MIJST
MIST International Journal of Science and Technology

Measuring Effectiveness of Non-Motorized Vehicles on Spatial Extent for TOD Development: A Case Study for MRT 6 in Dhaka

Md. Anwar Uddin[1*] and Md. Shamsul Hoque[2]

[1]Department of Civil Engineering, Military Institute of Science and Technology (MIST), Dhaka, Bangladesh
[2]Department of Civil Engineering, Bangladesh University of Engineering and Technology (BUET), Dhaka, Bangladesh

emails: *[*1]anwar@ce.mist.ac.bd; and [2]shoque@ce.buet.ac.bd*

ARTICLE INFO

Article History:

Received: 29th May, 2022
Revised: 12th March 2023
Accepted: 12th March 2023
Published: 25th June 2023

Keywords:

Transit-Oriented Development
Trip Chain
Public Transport
Non-Motorized Vehicle
Spatial Extent

ABSTRACT

To improve the effectiveness of conventional walking-based Transit-Oriented Development (TOD), introducing Non-Motorized Vehicles (NMV)-based TOD will be a more efficient alternative since it will increase the spatial extent of the TOD node's buffer area. This paper discusses the available Bicycle-based TOD (BTOD) concept. Based on this concept, the spatial extent of NMV-based TOD (NTOD) has been calculated. A trip-based survey has been conducted on the selected regions of Dhaka along the line of MRT 6 regarding who uses NMV (Rickshaw, Bicycle) and public transport (PT) for his daily commuting. A trip chain analysis was performed first to capture the trip pattern of daily commuters. From the trip chain analysis, it has been found that PT-based trip chains dominated the city's entire trip chain. Consequently, it has also been found that walking-only and walking-NVM accessible trips dominate 32% and 23% of the entire PT trip chains. However, based on the findings of trip chain analysis to calculate the spatial extent by developing regression models, it has been observed that the access trip length for walking ranges from 1.2-1.4 km, whereas the access trip length for NVM ranges from 4-4.7 km. In Dhaka, the catchment area of NTOD can increase the accessibility potentially by spatial extent expansion of about 70% from the conventional TOD. Therefore, it can be inferred that NVM will give more spatial accessibility than walking. As a result, a new window of planning and design strategies will be opened for the planners and policymakers around TOD station area planning considering NMV. Along with strategic recommendations, limitations, and future research agendas have also been discussed in this paper.

1. INTRODUCTION

Transit-oriented development (TOD) is a planning idea that promotes using public transport (PT). It efficiently combines land use and transportation planning (Deng *et al.*, 2022). Calthorpe (1993) describes TOD as a "Pedestrian Pocket," "Compact Neighborhood Development," or even an "Urban Village." According to Bertolini (1999), public transportation is the spine of the transportation system in TOD, with strategically placed transit stations.

However, TOD has some advantages over other urban planning strategies. Such as, the TOD framework reduces motorized journeys, increases the share of non-motorized travel, and decreases travel distances, reducing automobile occupancy levels (Cervero & Kockelman, 1997). Furthermore, it is imperative to mention that decades of auto-dependency have brought adverse upshots such as traffic congestion, noise, poor health, and reduced social life, hindering sustainable development (Cervero, 2002; Cervero & Dai, 2014; Cervero & Day, 2008; Curtis & Scheurer, 2017). So, TOD is contrary to conventional auto-dependent growth. Further studies show that well-planned and designed communities and neighborhoods benefit from making public transit accessible and bicycling and walking more convenient (Samimi *et al.*, 2009). However, the fundamental concept of TOD supports sustainable development (Li & Lai, 2009) by promoting economic, environmental, and social sustainability (Uddin *et al.*, 2023).

Although some advantages are discussed above, conventional TOD has several criticisms. Firstly, reduced haphazard urban sprawl and enhanced density are required to foster transit ridership in TOD. However, such interferences will subdue the station's surroundings' quality of life and integrity (Lin & Gau, 2006). Secondly, adequate density must be promoted for TOD growth in the core of the cities. Therefore any stratified and medium-density or hybrid construction inducing density becomes challenging to reshape this growth (Nelson & Niles, 1999). Thirdly, according to Uddin *et al.* (2023), density should be the primary indicator for TOD planning in a developing city like Dhaka. However, density is often defined by the number of people who use a transit station. Especially in non-core areas, passenger transit load is considered the most critical factor (Jin *et al.*, 2023). Nevertheless, the dwelling unit is vital in demand for transit use to supply PT in that region. According to Calthorpe (1993), at about 2,000 sq. ft per acre, the housing unit has a moderate to high density, proving PT will effectively promote the TOD. However, similar PT service in places with low travel demand yet high dwelling unit exits is impracticable because no relevant areas can be developed (Black, 1996).

Therefore, the conventional TOD's weaknesses should be addressed for sustainable planning and development. So, a new Bicycle-based TOD (BTOD) concept has been introduced, addressing all the criticisms of walking-based TOD. It amalgamates the conventional TOD design and cycling, creating a station-oriented layout and location. There are some advantages of BTOD to conventional TOD. Firstly, The BTOD is competent in hoisting transit ridership. Secondly, the catchment area of BTOD can be 36 times larger than conventional TOD. Therefore, BTOD is reasonably applicable and feasible even for a relatively small population in an over-developed area. Finally, BTOD enjoins spatial and functional reconfiguration of the right-of-way (Lee *et al.*, 2016).

