100	3,992	72.20 → 73 ²
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Then, *Figure 4* visualizes the resulting percentile-based distribution of population density, further revealing the decentralization of downtown Detroit, with pockets of high-density suburbs surrounding the downtown area, and a with downtown that is not necessarily denser than its surrounding suburbs.

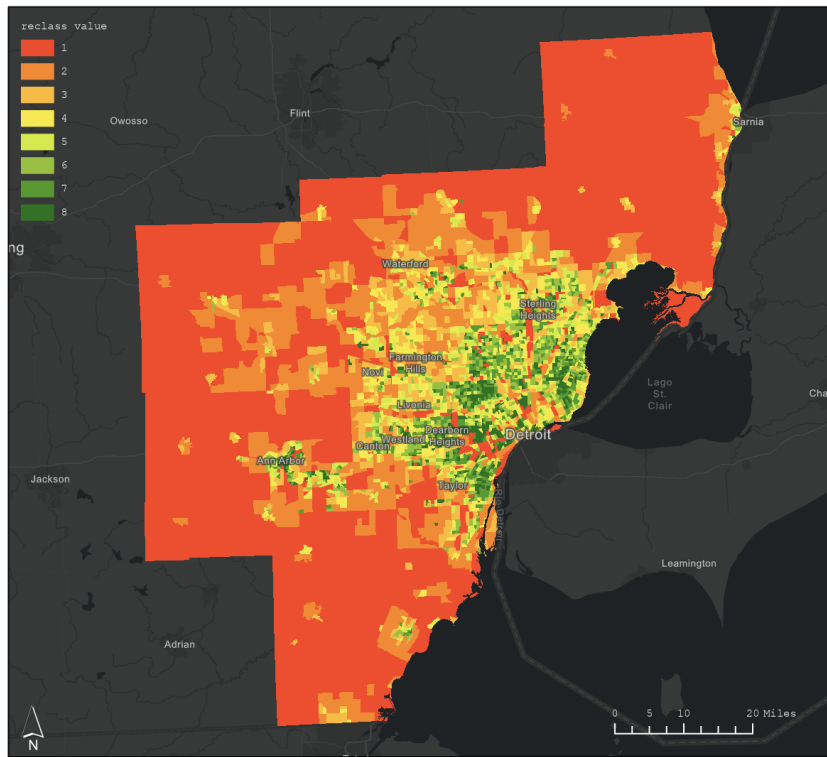


Figure 4 | Population Density Reclassification

Destination Demand: Land Use

Land Use, on the other hand, is treated as binary, in determining land use as favorable or unfavorable. That said, as seen in *Table 3*, favorable land use will be classified at the highest level (8) and unfavorable land use will be classified as restricted (0). Land use is considered favorable if it qualifies as an assumed demand attraction, for function or

² Rounded up to ensure maximum population density included in reclassification range

leisure purposes, for a significant portion of the general population.

Table 3 | Land Use Reclassification

Classification Value	Land Use Type	Land Use Values
0	Unfavorable	vacant, industrial, parking, agricultural / rural res, water, not parceled, TCU ³ , extractive, cemetery
8	Favorable	single-family housing, recreation / open space, retail, office, hospitality, multi-family housing, medical, mixed use, attached condo housing, mobile home, golf course, institutional ⁴

Figure 5 suggests a favorable clustered land use mix in the immediate sprawl from the downtown area, seen by the denser green zones extending from the city center outward.

³ TCU (transportation, communications, utilities) is considered unfavorable as it is observed to be mainly utility plants

⁴ Institutional includes city/municipal land use (parks, schools, etc.)

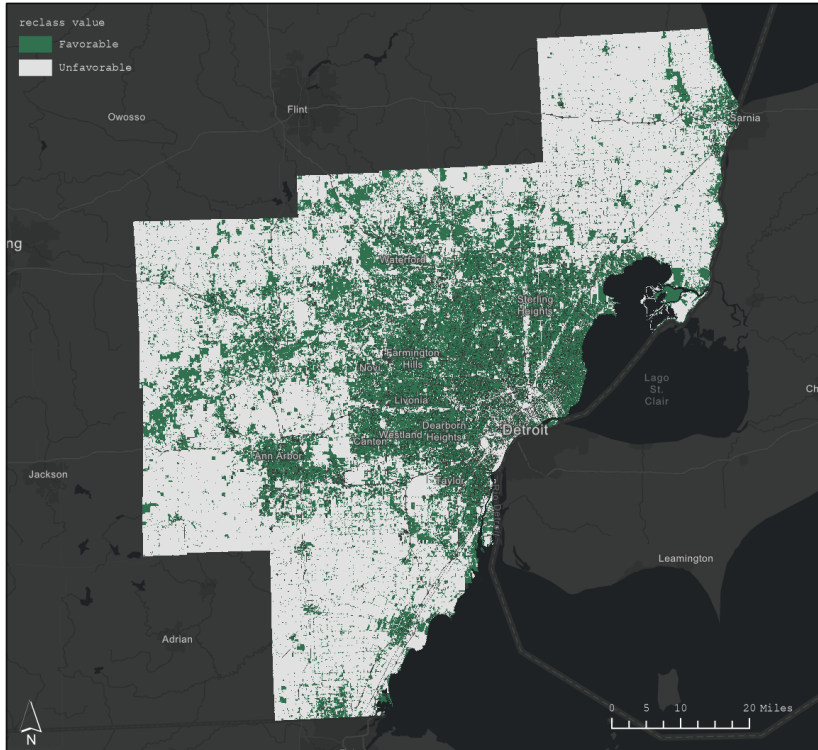


Figure 5 | Land Use Reclassification

Route Demand: Traffic Volume

Similar to population density, AADT is treated as non-binary and shows a non-normal distribution weighted toward the lower-end in *Figure 6*, hence using a similar percentile distribution approach to reclassification in *Table 4*.

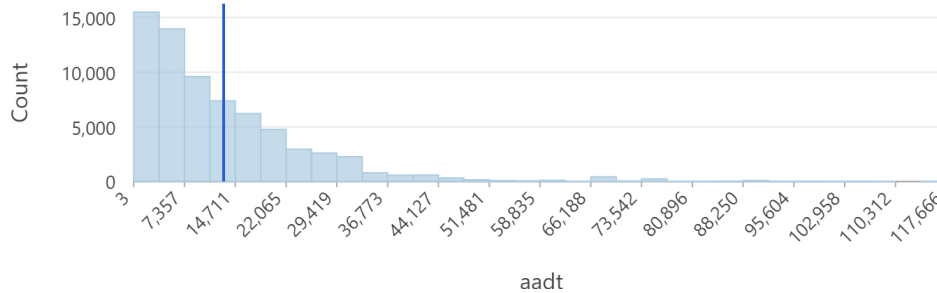


Figure 6 | AADT Distribution

Table 4 | Traffic Volume Reclassification

Classification	Percentile	Value Count ⁵	Upper Range AADT
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⁵ Value counts rounded to nearest integer to correspond with count of data

Value			
1	12.5	8,631	2,343
2	25	17,261	4,098
3	37.5	25,892	6,545
4	50	34,523	9,412
5	62.5	43,153	12,925
6	75	51,784	17,749
7	87.5	60,414	25,851
8	100	69,045	117,666 ⁶

Figure 7 portrays an infrastructure of Metro Detroit’s most commonly used roads connecting downtown Detroit to its highly populated suburban hubs, surrounded by a network of less used streets.

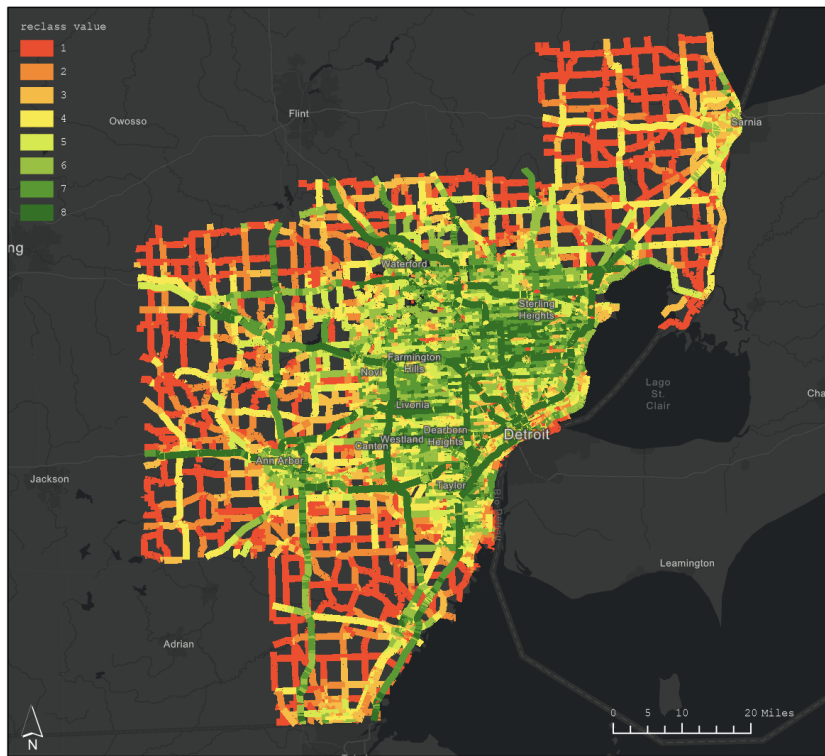


Figure 7 | Traffic Volume Reclassification

⁶ Rounded up to ensure maximum AADT included in reclassification range

Using the reclassified determinants of demand, the *Weighted Overlay* tool is then used to create two distinct models:

Model 1: Weighted Demand for Locating BRT Routes

This model will weigh origin, destination, and route demand variables evenly, as it is assumed that each component evenly contributes and determines BRT routes demand. This model will then support the selection of BRT routes.

