DEVELOPING AND VALIDATING A MULTI-CRITERIA APPROACH FOR LOCATING MULTIMODAL MOBILITY HUBS

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ABSTRACT

In recent years, mobility hubs (MHs) have emerged as a novel concept to enhance multimodal travel. A mobility hub provides supporting infrastructure, amenities, and services for multimodal travelers at strategic locations, facilitating the seamless integration of various travel modes. While many cities and transit agencies have planned to develop MHs, an established methodology for selecting candidate sites for MH implementation is still lacking. In this paper, we propose a multi-criteria approach to locate ideal sites for MH development based on five key criteria: transit supply and connectivity, first-/last-mile connections, infrastructure readiness, equity, and spatial accessibility. Our approach consists of five steps: (1) determine key criteria (2) compute MH index, (3) identify typology for each MH (e.g., neighborhood, district, and regional), (4) generate results under different planning scenarios, and (5) validation. This approach differs from previously developed MH identification methods in several key aspects. The unit of analysis is clusters of transit stops, the MHs can be classified into one of three typologies, and first-/last-mile connectivity is a primary consideration. We demonstrate the approach by conducting case studies in Gainesville, Florida, and West Palm Beach, Florida. The proposed methodology can serve as a planning and decision-support tool for transportation planners and policymakers in various contexts.

Keywords: Mobility hubs, location planning, multi-criteria analysis, first/last mile, new mobility

INTRODUCTION

In recent years, mobility hubs (MHs) have emerged as an innovative strategy to enhance multimodal travel. A MH facilitates the seamless integration of multiple modes of transportation by providing supporting infrastructure, amenities, and services for multimodal travelers at strategic locations (*1–3*). By integrating various travel modes with public transit, MHs can not only enhance the experience of traveling multimodally but also contribute to a sense of place. Cities worldwide are conducting MH pilots to assess their impacts. Prominent examples include the SmartHubs EIT (*4*) and SmartHubs Urban Europe (*5*) projects in Europe and the Minneapolis (*6*), Boston (*7*) and Austin (*8*) pilots in the United States. Accordingly, there has been a growing research interest on the topic of MHs, including their typologies (*9–11*), user preferences (*12–14*) and potential impacts (*15, 16*).

While many cities and transit agencies have planned MHs as part of their transportation investment programs, there is not yet an established methodology for selecting the most suitable locations for MH development. Identifying candidate locations is a challenging task; planners must consider a variety of factors as well as the competing priorities of local governments, transit agencies, and potential users. It is essential that MHs are carefully sited, as their locations can significantly impact their potential to achieve transportation objectives.

A few studies have developed methodologies for locating mobility hubs, but the existing methods have several key limitations. First, the existing methods usually use zones such as census tracts as the unit of analysis to identify locations for MH development, which are too large in area to be of practical use for transportation planners. Also, most studies do not identify the hub's typology even though different types of MHs have distinct functions and support different modes and amenities depending on their function. Additionally, while it is widely recognized that a major potential of MH is to address gaps in first-/last-mile connectivity, this potential has been inadequately considered or measured by existing methods of MH site selection. Finally, existing methods are rarely validated by obtaining stakeholder and community feedback on the selected MH locations.

To address these limitations, we develop a multi-criteria analytical framework for site selection of MHs. We first determine the primary criteria which should inform MH allocation: spatial accessibility, first-/last-mile connections, transit supply, infrastructure readiness, and equity. Then, we evaluate clusters of transit stops for MH suitability under multiple scenarios which represent various planning priorities. The approach makes use of publicly available data sets, ensuring that it can be easily applied to various cities and regions. The proposed approach is first applied in Gainesville, Florida, and then validated in West Palm Beach, Florida. Community feedback on the MH locations identified with the approach is mostly positive, which validates the usefulness of the proposed methodology.

This paper is structured as follows. In the next section, we summarize the existing literature regarding MH development, including key criteria and methods for locating MHs. Then, we provide an overview of our proposed approach, followed by a detailed description of its application to two study areas and validation through community feedback. Finally, we discuss the contributions of this study, the limitations of the proposed approach, and future research directions.

LITERATURE REVIEW

There has been growing interest in mobility hubs as evidenced by the rising number of peer-reviewed journal articles and MH pilots. The following section includes an overview of MHs and their typologies, key criteria considered for locating MHs, and methods developed to locate MHs.

Mobility hubs and their typologies

Mobility hubs have generally been considered a location which facilitates the seamless integration of multiple modes of transportation, but a more specific definition of MHs has not been established in the literature. MH definitions typically include two distinct parts: one highlighting the connection of various transport modes and another highlighting the supporting services and built environment surrounding the MH (e.g., (*2, 17–19*)). Because the definition of mobility hubs is quite general, typologies have been introduced to distinguish different types of MHs.