In the TOD framework, active travel is the influencing factor. Active travel typically includes walking and cycling, positively influencing health and environmental prospects. For example, a study by Xiao & Wei (2023) reveals that more retail facilities attract walking-based trips. In contrast, more dwelling units generate bicycle-based trips. Therefore, TOD can use walking and bicycling as principal access modes. Access mode plays a vital role in achieving the principles and goals of TOD. However, TOD will capture more ridership through densified development and high land use mixedness; conversely, it will also degrade the livability of the node areas and exacerbate congestion. Therefore, to balance the standard of living and ridership, access distance should be extended for TOD planning, which may not be achievable only by walking. Moreover, proper access modes improve connectivity between transit nodes and multi-modal hubs, which is one of the critical factors in equitable TOD planning (Chen *et al.*, 2022). Therefore, discovering other access modes and introducing a new concept based on BTOD are the primary contributions of this research.

Therefore, based on BTOD, we want to introduce a new Non-Motorized vehicle based TOD (NTOD) concept in this research. There is a reason to choose this new concept where NMV is the access mode for TOD hubs. (JICA & DTCA, 2015) study reveals that "Walking" is the primary means of transportation for low-income groups, whereas "Car-sharing" is more popular as income increases. "Bicycle" and "Motorcycle" have little overlap in either of the groups. This study also depicts that "Bus" is chosen for long-distance travel while "Walking" and "Rickshaws" are best suited for short-distance travel, which shows us potential access modes to TOD nodes. Moreover, as a sustainable mode of transport, this research focuses on incorporating a rickshaw with the bicycle termed NMV mode in Dhaka city. However, spatial extent measurement is very critical for BTOD planning and implementation. Access to public transportation can be measured by the access distance of the access mode, i.e., bicycle for BTOD. Some studies have been conducted on measuring and fixing bicycle access distance. These studies suggested different methodologies to measure access distance for developed countries. Rastogi & Rao (2003) conducted a study in India, our neighboring country. They measured the access distance of bicycles for PT, and they proposed it between 1.8 km and 4.07 km for Mumbai, India. As access distance between bicycles and PT has been measured by different methods, measuring access distance between NMV and PT in Dhaka should have a proper method.

In this research, we have taken the corridor along Mass Rapid Transit (MRT) line 6 in Dhaka, one of the world's most densely inhabited cities. Almost 17 million people live here, rising to 20 million by 2030 (TYPSA, 2020) and 30 million by 2035 (World Bank, 2019). In Bangladesh, most living amenities and jobs are based in Dhaka, making Dhaka a significant area for human migration. Around 38.7% of the Dhaka population were migrants recently from other country districts (BBS & SID, 2015). Therefore, to make Dhaka a sustainable city, Five MRT lines and two BRT lines have been proposed, and among them, MRT 6 and BRT 7 are in the construction stage (JICA & DTCA, 2015). Moreover, ten MRT/BRT hubs and four multi-modal hubs have also been proposed with high TOD potential (TYPSA, 2020).

In this paper, the resolution of the spatial extent of NTOD will be entwined in some significant acumens. Firstly, based on the bicycle's spatial extent (access distance), a methodology will be developed for measuring the spatial extent of NMV. Secondly, measurement of the access distance of NMV will be performed by developed regression models. Consequently, a comparison with the spatial extent of the walking will be conducted based on measured access distance. Finally, recommended policy guidelines for NTOD node planning will emerge based on the measured spatial extent.

2. METHODOLOGY

A. Study Area

In this research, MRT 6 has been selected as a study area (Figure 1) for developing models of the spatial extent of walking and NMV. MRT 6 has 17 nodes or stations. As the stations of MRT 6 are not operational yet, we have taken the spatial extent of PT as a shadow for the nodal spatial extent of MRT 6. This analysis will explain the spatial extent of the walking and NMV. These ideas will be convenient for node-based accessibility of TOD. Moreover, if we get an idea about accessibility before the operation of transit hubs, more secondary route development with more station access can be implemented parallelly, which will be a helpful tool for policymakers and planners.

