EVALUATING THE ACCESSIBILITY OF A SUSTAINABLE CITY: CASE STUDY OF MASDAR CITY, UAE

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ABSTRACT
An epitome of a sustainable city, Masdar City in the United Arab Emirates, boasts of its integrated land use and multi-modal transportation network. When developed as planned, it could be an example for designing future cities. However, little is known of how accessible it could be in spite of its unique design. Conversely, accessibility, as a conceptual and operational definition, has gone through several iterations. However, it still remains an often misunderstood and poorly defined and measured construct. Masdar City, as planned, consists of several types of sustainable transportation options including walking, biking, personal rapid transit (PRT), group rapid transit (GRT), bus/light rapid transit, and metro. The hierarchical additive approach (considering both spatial analysis and the time-based analysis), reports that majority of Masdar City has low accessibility to the regional metro station. Also, the result indicates that more than half of the city will need between 13.1 to 25 minutes, with an average of 15 minutes, to reach the metro station. In all, the city has medium accessibility to the metro station with opportunities to enhance the overall accessibility. Elimination of transit stops that are redundant can reduce the headway and stalling time and hence the total travel time. Also, by locating new transit stops (bus, PRT or LRT) in grids where access to closest public transit is more than 400 m by walking can help balance the capital cost of infrastructure (public transit) while improving the accessibility to the regional metro for its residents. The follow-up analysis reported that the medium accessibility increased from 20% to 24%. Evaluation of accessibility in planned areas (city or neighbourhood) can provide insights on efficiency of a sustainable city such as Masdar City.
Keywords: sustainable city, Masdar City, accessibility, United Arab Emirates, transportation network.

1 INTRODUCTION

Major cities around the world are facing unprecedented challenges that might change its demographic, environmental, economic and social aspects owing to an exponential increase in urban population [1]. It is projected that in the next 15 years the world population would continue to grow by more than one billion a year to about 8.5 billion in 2030; 9.7 billion in 2050; and about 11.2 billion by 2100 [2]. Most of this growth is projected to happen in urban areas and its periphery, which has followed the trend of sprawling over the last six decades.

Urban sprawl, term use to describe the complex undesired urban expansion pattern, is a phenomenon that is a result of the rapid population growth (both total and urban). These expansion areas are poorly designed neighbourhood forcing its dwellers to use cars for most of their trips – including the short trip to the grocery – that result in higher automobile dependency [3]. Urban designer, planners and architects have proposed several strategies and approaches to combat this ad hoc developmental approach around the world.

Planning paradigm such as smart growth, new urbanism and transit-oriented development are some approaches proposed to design and develop sustainable cities. These approach encourages diversity in land-use, compact development, diversity in housing type, walkable neighbourhoods, create a sense of community, preserve open space, farmland, and critical habitat, infill development and offer a variety of transportation modes [4].

Cities have been assessed for its shortcomings and success on adapting these approaches at various scales from regional, local to neighbourhood level and for its implication on land-

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use planning, transportation services, climate change, social capital, and health outcomes [5]–[7]. However, little research exists that analyse a city planned to be developed for its implications on these outcomes. Such investigations can provide insights to recommend changes that can enhance the social, environmental and economic liveability of future habitats of cities around the world.

Masdar City, in the Abu Dhabi Emirate of the United Arab Emirates is proposed as a carbon neutral city and has been identified as an epitome of sustainable city. The city, designed by renowned architect and planner Norman Foster, planned it to be a sustainable development benchmark and a green-print for how cities can manage the rapid urbanization and reduce the consumption of energy, water, and waste impact on the environment with the renewal source of energy [8]–[10]. This city, as planned, boasts of mixed-use development which will include residential, retail, educational, recreational, light industrial, and office areas, which will provide a place to live–work–play for its residents. Moreover, the city is designed to offer a friendly pedestrians and cycling environment with an integrated smart transportation network that makes the city more accessible and liveable. This integrated smart transportation network hopes to provide efficient accessibility for its users across various destinations within the city [11]. However, while high accessibility can be presumed for a new development such as Masdar City, its assessment can provide insights into the efficiency of this integration of transportation network.

