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Optimizing Multimodal Transportation Access to Support Commuting Among Low-Income Transit Riders with Social Distancing

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16. Abstract

During the COVID-19 pandemic, LA Metro has encouraged social distancing among passengers—especially at stations of high-demand routes—and has increased fixed-route transit (FRT) services. However, potential impacts of social distancing on the performance of FRT services remain mostly unknown. This research evaluates the accessibility of FRT buses with social distancing using the ridership data collected on four FRT routes: 105, 108, 111, and 115 of the LA Metro's A Line stations located in low-income neighborhoods. This research shows that social distancing of six feet can impact FRT's accessibility to destination stations, and maximum accessibility is achieved only for a certain number of stops served—which is less than the current number of stops served. The FRT routes 105, 108, 111 and 115 have maximum accessibility with social distancing for the number of stops served equal to 65, 52, 52 and 50, respectively. The methodology used in this research can help decision-makers understand how FRT bus frequencies are impacted by social distancing measures, and the results can guide the transit authorities developing FRT service among low-income commuters during and after the pandemic.

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Executive Summary

With the onset of the COVID-19 pandemic, transit agencies have followed best practices in promoting social distancing amongst their passengers. For example, Bay Area Rapid Transit (BART) in California provides weekly train car loading for its passengers, which gives a snapshot of the number of riders present in each train car. With this information, passengers can choose in advance which train car to board to avoid and to assess the possibility of maintaining a physical distance of six feet from other riders on-board train cars. Other major transit agencies in California have taken similar steps. For example, the Los Angeles County Metropolitan Transportation Authority (LA Metro) launched its official smartphone app called Transit to predict the crowding levels on Metro buses. LA Metro has further increased its transit service frequencies to minimize crowding at train stations, especially on some select bus routes, designated as fixed-route transit (FRT), serving train stations. The FRT buses serve as feeder transit mode with a fixed schedule of passenger pick-up at stops, and they provide access to LA Metro's train stations of the A Line, B Line, C Line, D Line, E Line, and L Line. Amongst these rail lines, the LA Metro's A Line serves one of California's high-density populations with low-income households from essential services such as jobs related to health care, public works etc. For these workers, the A Line and its associated FRT bus services are vital for commuting during all periods—whether before, during, or after the pandemic.

The FRT bus ridership of LA Metro had been experiencing a steady decline in ridership during the pre-COVID-19 period in early 2020. However, LA Metro's FRT buses, popular among low-income riders, experienced as much as over 50% ridership decline with the pandemic's onset (compared to pre-pandemic years), and ridership has been steadily rising since then, albeit at a slower pace. Transit authorities increased FRT services in the pandemic periods to ensure minimal crowding at the bus stops and inside the buses. With COVID-19 seriously impacting the livelihood of low-income households, the affordability of using private vehicles for commuting has been reduced for low-income residents. Thus, dependency on the A Line has only further increased during these pandemic periods and could remain the same or worsen post-pandemic. Dependency on transit also raises another major challenge of crowding on several public transit system components (buses, trains, stops, stations, etc.) as travel activity picks up with time. Undoubtedly, social distancing measures could see an increased number of violations as the pandemic persists. Crowding and non-compliant passenger behaviors will only add to the woes of low-income riders who would have to continue to endure unsafe travel situations. However, better planning of FRT services as a feeder service providing access to train stations can help mitigate safety concerns for transit authorities and low-income riders.

Transit agencies worldwide have taken measures to limit visits at rush-hour stations, even closing stations entirely to compel riders to walk more or take alternative routes. However, some transit operators place passenger limits on FRT buses. Once a bus is deemed full, the driver contacts a dispatcher to provide another vehicle to receive the remaining passengers. It This is an effort by transit operators to increase the accessibility provided to passengers to reach specific transfer or terminal stations. These measures add up to improved accessibility for FRT by the passengers and ultimately finding popularity among potential riders. However, a challenge remains: namely, integrating such accessibility measures with passenger behavior in view of the crowding potential at such transfer stations, which often involve violations of social distancing.

A unique contribution of this research is the integration of social distancing into the accessibility formulation—which, to the best of our knowledge, is being executed here for the first time in transit accessibility research. The accessibility is modeled and evaluated for the FRT routes 105, 108, 111, and 115 of the LA Metro's A Line, popular among low-income riders of Los Angeles County.

This research shows that social distancing impacts the accessibility of FRT routes 105, 108, 111, and 115 to the LA Metro A Line stations, which are quite popular among low-income commuters of Los Angeles County. The findings indicate that the maximum FRT accessibility is achieved only for a certain number of stops served. The FRT routes 105, 108, 111, and 115 have maximum accessibility for the case with social distancing for the number of stops served equal to 65, 52, 52, and 50, respectively. Therefore, if the goal of the transit agencies is to provide first-/last-mile FRT accessibility to a major transit line, the model developed in this research could help determine the optimal number of stops that the FRT should serve to maximize accessibility - which could often mean service to an increased number of stops or truncating currently served stops from FRT services In the former case, ta a further increase in the FRT service frequencies would be beneficial to keep up with a maximum accessibility.

1. Introduction and Background

The Federal Transit Administration (FTA) has allocated $25 billion through the Coronavirus Aid, Relief, and Economic Security (CARES) Act to support capital, operating, and other public transport expenses for prevention, preparation, and response related to the COVID-19 pandemic (FTA Coronavirus Aid, 2020). FTA's safety advisory recommends that transit agencies follow procedures and practices of social distancing consistent with the guidelines from the Centers for Disease Control and Prevention (CDC). However, various reports indicate instances of passengers' non-compliant behaviors with respect to social distancing requirements at major transit stations, particularly in New York and California (Hardy, 2020; Gauthier-Villars et al., 2020).