Typologies are classifications of MHs which can be based on different characteristics including urban context, size, spatial scale, function, or a combination of these (*11*). Many currently proposed typologies are hierarchies, with higher-level MHs incorporating all the functions of lower-level MHs and additional ones. A few researchers have proposed a set of comprehensive typologies. For example, Weustenenk and Mingardo (10) conducted expert interviews, a panel discussion, and text analysis of policy and planning publications to develop six MH typologies: city centre, city district, city edge, suburban, neighborhood, and community. Roukouni et al. (11) proposed a typology for European hubs which are primarily defined by their urban contexts and can be further defined by four additional dimensions: function, spatial scale, services, and proximity to public transport. Both studies emphasized the importance of flexibility in the development of typologies and had overlapping characteristics among different categories.

An examination of a MH's function can highlight the similarities across different typologies. For example, a neighborhood hub is named for its catchment area, but its function as a connection between residential areas and dense employment centers means that it can be compared to other types of hubs such as community hubs (*15*), suburban hubs (*10, 12*), and commuter transit centers (*20*). Similarly, district hubs provide connections to dense areas and key destinations, so they can be compared to central hubs (*21*) or gateway hubs (*22*). Regional hubs are large interchanges which provide interregional connections like urban transit nodes (*17*) and city edge hubs (*10*).

Important considerations for locating mobility hubs

Planning for mobility hubs requires the consideration of a variety of factors related to transportation, the built environment, and the catchment area's characteristics. The factors considered in various location selection models in the literature are summarized in Table 1. Most models consider the socioeconomic or demographic characteristics of the area surrounding the mobility hub, such as total population, vehicle ownership, and income. Additionally, all models consider some transportation related factors, such as proximity to transit stations, car-/bike-sharing locations, potential demand, or other mobility measures.

Methods for siting mobility hubs

Several methods for siting (i.e., positioning) MHs have been developed. Most studies employ some multi-criteria decision analysis or optimization model to locate MHs, and a few integrate qualitative input from potential users, experts, or stakeholders, in the process.

Anderson et al. (23) proposes a four-step multicriteria suitability analysis framework to determine the optimal spatial distribution of MHs. The framework was applied to the city of Oak-

TABLE 1: Factors considered in several mobility hub allocation models in the literature

Categories	**Factors**	**Source**
Socio-demographics	Socioeconomics	1, 2, 3, 7
	Demographics	1, 2, 3, 5, 7
Transportation	Terminals & stations	1
	Transit stops & schedules	1, 7
	Car-share locations	1, 7
	Bike-share locations	7
	Mobility	2, 5
	Potential demand	4, 5, 6
	Network centrality measures	2
	Travel time	6
	Railway line capacity	6
Access to Destinations	Employment	1, 2, 5
	Points of Interest	2, 5, 6
	Public services	1, 2
	Access to facilities in surroundings	3, 4
Feasibility	Costs	4, 5, 6
	Impact	4, 6
	Resiliency	1
	Public Interest	3
	Time of project realization	6
	Access mode	6
	Structural suitability	3
Built Environment	Land-use	1, 2
	Housing	1
	Road networks and infrastructure	7
	Cycling infrastructure	2

Note: 1 = Anderson et al. (23); 2 = Arias-Molinares et al. (24); 3 = Aydin et al. (25); 4 = Blad et al. (2) 5 = Frank et al. (26); 6 = Petrović et al. (27); 7 = Tran and Draeger (28).

land as a case study and allows transportation planners to advance qualitative objectives such as equity and resiliency in their practice. Blad et al. (2) follow a similar process to identify regional MHs in Rotterdam with an additional step for sensitivity analysis. They emphasize the perspectives of different stakeholders (operator, government, and end-user) in the determination of criteria weights.

Aydin et al. (25) proposed an integrated fuzzy multi-criteria decision-making method to identify the ideal location for one new MH on the Anatolian side of Istanbul. Four candidate locations are predetermined and evaluated based on four main criteria; the selected location is validated using sensitivity analysis. Tran and Draeger (28) integrate network science and urban data analytics to locate and evaluate potential MHs based on multiple criteria, including sustainability and equity impacts. Portland, Seattle, and Vancouver were chosen as a case study for siting the mobility hubs under different scenarios that prioritize current mode split, high transit capacity, and multimodal service. Arias-Molinares et al. (24) focus on the importance of micromobility ridership for locating MHs. They first explore the built environment factors associated with usage of micromobility and propose a method for incorporating data from multiple micromobility modes when locating MHs in Madrid.

A few studies make use of optimization models to locate MHs. Frank et al. (26) used two optimization models to guide location planning of MHs in the rural region of Heinsberg, Germany. One model evaluated accessibility to points-of-interest, and another considered accessibility to workplaces. The researchers concluded that hubs can improve access both to POIs and workplaces, but different locations are selected when prioritizing access to one destination over another. Xanthopoulos et al. (29) incorporate a model to optimize the location and capacity of MHs into a multi-stage design algorithm intended to maximize utility for travelers. The method incorporated multimodal trips in Amsterdam and the resulting networks were evaluated based on modal split, service level, environmental factors, and economic feasibility. Petrović et al. (27) identify the locations of intermodal hubs along a railway line using a two-step methodology; they measured the population of the catchment area before implementing an optimization algorithm which considers travel time, costs, and environmental impact.