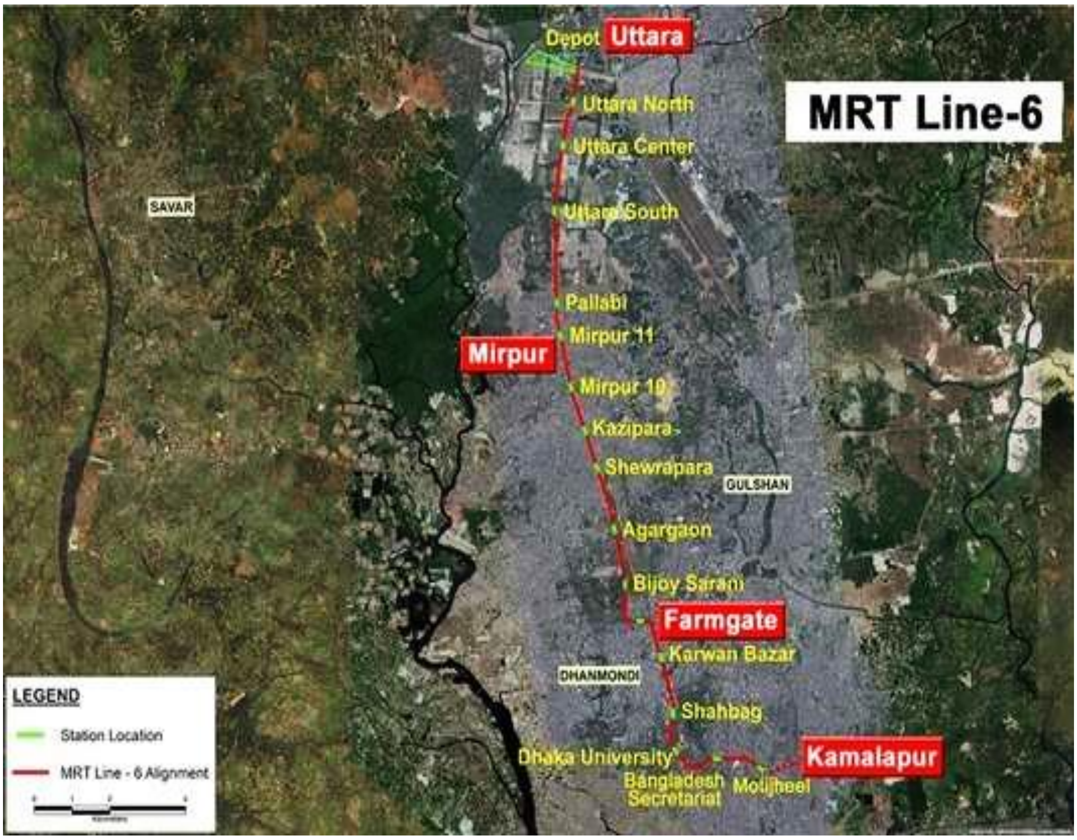


Figure 1: MRT Line 6 with 17 Stations as Study Area (DMTCL Website)

B. Data Collection

The spatial extent of entry and egress trips for PT has been analyzed through questionnaires (500 samples) along the corridor around the 17 nodes of MRT 6, Dhaka. The survey was conducted between March to April 2020. In the survey, both NMV users and non-NMV users were interviewed randomly. Questions frequently asked during the survey included the transfer, current transport routes, and access mode from home, transfer time, entry distance, and exit distance. A detailed questionnaire survey has been depicted in Table 1.

Table 1
The main questions asked during the survey

No.	Questions
1	Regular traveling/ commuting purposes?
2	What is your regular mode of travel?
3	What is your secondary mode of travel?
4	What combination of travel modes do you usually use?
5	What access mode do you use from home?
6	What egress mode do you prefer from the bus station?
7	What is the approximate distance to your public bus station from your home if you use public transport?
8	If you use public transport, what is the approximate distance of the public bus station to ride from your educational institute/ other job-based locations?
9	Willingness to use NMV?
10	What reason for using NMV as an access mode?

C. Analysis Approach

As our primary purpose of this research is to measure the access distance of NMV, the arrival cumulative percent graph (Figure 2) was used in this case. Hino *et al.* (2000) advocated this for the first time to map the accessible PT station area's spatial extent. Here, Ki is defined as the accessibility indicator in cumulative percent (Eq. 1).

$$K_i = \int_0^D A\,X\,dx \qquad (1)$$

Ki denotes the average distance a commuter can reach at the nodes in a specific period. To compute this number, it is necessary to determine the geographical extent of distance or time. However, the current study employed boundary value instead of the average value to the approximate spatial extent or the marginal distance. When determining the overall cumulative percentage of access, the essential element is the percentage of persons who have arrived thus far, not the average arrival. That is why developing a cumulative percent graph is one of the critical factors in this research.

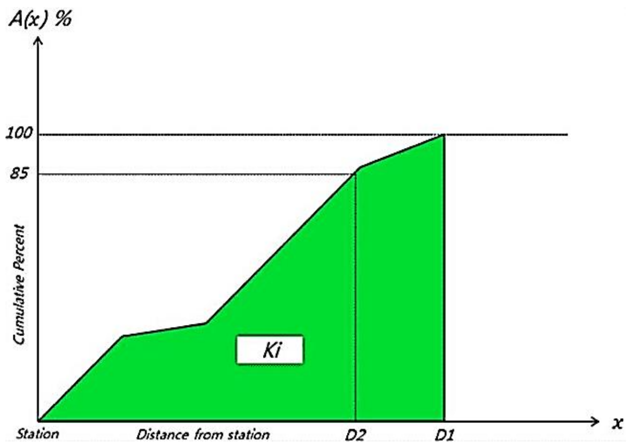


Figure 2: Cumulative Percent Graph vs. Access Distance (Space) (Hino *et al.*, 2000)

In the final part of this research, regression models were developed to determine the access distance where x and y variables were used as access distance and cumulative arrival distribution percent, respectively. As the commuter access to or egress from the stations are part of a different trip chain, a trip chain analysis was also conducted to find support for rationale of choosing NMV over walking as access mode. Moroeover, it is predicated on the idea that passengers can enter or exit a trip chain from either the destination or the point of origin at a PT stop (Lee *et al.*, 2016).

Finally, access distance for walking and NMV was measured using the developed regression model and applying the cumulative trip distribution that meets the 85^{th} percentile of the total. In this case, the dependent variable (y) was fixed as 85%, and the access distance (x) was calculated from the most statistically significant regression model. A comparative study between the conventional TOD and NTOD was conducted with the measured access distance using the geographic information system (GIS) by developing buffer maps. Moreover, we did not confine our study to only the spatial spectrum of TOD. Our research was also conducted on cost-effectiveness, congestion perspective, and land value capture of NTOD to prove that the NTOD would perform better than conventional TOD. Therefore, NTOD can be implemented in Dhaka shortly.

3. RESULTS AND DISCUSSION

A. Trip Chain Analysis

A trip chain analysis has been conducted to evaluate the spatial extent of the modes of walking and NMV (i.e., Bicycle and Rickshaw). From various responses, 25 categories of the trip chain have been identified along the MRT 6 of Dhaka. The trip chain analysis shows that the PT-based trip chain dominates the entire trip chain in the study area. Therefore, the PT-based trip chain has been studied for research purposes. However, on the other hand, the whole trip chain analysis aims to see whether our research purpose is justified. Hence, walking and NMV-accessible PT-based trip chains are the most common and dominant.

