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Post-COVID-19 performance evaluation of urban metro transit system in Delhi and influence on access mode

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ABSTRACT

The impact of the COVID-19 pandemic has been observed to affect the travel patterns, routes and traffic in public transportation systems across the world. It is important to evaluate the performance of the Delhi Metro (DM) post-COVID-19 pandemic for its successful operation. In this study, the BLUE line of DM with the longest route and highest number of metro stations has been examined for performance evaluation. The performance is evaluated based on travel time components (access, egress, transfer, waiting and main haul time) to calculate various performance indicators i.e., Level of Service (LOS), Service Time Ratio (STR), Passengers Waiting Index (PWI), Total Travel Ratio (TTR) and Interconnectivity Ratio (IR). The post-COVID-19 LOS evaluation indicates that the users are spending 72.6 % to 84.4 % of their main haul time on their access-egress trips. The STR shows that the users are spending 10.9 % to 12.6 % of their total travel time in waiting and transferring only during the main haul trip. The mean PWI, RI and TTR are noted as 1.008, 0.794 and 2.069 respectively. The IR is observed to improve the UMTS performance.

1. Introduction

The public transport (PT) system is widely considered an essential means of transport, especially for captive riders in urban and connected satellite suburban areas. The performance evaluation of the PT system is a momentous and dynamic process for operators. It facilitates verifying the efficiency and effectiveness of the PT system as well as identifying the scope of further performance improvement, to ensure the satisfaction of users. One of the perspectives of the periodic evaluation is to measure and compare the PT performance with acceptable operational standards (Sheth et al., 2007). The multimodal last-mile connectivity to reach destinations and number of destinations served. The second component is related to service quality, such as out-vehicle travel time (OVTT), in-vehicle travel time (IVTT), waiting time, total travel time (TTT), number of transfers needed to reach destinations and number of destinations served. The second component is a function of the extent of the network and coverage of the different routes of the transit system (Lam, 1982). The Delhi metro (DM), since its commissioning in December 2002, has expanded its network routes and length significantly. The ridership witnessed an increasing trend till 2017–2018 before metro fare revision. Post the hike in fares, the pattern of growth in DM ridership has been observed to increase in fare prices.
become diminished in reference to route/network. The DM further witnessed a significant drop in ridership post-COVID-19 era. The DM has internally conducted a few performance evaluations pre-COVID-19 period, however, similar performance evaluations have not been conducted post-COVID-19. The aim and scope of the present study is the post COVID-19 performance evaluation of DM and its influence on access mode.

2. Literature review

Transport is a critical element of the urban system and PT is required to be effective means for providing better, advanced, efficient and effective mass transit services. It has been noted that the efficiency of any PT system shall depend on the availability and accessibility of access-egress modes, pedestrian flow at transfer location, route network, frequency of services etc. (Kumar et al., 2009). Further, easy and accessible connectivity to PT is important for efficient public transit, defined as the coordination of the transit routes, catchment area, operational capacity, frequency, scheduling etc. (Misra et al., 2012). In addition to this, it has also been observed that performance evaluation is dependent on the speed, delay, and reliability of the multimodal system. The findings also reveal that transportation system performance measurement continues to be modally oriented (Sinclair and Schaefer, 2019).

In another study it is noted that access and egress characteristics and other demographic factors influence the likelihood of using the PT system and should the users face unreasonable access and egress trip time, the PT trip may be ruled out as an alternative to unimodal transport (Li, 2015). It is observed that the ratio of OVTT/IVTT is noted to influence the notion and PT mode choice. The following operational performance indicators of metro are defined as the coordination of the transit routes, catchment area, operational capacity, frequency, scheduling etc. (Turcotte, 2006). Hence, it can be inferred that with the increase in TTT the suitability of PT mode decreases.

The factors studied by other researchers to evaluate the efficiency of bus transit system include total riders, number of buses, seat kilometres, operating costs, route length, fare, stops per km, population density, total travel time and other such factors (Giner and Coskun, 2019, Tran et al., 2016, Hahn et al., 2011). The factors examined in another study on a smaller stretch of red and yellow line of DM including performance measures such as travel time ratio, level of service, interconnectivity ratio, passenger waiting index etc. are evaluated (Kumar et al., 2013). Another research reveals the influence of TTT on performance and efficiency of PT choice (Turcotte, 2006). A few macro level researches in pre-COVID-19 era have been conducted to evaluate the performance of DM. However, micro-level study on performance evaluation of DM has not been conducted post-COVID-19 and as such has further potential scope of research.