Mobility hub pilots have been conducted worldwide, with many cities using multi-criteria methodologies to identify MHs. In Lisbon, for example, existing and planned bike share locations were considered candidate sites; these sites were then evaluated for suitability based on criteria including population density and transportation infrastructure (*30*). City of Minneapolis Public Works (6) collaborated with consultants to identify 12 candidate MHs based on five criteria categories. However, they integrated community perspectives into their approach; the city sought feedback from neighborhood groups on the identified spots before recommending the final MH sites.

PROPOSED APPROACH

The aim of this work is to develop a novel method for selecting MH candidates which considers important spatial criteria, stakeholder perspectives, and community feedback. The conceptual framework for this methodology is displayed in Figure 1. The framework can be divided into five stages: determine key criteria, compute mobility hub index, identify mobility hub typology, generate results under different scenarios, and validate results.

The proposed approach contributes to the literature by addressing key limitations in the existing site selection methodologies. While most approaches use an areal unit (e.g., block groups)

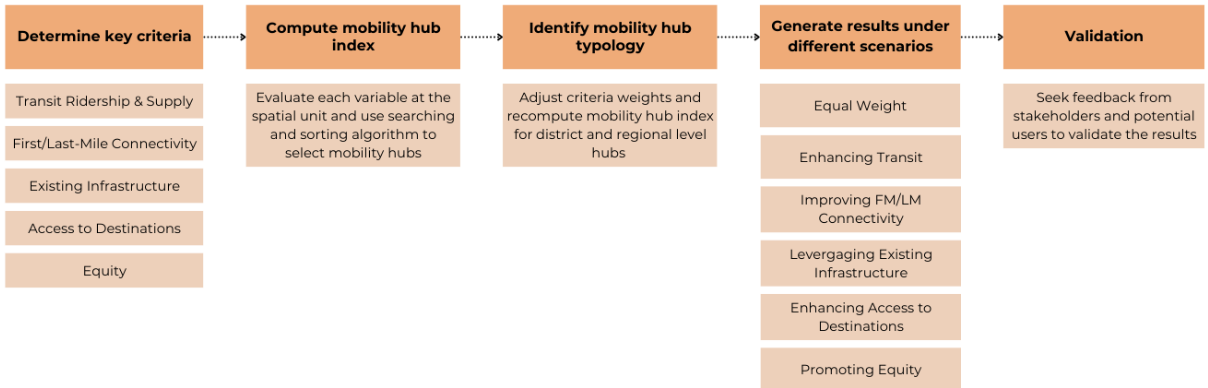

FIGURE 1: Overview of the proposed approach.

for the spatial analysis, this analysis is based on clusters of transit stops. The decision to analyze clusters of transit stops is based on the principle that mobility hubs should be anchored by public transit, so the location and quantity of transit stops should be a primary consideration. Additionally, the use of transit stops as a primary criterion ensures that the identified locations are specific enough to be practical for implementation.

A key function of MHs is to enhance first-/last-mile (FM/LM) connections (*5, 21, 23*). Thus, we have developed a novel approach for quantifying FM/LM gaps, and we consider the severity of the FM/LM gap problem in addition to the existing FM/LM micromobility trips when locating mobility hubs.

Another innovative aspect of our approach is the ability to distinguish the typology of each MH. MHs can vary widely in size, function, and availability of amenities and services. However, the existing mobility hub identification methods do not consider hub typologies. Our approach addresses this deficiency by classifying mobility hubs into three levels (neighborhood, district, and regional) and identifying them in a sequential fashion.

To validate the method, we have conducted case studies in two cities with distinct urban contexts. In both cities, the MH locations identified are highly valued by community members, demonstrating the efficacy of our proposed approach in locating MHs which are strategically placed and reflect the needs of potential users.

Identifying Key Criteria

The first step of the framework is to determine key criteria for locating mobility hubs. The criteria considered in this model were determined based on extensive review of MH development in the literature, case studies of MH pilots, and discussions with stakeholders. The identification of key criteria should be guided by the objectives of MHs, namely enhancing access to key destinations, facilitating first-/last-mile connectivity, and increasing the attractiveness of transit and multimodal travel. Considering these objectives, we have identified five criteria which are essential for locating mobility hubs: transit ridership, supporting infrastructure, spatial accessibility, first-/last-mile connectivity, and equity.

The criteria, their associated variables, and data sources are described below and summarized in Table 2. Almost all variables in the proposed approach can be measured using publicly accessible data that are widely available in the United States; this ensures that the approach can be readily applied in various contexts.