Nine categories of all PT-based trips have been depicted in Table 2 below. In addition, it has been discovered that 32% of the entire PT trip chains are dominated by only walking-accessible PT trip chains (Home→Walking→PT→NMV→Destination).

Table 2
PT Based on Trip Chains

Trip Chain Type	PT Based Trip Chain
Type 1	Home→NMV→PT→NMV→Destination
Type 2	Home→NMV→PT→NMV→Walking→Destination
Type 3	Home→NMV→PT→Walking→Destination
Type 4	Home→Walk→NMV→PT→NMV→Destination
Type 5	Home→Walk→NMV→PT→NMV→Walking→Destination
Type 6	Home→Walk→NMV→PT→Walking→Destination
Type 7	Home→Walk→PT→Leguna→Walking→Destination
Type 8	Home→Walk→PT→NMV→Destination
Type 9	Home→Walk→PT→Walking→Destination

As our main study concerns walking and NMV modes for accessibility with PT, there is a need for further individual investigation of these modes. We have observed that 39% of the walking-based PT access trip is contributed by the Home→Walking→PT→Walking→Destination trip chain, in which entry and egress trips are contributed by walking (Figure 3(a)). However, 34% of NMV and PT-based trips are contributed by the Home→Walking→PT→NMV→Destination trip chain (Figure 3(b)).

B. Developing Cumulative Percent Graph

The final purpose of this investigation is to discover the level of access required. This approach, however, is unwieldy since it only averages out the access distances and fails to consider the unequal distribution of these distances. Therefore, for Establishing a regression model, users' distribution and cumulative ratio were calculated for variable x (spatial extent) and evaluated using the findings y (cumulative percent of frequency). In the initial phase, the 'y-value' is quite sensitive; however, the access distance level is limited at the end, so the 'y-value' becomes less critical. Therefore, cumulative percentages for entry and egress walking and NMV-based trips have been developed. Based on that graph, the regression model has been developed to get the spatial extent of both access modes. Here, PT is considered a shadow access point. Figure 4 shows the cumulative percentage of walking and NMV-based entry and egress trips.