Some transit agencies have followed the best practices and promoted social distancing amongst their passengers. For example, the Bay Area Rapid Transit (BART) in California provides weekly train car loading charts (called "crowding charts") for its passengers, which offer a snapshot of the number of riders present in each car of the train (BART, 2020). This allows passengers to assess the possibility of maintaining a social distance of six feet on-board train cars. Other major transit agencies in California have taken similar steps. For example, the Los Angeles County Metropolitan Transportation Authority (LA Metro) launched its official smartphone app called Transit to predict the crowding levels on Metro buses (Metro, 2020a).

LA Metro has increased its service frequencies to minimize crowding at train stations and on trains and buses, especially on some select bus routes called fixed-route transit (FRT) routes (Metro, 2020b). The FRT buses serve as feeder transit services with a fixed schedule of passenger pick-up at stops, and they provide access to LA Metro's train stations along the A Line, B Line, C Line, D Line, E Line, and L Line. Among these rail lines, the A Line serves one of California's high-density populations with low-income households that are also workforce to essential services which could include industries from the health care, public works etc. (see Fig. 1, Data Source for map: LEHD, 2020). For these workers, the A Line and its associated FRT bus services are vital for commuting.

In California, LA Metro's FRT buses had been experiencing a steady decline in ridership prior to the onset of the COVID-19 pandemic in early 2020 (APTA, 2020; LA Metro, 2020). However, LA Metro's FRT buses, popular among low-income riders, experienced as much as over 50% ridership decline with the pandemic's onset when compared to pre-pandemic years. Despite dwindling ridership numbers, authorities have increased FRT services in the pandemic periods to ensure minimal crowding at the bus stops and inside the buses.

With COVID-19 seriously impacting the livelihood of low-income households, the affordability of using private vehicles for commuting has been reduced (Taylor and Wasserman, 2020). Thus, the dependency on the A Line has only increased during these pandemic periods and could remain the same or worsen post-pandemic. This raises a major challenge of crowding on several public transit system components (buses, trains, stops, stations, etc.) as travel activity picks up with time.

Undoubtedly, social distancing measures could see an increased number of violations in coming times as the pandemic persists. Crowding and not following social distancing leading to non-compliant passenger behaviors will only add to the woes of low-income riders who would have to continue to endure unsafe travel situations. However, better planning of FRT services as a feeder to access train stations can help mitigate safety concerns for transit authorities and low-income riders.

Transit agencies worldwide have taken measures to limit visits at rush-hour stations, even closing stations entirely to compel riders to walk more or take alternative routes (McKinsey & Company, 2020). However, some transit operators place passenger limits on FRT buses. Once a bus is deemed full, the driver contacts a dispatcher to provide another vehicle to receive the remaining passengers (Danville, 2020). This is an effort to increase the accessibility provided to passengers and enable them to reach specific transfer or terminal stations. These measures add up to improved accessibility for FRT - which would mean an increased number of passengers could be served without diminishing the travel time significantly - (Chandra and Quadrifoglio, 2013). However, the challenge remains to integrate such accessibility measures that would be sensitive to passenger behavior while boarding or alighting a transit bus at a stop.

FRT buses provide passengers access to mainline train stations serving as transfer or terminal stops in public transit operations. Studies show that the increase in FRT service frequencies, if FRT's scheduling is not in sync with the mainline train frequency, impacts the riders' seamless and multimodal travel experience. With an unsynchronized scheduling with mainline trains, the riders could end up waiting for longer durations at the train station - dissuading them to ride FRT. Unnecessary waiting time and delays result in passengers seeking other modes to reach destinations in time, and could possibly require transfers via multiple modes if they are dependent on two different modes of transport to complete a trip (Manser et al., 2020). Increasing multimodal transport efficiency, including FRT accessibility and effective passenger management (especially with social distancing measures), requires more in-depth research, including research yielding behavioral knowledge of passengers' movement in a crowd. The present research addresses this critical need by integrating an accessibility formulation for FRT with the social distancing requirement of six feet (or about a 5-second time gap) between two boarding/alighting passengers in transit.

The sketch in Figure 2 represents an integrated model which is used to develop accessibility formulation considering social distancing of passengers. The aim is to improve the multimodal transportation system's efficiency.

Thus, this research investigates the impact of social distancing on FRT accessibility, an important measure of transit performance. The accessibility is modeled and evaluated for FRT routes 105, 108, 111, and 115 of the LA Metro's A Line.

Figure 1. Spatial Distribution of Home Locations of Low-Income Workers around LA Metro's A Line (Blue)