Transit ridership and supply is a key criterion because MHs must be anchored by high-quality public transit. Infrastructure readiness is considered because MH users, particularly pedestrians and cyclists, depend on the surrounding infrastructure to access MHs. We consider access to destinations in the MH's catchment area via different modes based on the idea that MHs should increase access to points of interest. Socioeconomic and demographic variables are considered to ensure that the siting of MHs considers the needs of transportation-disadvantaged individuals.

The first-/last-mile connectivity criterion considers both the number of first-/last-mile (FM/LM) trips currently observed and the extent of the FM/LM gap problem. To measure the number of existing FM/LM trips, we consider the number of bicycle boardings on buses as well as the number of shared micromobility trips ending within 100 feet of a bus stop. If such data are not available, we recommend to only consider the FM/LM gap within this criterion. To identify the areas with the most severe FM/LM gap, we developed a process for assigning a FM/LM gap score to each cluster. The procedure is as follows: (1) calculate the number of jobs plus the total population of each census block group centroid; (2) find the distance from each block centroid to the nearest bus stop; (3) compute FM/LM gap score by multiplying the number of jobs plus residents by the nearest distance; (4) aggregate the total values of centroid-level FM/LM gap score to the spatial unit.

Computing mobility hub index

The variables were preprocessed and aggregated at the spatial unit of analysis: a buffer zone surrounding groups of adjacent transit stops. To group adjacent transit stops, we applied Density-Based Spatial Clustering of Applications with Noise (DBSCAN) clustering algorithm with two input parameters: the radius around each point and the minimum number of points within that radius for a region to be considered dense. The choice of the input parameters to be specified should be informed by the local context, but we generally recommend a minimum of two stops within 100 meter radius.

The mobility hub index is the weighted sum of index score for each criterion. For computing the MH indices for an initial "equal weight" scenario, all five criteria categories are weighted at 20%. Each cluster of transit stops is scored, and an algorithm with the following steps is developed to choose the ideal sites using the scores:

1. Select the existing (or planned) mobility hubs.
2. Exclude all potential hubs within the catchment area of the selected hubs.
3. Select the hub with the highest mobility hub index as the next hub.
4. Repeat steps 2 and 3 until the service coverage or the total number of hubs reaches a pre-set value.

This algorithm minimizes the overlap between MHs service areas and ensures that the hub sites are distributed throughout the study area to form a MH network.

Identifying mobility hub typology

Once the locations for potential hubs are determined, the potential hubs can be distinguished by typology. Our approach distinguishes the potential MHs into three levels: neighborhood, district, and regional. Neighborhood-level mobility hubs are smallest in scale, and they fill service gaps by

TABLE 2: Criteria categories, variables, weights, and data sources

Category	Sub-category	Variable	Weight
Transit Ridership and Supply	**Ridership**	Passenger count	0.4
		Number of wheelchair boardings	0.1
	Service frequency	Number of unique bus routes	0.1
		Number of bus stops in cluster	0.1
		Total number of buses passing the stop	0.3
First-/last-mile Connectivity	**Existing FM/LM trips**	Number of bicycle boardings at cluster	0.15
		Number of shared micromobility trips within 100 feet	0.15
		Number of microtransit trips within 100 feet	0.15
	FM/LM gap	FM/LM gap score	0.55
Infrastructure Readiness	**Intersection density**	Multimodal intersection density	0.167
		Pedestrian-oriented intersection density	0.167
	Bike lanes	Bike lane length	0.167
		Ratio of bike lane length to road network length	0.167
	Sidewalks	Sidewalk length	0.167
		Ratio of sidewalk length to road network length	0.167
Equity	**Socio-economic and demographic variables**	% households without vehicles	0.2
		% Black residents	0.2
		% residents living in rental units	0.2
		% residents in poverty	0.2
		% residents with disabilities	0.2
Spatial Accessibility	**Accessibility via auto**	Number of jobs within 45-minute travel time by automobile	0
	Accessibility via transit	Number of jobs within 45-minute travel time by transit	0.25
	Walkability	Walkscore	0.75

TABLE 3: Buffer size and variable weights used to calculate mobility hub index for each typology

Typology	Access mode	Buffer size	Variable: weight
Neighbor-hood	Walk, micromobility	1 mile (15-20 min walking)	Accessibility via auto: 0 Accessibility via transit: 0.25 Walkability: 0.75
District	Walk, micromobility, microtransit, rideshare	3 miles (10-15 min biking)	Accessibility via auto: 0.2 Accessibility via transit: 0.3 Walkability: 0.5
Regional	Walk, micromobility, microtransit, rideshare, car	5 miles (5-10 min driving)	Accessibility via auto: 0.33 Accessibility via transit: 0.33 Walkability: 0.33

facilitating short-distance FM/LM connections made by walking and micromobility. District level mobility hubs can additionally serve medium-distance connections made by micromobility, microtransit, or ridesharing. Regional hubs accommodate long-distance travel, and thus accommodate personal cars in addition to the modes included at neighborhood-level and district-level hubs.