Model 2: Weighted Demand for Locating BRT Stops

This model will weigh origin and destination demand evenly, assuming an even contribution to BRT stops demand. This model will then support the creation and weighing of demand points which will influence the placement of BRT stops.

LOCATING DEMAND FOR ROUTES

The resulting *Model 1* of weighted demand for locating BRT routes in *Figures 8* and *9* begins to naturally define origin, destination, and route patterns, with dark green as the most favorably weighted areas and red as the least, informing patterns for optimal BRT route options.

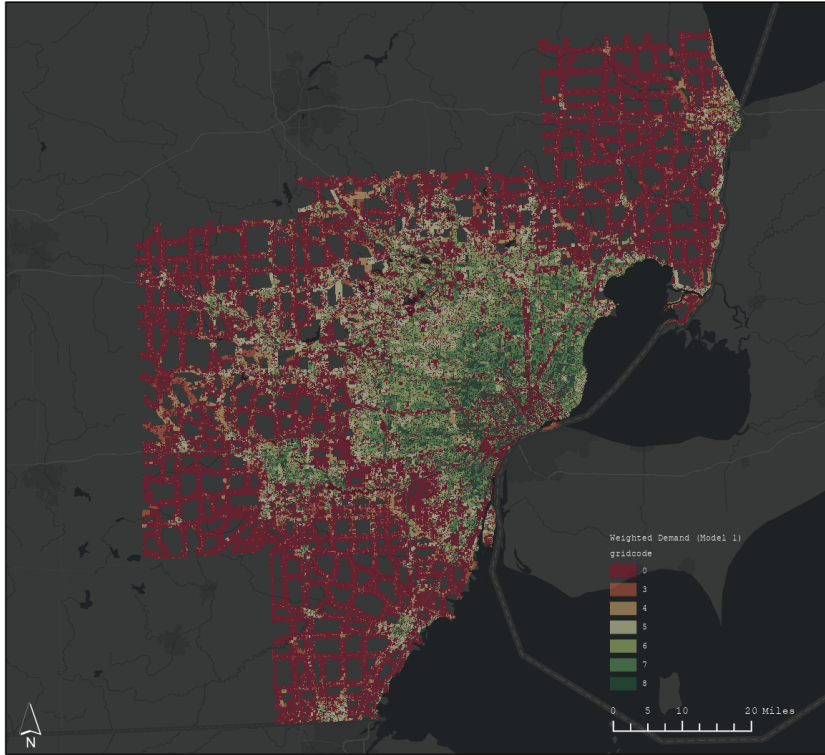


Figure 8 | Model 1: Weighted Demand for Locating BRT Routes

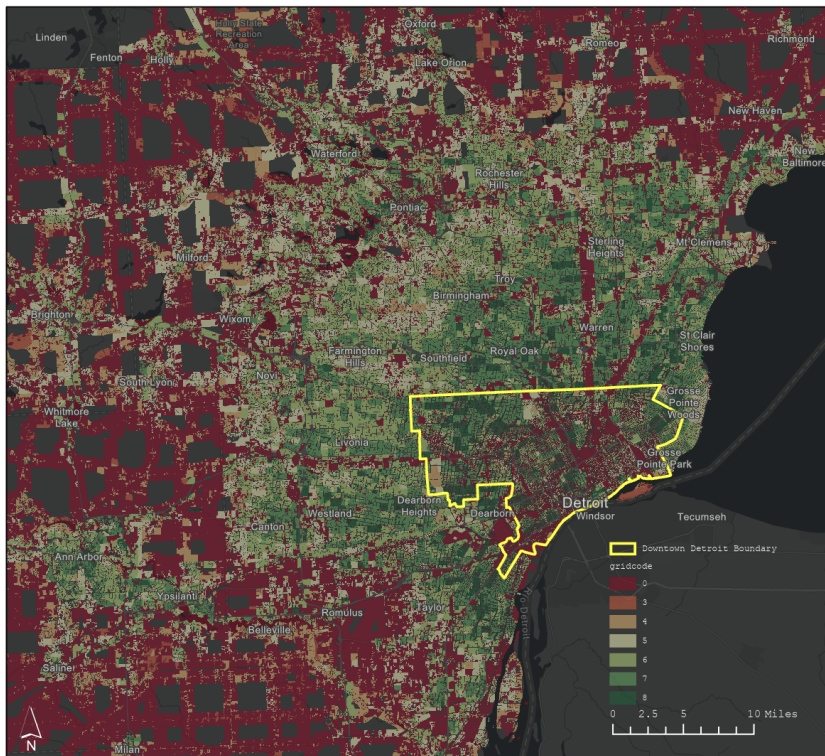


Figure 9 | Model 1: Weighted Demand for Locating BRT Routes

Observing the results of *Model 1*, two layers of sprawl are revealed with two relative levels of demand: a distinguished sprawl zone extending from the downtown area with relatively high weighted demand, and a secondary more distanced sprawl wave with relatively lower weighted demand.

In alignment with the objectives of selecting routes in accordance with BRT criteria, it is important to note that BRT routes should prioritize straightaway trajectories, minimizing turns, making use of long stretches of main roads with availability for a dedicated BRT lane. That said, the use of freeways should be generally avoided due to difficulty and dangers of respective stop placement, unless the freeway is used as a rapid transit measure between highly spaced stops on a parallel non-freeway road.

To synthesize and visualize the results of *Model 1* with the stated BRT routes criteria for road segments, *Model 1* is joined with the roads and traffic buffer layer (*Spatial Join*), and then road segments are selected based on the following attributes: 3+ lanes, a weighted overlay gridcode of 8 (most favorable), and excluding freeways. This highlights various prolonged straightaway extensions of road segments that are deemed viable as BRT routes. This same *Select by Attributes* is repeated with a gridcode of 7, then 6, reinforcing and filling in natural road candidates for BRT routes.

The resulting *Figure 10* visualizes the selection of BRT routes which maximize determined route demand while complying with BRT criteria:

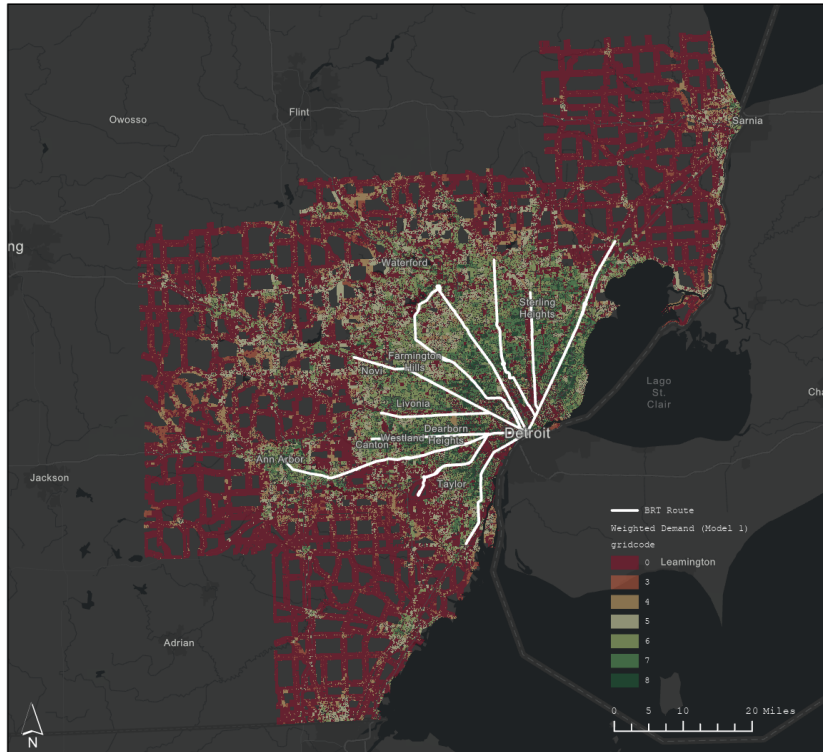


Figure 10 | BRT Routes Selection

The selected candidate routes are then converted from feature line segments to points, representing candidate points for BRT stops along the routes to be used in the *Location-Allocation* model.

LOCATING DEMAND FOR STOPS

Next, *Model 2* in *Figures 11* and *12* weighs total demand evenly across population density as origin demand and favorable land use as destination demand, and is then used to locate demand points that will inform the placement and distribution of BRT stops along each route.