Therefore, based on the above-mentioned scope of the research, this micro-level study considering socio-economic and demographic conditions of the catchment area of BLUE line being longest line with 65.35 Kms route and connected through 56 stations is conducted. The aim of the present study is to evaluate the performance of DM and access mode choice based on several performance indicators post COVID-19 travel restrictions. In continuation, the objectives of the study are to evaluate various performance indicators including Level of Service (LOS), Service Time Ratio (STR), Passenger Waiting Index (PWI), Running Index (RI), Travel Time Ratio (TTR) & Interconnectivity Ratio (IR), and to identify the influence of level of service (LOS), running index (RI), passenger waiting index (PWI), Access-Egress trip fare and metro fare associated with BLUE line on access mode choice.

2.1. Public transportation in Delhi

The increasing population in Delhi has exerted pressure on the PT systems due to which they have not been able to meet these expected demands. It has been revealed through various studies that the PT share is not growing corresponding to the travel demand due to surge in the share of private vehicle. The share of public transport in Delhi was 42 % in 2002 (Tiwari, 2003), which further decreased to 29 % in 2008 (RIDES et al., 2010). Passengers have shifted to personalized modes and other intermediate PT due to deteriorated urban bus services (ESD, 2019), (Mohan, 2013). Further, it has been noted that during 2018–2019, on an average 0.15 million private vehicles were added to the congested roads of Delhi (DES, 2019).

The DM’s first section of Red Line (Line 1) between Shahdara and Tees Hazari was commissioned on 25th December 2002. The “Blue Line” (lines 3 & 4) being the longest origin–destination line between Barakhamba road and Dwarka was commissioned in December 2005. With the most recent expansion of Blue line in March 2019, the entire route of 65.35 km of Blue line is served through 56 stations including 5 underground, 51 elevated and 1 at grade (DES, 2020).

It is noted, that the average daily metro ridership per coach has decreased from 2444 in 2009–2010 to 1214 in 2018–2019. Considering a rise of 335 % in operational metro network and 57 % in rolling stock, the average ridership per coach/day has reduced down to 50 % over a period of 10 years. It is a significant drop considering a steady growth of private vehicle by more than 5 % annually (DES, 2019), (DES, 2021).

3. Operational performance indicators of metro

The following operational performance indicators of metro are considered for the performance evaluation in the study.

a) Level of Service (LOS): It is noted that several LOS indicators based on service quality parameters are proposed considering different assumptions and computational methods (Azadpeyma and Kashi, 2019). In a study, the LOS has been taken in temporal context (Fu and Xin, 2007). The authors in their studies based on the user’s perceptions on various travel time components have suggested that “Out Vehicle Travel Time” (OVTT) which includes waiting time, transfer time, and access/egress time, is at least twice as important as “In Vehicle Travel Time” (IVTT) (SHUNK et al., 1970), (Quarmby, 1967). The authors (Swami and Parida, 2015) explored IVTT and OVTT to evaluate LOS of the UMTS. The passengers “waiting time” and “walking time” at the nearest metro stations to evaluate LOS of the metro route was conducted by (Li et al., 2020) and (Li et al., 2021). Further, (Qi et al., 2021) and (Xu et al., 2021) studied station travel time reliability (STTR) and travel time reliability (TTRe) to evaluate LOS based on actual time and standard travel time components along with “Passengers flow”, “Train running interval” and “Station Location”. In view of the research outcomes of the previous studies, the LOS in the present research considering the temporal context i.e. travel time components (Fu and Xin, 2007) is defined as the ratio of (Access + Egress) trip time to main haul time (MHT) and expressed as (Taccess + Tegress)/(Tmain haul). LOS is considered one of the performance indicators for PT systems and is also used to assess demand elasticity. The authors (Swami and Parida, 2015)
report the range of LOS for most of the multimodal trips as 0.5–5. It is observed that larger LOS value signifies the bad performance of PT which makes it less attractive and an alternative.

b) Service Time Ratio (STR): It is defined as the ratio of the penalty time (waiting time + transfer time) to the total travel time (TTT). It is expressed as \( \frac{TW + Ttransfer}{TTT} \). For most of the multimodal trips, the STR value lies between 0 and 0.5 and it is observed that the higher the STR, the PT becomes less attractive. In a study conducted in Gaza, the TTT along with other factors is observed to influence the mode choice of employed people (Almasri and Alraee, 2013).

c) Passenger Waiting Index (PWI): It is defined as the ratio of the mean passenger waiting time to the frequency of the transport service and is expressed as Waiting/Frequency of metro. For metros, the PWI value lies between 0 and 1. Practically, PWI cannot be equal to 0, however, it is desirable to have low PWI, to make the PT more attractive.