We consider all initially identified MHs as neighborhood hubs. Then, we can identify which of these initial MHs can be designated as district and regional hubs by redefining certain criteria to reflect the specific characteristics of each typology. We construct a district and regional index by adjusting the buffer size for FM/LM gap score, the buffer size for infrastructure readiness score, and the variable weights for spatial accessibility criterion. The recommended adjustments are summarized in Table 3.

The neighborhood hubs which score highest based on the district index can be designated as district hubs. Then, the district hubs can be rescored using the regional index, and the top scoring hubs can be designated as regional hubs.

Generating results under different planning scenarios

Cities and transit agencies often need to carefully evaluate competing priorities when planning for mobility hubs. To aid the allocation of infrastructure investments based on different planning priorities, our approach allows one to adjust the variable weights to generate different results for each planning scenario. Here we illustrate the approach with the consideration of six planning scenarios: equal weight, promoting equity, enhancing access, leveraging existing infrastructure, improving FM/LM connections, and enhancing transit. The weighting scheme used for each scenario is displayed in Table 4.

Validation

We evaluate the validity of the proposed approach in two distinct ways. First, we apply it in two case study areas which have distinct urban contexts, population demographics, and transportation services. By testing the proposed approach in different areas, we demonstrate its flexibility and relevance to planners in a variety of situations. Additionally, in both cities, we validated the results using feedback from potential users via a web-based survey. The survey features interactive map components powered by JavaScript, allowing respondents to view maps with potential MHs

TABLE 4: Weights assigned to each criterion under six planning scenarios

	Transit Ridership + Supply	FM/LM Connectivity	Infrastructure Readiness	Spatial Accessibility	Equity
Equal Weight	0.2	0.2	0.2	0.2	0.2
Promoting Equity	0.125	0.125	0.125	0.125	0.5
Enhancing Access	0.125	0.125	0.125	0.5	0.125
Leveraging Existing Infrastructure	0.125	0.125	0.5	0.125	0.125
Improving FM/LM Connectivity	0.125	0.5	0.125	0.125	0.125
Enhancing Transit	0.5	0.125	0.125	0.125	0.125

represented as location markers.

CASE STUDY

Study area

The study area, Gainesville, is in north central Florida. Gainesville is home to two major educational institutions, the University of Florida (UF) and Santa Fe College, so a substantial portion of residents (36%) are enrolled as college or graduate students (*31*). Much of the student population is concentrated around campus areas, while youth and elderly primarily reside outside of the city boundary. 11% of households lack personal vehicles, emphasizing the need for public transit and walkable communities. It is estimated that 34% of Alachua County residents are transportation disadvantaged and 1.5% fall into the most vulnerable group (elderly, disabled, and low-income); this number is expected to increase between now and 2025. Therefore, the city is exploring innovative mobility solutions like micro-transit, autonomous vehicles, and mobility hubs to improve accessibility, particularly in areas with limited transit options.

Gainesville has a greater share of residents walking, cycling, or taking public transit to work when compared to state and national averages. Public transit in Gainesville is supplied by the Regional Transit System (RTS), which operates 39 fixed routes as of Spring 2024. During university holidays, city service is reduced, and campus services are paused. RTS also operates a low cost, paratransit service on demand for ADA certified riders. Shared e-scooters are supplied by Bird, Spin, and Veo throughout Gainesville. Shared cars are provided by ZipCar at designated locations in and around the UF campus. Uber and Lyft both operate in Gainesville. In addition, UF operates several transportation services available exclusively for students, faculty, and staff; these services include campus shuttles, shuttles for individuals with disabilities, and on-demand nighttime shuttles.

Applying method in Gainesville

The unit of analysis for neighborhood MHs in Gainesville is the 1-mile buffer zone surrounding clusters of adjacent transit stops. We set the search distance for the DBSCAN algorithm as 100 meters and the minimum bus stop number of each cluster as 2. This generates 628 grouped clusters among 1081 stops. We compute the MH index for each cluster using the weighted sum of the five criteria and their corresponding indicators. Table 5 lists the data sources and descriptive statistics for each variable when computing neighborhood MH index at cluster level.

To identify a network of MHs, we follow the algorithm previously outlined. There are planned MHs at three locations in Gainesville, so these are selected as the first three hubs. To ensure that coverage area of each MH does not significantly overlap, we exclude all potential MHs within a catchment area of 1.5 miles of the planned MHs. Then, we identify the next-highest scoring cluster, until the ideal number of neighborhood MHs (12) is reached. We then identify four district MHs and one regional MH based on the district and regional indexes. This process is repeated five times using different weighting schemes which reflect various planning priorities.