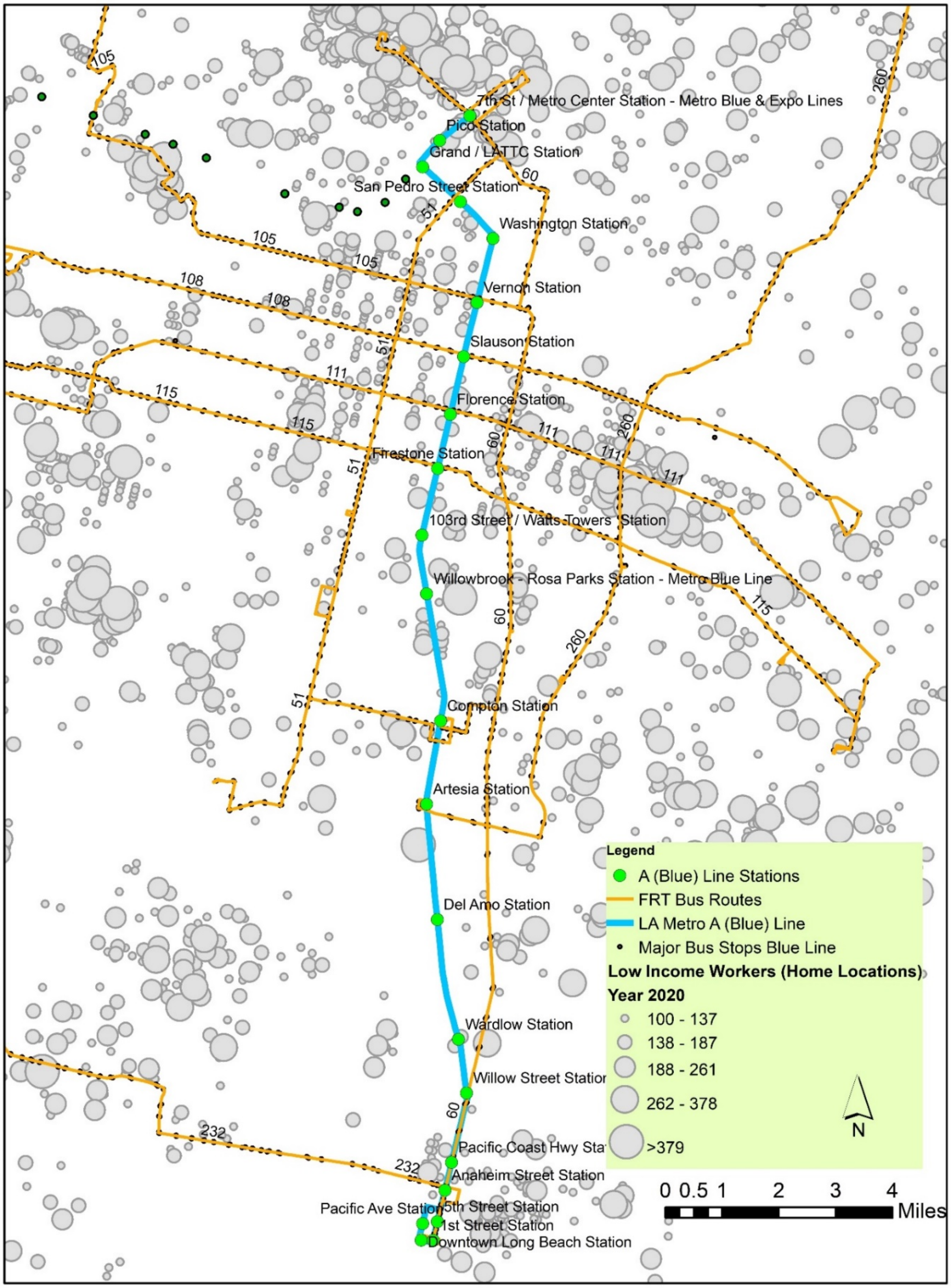
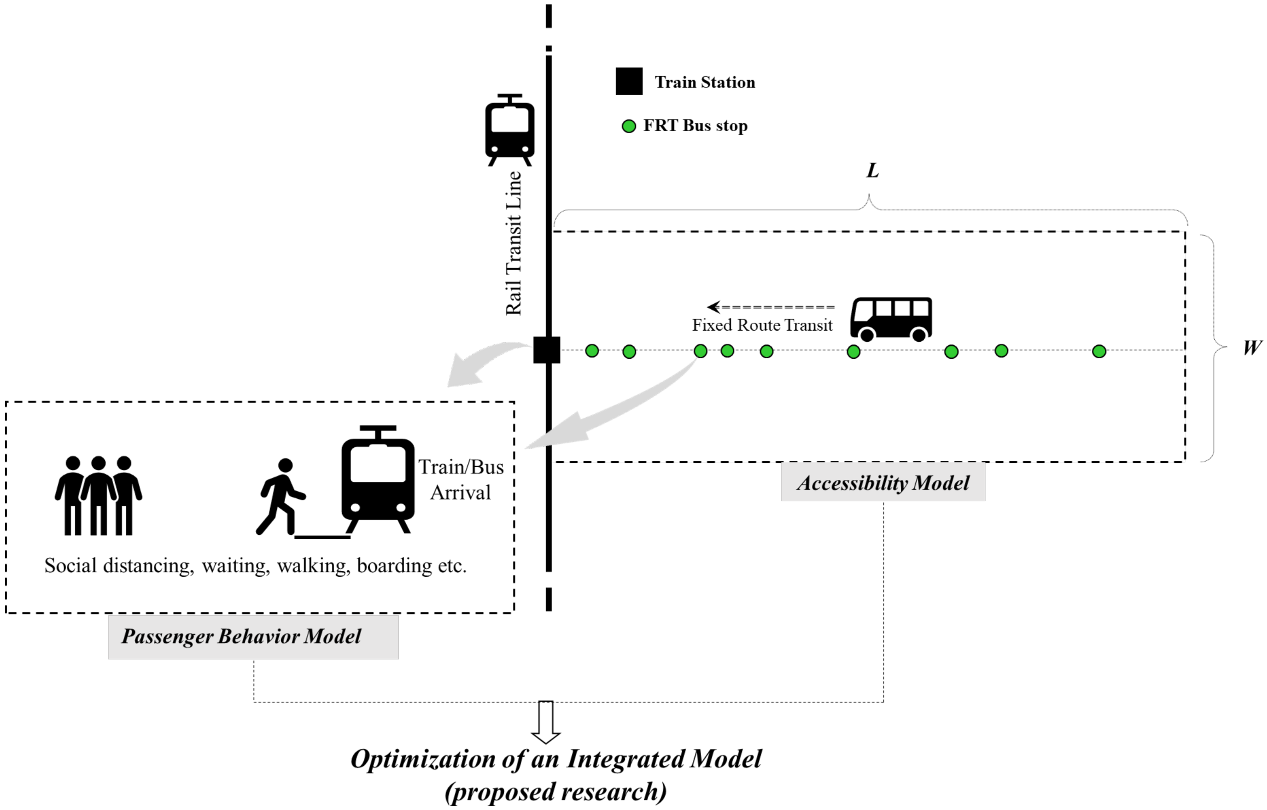