This study therefore uses measure of accessibility using the transportation components to evaluate the percentage of area most to least accessible through various modes of travel proposed for the city. Furthermore, we discuss implication and recommendation to enhance the accessibility of the city. Implications target the reduction in lifecycle cost of transportation infrastructure that can reduce fiscal impact of planned and unplanned cities in future.

2 MEASURES OF ACCESSIBILITY

Scholars define accessibility as “the potential of opportunities for interaction” [12]. It is further defined as the ability and opportunities of reaching desired products, services, activities or destinations [13]. Unlike mobility that focuses on movement, accessibility focuses on making products and goods closer to the consumers, such as improving the accessibility to schools and retail stores by locating them in the middle of a neighbourhood and accommodate the needs of people by reducing the travel distance and time [13].

Therefore, accessibility measures help to predict the impacts of any transportation investment and evaluate their effectiveness on the dweller’s daily behaviour. It provides insights to planners and decision makers to assess the distribution of activities, land use and transportation facilities and services [14], [15].

While several measures of accessibility have been proposed [16], Yigitcanlar et al. [17] developed a GIS-based land use and public transport accessibility indexing model (LUPTAI). LUPTAI is a comprehensive – origin-based accessibility-indexing model that targets to measure the ease of accessing common land use destinations such as residential, commercial, health and retail either by walking or using public transit. It is one of the first models that consider public transit as the methods of access, not a service to be accessed. It relies on information about land-use destinations, road network, pedestrian routes and public transit network. The main aim of this model is to assist in evaluating the accessibility to specific destinations within the city planning and the decision-making phases.

3 METHODS

The accessibility measure developed by Yigitcanlar et al. [17] and modified by Albacete et al. [12] was identified as the most appropriate method to assess accessibility with Masdar City for two reasons. Firstly, Masdar City, as planned, is yet to be developed to the extent to which we could assess the temporal and individual components of accessibility [16]. Without any residents, it would be impossible to assess these components. Secondly, the development as proposed will occur in phases while the transportation network remains as planned irrespective of any change in land-use. Hence the accessibility measure using the location-based approach was applicable for a city at its infancy of development.

Table 1 indicates the range and approach of reporting the level of accessibility for each grid. Using the same standards and measures of distance and time, access to the only metro station within the city that connects to the mainland Abu Dhabi (major source of employment and hence possible destination for intercity travellers) was evaluated and mapped in GIS. The procedure for the same is described in the following section.

Table 1: Walking, public transit, and land use accessibility measure scores. *(Source: Adapted from [12], [17].)*

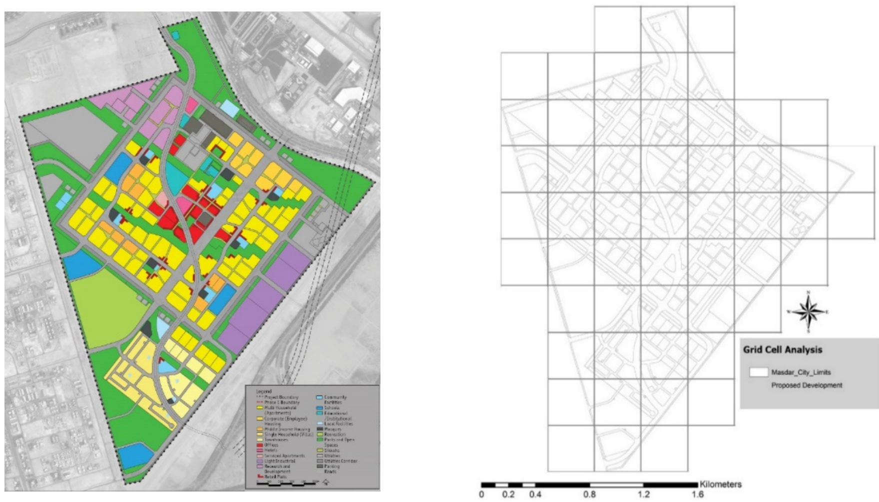
Layer	**High 4**	**Medium 3**	**Low 2**	**Poor 1**	**Very poor 0**
Walking to transit (in meters)	0–300	301–400	401–800	801–1200	> 1201
Total time to public transit (in minutes)	0–6	6.1–13	13.1–25	25.1–38	>38.1