Results

We identified 17 candidate MH sites across six scenarios using the proposed approach, three of which were automatically selected because they are currently under development. The neighborhood, district, and regional MHs identified in each scenario are displayed in Figure 2.

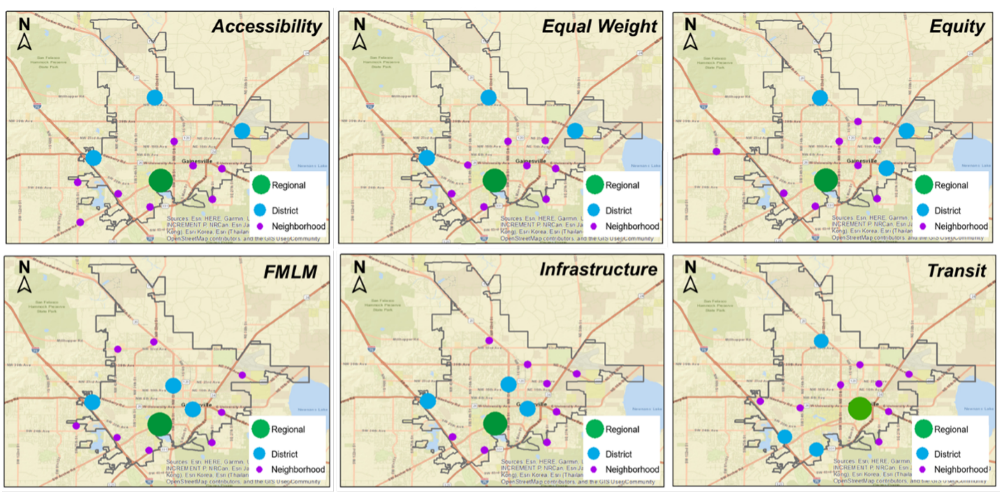

FIGURE 2: Mobility hubs identified under six different planning scenarios.

There is significant overlap between each scenario, with 10 MHs emerging across at least five of six scenarios, possibly meaning these locations possess characteristics ideal for MH development under a variety of planning priorities. This could also be because the searching and sorting algorithm excludes locations within the catchment area of previously selected hubs to maximize coverage in the study area. Thus, if high-scoring clusters are concentrated in a small area for a given scenario, MHs will be allocated to locations which are highly ranked relative to the immediate clusters but may not be highly ranked overall, resulting in similarities across scenarios.

The regional level MH identified in five of six scenarios is Shands Hospital. This is expected, as the hospital is a major employment and education hub situated at the intersection of two heavily trafficked roads. It is bordered by UF campus to the north and mixed-use residential areas

TABLE 5: List of data sources and descriptive statistics for variables in Gainesville case study

Variable	Sources	Mean	Med.	Max.	Min.
Passenger count	RTS (2022)	94.13	14	6922	0
Number of wheelchair boardings		36.85	5	4325	0
Number of unique bus routes		3.2	2	26	1
Number of bus stops in cluster		71.57	63	151	2
Number of buses passing stop		344.26	140	4488	15
Number of bicycle boardings		31.06	5	1681	0
Number of microtransit trips within 100 feet		539.28	0	4367	0
Number of shared micromobility trips within 100 feet	Bird, Spin, Veo (2022)	24632.1	4171	166044	0
FM/LM gap score	ACS, LODES (2020)	2103.8	1220	11282	0
Multimodal intersection density	SLD (2021)	6.03	3.97	19.8	0
Pedestrian-oriented intersection density		23.39	11.28	75.26	1.87
Bike lane length	OSM (2023)	38916.1	39349.3	59723	6030.1
Ratio of bike lane length to road network length		28.75	28.13	90.63	6.84
Sidewalk length		128699.8	98763.6	412638	0
Ratio of sidewalk length to road network length		83.86	72.77	100	0
% households without vehicles	ACS (2020)	10.28	10.58	22.61	2.10
% Black residents		24.55	16.93	74.94	5.09
% residents living in rental units		60.20	59.08	92.20	20.27
% residents in poverty		25.50	27.44	46.75	4.50
% residents with disabilities		6.03	5.07	13.89	2.39
Number of jobs within 45-minute travel time by automobile	SLD (2021)	22687.3	23194.4	29601.8	12182.0
Number of jobs within 45-minute travel time by transit		20536.0	25861.2	54539.9	-60941.2
Walkscore	Walkscore API (2023)	44.77	44.98	82.81	4.00

Note: RTS = Regional Transit System, ACS = American Community Survey, LODES = Longitudinal Employer-Household Dynamics Origin-Destination Employment Statistics, OSM = OpenStreetMap, SLD = Smart Location Database.

to the east, making the area a hot spot for activity. Shands Hospital was not identified as a MH in the "Enhancing Transit" scenario, indicating that the area has a shortage of transit supply and could benefit from the addition of infrastructure for alternative modes. Additionally, while it is easily accessible by car and bike, it is less walkable than nearby areas. Therefore, it is suitable for the implementation of a regional MH which facilitates long-distance and interregional travel.