Figure 2. Illustration of the Interaction between FRT Accessibility and Passenger Behavior Models



2. Research Contribution

Low-income commuters who depend on public transport face an unprecedented challenge worldwide due to the COVID-19 pandemic. In the current pandemic, transit agencies are making every effort to provide safe and efficient services to low-income riders and try to boost ridership. However, the new safety protocol of social distancing that passengers need to follow has its own sets of challenges in the shared space of transit stations as well as inside trains and buses.

Transit agencies also have the challenge of understanding passenger behaviors during the pandemic. Although passenger behaviors have been studied in existing literature, these studies are limited to pre-pandemic periods or unexpected situations involving evacuations. In view of the COVID-19 pandemic, transit agencies have increased FRT bus frequencies to encourage social distancing among passengers at stations and on high-demand routes. Unfortunately, knowledge about how FRT accessibility would be impacted due to social distancing is currently limited or absent. This research contributes to developing an understanding of how FRT accessibility is impacted due to social distancing using FRT ridership data on example routes and train stations of LA Metro's A Line and by optimizing the accessibility for the number of stops served by FRT.

This research promises to help decision-makers determine optimal FRT accessibility for the number of stops they serve and their connectivity to mail line transit. With recommendations to improve accessibility, this research could be an important reference source for enhancing FRT and major transit line transit ridership among low-income commuters during and after the pandemic.

3. Methodology

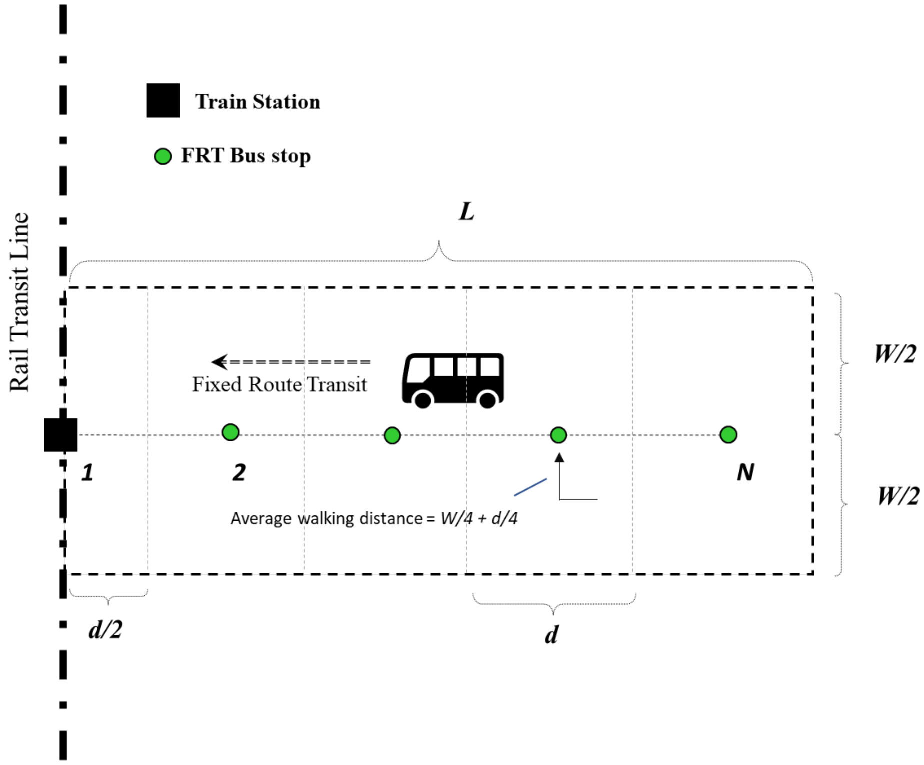
There are several FRT accessibility models used in practice (Jiang et al., 2020; Tang and Du, 2020). However, those do not integrate accessibility with passengers' key behavioral factors, such as speeds and social distancing compliance. In general, the behavioral models depend on the walking speed of the passenger (agent), obstacles (walls), and signs (guidance), as well as the presence of other agents at the station (Li et al., 2020; Su et al., 2020). When integrated with accessibility, these considerations could produce a strong measure of multimodal transportation efficiency for FRT.

The methodology adopted in this research involves a modified formula for transit accessibility incorporating the behavior of passengers while boarding the transit vehicle at stops/stations considering social distancing.