3.1 Grid cells assessment

A grid of 400 m × 400 m was spatially laid over the city area in GIS as unit of accessibility measure (Fig. 1). According to the transit-oriented development (TOD) guidelines, the common standards, a 5-minute walk (equivalent to 400 m) is an acceptable walking distance/ time to access public transit with a walking speed of 5 km/h or about 80 m/min [18]. Also given the hot arid temperature in UAE, several studies use this measure as acceptable walking distance for their analysis [19], [20]. Each of these cells will be assigned an accessibility score (Table 1) based on its ease of access to public transit, and various land uses in the city [12], [17], [21]. The scores ranged from 0 (being very poor accessible) to 4 (high accessibility) for each mode of travel. Based on the time to destination (metro stop) from the centre of the grid, each cell or grid was assigned an accessibility score for its respective mode of travel such as automated personal rapid transit (PRT), light rail transit (LRT) and the bus rapid transit (BRT) systems.

3.2 Spatial assessment

The spatial assessment consists of estimating the walking distance to the nearest public transit stations for each cell. This assessment was conducted for all stations and all modes of public transit to be available in Masdar City (PRT, LRT, bus, and metro). The walking distance was measured as a straight-line distance from the centre of each cell to all the closest public transit stops. Hence, the outcome of this spatial assessment was to identify which stop/station of the selected public transit mode is at the closest proximity to each grid cell centre (Fig. 2). Based on walking speed, the time to walk from the grid centre to the closest stop was calculated and categorized by its level of accessibility (by distance measure).



(a) (b)

Figure 1: Masdar City. (a) Master plan; and (b) Grid layout over the city.

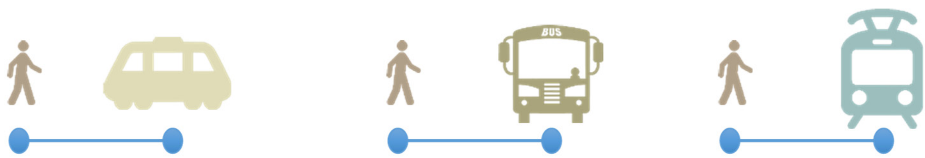
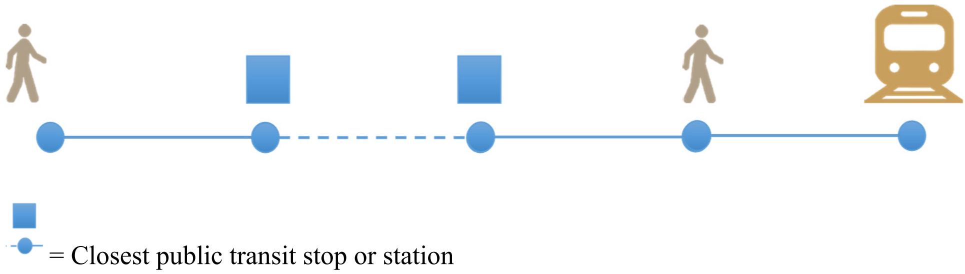


Figure 2: Spatial assessment of accessibility to the closest transit stop: PRT, bus and LRT.

3.3 Public transit assessment: Additive approach

For the public transit analysis, the metro station in the city was selected as the public transit destination. The accessibility measured was obtained by considering the time taken to walk from the centre of the grid to the closest station or stop of any of the three public transit service, taking that transit to reach the stop closest to the metro station and final access by walk to the metro station (Fig. 3). Total transit travel time was calculated by totalling the spatial assessment (converted from distance to time), the transit travel time which included average headway time, travel time and waiting time, and walking distance from destination to metro stop (converted from distance to time). In some instances, it was observed that a transfer to another mode of transportation reported higher accessibility, in spite of transfer time and waiting time, than continuity on the same network. Based on the total time to metro station, each grid was classified using Table 1 for very poor to high accessibility.

It is apparent that grids closest to the metro station will report highest accessibility in comparison to those farther away. However, this study examines the extent of reduction in accessibility and proposes approaches to enhance the accessibility for the location farther from the metro station.



= Closest public transit stop or station

Figure 3: Additive approach to access metro station.