Five MHs emerged as district hubs in more than one scenario, and these five hubs have distinct traits. For example, North Gainesville and Gainesville Regional Airport emerge as potential district hubs in the accessibility, equal weight, and equity scenarios. These locations are on the periphery of the public transit service area, so they are easily accessible by car but could benefit from increased connectivity via alternative modes. On the other hand, Rosa Parks Transfer Station and Gainesville High School emerge as potential district hubs in different scenarios; their position near population dense areas with supporting bike and pedestrian infrastructure makes them ideal candidates in FM/LM and infrastructure scenarios. Oaks Mall shares characteristics from each of the two groups and emerges in four scenarios. Interestingly, two of the district MHs identified in the transit scenario are not district MHs in any other scenario, possibly meaning that the locations best served by transit lack other characteristics which make them ideal for development of a district MH.

The location of neighborhood MHs varies more widely across scenarios. For example, the neighborhood MHs are concentrated near downtown and east Gainesville in the equity, infrastructure, and transit scenarios. MHs are distributed more evenly throughout the city in the accessibility and equal weighting scenarios. In the FM/LM scenario, MHs are located on the periphery of the transit service area where the FM/LM gap is most severe. The differences between scenarios demonstrate that neighborhood MHs are more sensitive to the changes in variable weighting than higher level MHs. Though the specific location of neighborhood MHs varies, they are generally situated in areas which cater to local traffic and are essential for filling gaps in service coverage.

Validation of results

To ensure that the MHs are valued by the community, we developed a web-based survey to gather feedback from potential users. We primarily promoted the survey on in-bus monitors, the RTS website, and the RTS mobile app. Respondents were presented with a map of the MHs identified in two scenarios and asked if they would be likely to use at least one MH, which MHs they are likely to use (if any), and which MHs are located in inconvenient or undesirable locations (if any). This series of questions allows us to evaluate the validity of our method by exploring how the potential users value the MH locations identified.

After cleaning the data, we received 529 valid responses. The results show that the identified MHs are highly valued by the community: 88% of respondents indicated that they would be willing to use at least one of the MHs presented. Respondents' intentions to use each hub are displayed in Figure 3. Results from the interactive mapping exercise highlight overall preferences for MHs located near central areas, including UF campus, downtown, and Butler Plaza. This is expected, as these locations were designated as higher-level district and regional MHs and demonstrate potential to advance multiple objectives. Respondents tended to redistribute hubs in eastern and northern Gainesville more evenly and towards campus areas. The preference for MHs in central areas reinforces the importance of scale: the most popular MHs should be greater in scale to accommodate increased demand, while small-scale MHs are more appropriate for implementation in secondary locations. Overall, the generally positive feedback on the identified locations and the high intention to use at least one demonstrate the validity of proposed approach for identifying high potential MH locations.

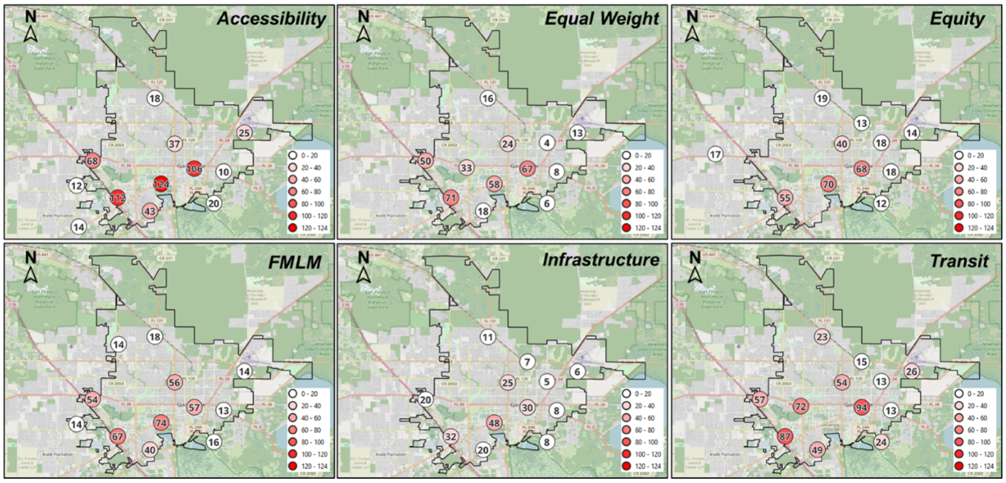

FIGURE 3: Frequency that survey participants selected they intend to use each mobility hub in Gainesville.