Accessibility to a transit stop can be impacted by both the ridership and impedance (which could be in the form of travel time, distance, or a generalized cost) involved in accessing the stop. A high passenger ridership at a stop could mean that the accessibility of the stop is high, while a low number could indicate that the transit is not accessible to a large population. One of the reasons for poor accessibility is that there could be a significant walking distance to a stop from the passenger's trip origin, such as the home location. The number of fixed stops on the route could impact accessibility for a FRT service.

Too many stops on the FRT route make accessibility to the major transit line smaller in magnitude because of the increase in travel time, but a low number of stops deprives many potential passengers of FRT access. For a constant number of FRT passengers, the inclusion of social distancing in accessibility would increase the boarding time at a stop - i.e. a passenger would take longer times to walk and board the same bus following social distancing. This would increase the travel time of the FRT to the major transit line, decreasing the FRT's accessibility. Therefore, an optimal number of stops could maximize FRT accessibility to the major transit line with a fixed number of stops. This is demonstrated using the simplified set-up shown in Figure 3. The sketch has been adopted from the work of Quadrifoglio and Li (2009) with the following variables: L = FRT service area length, W = FRT service area width, and d = distance between two FRT stops. It is assumed that the population that resides close to the major transit line (rail line) terminal at location 1 is within $d/2$. The people living close to terminal 1 would prefer to walk (or use any non-motorized modes) to the major transit line. Note that $d = L/(N\text{-}1/2)$, where N = number of stops.

Figure 3. Fixed-Route Transit (FRT) Service Operation



Based on the sketch in Figure 3, the average shortest path walking distance to any FRT stop is $W/4 + d/4$. With an assumed trip travel time defined as T_{ij}, using the gravity-based formula for the accessibility (P_{FRT}), we have:

$$P_{FRT} = \sum_{j=2}^{N} \frac{A_j}{T_{1,j}^{\beta}} \tag{1}$$

where

$A_j = \rho_1 W d \;\; \forall j \in \{2, \ldots, N\}$ with ρ_1 being the unform demand density across the whole rectangular service area and β being the decay parameter.

3.1 Derivation of Travel Time

The expected riding time denoted by $E[T_{rd}]$ of combined pick-up and drop-off for passengers at a stop as derived by Quadrifoglio and Li (2009) is

$$E[T_{rd}] = \frac{N(N-1)}{(2N-1)}\left(\frac{d}{V} + t\right) \tag{2}$$

where V is the average speed of the shuttle and the variable t is the dwell time of the feeder shuttle at each stop, expressed as

$$t = \lambda\left(\frac{\rho LW}{N - \frac{1}{2}} - 1\right) \approx \lambda\left(\frac{\rho LW - N}{N}\right)$$

with λ being the time headway between two passengers at a stop while boarding the transit vehicle with social distancing.

With simplification $(N - 1) \approx (N - 1/2)$, this yields

$$E[T_{rd}] \approx \frac{N}{2}\left(\frac{d}{V} + t\right). \tag{3}$$

The average walking time to the closest FRT stop denoted by $E[T_{wk}]$ is written as,

$$E[T_{wk}] = \frac{1}{V_{wk}}\left(\frac{W}{4} + \frac{d}{4}\right) \tag{4}$$

where V_{wk} is the average walking speed of passengers.

The passengers' net average riding time, $E[T_{nrd}]$, is $E[T_{nrd}] = E[T_{rd}] + \gamma E[T_{wk}]$, where γ is the weight for walking time. On further approximation,

$$E[T_{nrd}] \approx \frac{N}{2}\left(\frac{d}{V} + t\right) + \frac{\gamma}{4V_{wk}}(W + d). \tag{5}$$

Considering the travel time equal to riding time and the waiting time combined in the form of impedance, we have the expression for accessibility from Eq. (1) as

$$P_{FRT} = \sum_{j=2}^{N} \frac{\rho Wd}{\left[\left(\frac{N}{2}\right)\left(\frac{d}{V} + t\right) + \frac{\gamma}{4V_{wk}}(W + d)\right]^{\beta}} = \frac{\rho Wd(N-1)}{\left[\left(\frac{N}{2}\right)\left(\frac{d}{V} - \lambda\right) + \frac{\lambda \rho LW}{2} + \frac{\gamma}{4V_{wk}}(W + d)\right]^{\beta}}. \tag{6}$$

The accessibility in Eq. (6) is further analyzed for maximization and can be rewritten in a simplified form as

$$P_{FRT} = \left(\frac{\rho W d}{R}\right) \tag{7}$$

where $R = \frac{\left[\left(\frac{N}{2}\right) r_1 + r_2\right]^{\beta}}{(N-1)}$ with $r_1 = \left(\frac{d}{V} - \lambda\right)$ and $r_2 = \frac{\lambda \rho L W}{2} + \frac{\gamma}{4V_{wk}}(W+d)$.

Therefore, a maximum (or minimum) of *R* should result in a minimum (or maximum) accessibility P_{FRT} in Eq. (6).

The critical values of $N = N^*$ for *R* in Eq. (7) is obtained by setting the first-order derivative of *R* equal to zero ($\frac{dR}{dN} = 0$), yielding

$$\frac{dR}{dN} = \frac{\frac{\beta r_1}{2}\left[\left(\frac{N}{2}\right) r_1 + r_2\right]^{\beta-1}}{(N-1)} - \frac{\left[\left(\frac{N}{2}\right) r_1 + r_2\right]^{\beta}}{(N-1)^2} = 0 \tag{8}$$

$$\Rightarrow N = N^* = \frac{\frac{\beta r_1}{2} + r_2}{\left(\frac{\beta r_1}{2} - \frac{r_1}{2}\right)} = \frac{\beta + \frac{2r_2}{r_1}}{(\beta - 1)}. \tag{9}$$

The second-order derivative of *R* gives

$$\frac{d^2 R}{dN^2} = \frac{\frac{1}{2^{\beta}} \beta (\beta-1)^2 r_1^{\beta} \left[N + \frac{2r_2}{r_1}\right]^{\beta-2}}{\left(\frac{2r_2}{r_1} + 1\right)}. \tag{10}$$

The condition for minimum (or maximum) *R* at critical *N* (defined using notation *N**) is $\frac{d^2 R}{dN^2} > 0$ (or < 0).