4. Methods

In the present research to evaluate the DM performance, information related to travel time components of users including access-egress trips, waiting, transfer & MHT and respective fare components is needed. To gather such data a sizeable and detailed commuter travel data is required. A physical on-board survey through a comprehensive and suitable survey proforma is conducted post-COVID-19 period on weekdays in February-March 2021. The survey proforma is designed to extract the following information.

Travel Information of the passenger: Origin-destination, access-egress mode, access-egress distance & time, waiting time, transfer time, main haul distance (MHD) & MHT, average metro fare per trip, average access-egress trip fare, total transportation cost per day and change in total travel time using DM comparing other PT modes pre and post COVID-19.

The power analysis is aimed to decide the study sample size. Figs. 1 and 2 show that the sample size needed is 26 and 12 respondents for nonlinear regression analysis between LOS-MHD and TTR-MHD respectively. Fig. 3 shows the sample size needed is 80 respondents for multinomial logistic (MNL) regression analysis to identify the influence of operator’s performance indicators on access mode choice. All the variables in the power analysis are tested at a confidence level <1 % (p < 0.01).

A total of 742 random passengers boarding at 34 stations of BLUE line falling in Delhi are interviewed and based on data sorting, the final data of 630 passengers consisting of 364 male and 266 female respondents is used for the analysis. In this survey, the completion rate observed is app. 84.9 %. The data based on the survey proforma is tabulated in a statistically standard format and scrutinized logically.

The results of the power analysis suggest that the sample size of 630 respondents is sufficient and validated for the present research objectives.

The analysis of survey data is performed using various statistical methods including descriptive statistics and cross-tabulation. Subsequently, MNL regression is performed to understand the inter-relationship among various operational performance indicators of the metro on access mode choice and nonlinear regression is also performed to establish the interrelationship among various operational performance indicators. The results of the analysis are presented in the subsequent sections.

5. Results and discussion

5.1. Demographics analysis

The socio-economic and demographic characteristics of the respondents are summarized in Table 1. It is noted that 58 % and 42 % are the proportion of male and female users of DM respectively.

It is seen that over 58 % of users are <30 years of age whereas 37.5 % of users are between the age group of 30–50 years. Further, the data shows that commuters over 50 years are marginal and constitute(s) 4.5 % only. It is also observed that 58 % and 38 % of respondents are undergraduate and post-graduate respectively. Additionally, it is revealed that over 46.5 % of respondents have no personal vehicle and are classified as captive riders whereas 51 % of respondents have at least one personal vehicle and are classified as choice riders.

5.2. Operational performance indicators analysis

Several operators’ parameters based on various time components and as discussed above are calculated. The parameters are calculated for 4 different BLUE line corridors and for entire stretch consisting of 34 stations between Dwarka Sector-21 and Yamuna Bank. The results are presented in Table 2.

Table 2 shows that the operational performance indicators are varying across different corridors of the same line. This gives an idea that each corridor has a different set of user’s behaviour, access-egress idiosyncratic, access-egress modes and socio-economic factors (Kanafani and Wang, 2010). The above results suggest that each of the corridors have a particular set of behaviour, challenges, and micro-level planning is needed to address the issues.

The result shows that LOS value varies from 0.726 to 0.844 wherein...
Barakhamba Road to Yamuna Bank stretch has the lowest LOS and Dwarka Sector-21 to Dwarka Sector-9 stretch has the highest LOS. For 34 stations of BLUE line corridors (36 Km.) the average LOS is noted to be 0.775. It is revealed that commuters are spending 72.6% to 84.4% of their main haul time in their access-egress trips. In a study conducted in the pre-COVID-19 period, LOS calculated for YELLOW line corridors is 0.545 to 0.714 and 0.587 to 0.796 for RED line corridors respectively (Swami and Parida, 2015). The above results suggest that the LOS value
post-COVID-19 has increased which implies an unsatisfactory Blue Line performance indicator thereby making it less attractive as PT. One possible explanation is the reduced DM plying capacity up to 50% of its seating capacity to keep passengers at safe distance from each other. The stoppage/dwell time of trains at stations has been increased to ensure social distancing between travellers while boarding and de-boarding trains (Debjani Chatterjee, 2020). The access, egress and waiting time increases due to limited availability of access-egress modes with reduced frequency conforming to the travel advisory issued by the competent authority regarding DM and other modes (Times Now Digital, 2020). Moreover, post COVID-19, due to the reduced transit work-force, the sharp drop in fare revenue because of reduced ridership and other reasons, DM has reduced their service hours and routes thereby increasing the travel time components.