4 RESULTS AND DISCUSSION

4.1 Accessibility to modes of travel

The spatial assessment to estimate accessibility to each public transit was calculated, categorized, and spatially mapped (Fig. 4(a)–(c)). The PRT system report high accessibility of just 11%, while 60% of the grid cells report poor to very poor accessibility. This is justifiable given that the current network of PRT system serves only the core of the city. Without its expansion (possible at very high cost due to its automation system), the residential development (of villas) in the southern part of the city remain almost inaccessible through the PRT system.

As planned, the LRT route runs from the northwest of Masdar City to the southeast through both the large and small development squares to ensure good connectivity. While this network of LRT system reports high or medium accessibility in one-quarter of the city, the poor to very poor accessibility is around 36% of the city area. The majority of the area reports low accessibility of over 40% of the city. In comparison to the PRT system the residential development of villas in the south report better accessibility to the LRT system.

The bus network serves the majority of city and planned to be the main public transit system serving the inhabitants of the city. This network reports high to medium accessibility in about 60% of the city area. Only 6% of the city area, at the edge of the city with no planned development report poor accessibility. Most developed area, including the residential villas are well served through the bus service system.

4.2 Accessibility to metro station: Additive approach

The additive approach reported 19% of the city area with poor accessibility (Fig. 4(d)). However, upon spatial mapping of the same, all but one grid lay at the edge of the city with no proposed development. With respect to access to the metro station, about half the city reported low accessibility to the metro station and about quarter of the city reported high to medium accessibility with under 15 minutes of travel time to the metro. The recent discussion on the 15-minute city proposes such interconnected transportation and land uses, as it can enhance the liveability of cities by reducing emission and health impacts on its residents [22]. In all, this city reports decent to good accessibility, especially if the poor accessibility cells at the edge of the city with no planned development are eliminated from the overall analysis. This aligns with the vision of Masdar City to be a global example of sustainable city.

The additive approach also provided opportunity to identify stops or stations that were either redundant or unused as part of access to the metro station. Henceforth, to test the impact