Using the critical value of $N = N^* = \frac{\beta + \left[\lambda \rho L W + \frac{\gamma}{2V_{wk}}(W+d)\right] \Big/ \left(\frac{d}{V} - \lambda\right)}{(\beta - 1)}$, *R* is at a minimum for any $\beta > 1$ and $\left(\frac{d}{V} > \lambda\right)$.

The minimum value of R results in maximum potential accessibility value for the relationship expressed in Eq. (7). At β = 1, the expression for $\frac{dR}{dN} < 0$ results in potential accessibility expression in Eq. (7) a monotonically increasing function with respect to N. This means that the higher the number of stops, the larger will be the accessibility at β = 1. These findings have been summarized in Table 1.

In summary, based on the analysis above w.r.t Eq. (6) and (7) that have social distancing parameter embedded in the formula, the accessibility of FRT routes can achieve an optimal value with a certain number of stops, and the decay parameter, β, plays an important role.

Table 1. Accessibility Variation with N (i.e., N^*) and Decay Parameter (β)

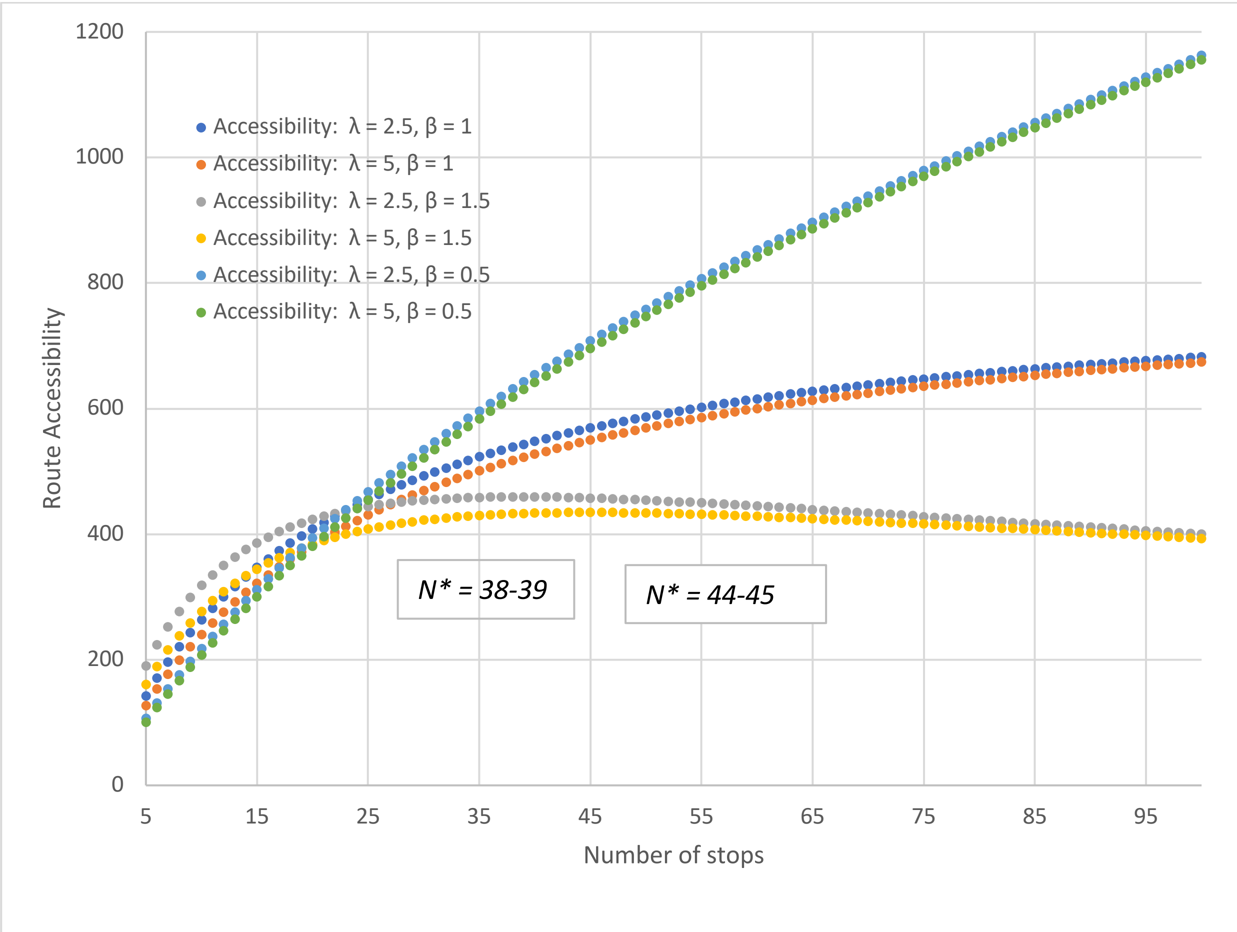
Impedance Decay Parameter (β)	***Accessibility***	***N****
$0 \le \beta < 1$	$\dfrac{\rho W d(N-1)}{\left[\left(\frac{N}{2}\right)\left(\frac{d}{V}-\lambda\right)+\frac{\lambda\rho LW}{2}+\frac{\gamma}{4V_{wk}}(W+d)\right]^{\beta}}$	N/A
$\beta = 1$	$\dfrac{\rho W d(N-1)}{\left[\left(\frac{N}{2}\right)\left(\frac{d}{V}-\lambda\right)+\frac{\lambda\rho LW}{2}+\frac{\gamma}{4V_{wk}}(W+d)\right]^{\beta}}$	infinite
$\beta > 1$	$\dfrac{\rho W d(N-1)}{\left[\left(\frac{N}{2}\right)\left(\frac{d}{V}-\lambda\right)+\frac{\lambda\rho LW}{2}+\frac{\gamma}{4V_{wk}}(W+d)\right]^{\beta}}$ (Maximized)	$\dfrac{\beta+\left[\lambda\rho LW+\frac{\gamma}{2V_{wk}}(W+d)\right]\Big/\left(\frac{d}{V}-\lambda\right)}{(\beta-1)}$ for $\left(\frac{d}{V}>\lambda\right)$