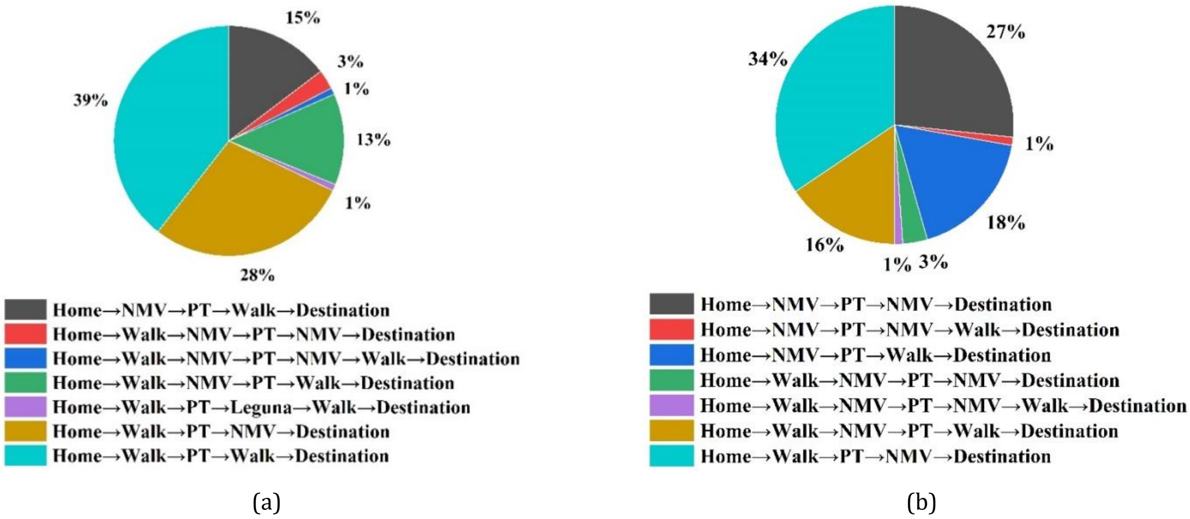


Figure 3: Percent of PT Based Trip Chains for (a) Walking and (b) NMV

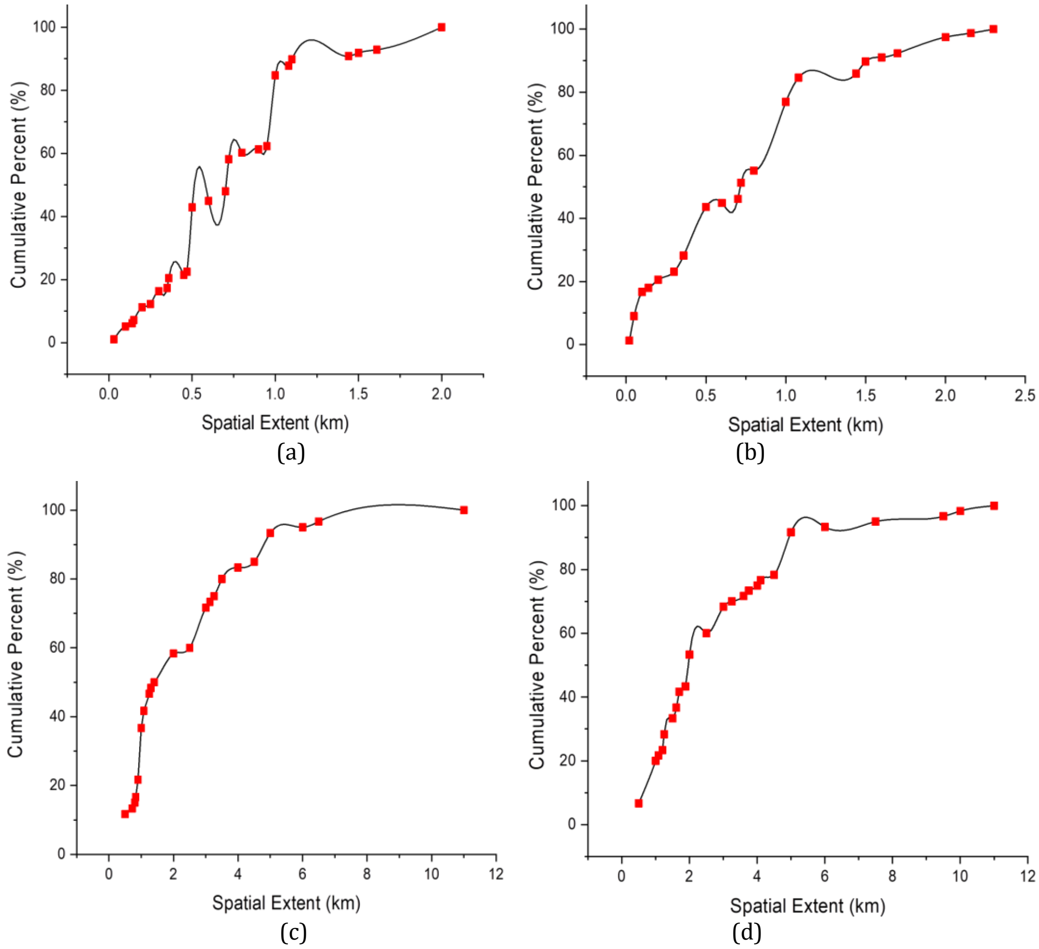


Figure 4: Cumulative Percent vs. Spatial Extent Curve for (a) Walking Based PT Entry Trip, (b) Walking Based PT Egress Trip, (c) NMV Based PT Entry Trip, and (d) NMV Based PT Egress Trip

C. Developing Regression Model

A cumulative trip distribution was utilized at least 85th percentile of the total to determine the access distances to the station. In other words, the value of y (cumulative percent) was set to 85 percent, and the value of x (spatial extent) was generated. Five regression models have been developed: Linear, Quadratic, Cubic, Logarithmic, and S-curve. All models are statistically significant. These five types of regression models have been seen in Figure 5, where four types of PT trips have been classified.

The cubic model is the best regression model for PT-based entry and egress trip spatial extent (Table 3). For example, the R^2 value for a walking-based PT entry trip is 0.968, the best among all other models of this type of trip. However, these values for walking-based egress, NMV-based entry, and egress trips are 0.985, 0.962, and 0.991, respectively.