The result further indicates that STR varies from 0.109 to 0.126 wherein Dwarka Sector-9 to Dwarka stretch has the lowest STR of 0.109 and the highest STR of 0.126 is noted for Barakhamba Road to Yamuna Bank corridor. For all the four corridors of the BLUE line the average STR is noted to be 0.114. It is observed that commuters are spending 10.9 % to 12.6 % of their total travel time in waiting and transfer during main haul trip (metro). In a study, STR calculated for the YELLOW line is 0.191 to 0.244 and 0.239 to 0.269 for the RED line respectively (Swami and Parida, 2015). The above results suggest that STR post-COVID-19 has decreased. One possible explanation is the increase in the stoppage/dwell time of trains at stations to ensure social distancing between travellers while boarding and de-boarding trains (Debjani Chatterjee, 2020). The access, egress and waiting time also increases due to limited availability of access-egress modes with reduced frequency conforming to the travel advisory issued by the competent authority regarding DM and other modes (Times Now Digital, 2020).

It is noted that PWI vacillates from 0.752 to 1.267 wherein Dwarka Sector-9 to Dwarka stretch has the lowest PWI of 0.752 and the highest PWI of 1.267 is noted for Barakhamba Road to Yamuna Bank corridor. For all the four corridors of the BLUE line the average PWI is noted to be 1.008 wherein the commuters are spending 78.3 % to 79.6 % of their total travel time in their trips. It is further noted that the remaining 20.4 % to 21.7 % of TTT is consumed in waiting and transfer time components. In a research, cumulative RI calculated for RED line and YELLOW line (Kashmiri Gate-Saket) is observed to be 0.768 (Swami and Parida, 2015). The above results suggest that PWI post-COVID-19 has increased to a value greater than 1 which is undesirable. One possible explanation is the drop in ridership due to which the DM has reduced the operating frequency of the trains. It is another unsatisfactory performance indicator thereby making it less attractive as PT.

It is observed in the results that RI changes from 0.783 to 0.796 wherein Barakhamba Road to Yamuna Bank stretch has the lowest and Dwarka to Barakhamba Road stretch has the highest RI. For 34 stations of BLUE line corridors the average RI is noted to be 0.794 wherein the users are spending 78.3 % to 79.6 % of their total travel time in their (IVTT and OVTT) trips. It is further noted that the remaining 20.4 % to 21.7 % of TTT is consumed in waiting and transfer time components. In a research, cumulative RI calculated for RED line and YELLOW line (Kashmiri Gate-Saket) is observed to be 0.768 (Swami and Parida, 2015). The above results suggest that RI post-COVID-19 has increased which is undesirable. One possible explanation is the increase in the stoppage/dwell time of trains at stations to ensure social distancing between travellers while boarding and de-boarding trains along with access, egress and waiting time due to limited availability of access-egress modes with reduced frequency.

The results reveal that TTR varies between 2.053 and 2.171 wherein Dwarka to Barakhamba Road stretch has the lowest and Dwarka Sector-21 to Dwarka Sector-9 stretch has the highest TTR. For 34 stations of BLUE line corridors the average TTR is noted to be 2.069 wherein the users are spending 205.3 % to 217.1 % in total travel time taken by DM compared to total travel time taken had the trip covered by personal mode between same origin and destination. In a research, TTR calculated for RED line corridors is 2.087 to 2.552 and 2.085 to 2.501 for YELLOW line corridors respectively (Swami and Parida, 2015). The above results suggest that TTR post-COVID-19 has increased which is undesirable. One possible explanation is the increase in the stoppage/dwell time of trains at stations along with access, egress and waiting time due to limited availability of access-egress modes with reduced frequency.
28.6 % to 31.3 % of total travel time in their access-egress trips. In a study, IR calculated for YELLOW line corridors is 0.269 to 0.322 and 0.273 to 0.324 for RED line corridors respectively (Swami and Parida, 2015). The above results suggest that IR post-COVID-19 has increased which is undesirable. One possible explanation is the increase in the access, egress and waiting time due to limited availability of access-egress modes with reduced frequency.