Note: N/A means not applicable.

An application of the above theoretical derivations is presented in Figure 4. That chart has been prepared with an assumed weight for walking λ = 2.5, 5 seconds as time headway between two passengers at a stop, and variable decay parameters of β = 0.5, 1, and 1.5. Other assumptions include the speed of the FRT bus (V = 20 miles per hour) and walking speed (v = 3 miles per hour).

Figure 4 shows that when β = 1.5, the maximum accessibility obtains when the number of stops served is approximately 38 for λ = 2.5 and about 44 for λ = 5. For other decay parameter values, the accessibility monotonically increases.

Figure 4. Fixed-Route Transit (FRT) Accessibility Variation with Parameters



4. Application of the Method

The application of the theoretically derived formulation for accessibility (incorporating social distancing into the formula) was carried with data on the FRT buses of the LA Metro's A Line transit. These routes included the FRTs that serve the stops of Firestone Station, Florence Station, Slauson Station, and Vernon Station, i.e., the bus routes 105, 108, 111, and 115, respectively (LA Metro, 2021a). These four routes serve a large population from low-income communities. The map in Figure 5 shows the spatial location of the LA Metro A Line service area and stations, with the four FRT routes. The home location clusters for the low-income population served in the vicinity of the A Line are obtained for the year 2020 by extrapolating 2012-2018 data from the Longitudinal Employer-Household Dynamics (LEHD, 2021). Data for ridership are collected by the researchers during the assumed peak hours of travel from 7 am to 10 am on Tuesdays and Wednesdays with on-site visits to the four A Line stations for two weeks during June 2021. The data obtained for ridership was corroborated with the estimated ridership stats of the four FRT lines of the LA Metro A Line (2021b). This was required to generate the peak hour demand density for the four FRT lines. The width, W, was assumed to be equal to half a mile within walking distance from residence to a FRT stop. Research shows that the parameter value of γ = 1.7 is appropriate as the walking weight (Wardman, 2004). The value of λ is the time headway between two passengers adhering to six feet social distancing. The assumption is made that each passenger takes about 5 seconds to board the FRT vehicle, so λ = 5 seconds. Further, passenger walking speed, v, is assumed to be 3 miles per hour. Table 2 summarizes the data used in the accessibility calculations. To compute the accessibility, the speed of the FRT vehicle is assumed to be 25 miles per hour, and the decay parameter (β) is assumed to be 1.5.

Figure 5. Spatial Location of the Four FRT Routes, the A Line Transit, and Low-Income Home Locations