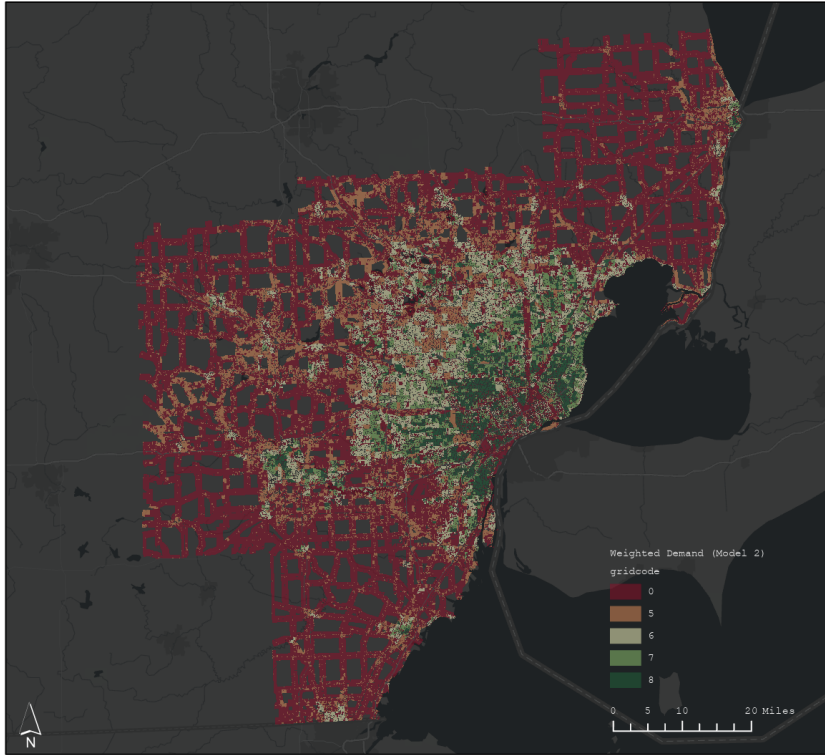


Figure 11 | Model 2: Weighted Demand for Locating BRT Stops

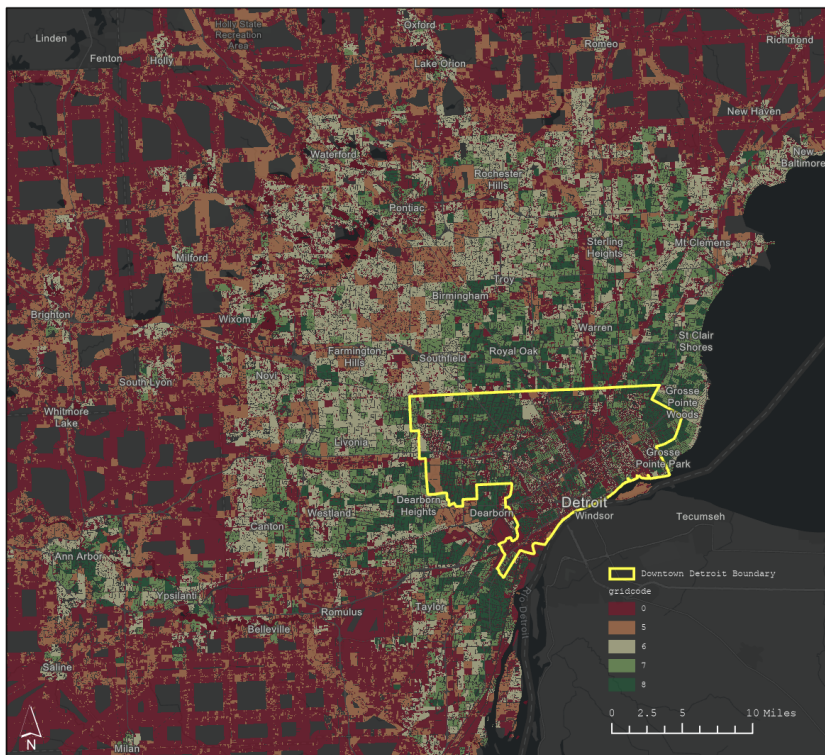


Figure 12 | Model 2: Weighted Demand for Locating BRT Stops

Observing *Figures 11 and 12*, it is clear that while some high demand origin and destination areas are continuous, there are other areas of high demand clusters without clear connecting paths, for example, in the case of Ann Arbor seen on the southwest side of *Figure 12*. In cases as such, the results of the analysis may show long stretches of BRT routes with minimal stops along route areas of lower demand, again reinforcing the exclusion of traffic data in determining candidate stops.

Next, the results of the *Model 2* weighted overlay are transformed into demand points which will influence the placement of BRT stops. In order to evenly distribute and assign weighted demand across the area of study, *Model 2* demand weights are spatially joined (*Spatial Join*) with a tessellation created across the area of study (*Create Tessellation*), and then converted to point features (*Feature to Point*). Each tessellation unit covers an area of 0.5 miles, again considered and explained in the *State of the Art* as a reasonably accepted distance in evaluating thresholds in demand for transit.

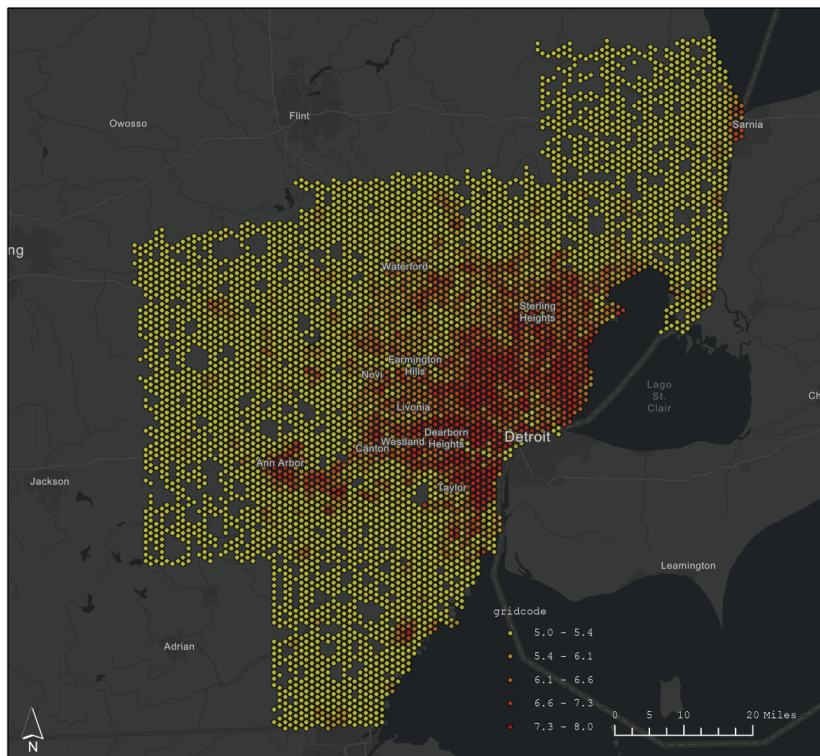


Figure 13 | Demand Points from Model 2

LOCATION-ALLOCATION

Finally, the *Location-Allocation* capabilities of *Network Analysis* in *ArcGIS Pro* provide intelligent and data-driven processes to find optimal locations for BRT stops given the determined set of demand locations.

With the objective of accessibility and inclusivity, the *Maximize Coverage* model is selected as a best fit, as this model places BRT stops such that all or the greatest amount of demand is within the specified impedance cutoff.

In defining impedance cutoff, a substantially large distance threshold is chosen in order to include all demand points within Metro Detroit. For one, this allows for an evaluation and comparison in allocating all weighted demand across Metro Detroit in various proposed BRT scenarios. Additionally, while ideally proximity to public transit is within the earlier defined preferred threshold of 0.5 miles, the nature of a BRT system also encourages high speed mobility with a lower concentration of stops. Therefore, it should be considered reasonable in various cases to access the BRT system by other modes of transit, such as via bicycle or private vehicle, as seen in the case of 'park and ride'. This concept introduces parking areas in the peripheral of cities, linked to public transit entry points, hence providing a space to park bikes and/or private vehicles for free, connecting riders without the luxury of living within walking distance to public transit, hence reducing congestion of private vehicles in cities, improving air quality, and promoting intermodality between systems of private and public transit (ZICLA, 2017).

Then, per the objective of generating mobility options between Metro Detroit and downtown Detroit, the BRT system will be complementary with the existing inner-Detroit DDOT system, which already serves transportation within the Detroit boundary. Hence, the existing DDOT stops are seen as *Required* facilities in the model, and the centroid points of road segments along determined BRT routes are seen as *Candidates* for BRT stop placement. Therefore, the placement of BRT stops will skip placement inside Detroit's boundary, with the exception of

one manually placed BRT stop, connecting all BRT routes, at an origin transit point downtown, allowing riders to board and disembark from downtown Detroit.

This model is then run across five distinct scenarios, each with a different designated number of BRT stops (15, 25, 35, 45, and 55), allowing for comparison of results across various scenarios.

RESULTS

The following results and analysis all take a macro approach, evaluating results of the BRT system across respective scenarios, rather than a micro approach, evaluating differences between specific stops within each scenario. This is noted as an area of future analysis.

The resulting five scenarios of the *Maximum Coverage* model are seen in *Figures 14 - 23* below. The results of each scenario are then observed and compared using metrics on weighted distance, weighted demand, and service area accessibility.