It is important to note that a significant proportion over 28 % and 43 % of respondents reported an increase in their total travel time by 15–30 min and 0–15 min between same origin-destination using DM post-COVID-19 respectively. Due to an increase in travel time, the choice rider decreases the usage of DM services and instead shifts to the use of private vehicles, cabs and auto-rickshaws. About 36 % of respondents stated that they are likely to change their mode of transport for work trips post COVID-19 from DM to private vehicles (Thakur et al., 2020). The authors of a study reported that the educated and affluent i.e. choice riders with stable income and employment have more reductions in metro ridership and shift to private vehicles post COVID-19 (Qi et al., 2021). These findings confirm the outcomes of the present study.

6. Non-linear regression models analysis

It is hypothesized that multimodal transportation reflects not only unique trip and stage characteristics but also unique users, socio-economic and demographic attributes (Krygsman et al., 2004). The multicollinearity test between TTR-MHD and LOS-MHD is conducted and results suggest (VIF = 1.0) that the dependent and predictive variables in both the models are highly uncorrelated. Kolmogorov-Smirnov tests of normality are conducted to check the sample data distribution. It is seen in Table 3 that the relationship between TTR-MHD and LOS-MHD is non-normal distributed and therefore nonlinear regression analysis is conducted to propose two sets of models to identify post COVID-19 interrelationship between TTR-MHD and LOS-MHD. It is found that the relationship between variables is statistically significant at <1 % confidence level. The first set of models is analysed considering TTR and MHD per trip and the second set of models is analysed considering LOS and MHD per trip. Figs. 4 and 5 show best fit curve estimation between the dependent and independent variables for above mentioned set of models respectively. Tables 4 and 5 show nonlinear regression models between the above-mentioned variables respectively.

From Fig. 4, it is observed that few best fit curves are obtained from non-linear regression. The best fit curves so chosen with identical R-square value follow inverse and power functional forms. It is noted that for less MHD values, the LOS has a significantly higher value which makes PT unattractive. It is also observed that for LOS to be in a range between 1 and 2 the corresponding MHD lies between 3rd and 4th division on X-scale representing (05–12) to (12–21) Kms. It is revealed that the observed mean value of LOS is (0.775 ± 0.575). The mean LOS value obtained through empirical method is found slightly more than 0.871 (Y-scale) which validates the results. According to a study conducted for YELLOW and RED line of DM, the LOS observed is 0.651 and 0.719 respectively (Swami & Parida, 2015). The mean MHD per trip across all access modes is observed to be (19.69 ± 11.19) Km. The curve also reconfirms that the higher the MHD lesser the LOS value and better the PT mode.

From Table 5, it is noted that both the models have identical ‘R-square’ value thereby explaining the variance equally and are statistically significant at <1 % confidence level. In the models the dependent variable is LOS and independent variable is MHD per trip. The observed R-square value noted for both the models is ~ 0.771. It is seen in the model with inverse function the LOS decreases with an increase in MHD, thus making service feasible. It is noted that the relationship between LOS and MHD is vacillating at the macro level across all corridors of the Blue line and is not a function of MHT only which further implies that different travel time components (access, egress, transfer and waiting) of a particular corridor serving a catchment have nonuniform characteristics. The above results reveal that in order to minimize TTR to make DM as a PT alternative, it is important to address each corridor individually based on respective characteristics to improve access-egress, transfer and waiting travel time components. The above models suggest an empirical relationship between TTR and MHD based on which optimized travel time components including (access, waiting, transfer, egress, main haul) of metro travel corresponding to MHD can be proposed and evaluated for improved performance of DM.

From Fig. 5, it is observed that few best fit curves are obtained between LOS and MHD from non-linear regression. The best fit curves so chosen with identical R-square value follow inverse and cubic functional forms. It is observed that for less MHD values, the LOS has a significantly higher value which makes PT unattractive. It is also observed that for LOS to be in a range between 1 and 2 the corresponding MHD lies between 3rd and 4th division on X-scale representing (05–12) to (12–21) Kms. It is revealed that the observed mean value of LOS is (0.775 ± 0.575). The mean LOS value obtained through empirical method is found slightly more than 0.871 (Y-scale) which validates the results. According to a study conducted for YELLOW and RED line of DM, the LOS observed is 0.651 and 0.719 respectively (Swami & Parida, 2015). The mean MHD per trip across all access modes is observed to be (19.69 ± 11.19) Km. The curve also reconfirms that the higher the MHD lesser the LOS value and better the PT mode.