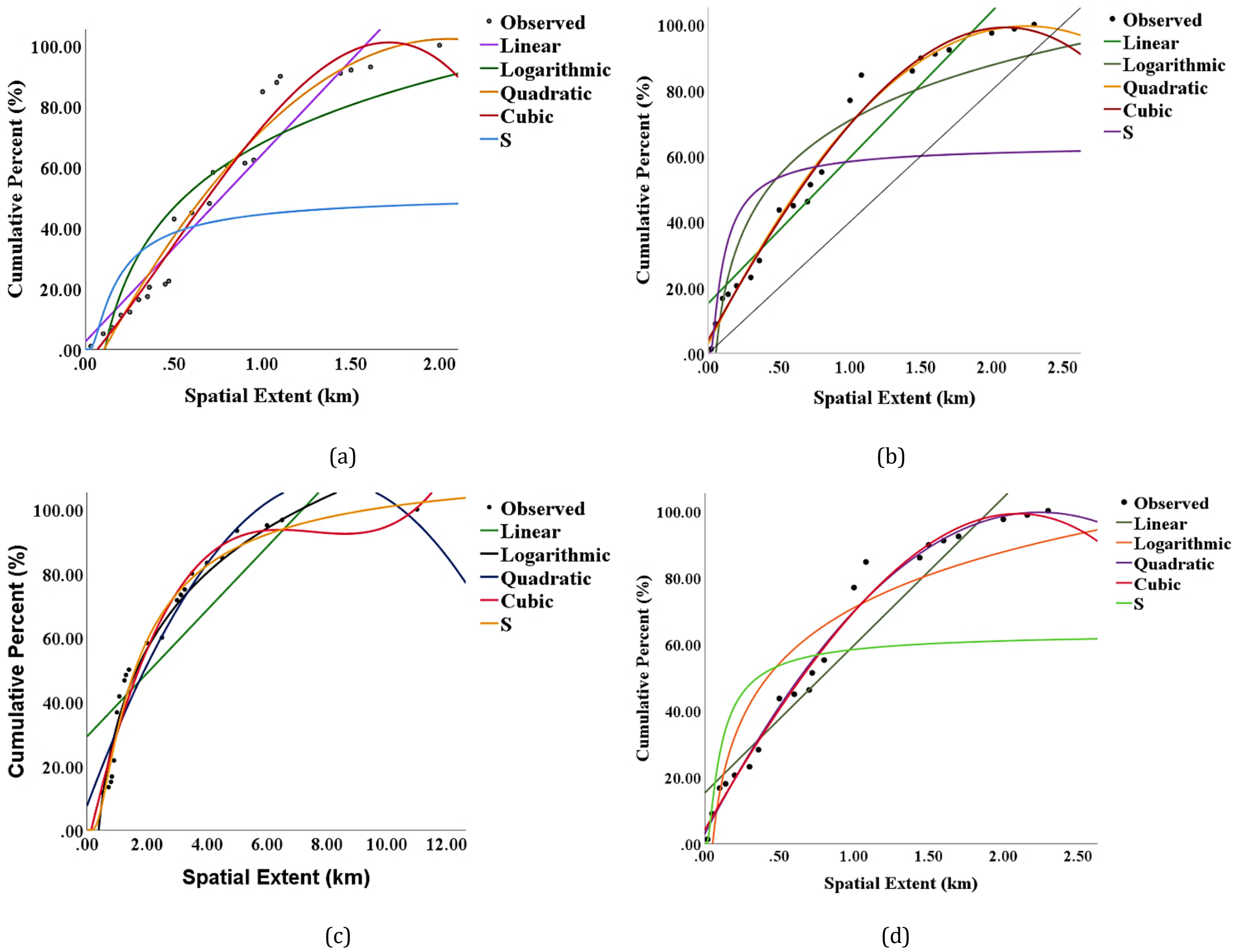


Figure 5: Cum. Percent vs. Spatial Extent of (a) Walking Based PT Entry Trip, (b) Walking Based PT Egress Trip, (c) NMV Based PT Entry Trip, and (d) NMV Based PT Egress Trip

Table 3

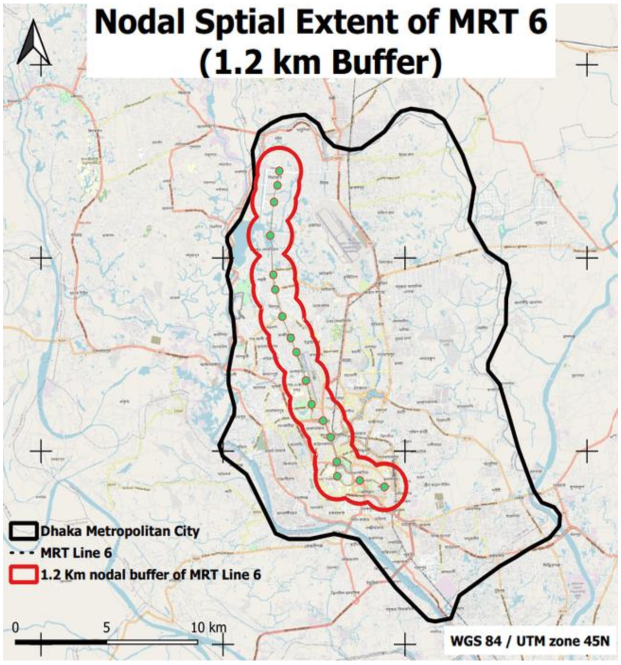
Regression Models of Spatial Extent of Different Walking and NMV Based PT Trips

Regression Model	R2	F	Sig	Type of Regression Model	Type of Trip
$y = -18.322x^3 + 26.830x^2 + 69.52x - 4.785$	0.968	212.077	0.000	Cubic Model	Walking Based PT Entry Trip
$y = -2.855x^3 - 9.610x^2 + 78.032x + 4.069$	0.985	363.212	0.000	Cubic Model	Walking Based PT Egress Trip
$y = 0.249x^3 - 5.602x^2 + 41.209x - 5.818$	0.962	152.201	0.000	Cubic Model	NMV Based PT Entry Trip
$y = 0.175x^3 - 4.390x^2 + 37.332x - 11.986$	0.991	751.433	0.000	Cubic Model	NMV Based PT Egress Trip

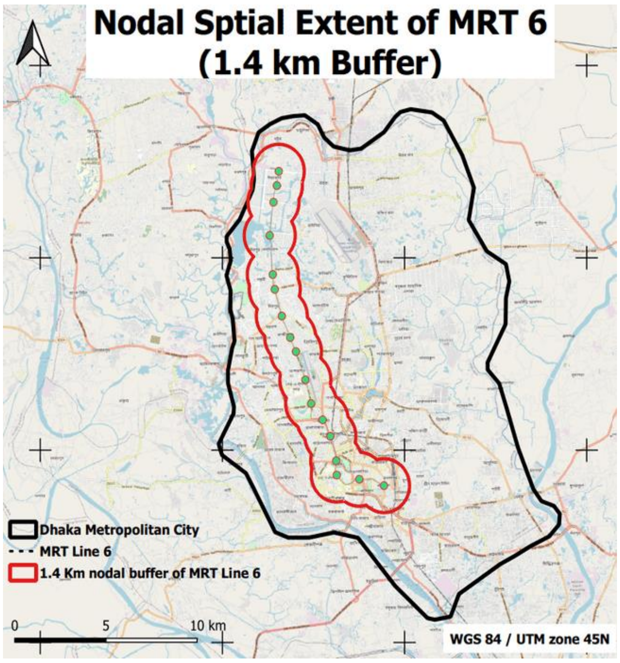
Moreover, we have two equations of the spatial extent of walking as secondary access mode from regression model analysis. First, the spatial extent for walking-based entry and egress trips is 1.2 km and 1.4 km. Similarly, for NMV-based entry and egress trips, it is 4 km and 4.7 km.

From the spatial extent measurement by developing regression models, we have found that the access trip length for walking ranges from 1.2-1.4 km, whereas the access trip length for NMV ranges from 4-4.7 km. So, it has been found from the research that NTOD can increase the accessibility potentially by spatial extent expansion of about 70% for MRT 6 in Dhaka.

Figure 6 shows a spatial comparison of nodal buffer based on the access distance of the walking and NTOD. The spatial extent of walking covers 15% to 18% of Dhaka, whereas the spatial extent of NMV covers 51% to 58% of Dhaka. So, from this analysis, it can be inferred that NMV-based accessible modes will give more spatial accessibility than conventional walking-based accessible modes.