MAXIMIZE COVERAGE MODELS

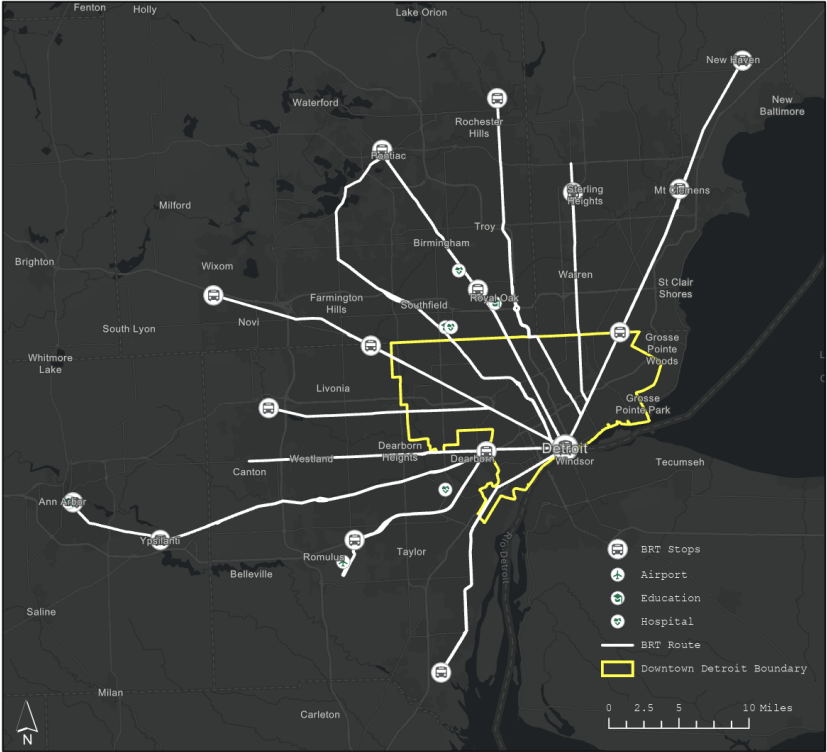


Figure 14 | 15 Stops Scenario

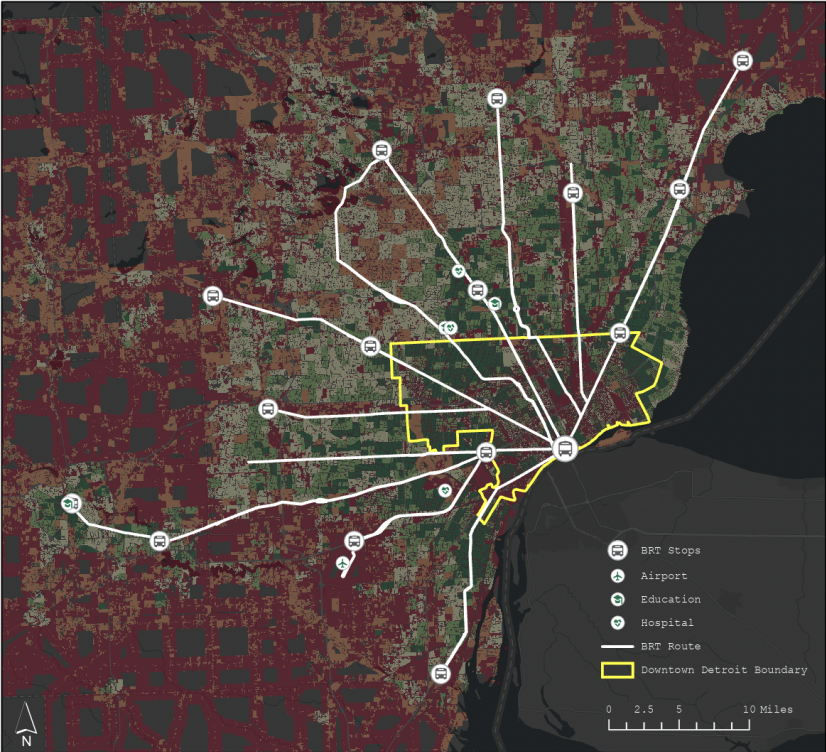


Figure 15 | 15 Stops Scenario with Weighted Demand (Model 2)

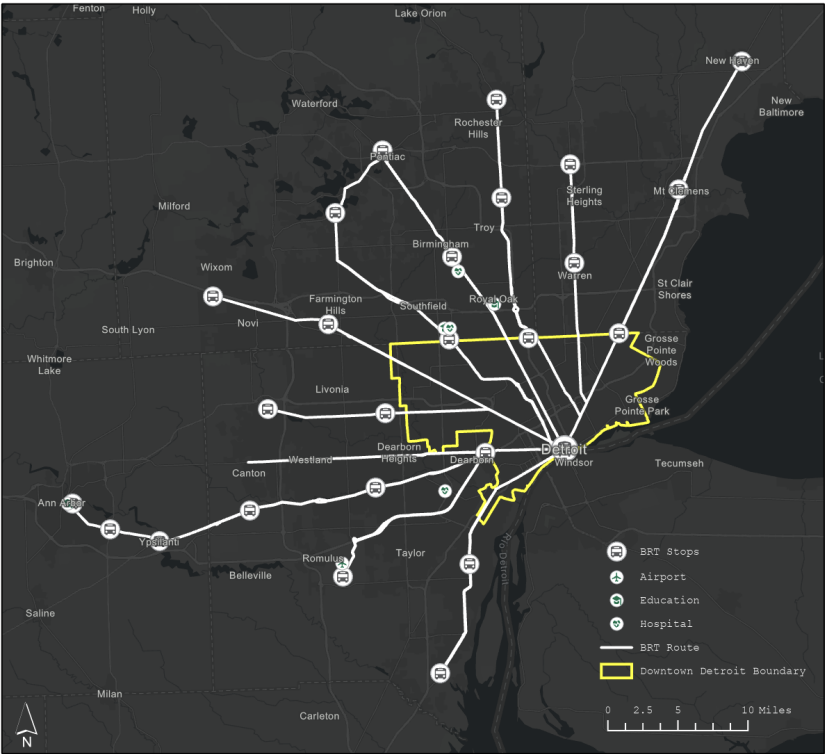


Figure 16 | 25 Stops Scenario

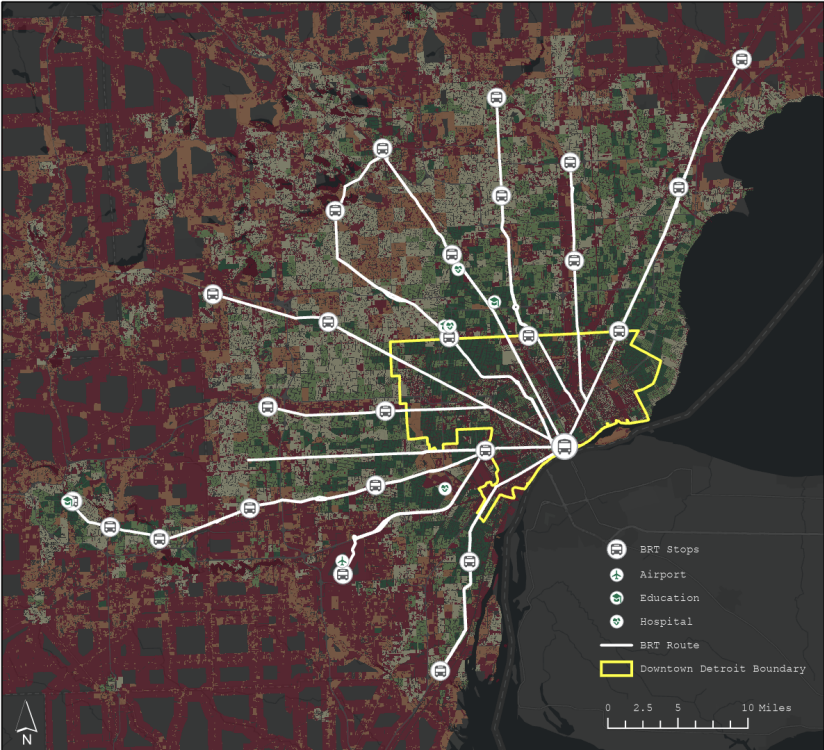


Figure 17 | 25 Stops Scenario with Weighted Demand (Model 2)