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Table 3
Tests of Normality (Kolmogorov-Smirnov).

| MHD | Dependent Variable (Total Travel Time Ratio) | Statistics | df | Sig. | Dependent Variable (Level of Service) | Statistics | df | Sig. |
|-----|---------------------------------------------|------------|----|-----|---------------------------------------|------------|----|-----|
| 0-2 | 0.266                                       | 4          | 0.00 |     | 0.275                                 | 4          | 0.00 |     |
| 2-5 | 0.237                                       | 33         | 0.00 |     | 0.218                                 | 33         | 0.00 |     |
| 5-12| 0.114                                       | 125        | 0.00 |     | 0.107                                 | 125        | 0.00 |     |
| 12-21| 0.121                                     | 244        | 0.00 |     | 0.103                                 | 244        | 0.00 |     |
| 21-32| 0.094                                     | 156        | 0.002 |     | 0.118                                 | 156        | 0.00 |     |
| 32-58| 0.101                                     | 68         | 0.091 |     | 0.116                                 | 68         | 0.024 |     |
Table 4
Non-linear regression model between TTR and Main Haul Distance.

| S. No. | Function | Constant | Coefficients | Regression Function | R-Square |
|--------|----------|----------|--------------|---------------------|----------|
| 1      | Inverse*** | -0.113** | 8.301*** | \( Y = -0.113 + 8.301 (X)^{-1} \) | 0.778 |
| 2      | Power***  | 7.434*** | -0.967*** | \( Y = 7.434 - 0.967 (X)^{n} \) | 0.776 |

Dependent Variable = \( Y = \) Travel Time Ratio (TTR).
Independent Variable = \( X = \) Main Haul Distance per trip (Km.)
Statistically significance = *** \( P < 0.01 \), ** \( P < 0.05 \).
proposed and evaluated for improved performance of DM.

7. Multinomial logistic regression model analysis

In this section, the result of MNL regression model for access mode choice post-COVID-19 is presented. The predictor variables considered in the regression model include metro fare per trip, total access-egress trip cost per day along with performance indicators LOS, RI and PWI. The dependent variable analysed is access mode choice. The basis of input and output variables so chosen in the model is to establish the relationship between travel cost and travel time factors (in form of performance indicators) on access mode choice. The LOS, RI and PWI are the performance indicators of DM based on the travel time components whereas metro fare per trip and total access-egress trip cost are the factors based on travel cost. The model has been developed considering private vehicle as the reference category. The results are shown in Table 6 and have been discussed further. The variance explained by the model is 57.2%.

In model (Table 6), five categories of access mode (dependent variables) are analysed. The model suggests that metro fare per trip is a highly significant variable for walking and Auto-rickshaw modes with respect to private vehicle. A positive coefficient indicates the likelihood of using that mode for access trip. Since walking has the highest positive coefficient, it is the most preferred mode due to no cost involved in the access trip with the only cost involved being the metro fare. It may also be relevant post-COVID-19 due to health and safety protocols. A negative coefficient indicates less likelihood of using that mode for access trip. Since auto-rickshaw has the highest negative coefficient, it is the least preferred mode due to additional money involved for the access trip along with the metro fare as well as post-COVID-19 safety protocols. It is observed that the preference of access mode considering metro fare per trip is in the order of walking, e-rickshaw, DTC bus, auto-rickshaw and private vehicle which confirm the results otherwise.

The model suggests that total access-egress trip cost per day is a highly significant variable for walking and Auto-rickshaw modes with respect to private vehicle. A higher negative coefficient of walking indicates that the users opting walking mode are more sensitive towards the total access-egress trip cost and prefer walking as access mode. Moreover, any additional cost towards access-egress trip may affect the metro ridership negatively. The users opting auto-rickshaw mode are also sensitive towards total access-egress trip cost and an increase in this cost either due to increase in auto-rickshaw or metro fare will affect their decision in using metro as their primary PT system. In a study conducted, the authors suggested that both travel time reduction and cost reduction will encourage commuters to switch to public transportation (Ganjii et al., 2013).

The model also indicates that LOS is a significant variable for walking and Auto-rickshaw modes with respect to private vehicle. A higher negative coefficient of auto-rickshaw indicates that the users opting auto-rickshaw as access mode are more sensitive towards the OVTT as higher access time will increase the LOS and reduce the efficiency of metro as PT system. Any increase of OVTT i.e., LOS for walking mode and other modes will affect the metro ridership negatively. The users opting auto-rickshaw and walking modes are more sensitive towards LOS and an increase in this factor will affect their decision in using metro as their primary PT system.

The model further points out that RI is a significant variable for walking, e-rickshaw and Auto-rickshaw modes. A positive coefficient of access modes indicates the likelihood of using that mode for access trip. Since Auto-rickshaw has the highest positive coefficient, it is the most preferred mode considering time factors involved. The order of access mode choice considering RI is in the order of Auto-rickshaw, walking, e-rickshaw.