(a)



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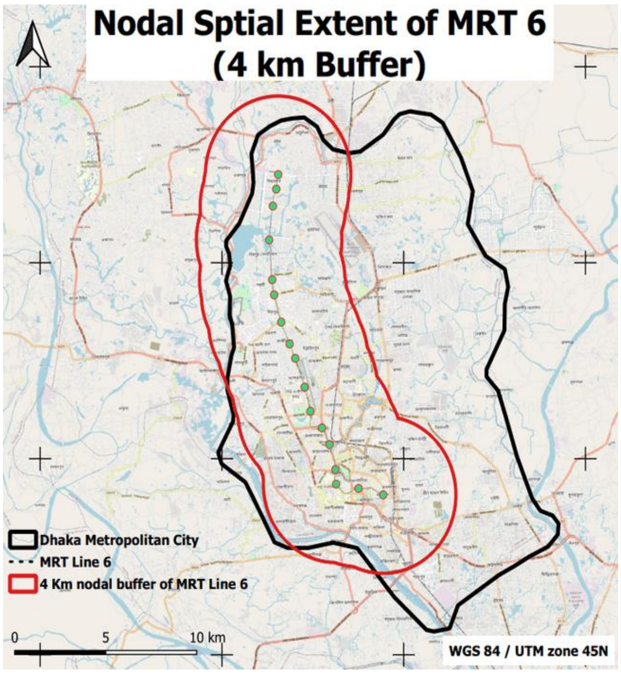
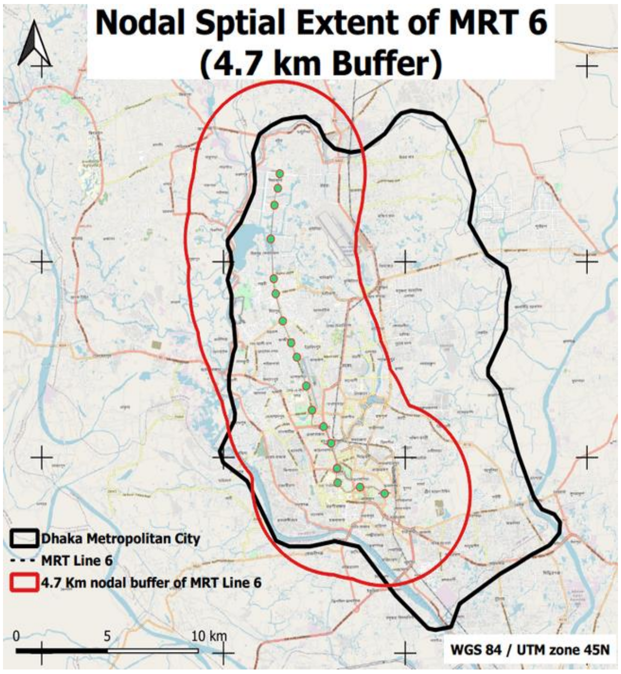


(a)



(b)

Figure 6: Comparative Visual Representation of Nodal Spatial Extent of MRT 6 for (a) 1.2 km buffer, (b) 1.4 km buffer, (c) 4 km buffer, and (d) 4.7 km buffer

The significant findings of this research are that the estimated access distance from home to station and station to work is 1.2 km and 1.4 km, respectively, for walking. On the other hand, the access distance for NMV from home to station and station to work is 4 km and 4.7 km, respectively. A study by Lee *et al.* (2016) found that a bicycle's access distance for Daejeon city in Korea was 1.96 km to 2.13 km. This is almost the access distance of NMV in Dhaka. That means an NMV covers more spatial distance in Dhaka than in other cities.

Moreover, Daejeon is a mono-centric city, and Dhaka is a polycentric city. For a polycentric city, travel distance is typically higher (Su *et al.*, 2021) than in a monocentric city. So spatial coverage goes higher. As Lee *et al.* (2016) found, there is a massive potential for BTOD in Daejeon. Therefore, NTOD will be more effective for Dhaka. Moreover, for Dajeong city, the catchment area was 12.06 km^2 which was 11 times higher than the conventional TOD of Daejeon city. Whereas for Dhaka, the catchment area for NTOD covers 50.27 km^2 to 69.4 km^2, which was more than 11 times higher than the conventional TOD of Dhaka.

Moreover, considering the hypothesis that NTOD will be enhanced by choosing NMV as the access mode, a stated preference survey (Table 1) was also conducted to determine people's perception of moving to NMV from other modes, which has been depicted in figure 6. As a result, it has been found that 30% of people will mode NMV, whereas walking and car cover only 15% and 12%, respectively.

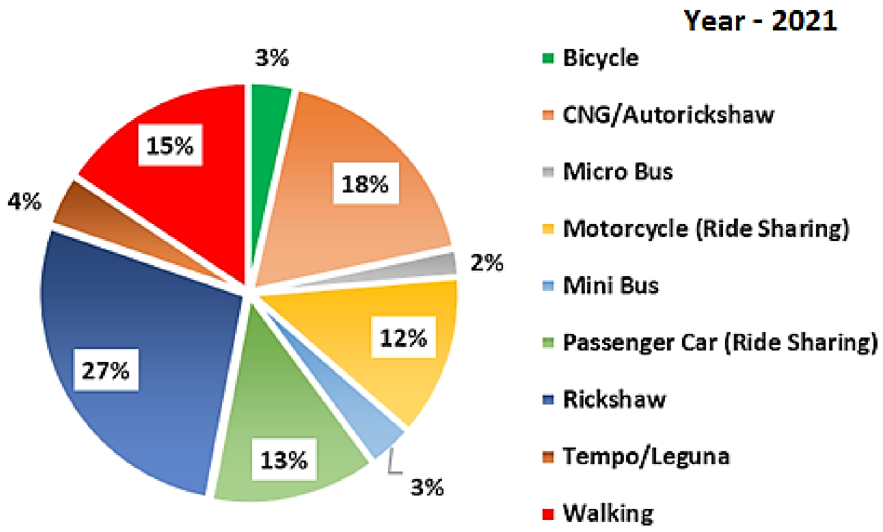


Figure 7: Willingness to Use NMV (Bicycle and Rickshaw) as Access Mode in NTOD Environment

D. *Justification of NTOD for Implementation in Dhaka*

After developing the regression model and determining the spatial extent of NTOD, we have a picture of its benefits in the spatial aspect. First, however, we should justify the three key aspects that arise: the built-up area with high population density, the cost-effectiveness of the NTOD idea, and additional traffic jam due to NMV.