VALIDATION IN WEST PALM BEACH

Study area

West Palm Beach is the largest city in Palm Beach County, serving as the county's employment hub and transit center. While the county spans from the Atlantic Ocean to the everglades and Lake Okeechobee, the population is concentrated on the eastern third of the country around the I-95 and Tri-Rail corridors. There are some small, predominantly minority communities in western Palm Beach County near Lake Okeechobee, collectively known as "The Glades."

There are three bus and rail services operating in Palm Beach County. Palm Tran is a public sector transit agency which operates buses and paratransit. Tri-Rail is a north-south commuter rail corridor with six stations in Palm Beach County (one in West Palm Beach); this service connects commuters in Palm Beach County to destinations in Broward and Miami-Dade Counties. Brightline is a private-sector company which operates a high-speed rail line from Miami to Orlando; there are two stops in Palm Beach County (one in West Palm Beach).

Applying method in West Palm Beach

To identify MHs in West Palm Beach, we applied the method outlined in an earlier with some modifications. Specifically, we removed some variables for which we lacked data, and included Tri-Rail and Brightline train stations alongside bus stops in the analysis. Additionally, we adjusted some parameters to better reflect the urban context of the city. The modifications and parameters are summarized in Table 6.

Results

We identified five MH locations in the City of West Palm Beach using an equal weighting for all five criteria. Many of the locations were highly valued by the community. A regional MH is recommended at the West Palm Beach Tri-Rail Station, and 70% of survey respondents affirmed

TABLE 6: Adjustments made for applying the approach in West Palm Beach

Modification	**Explanation**
Wheelchair passenger boardings not included	Lack wheelchair boarding data
FM/LM micromobility trips	Lack micromobility trip data
Tri-Rail and Brightline stations automatically included in analysis	DBSCAN clustering algorithm excludes train stations
Parameter	**Value**
DBSCAN search distance	100 meters
DBSCAN minimum number of points	2
Catchment area	1.2 miles
Number of MHs in Palm Beach County	50
Number of MHs in West Palm Beach	5

the usefulness of this location. A district MH is recommended at the Tanger Outlets Palm Beach shopping center and park-and-ride; about half of survey respondents value this location. Neighborhood MHs are recommended at three other locations; two of which are along the US-1 corridor and another at the intersection of two proposed transit corridors.

Overall, the proposed approach is easily applied to identify MHs in West Palm Beach after adjusting certain criteria and parameters. One potential hot spot for a MH which was not identified by the approach is the West Palm Beach Brightline Station; this location was excluded because it falls within the catchment area of the Tri-Rail Station. This highlights two key considerations regarding application of the approach in different contexts. First, the input parameters should be carefully evaluated to ensure they are appropriate for the study area. Second, the proposed approach should be used as a tool within a larger process in which local stakeholders can verify the accuracy and viability of the identified MH locations.

CONCLUSION

The strategic location of mobility hubs can facilitate multimodal trips by increasing the attractiveness of transit and enhancing first-/last-mile connectivity. We have developed a GIS-based analytical framework for identifying the most suitable locations for MHs. The proposed methodology is designed to evaluate and prioritize potential MHs locations at different scales by assigning scores and weights to five essential criteria: transit supply, first-/last-mile connectivity, spatial accessibility, infrastructure, and equity. We proposed an approach for quantifying FM/LM gap to identify areas with greatest need. Additionally, we distinguished the typology of MHs based on their catchment areas and access modes. To validate the proposed approach, we tested it in two different cities and sought input from potential users regarding the proposed locations for MHs. The validation of data-driven method with community feedback ensured that the final MH network is strategically placed and reflects the preferences of potential users.

The proposed methodology can serve as a tool for transportation planners and policymakers in various contexts. We have demonstrated its adaptability by applying it to two different urban contexts and testing a variety of planning scenarios which represent planning priorities. When applying our approach, one can flexibly adjust some parameters (e.g., catchment area, weights) so the results are tailored to their needs and the local contexts. The proposed approach primarily uses publicly and widely available datasets, which ensures its transferability to other areas and regions. To promote public awareness and widespread adoption of our approach, we have developed a project web page which contains a story map and downloading options (i.e., a set of ArcGIS toolbox and the underlying Python code).

Despite the highlighted contributions of our approach, there are a few limitations. The use of bus stop clusters as potential sites neglects locations which are not currently well-served by transit but possess other characteristics which make them suitable for MH development. Additionally, the analytical framework does not consider some criteria which are relevant for the implementation of MHs (e.g., costs, land availability, land-use restrictions, future developments). To accommodate these limitations, the proposed approach should be used as part of a stakeholder driven process.

There are several avenues for future research to build on this study. For example, the approach could be expanded to incorporate additional modes such as ride-sourcing and carpooling. Future work could evaluate the potential impacts of each proposed MH, including the changes in mode shift, carbon emissions, and travel time. The operation and maintenance of the identified locations also necessitates further explorations. Additionally, as the number of implemented MHs grows, researchers should study the usage patterns and demand for transportation services at existing hubs to inform the location and design of future hubs.

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