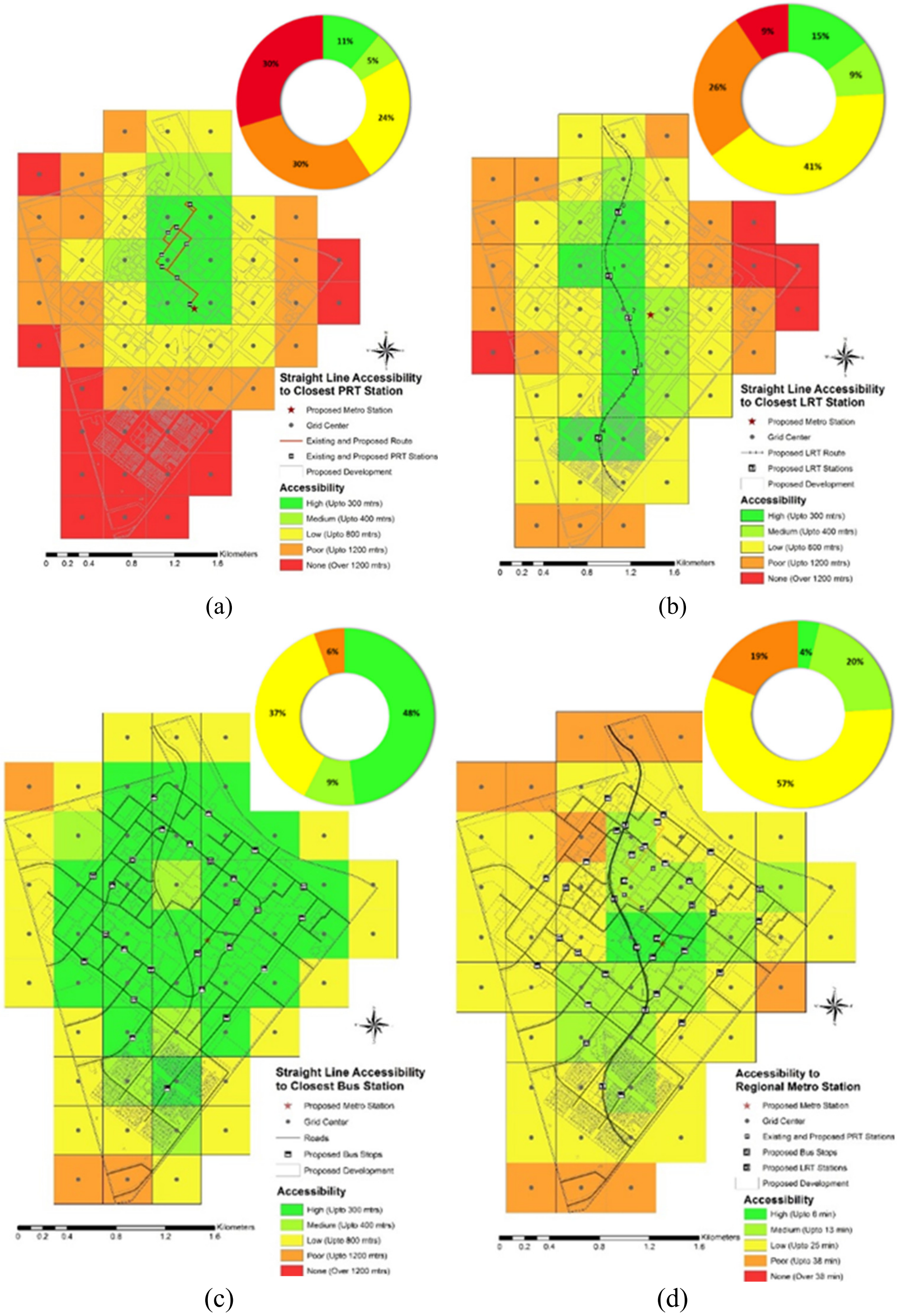
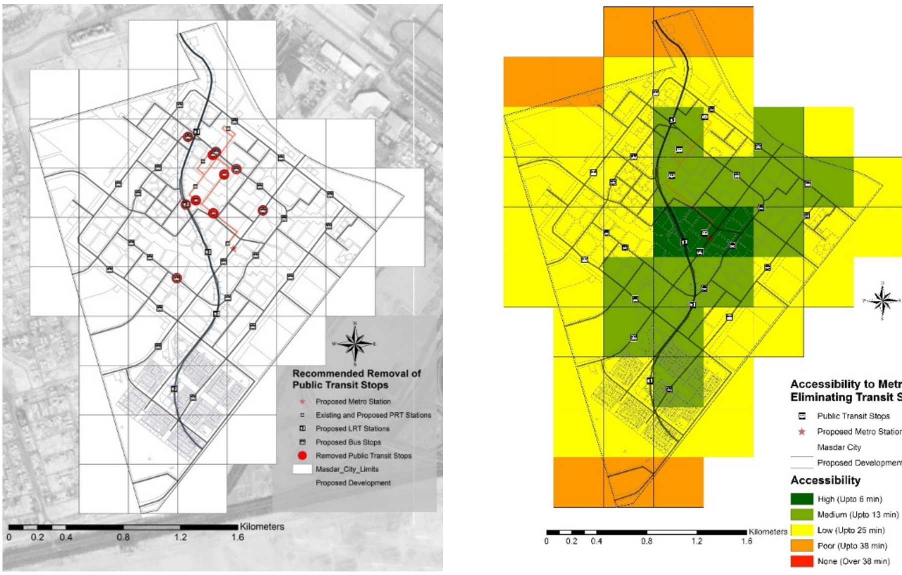


Figure 4: Measure of accessibility to metro station using: (a) PRT; (b) LRT; (c) Bus; and (d) Additive approach.



(a) (b)

Figure 5: (a) Location and type of redundant station or stop; and (b) Accessibility to metro station after removal of identified stops and stations.

of elimination of these stops on overall accessibility to the metro, five bus stops, one LRT station and four PRT stations were eliminated from the additive approach (Fig. 5(a)).

This was done to test if that improved the accessibility and if so, the benefit of elimination of these stops. The outcome reported that 17 grid cells reported improvement in accessibility (Figs 5(b) and 6). While the elimination of the LRT and PRT station did not change the level of accessibility it still reduced the time of travel to the metro station. At least five grid cells reported improvement in levels of accessibility either from poor to low or from low to medium accessibility. The total area of accessibility increase by sheer 2%. While the improvement in accessibility can be considered meagre, the elimination of these stops and station can result in tremendous saving for the city considering the life-cycle cost of development, maintenance, and operation of these transit stops, especially with negatively affecting the current accessibility of the city.