Firstly, Dhaka has a high population density with a shortage of new land acquisition. As a result, the land price is rising. However, for implementing NTOD, no new land acquisition is necessary. That is the beauty of this concept. In this case, land readjustment is the most cost-effective and suitable option inherent in NTOD. Additionally, acute phase development plans have already been applied in Taipei in Taiwan to capture land value adequately with four development aspects (Yen *et al.*, 2023). First, this could address the underdeveloped structures with reasonable accessibility. Land readjustment is also essential for rebuilding. Moreover, additional land parcels through land readjustment is an excellent way to determine and influence the urban form (JICA & DTCA, 2015).

Secondly, from the perspective of cost-effectiveness, as no new land development and land acquisition are not necessary, no extra cost will be added for implementing NTOD. Moreover, every conventional TOD requires station parking provision for motorized vehicles. In this case, the access mode will be used as NMV. Typically, in Dhaka, no dedicated rickshaw or bicycle stand is available. Nevertheless, a dedicated bicycle lane will be provided when any transport facility is proposed in the new DAP. So, in this case, additional cost for a bicycle should not be a problem as it will be inherent in any transport facility design. Moreover, NTOD requires spatial and functional reassignment and improvements regarding right-of-way with bicycle usage. Therefore, development is relatively more straightforward and involves fewer investment costs (Lee *et al.*, 2016). In addition, NTOD is more eco-friendly, meaning less fuel consumption, reducing fuel costs. Moreover, its accessibility by NMV (Samimi *et al.*, 2009) has more affordability and congestion reduction (Timpabi *et al.*, 2021). Therefore, the cost due to congestion will be reduced. So, NTOD can be inferred as a more cost-effective planning strategy than any other transport plan in Dhaka (Uddin *et al.*, 2023).

Finally, the rickshaw is already in significant para transit in our transport system. We cannot ignore it. So, we can harness the potential of the rickshaw properly, making an access mode for NTOD. Rickshaw is the eco-friendly mode, and TOD supports this access mode like a bicycle. Dedicated rickshaw lanes and parking stands can manage additional traffic jams generated by rickshaws (Uddin *et al.*, 2019). Moreover, TOD prioritizes less travel distance by automobiles and vehicle occupancy. As the rickshaw covers less travel distance than the car, only proper traffic management near TOD nodes will ease traffic congestion. Additionally, the rickshaw will provide door-to-door service from transit nodes which will work as an additional feeder service (Dey *et al.*, 2018). So, this has more benefits than the odds.

4. CONCLUSIONS

This paper has introduced a new concept for TOD in Dhaka based on the BTOD. Though walking-based trip chains primarily dominate for MRT 6, the contribution of NMV-based trip chains also shows considerable potential. For that, we can go to the new concept of NTOD for Dhaka. However, from the developed regression models for access trips, the cubic model is the most appropriate for determining the spatial extent of TOD. In Dhaka, the catchment area of NTOD can increase the accessibility potentially by spatial extent expansion of about 70% from the conventional TOD. So, it can be inferred that NVM will give more spatial accessibility than walking. As a result, a new window of planning and design strategies will be opened for the planners and policymakers around TOD station area planning considering NMV. Therefore, planners and policymakers should consider these pictures about area planning around stations. If NTOD is introduced, alternative strategies should be implemented for the TOD station development and the adjacent area. NTOD is very efficient in this manner. After rigorous analysis, we recommend NTOD as a future development tool for station area-based planning of the proposed MRT lines in Dhaka. NTOD means making more business and residential places, street amenities, and density accessible by bicycle and rickshaw. The station impact area should be re-established with bicycles and rickshaws as the principal access modes in an NTOD environment. The density criteria could be eased than in a TOD situation. Moreover, the new concept optimizes access to transportation centers by adjusting density distribution rather than total density. Planners and policymakers must consider parking provisions for bicycles and rickshaws to promote NTOD while planning station-wise.

Finally, this research is substantial in that it defined the idea of NTOD and recommended a spatial extension of NTOD for MRT 6 by integrating NMV and public transportation in Dhaka. Future results from a more comprehensive study could be utilized to scientifically quantify the NTOD extent in a particular city to ensure the correct implementation of the NMV facility. For instance, the expansion of cities, the forms of transit, and the sophistication of the network are all significant factors influencing the NTOD spatial extent. For this reason, prospective surveys ought to encompass the qualities mentioned earlier in acquiring a more comprehensive evaluation of the spatial extent.

ACKNOWLEDGEMENTS

The authors would like to express their gratitude to the Department of Civil Engineering, Military Institute of Science and Technology (MIST), Dhaka, Bangladesh; and the Department of Civil Engineering, Bangladesh University of Engineering and Technology (BUET), Dhaka, Bangladesh. They also would like to thank the anonymous reviewers and editors of MIJST for their insightful suggestions to improve the content of the article.

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