The model consequentially suggests that PWI is a significant variable for walking, e-rickshaw Auto-rickshaw and Feeder bus modes. A positive coefficient of access modes indicates the likelihood of using that mode for access trip. Since Auto-rickshaw has the highest positive coefficient, it is the most preferred mode considering the waiting time and frequency of metro involved. The order of preference mode considering PWI is in the order of Auto-rickshaw, feeder bus, walking and e-rickshaw. The above results suggest the influence of metro fare, total access-egress trip fare and various operators’ performance indicators based on travel time

| Table 6 | Multinomial regression model for access mode. |
|---|---|
| Intercept | Walking Coefficient | E-rickshaw Coefficient | Auto-Rickshaw Coefficient | Feeder Bus Coefficient | DTC Bus Coefficient | Likelihood ratio Tests Significance |
| 1.670** | –16** | –21.903*** | 6.598 | 32.819*** |
| 0.104*** | –0.053 | –0.121*** | 0.085 | 0.089 *** |
| 0.088*** | –0.007 | –0.025** | –0.16 | 0.0 *** |
| 0.121*** | –0.065 | 0.255*** | 22.373*** | –8.86 | –26.724 *** |
| 0.061*** | 0.771 | 0.785*** | 3.19*** | 2.819*** | 1.07 *** |

Model Fitting Information

| Goodness of Fit | Pseudo R-Square Negelkerke |
|---|---|
| Intercept Only | 1699.431 | 1425.707 |
| Chi-Square | 273.724 | 2855.352 |
| df | 30 | 3105 |
| Significance | 0.000 | 1.0 |

Table 6: Multinomial regression model for access mode.
components on the access mode choice. The results further establish that cost of access-egress trip have a negative impact on mode choice. The higher the cost of access-egress trip the more is the chance to switch from motorized to walking mode. The above results are in conformity of the findings of a study conducted (Ganji et al., 2013). The above results reveal that travel cost and time components influence the access mode choice. These MNL regression results suggest a way forward to the DM to facilitate a dedicated pedestrian walkway for commuters preferring walking as access mode along with a dedicated and synchronize e-rickshaw and auto-rickshaw motorway together with economical single fare system to make access and main haul trip attractive and viable both in terms of time and cost saving. A single fare system may also be examined with feeder and DTC bus as access modes to DM as main PT system in terms of time and cost saving.

8. Conclusions, recommendations and limitations of the present research

The results show that LOS of BLUE line (Dwarka Sector-21 to Yamuna bank) stations varies from 0.726 to 0.844 and the mean LOS of 34 stations covering a route length of 36.5 Km. is noted to be 0.775. It is observed that users spend 72.6 % to 84.4 % of their main haul time in their access-egress trip. These results are in marginal variations with the findings of other studies (Swami and Parida, 2015), (Goel and Tiwari, 2016). The above results reveal that the LOS indicator post-COVID-19 has increased which signifies unsatisfactory Blue Line performance. One possible reason is the increase in the access, egress and waiting time due to limited availability of access-egress modes. Another possible reason is the restricted service hours and routes due to the reduced transit work-force and ridership thereby resulting in an increase in the travel time components. It is also observed that mean STR of BLUE line is 0.114. Further, it has been noted that commuters are spending 10.9 % to 12.6 % of their total travel time in waiting and transfer during main haul trip (metro). These results are in marginal variations with the findings of another study (Swami and Parida, 2015). The mean PWI calculated is 1.008 wherein the commuters are spending 75.2 % to 126.7 % of the frequency of metro train as waiting time on the concourse. One possible reason is the restricted service frequency of DM due to the reduced transit work-force and ridership which thereby increases the travel time components. These results are in variation of the findings of another study conducted on different metro lines (Swami and Parida, 2015).

The mean RI calculated is 0.794 wherein the users are spending 78.3 % to 79.6 % of their TTT in their (IVTT and OVTT) trips. It is further noted that remaining 20.4 % to 21.7 % of TTT is consumed in waiting and transfer time components. These results partially confirm the findings of another study conducted on different DM corridors (Kumar et al., 2013). The mean TTR is noted to be 2.069 wherein the users are spending 205.3 % to 217.1 % in total travel time taken by metro compared to total travel time taken by personal vehicle. One of the possible reasons is the increase in the access, egress, waiting transfer and main haul time factors due to limited availability of access-egress modes. Another possible reason is the restricted service operating frequency, hours and routes due to the reduced transit work-force and ridership thereby resulting in an increase in all the travel time components. These results are in variation of the findings of another study conducted on different metro corridors (Swami and Parida, 2015). The mean IR for given sample size calculated is 0.321 wherein the users are spending 28.6 % to 31.3 % of total travel time in their access-egress trips. These results are in variation of the findings of another study conducted on other metro corridors (Swami and Parida, 2015).