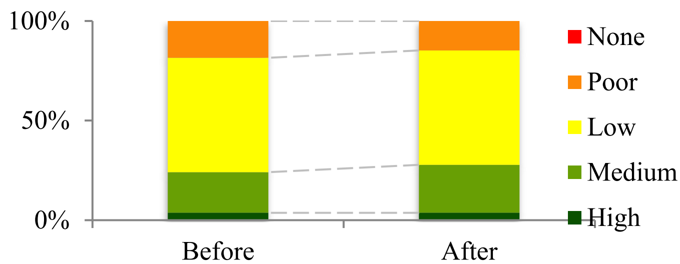


Figure 6: Change in overall accessibility in Masdar City after removal of redundant stops and stations.

5 IMPLICATIONS AND CONCLUSION

This study investigated the accessibility to the metro station using three modes of public transit service in the city. Based on the current master plan of the city, an innovative additive approach was used to assess the accessibility to the only metro station in the city, mimicing the actual behaviour of a potential habitat of Masdar City. Using existing methods of analysing accessibility and integrating those approaches, this study provides recommendations for enhancing the overall accessibility of the city. The results indicate that the city's vision to be a global example of sustainable city, especially with regards to the transportation system for this study, aligns with their objective. Almost no city area has poor or very poor accessibility, while majority of the area is within 25 minutes of travel time to the metro station. It has to be noted that, we used a very conservative approach in assessing the walking speed, as it can be assumed that most inhabitants using metro to reach the city would be workers who would tend to walk at a pace faster than 5 km/h.

As with all studies, this one also has its limitations. First, the use of grid system resulting in about 13 grids of the 54 grids with either less than half or very little of its area within the actual city limit. Future studies could use a grid system in multiple of 200 m to analyse the accessibility spatially. Second, as the city is in the development phase, the master plan presents the type of development proposed (residential or commercial). However, it is not clear if the residential development is multi-storey multi-family development and if so with what density. Finally, with the city in its infancy stage of development does not house enough residential population to evaluate the demand on transit use. Increase in population and possible demand on use of public transit could render use of some public transit service more difficult, leading to higher waiting time or skipping of the closest stop or station to reach another stop to avoid congestion.

Despite these limitations this research makes a valuable contribution by highlighting the use of accessibility measure for a planned city to inform its decision-makers about opportunities to improve future development. The specific implications from this study for infrastructure and planning a sustainable city include:

1. As a planning tool, this study emphasizes the value of assessing accessibility for newly planned communities before its development. Such an analysis can provide recommendations to improve the land uses and transit infrastructure of the new development.
2. Methodologically, this study proposed an additive method to analyse transit accessibility followed by access to various land-use destinations in the city. Although simple in concept, it is clear in sense of its implication for developing an interconnected sustainable city. As pointed out by Handy [23], a simple measure of accessibility is a way to understand the opportunities that the urban environment provides for its residents.
3. The redundant service/infrastructure such as the bus stops and PRT stations that are not easily accessible by walk, if removed can reduce the cost of infrastructure development and also improve the accessibility to various destinations within the city.
4. The land uses within the city are evolving. Hence an approach to improve the land-use mix that is accessible by walk should be considered in future developments of the city. A more comprehensive look of demand–supply side of accessibility [24] can provide implication of both sustainable development and sustainable transportation in cities targeting specific sustainable development goals.

Future research can use network distance analysis to estimate the accessibility to public transit more accurately. This study was limited with the available for such data. Also, future studies can conduct a cost–benefit analysis of eliminating the redundant stops or station for both planned and developed cities to estimate the reduction in fiscal burden for the cash-stricken cities of the world. Moving beyond the current components it is encouraged to reassess cities for its accessibility and to understand the quality of life [25] of its habitats to enhance the liveability of the cities, planned or developed. Finally, to help manage and achieve the trade-off between the quality of transit services and the transit stops accessibility, we recommend using optimization models to optimize public transit quality and system/services accessibility. Such optimization approach can help to re-allocate the stations in cities targeting the sustainable goals to achieve the trade-off and will result in maximizing the ridership coverage and minimizing travel time and cost.

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