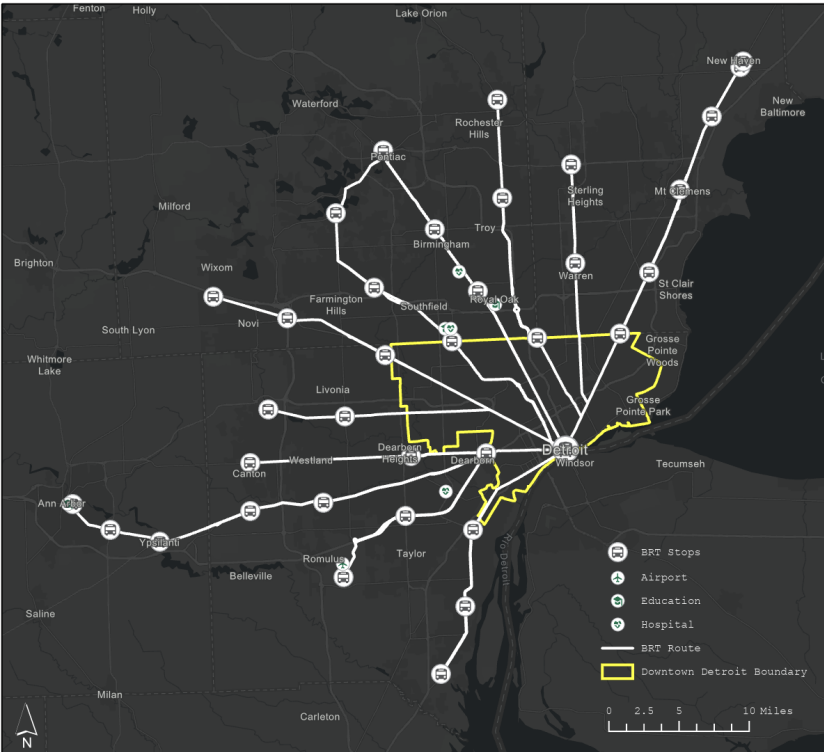


Figure 18 | 35 Stops Scenario

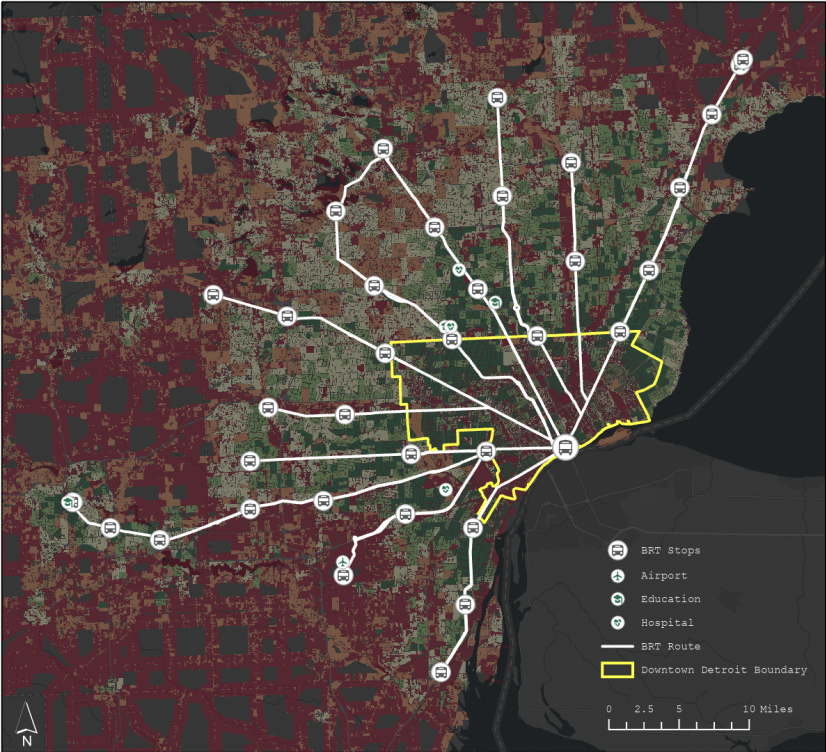


Figure 19 | 35 Stops Scenario with Weighted Demand (Model 2)

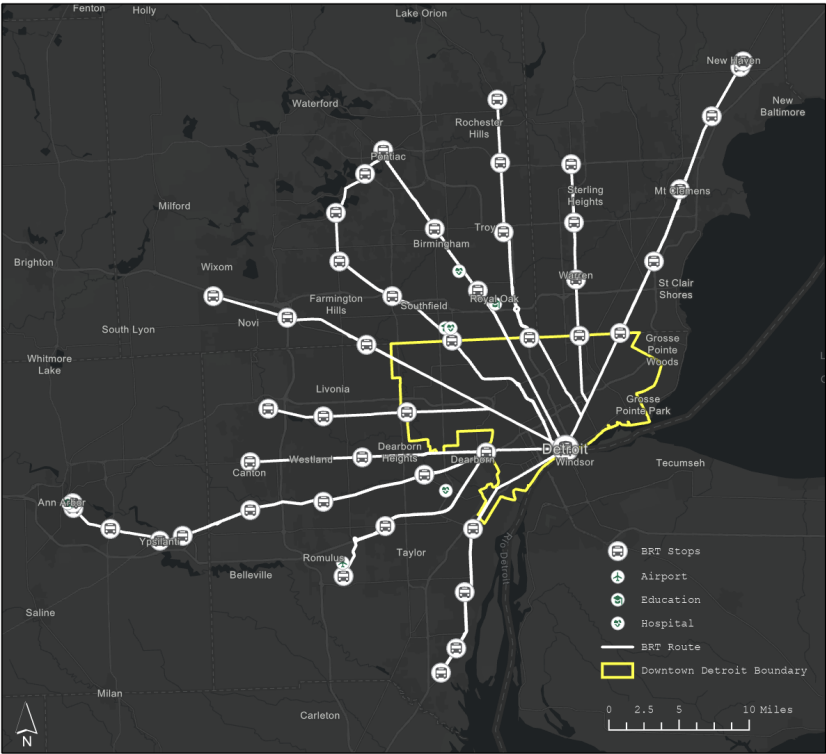


Figure 20 | 45 Stops Scenario

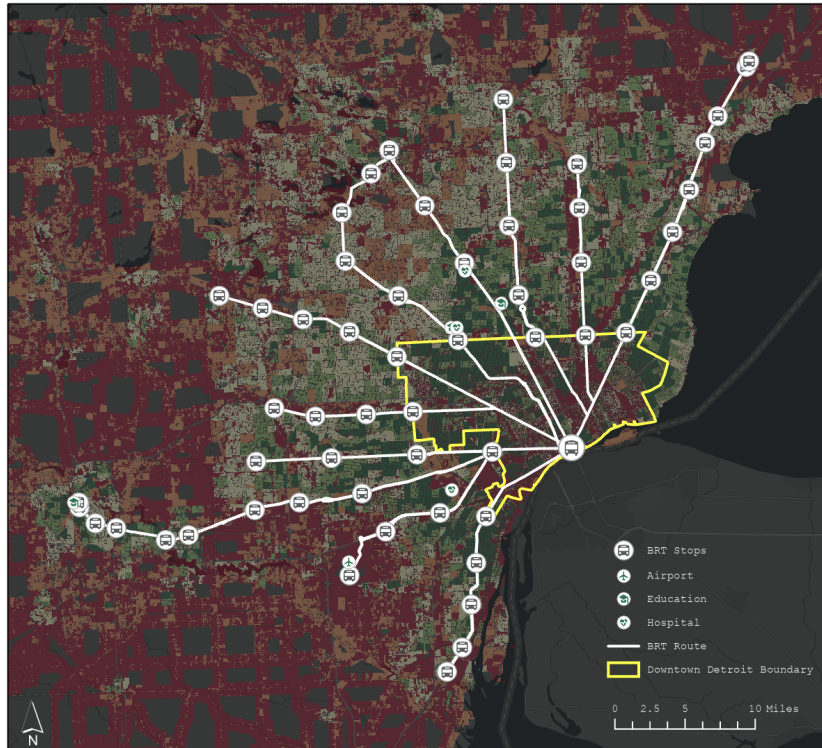


Figure 23 | 55 Stops Scenario with Weighted Demand (Model 2)

It is clear across all five scenarios how the proposed BRT scenarios enable mobility between Metro Detroit and downtown Detroit; as a further highlight, *Figures 14-23* also note basic value-add locations outside of downtown Detroit now accessible by the proposed BRT scenarios, such as the airport, hospitals, and universities.

Additionally, in *Figures 14 - 17* it becomes clear that in the case of scenarios with 15 - 25 BRT stops, the BRT route towards Canton/Westland should be cut, given the model for these scenarios generated no stops along this path.

COMPARISONS OF SCENARIOS

Next, three indicators of comparison are introduced across all five BRT stops scenarios to measure impact from various angles: weighted demand, weighted distance, and accessibility.

WEIGHTED DEMAND

Weighted demand indicates the sum of the weight from all demand

points that were allocated to each facility, seen across each scenario in *Table 5*. Hence, the statistics of this field importantly show the level at which each scenario satisfies the origin and destination demand, used in the location of BRT stops across all scenarios. The unit for this field is relative, as it comes from the weighted overlay between population density and favorable land use, which was used to inform origin and destination demand for BRT stop locations, hence generating a standard common relative unit of measure across various inputs, indicating levels of satisfying origin and destination demand.

Table 5 | Total Weighted Demand (relative unit indicating allocation of origin and destination demand)

BRT Stops Scenario	Sum	Max	Min	Mean \bar{x}	Median \tilde{x}	St Dev σ
15	31,836.4	5,253.5	761.7	2,122.4	1,194.8	1,482.2
25	31,836.4	5,253.5	367.6	1,273.5	676.8	1,301.9
35	31,836.4	4,094.1	286.1	909.6	405.3	1,030.7
45	31,836.4	4,048.6	190.1	707.5	323.0	879
55	31,836.4	3,977.1	125.5	578.8	243.6	810.9

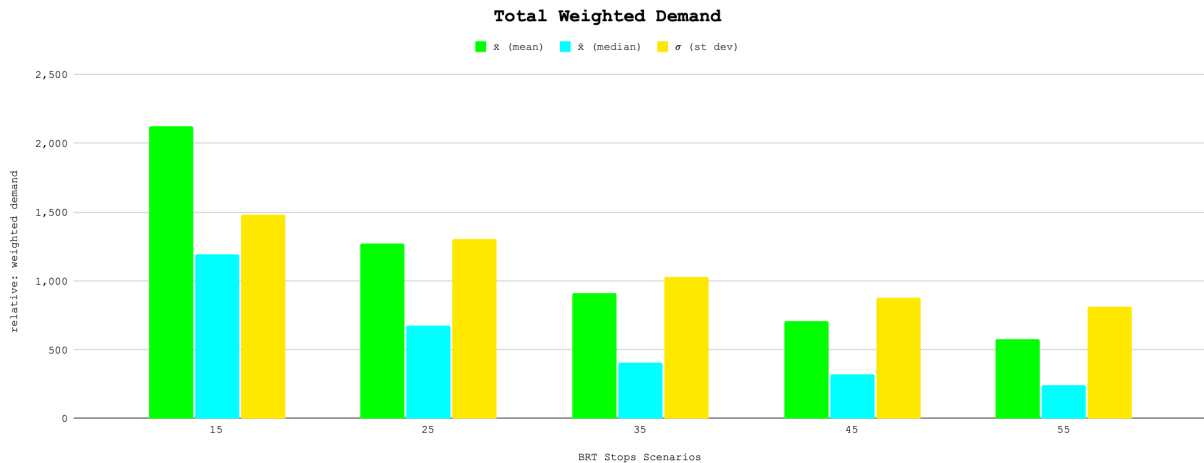


Figure 24 | Total Weighted Demand

In *Table 5*, the sum is the same across all scenarios, due to the large impedance cutoff including all demand points in Metro Detroit. Then *Figure 24* reveals how assigned demand per BRT stop goes down as more stops are introduced, given demand becomes more spread out, as seen by a decreasing mean and median. The median is clearly way lower than the mean in all scenarios, indicating that most BRT stops fall below the average weighted demand, with a few stops carrying much higher weighted demand, thus raising the average. The decreasing standard deviation indicates a decreasing dispersion of data, clustering more tightly around the mean as the number of stops increases, also seen in the decreasing difference between the mean and the median.