The mean MHD per trip across all access modes is observed to be (19.69 ± 11.19) Km. This result confirms the findings of another study conducted in Delhi-NCR (Goel and Tiwari, 2016). It is noted that TTR is dependent as an inverse function of MHD and TTR decreases with an increase in MHD. It is seen in the model with inverse function that the LOS decreases with increase in MHD, thus making service feasible. These results suggest that to improve LOS and TTR to make short MHD trips viable, the DM has to improve access-egress accessibility along with other travel time components. It is further observed that metro fare per trip, total access-egress trip cost per day are significant factors for mode selection in case of walking and auto rickshaw whereas LOS, RI and PWI are other significant operator’s performance indicators influencing the mode choice. These results confirm the findings of another study conducted on bus and metro routes (Brahmaiah et al., 2017). It is revealed that commuters prefer private vehicle and active access-egress modes (e.g., walking and E-rickshaw) and use DM lesser during and post-COVID-19. The findings of a study that people prefer to use safer (in terms of infection) transport modes during pandemics substantiate the findings of the present study (Abdullah et al., 2020). The results suggest that each of the corridors have a unique set of socio-demographic behaviour and challenges, and micro-level planning is needed to address the issues. The results suggest that the LOS, RI values are increased and PWI value post-COVID-19 has increased to more than 1 which is undesirable and implies unsatisfactory Blue Line performance indicators, thereby making it less attractive as PT resulting in reduced ridership. The regression results propose a direction to the DM to facilitate a dedicated pedestrian walkway for commuters preferring walking as access mode along with a dedicated and synchronize e-rickshaw and auto-rickshaw motorway to make DM as attractive and viable principal PT option both in terms of cost and time saving.

Considering the outcomes of the study following recommendations are proposed.

The IVTT and OVTT are significant factors in users’ mode choice. The OVTT & transfer times can be reduced by improving access-egress trips, transfer facilities and card access at PT systems. The other factors that need improvements are the development of designated pedestrian walkways, synchronized frequency of feeder services, and planning the network length to improve accessibility. A single fare system may also be investigated with e-rickshaw, auto-rickshaw, feeder and DTC bus as access modes to DM as the main PT mode in terms of time and cost saving.

It is understood that examining all the factors involved in the performance evaluation of UMTS is very challenging. In this research an attempt has been made to investigate a few out of several factors. Further, detailed researches are needed to examine the impact of other factors like comfort factors, intercity metro impact, socio-economic conditions and weather impact on performance evaluation of UMTS.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

Abdullah, M., Dix, C., Mulay, D., Shahin, M.d., 2020. Exploring the impacts of COVID-19 on travel behavior and mode preferences. Transp. Res. Intere. Spec. Perspect. 8, 100255 https://doi.org/10.1016/j.trip.2020.100255.
Almari, E., Alraee, S., 2013. Factors affecting mode choice of work trips in developing cities—gaza as a case study. J. Transp. Technol. 03, 247–259. https://doi.org/10.4236/jtts.2013.34026.
Azadpeyma, A., Kashi, E., 2019. Level of service analysis for metro station with transit cooperative research program (TCRP) manual: A case study—shohada station in Iran. Urban Rail Transit 5, 39–47. https://doi.org/10.1017/s006604180098917.
Bovy, P.H.L., Jansen, G.R.M., 1979. Travel times for disaggregate travel demand modelling: a discussion and a new travel time model. New Dev. Model. Travel Demand Urban Syst. Saxon House Engl. 129–158.
Brahmaiah, B., Tech-IITR, M., Prasad, A.D., Srinivas, K., 2017. A performance analysis of modelling route choice behavior on urban bus and multi mode transit route. Int. J. Adv. Inf. Sci, Technol, p. 11.
Chatterjee, D., 2020. Delhi metro resumes first time after COVID-19. Pics And Twitter Buzz, NDTV.
Des Delhi Statistical Handbook-2019 2019.
Des Delhi Statistical Handbook-2020 2020.
Des Delhi Statistical Handbook-2021 2021.
Esd, 2019. Economic Survey of Delhi(2018-2019).

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