The biggest difference across scenarios is seen in the jump from 15 to 25 stops, indicating the biggest absolute difference in coverage of assigned demand per facility per scenario. Noting capacity constraints and peak travel times, it can be suggested that the increase to 25 stops will yield the largest change in capacity assigned to each BRT scenario, smoothing demand coverage and hence generating higher system efficiency of assumed estimated ridership.

WEIGHTED DISTANCE

Weighted distance in *Table 6* is a measure of cumulative

weighted cost or impedance of the model, in this case being length, or distance, and represents the sum of the length between all demand points allocated to each facility multiplied by weighted demand, defined above. In other terms, this indicator reveals the cost of distance between demand points and BRT stops, weighted by origin and destination demand of respective demand points. The unit of distance, weighted miles, is once again a relative weight as described by the units of weighted demand.

Table 6 | Total Weighted Distance (relative unit indicating cost of distance)

BRT Stops Scenario	Sum	Max	Min	Mean \bar{x}	Median \tilde{x}	St Dev σ
15	408,230	94,824	3,313	27,215	6,866	30,841
25	394,947	94,824	1,157	15,798	3,197	25,777
35	389,134	79,031	690	11,118	1,276	20,410
45	386,029	78,222	394	8,578	987	17,591
55	384,093	77,922	231	6,984	684	15,993

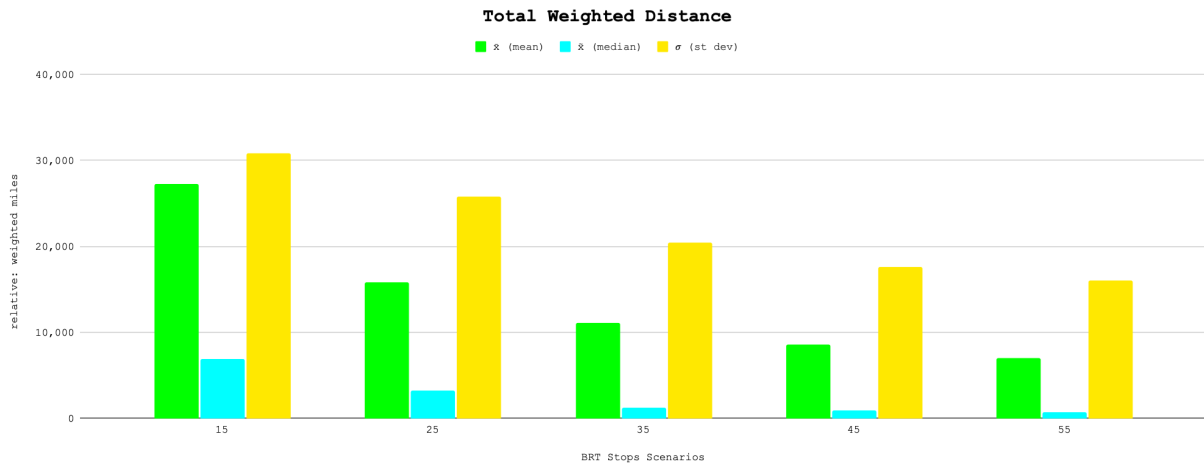


Figure 25 | Total Weighted Distance

Logically, weighted distance assigned to each facility decreases as BRT stops increase. While it appears odd that the standard deviation is so high, it should be noted that the *Location-Allocation* model cutoff was set extremely high in order to include all demand points in this part of the analysis, meaning that resulting data assigned to each facility is largely dispersed, compensating for all data points, far and near. Again, similar to weighted demand, the biggest jump in average weighted distance appears in the jump from 15 to 25 stops, again reinforcing the idea that the increased costs associated with implementing 25 stops will yield the highest return on benefits associated with weighted distance distribution.

SERVICE AREA ACCESSIBILITY

Next, a service area analysis helps to measure accessibility from origin points, where the population resides, across all five scenarios. For this portion of the study, a service area analysis is chosen over a simple buffer model, as service area models measure movement of people or things along defined and realistically simulated networks, whereas buffers assume unimpeded movement in any direction, which is not an accurate reflection of mobility. That said, measuring the population using a straight-line buffer would overstate the count of those who could truly reach the facility within a defined travel

distance.

Accessibility to BRT stops should include various modes of transport, which, as noted earlier, may include walking, biking, or even driving and using a 'park and ride'. Therefore, accessibility service areas are defined as 1 mile, 2 miles, and 5 miles. 1 mile is considered to be a walking distance, and 2 and 5 miles are considered a biking or driving distance, to access the BRT system. The resulting service areas are visualized in *Figures 26 - 30* below:

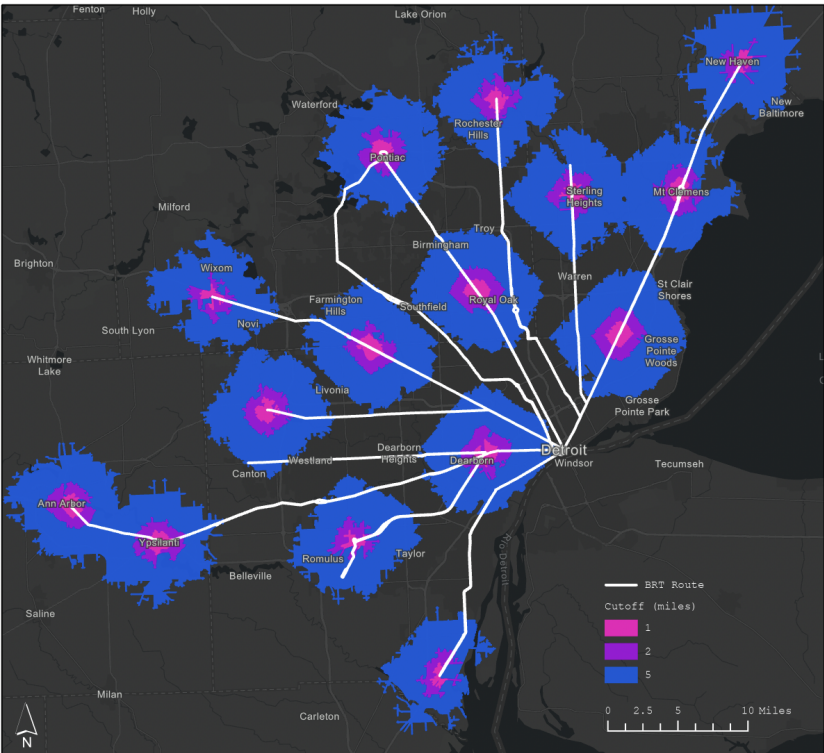


Figure 26 | Service Area Accessibility: 15 BRT Stops Scenario

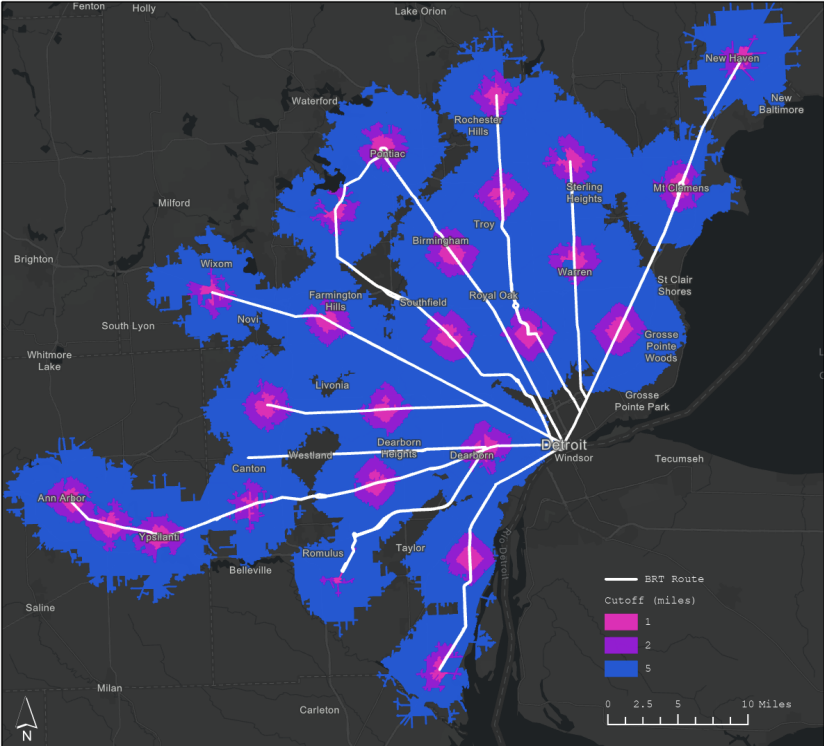


Figure 27 | Service Area Accessibility: 25 BRT Stops Scenario

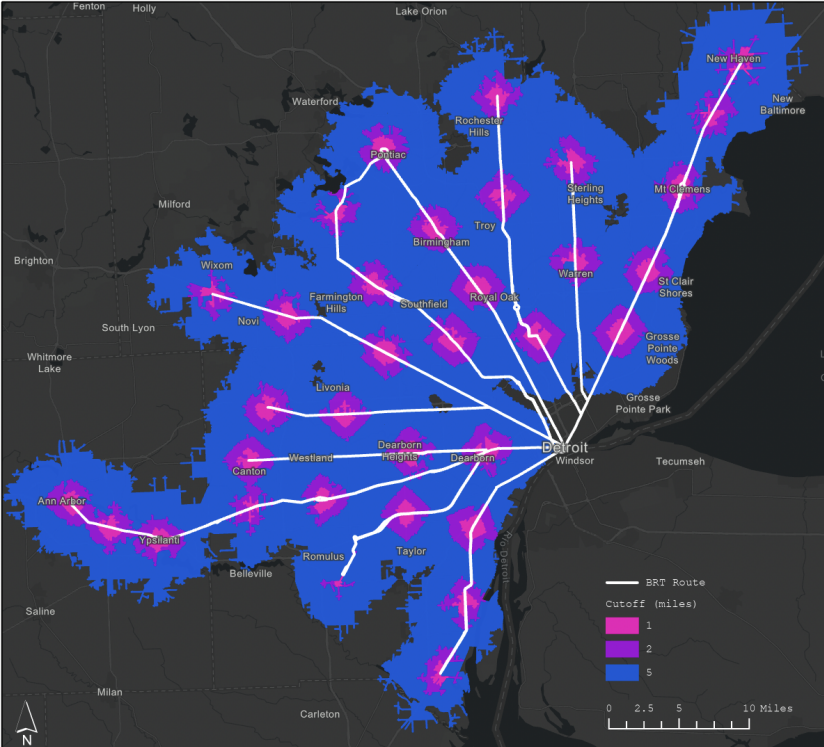


Figure 28 | Service Area Accessibility: 35 BRT Stops Scenario

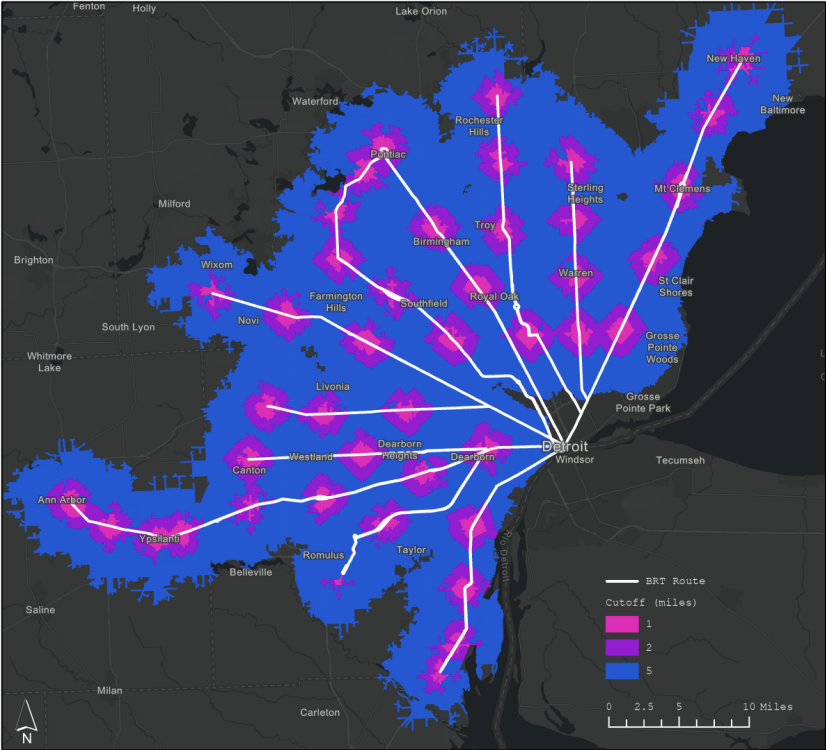


Figure 29 | Service Area Accessibility: 45 BRT Stops Scenario

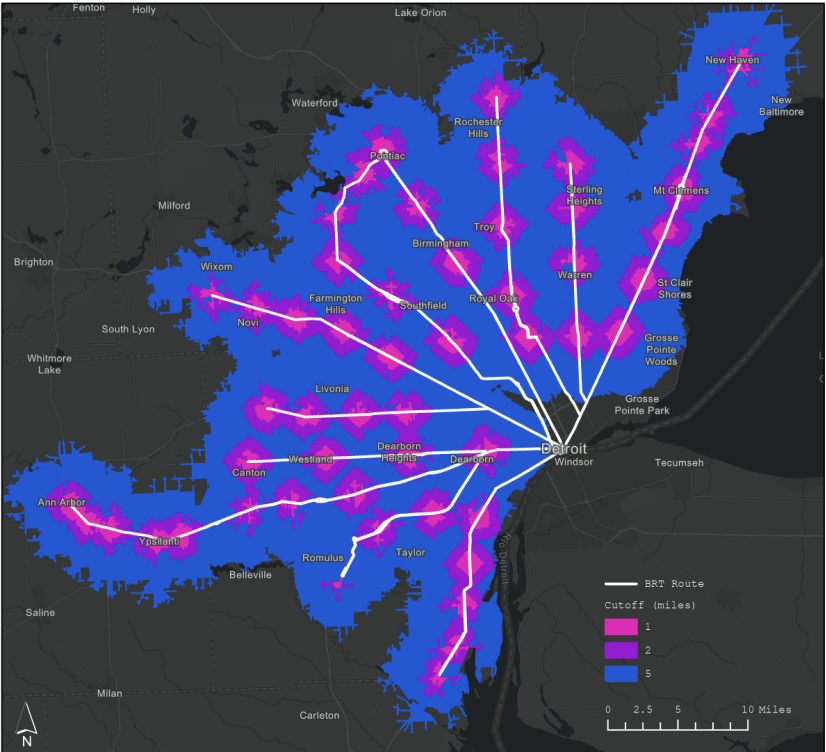


Figure 30 | Service Area Accessibility: 55 BRT Stops Scenario

Figures 26 - 30 reveal how service area sizes change for each BRT stop depending on distances along the defined mobility network. For example, the 1-mile and 2-miles service areas surrounding the BRT stop near Romulus are quite small, which at first glance may indicate a lack of infrastructure limiting accessibility, however noting its proximity to the airport suggests a highly valued demand destination point and justifies the lack of surrounding road infrastructure. Here, it becomes clear that at this point, the service area accessibility is simply a measurement of spatial coverage given the network dataset, and therefore, without representation of population data included in said coverage, can be misleading.

Then, in order to more holistically analyze accessibility as it relates to population included in service area coverage across scenarios, Table 6 introduces statistics surrounding Figures 26 - 30, including total shape area, total population, and total percent increase in population, all across the five BRT stops scenarios and across the three service areas. The subsequent Figures 31 and 32 then chart relationships between net population and population increase associated with each scenario and each corresponding service area.

Table 6 | Service Area Accessibility Statistics

BRT Stop s Scen ario	1 mile			2 miles			5 miles		
	Shape Area (sq ft)	Total Populat ion (ppl)	Populat ion Increas e (%)	Shape Area (sq ft)	Total Populat ion (ppl)	Populat ion Increas e (%)	Shape Area (sq ft)	Total Populat ion (ppl)	Populat ion Increas e (%)
15	751,620, 318	121,347	0.00%	2,990,2 54,678	410,506	0.00%	20,732, 374,581	2,135,3 89	0.00%
25	1,216,04 6,052	180,308	48.59%	4,960,4 06,839	668,837	62.93%	29,697, 894,574	3,209,3 06	50.29%
35	1,694,06 4,586	242,079	34.26%	6,925,0 02,131	924,214	38.18%	32,514, 342,372	3,453,9 98	7.62%

45	2,098,989,441	287,682	18.84%	8,568,701,708	1,093,262	18.29%	33,278,162,910	3,482,471	0.82%
55	2,569,685,152	332,063	15.43%	10,265,897,919	1,297,636	18.69%	10,265,897,919	3,518,088	1.02%

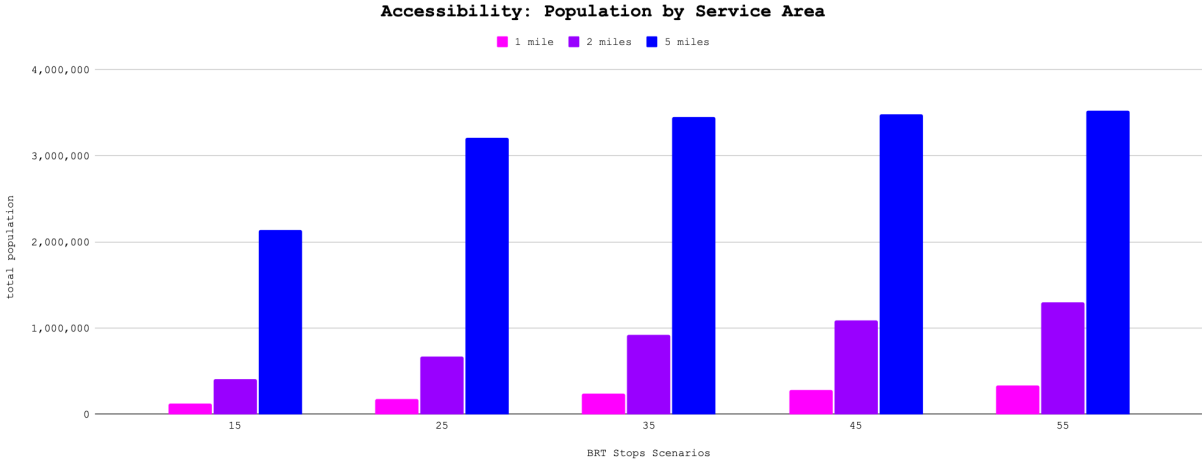


Figure 31 | Accessibility: Population by Service Area

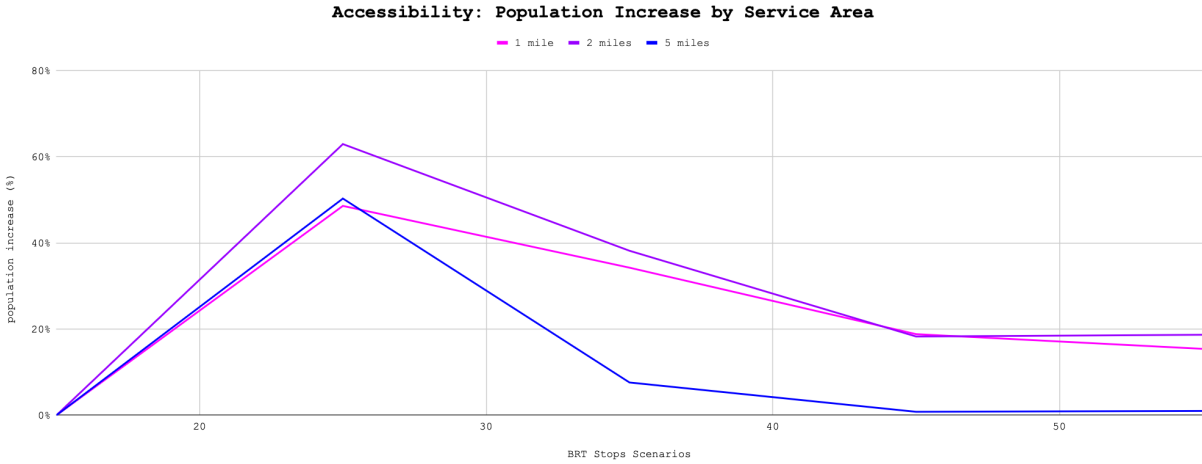


Figure 32 | Accessibility: Population Increase by Service Area

Figures 31 and 32 reveal how the relationship between accessibility in terms of population coverage and number of BRT stops is not positively linear, rather it hits a peak impact point and tends to level off, increasing at a slower rate after the 25 stops scenario mark. It should be noted that this

pattern is the strongest in the case of the 5-mile service area, and weakest in case of the 2-mile service area, as seen by the highest to lowest absolute slope in *Figure 32*.

This also shows itself cartologically in the progression of *Figures 26* through *30*, most visibly in the case of a 5-mile service area, where between the 15 stops scenario and the 25 stops scenario, there is a significant increase in the 5-mile coverage area, however in subsequent scenarios, increasing stops does not yield much additional coverage, as the 5-mile service area reach simply begins to overlap itself, not providing the additional benefits of increased coverage.

Figure 32 reveals the changes in *Figure 31* statistically highlighting this observation, that the added value of accessibility peaks at a 25 stops scenario, then thereafter faces diminishing returns on population coverage across all three service area distances as the stops scenarios increase. Therefore, in terms of impact on accessibility, the optimal number of BRT stops, for each service area, is where the percent change of increased accessibility is maximized, after which point faces decreasing returns of accessibility benefits. In this case, *Figures 31* and *32* reveal that 25 BRT stops sees the biggest increase in accessibility of BRT stops, therefore being the optimal choice in maximizing accessibility while minimizing the costs of additional stops.

On the other hand, in terms of variations across service area distances, the 2-mile cutoff sees the highest percent changes in accessibility across scenarios (*Figure 32*). Due to the sprawled nature of the suburban landscape, as discussed and explained contextually in the *Mobility in Detroit* section, populations in Metro Detroit are not highly concentrated in reasonable walking distances, but rather spread out and maximized in 2-mile cutoffs from the proposed BRT stops. That said, this indicator could be an important consideration in subsequent urban planning and future analysis, adopting methods to encourage ridership specifically targeted towards the 2-mile service area cutoff, hence maximizing targeted ridership. For example, given that 2-miles is likely not a walking distance for the majority of the population, implementing rider-friendly

access, like bike and car 'park and ride' access points, may further encourage increased ridership in this 2-mile population coverage.

CONCLUSIONS

CONCLUSIONS & LIMITATIONS

While the comparison of the five BRT stops scenarios across metrics of weighted demand, weighted distance, and service area accessibility suggests an optimal scenario of 25 stops, it is also true that these are a few of many approaches to measure BRT system impact, and many more should be taken into account in final decision-making for optimal BRT stops scenarios. Additionally, 25 stops could be considered few in the implementation of a BRT system. Therefore, areas of future research, such as micro-based, economic-based, environmental-based, and TOD-based analyses should be taken into account in final decision-making.

In terms of BRT decision-making, this analysis should serve as a methodology and sample approach to support decision-making for a city's BRT system, but it is limited in its scope. In reality, this is a piece of a much larger and holistic approach, incorporating participation and input from a web of interconnected stakeholders and decision-making centers across politics and governance, infrastructure design, and financial operations, aligning to support final decision-making in the development of a BRT system according to leading practices and criteria outlined in *Objectives*. As such, the nature of a BRT system crosses many municipalities, hence requiring heavy coordination, strategy, and participation across local governments. This may involve differences in zoning regulation, building permits, levels of public support, etc. in the development of proper BRT routes infrastructure (dedicated lane implementation, intersection treatment and signal priority), stops infrastructure (platform-level boarding, off-board fare collection), and information, communication and technology support (application-development for live schedule info and fare collection, intra-bus connectivity and communication) as well as other BRT criteria noted in *State of Bus Rapid Transit Systems*. Additionally, while the *Objectives* note that a BRT system should also be agile in its operations, it should also be noted as a limitation that while some urban planning projects may benefit from a progressive and segmented project

implementation approach, amortizing cost and resources over time, each BRT stops scenario locates stops differently, therefore requiring up-front decisiveness across all stakeholders, which can be a challenging task given the noted extensive involvement across municipalities.

Additionally, while giving proper credit to the breadth of publicly available data across the SEMCOG GIS Open Data Portal and the City of Detroit Open Data Portal, impressively up to date and organized, availability of some data can be noted as a limitation. Namely, it would have been interesting and relevant to consider data around employment in terms of classifying the attractiveness of destination demand for transit. More so, introducing a matrix of varied influences of origin and destination demand would support a more comprehensive and exhaustive approach to analyzing transit demand.

Above all, given the crossed network of decision-makers involved in proposing a BRT system, as well as the complexity and layered criteria of its success, it becomes clear how in cities like Detroit, private interests can easily sway public services. For that reason, despite its limitations, this type of proposed methodology that is research-backed and data-driven should be a leading practice in future BRT development.

AREAS OF FUTURE ANALYSIS

As noted throughout the study, there are various areas recognized for future analysis, namely elaborating on micro-based, economic-based, environmental-based and TOD-based analyses.

The results of this analysis emphasize a macro-based approach to analyzing BRT systems in each of the five BRT stops scenarios, but does not comment on differences in metrics within each route and/or stop for each proposed BRT scenario. A micro-based approach would introduce metrics such as route and stop capacities and route and stop frequencies and schedules according to demand and capacity. The introduction of travel time metrics would also be a useful point of study, simulating route and stop frequencies and travel times for riders using

various modes of travel, across both DDOT and a proposed BRT scenario. For example, comparing times for common origin-destination trips between Metro Detroit and Detroit, coordinating all legs of a simulated trip: walking/biking/driving from origin point to BRT stop, waiting time for next scheduled BRT arrival, BRT route to downtown Detroit BRT stop, walking/biking/driving from BRT stop to DDOT stop, waiting time for next scheduled DDOT arrival, DDOT route, walking/biking/driving time from DDOT stop to final destination point.

While this analysis suggests a data-driven approach to proposing a BRT system, it focuses on data related to influences of transit demand, but does not include economic factors in the form of implementation costs, operational costs, revenue streams, or economic forecasting. The economic aspect to the proposed BRT system could be an entirely new and complementary analysis supporting BRT decision-making. In doing so, a methodology should be created for data collection and analysis of cost per unit of BRT. Variable costs, in the form of cost per route, cost per stop, cost per time unit of operation, cost per bus per route, etc., as well as fixed costs, in the form of initial route and stop infrastructure development, bus purchases and maintenance, and fuel type, should all be measured and considered as inputs across BRT scenarios. Of course, variable and fixed income streams, such as trip-based revenue and monthly or yearly membership passes, should be accounted for as well in offsetting costs. The incorporation of these cost and revenue influences should be synthesized into a holistic economic model in determining economic efficiency and sustainability of BRT scenarios.

Of course, as outlined in *Guiding Principles*, a major and increasingly necessary component and objective of smart mobility is the associated environmental benefit of reduced emissions. While this analysis does not incorporate emissions-based metrics, it would be important to measure this type of environmental efficiency impact on a macro and micro level, further guiding BRT scenario selection. Aside from introducing environmental indicators at macro of BRT scenarios and at micro of route and stops metrics, an environmental-based

analysis would also consider the selection of vehicle type, weighing the environmental and economic benefits of fuel, hybrid, or electric fleets operating the selected BRT.

Finally, TOD should be considered and studied in the planning and implementation of BRT stops, as a means to physically alter landscape to meet and influence changing mobility demand in alignment with environmental goals. It would be a natural and progressive step to consider TOD as viable and relevant in the infrastructure and development of BRT stops; but even moreso, it would serve as a self-fulfilling prophecy, encouraging and augmenting demand for the larger BRT system. Upon further densifying the environment around BRT stations, increasing housing availability with accessible public transit coverage, increasing diversification of land use mix hence favoring increased and mixed destination demand, introducing cycle lanes networked with BRT stops for broadened accessibility, and naturally implementing self-vigilant security measures through increased and varied ridership, TOD presents a plethora of holistic approaches to meet BRT objectives.

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