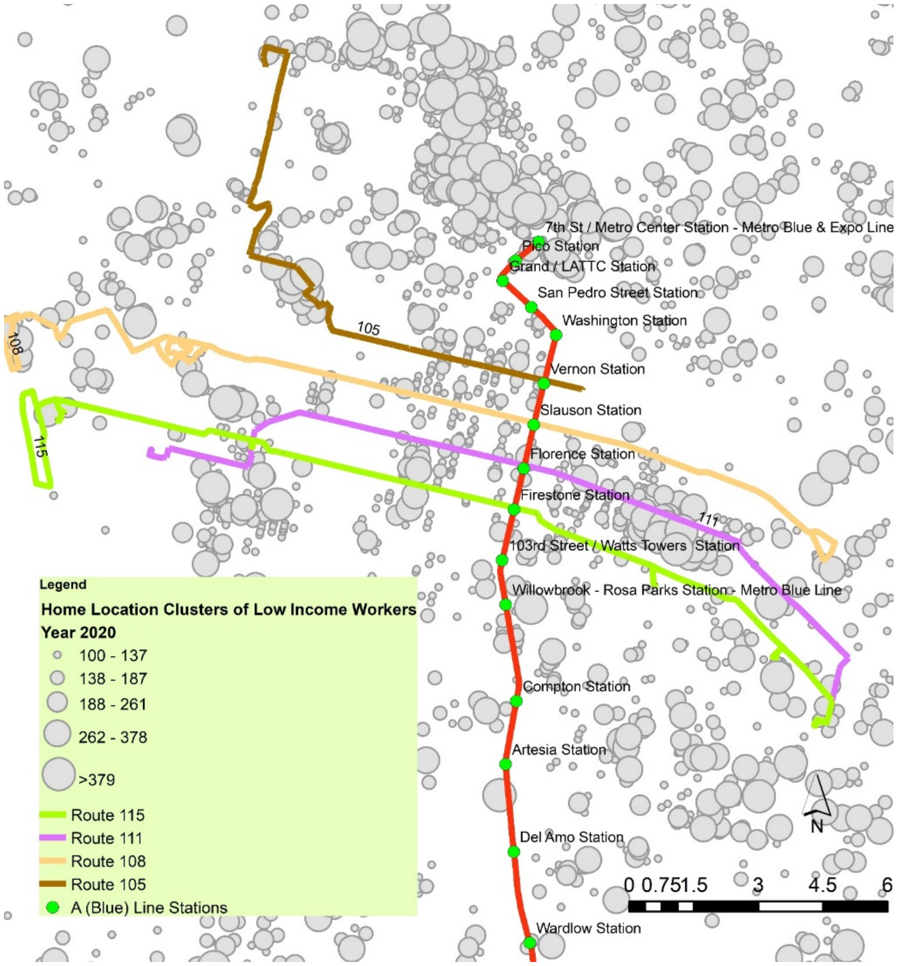


Table 2. Compilation of Data Collected for FRT

FRT Bus Route	Number of Stops, *N*	Route Length, *L* (miles)	Distance between Two Stops, *d* (in feet)	Approximate Bus Headway (in minutes)	FRT Stop Demand Density, *ρ* (passengers per sq. mile)
105	83	23.9	1,520	10	5
108	116	40.2	1,830	8	2
111	142	32.3	1,844	10	3
115	104	39.9	2,026	15	2

5. Results and Discussion

Plots of accessibility versus the number of stops of the four FRT routes (105, 108, 111, and 115) are shown in Figures 6 through 9. Each figure contains information on the cases with and without social distancing considerations. For the case with social distancing, λ is assumed to be 0.

The chart in Figure 6 shows that with an increase in the number of stops for FRT route 105, the accessibility of FRT increases for the cases with and without social distancing. The accessibility for the case without social distancing achieves a maximum at around 40 stops and decreases after that. For the case with social distancing, accessibility reaches a maximum at 67 stops and then declines. Serving passengers beyond the optimal number of stops leads to a decrease in accessibility. This indicates that an optimal number of stops should be served to achieve the largest accessibility for conditions both with and without social distancing requirements.

Similar observations are noted for the other three FRT routes (108, 111, and 115), with maximum accessibility occurring for the case with social distancing at 50, 52, and 48 stops, respectively. For the case without social distancing, the maximum accessibility for the three routes is achieved at 32, 34, and 33 stops, respectively.

Figure 6. Accessibility Variation with Number of Stops for FRT 105

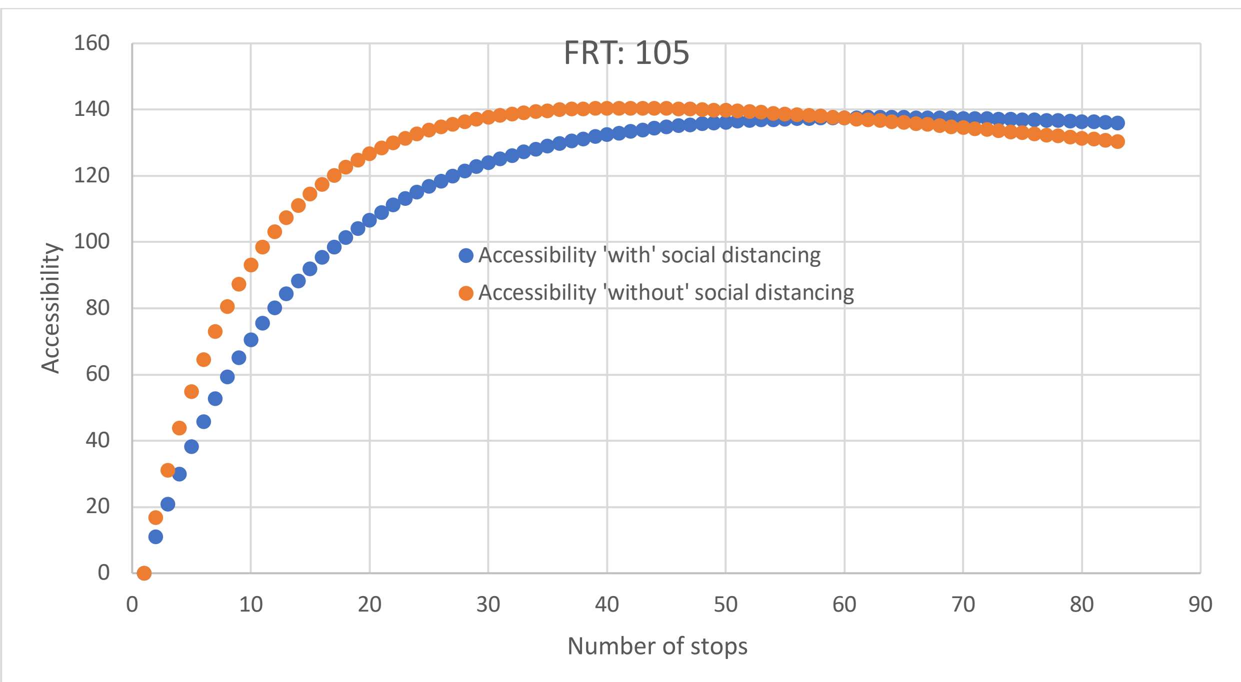


Figure 7. Accessibility Variation with Number of Stops for FRT 108

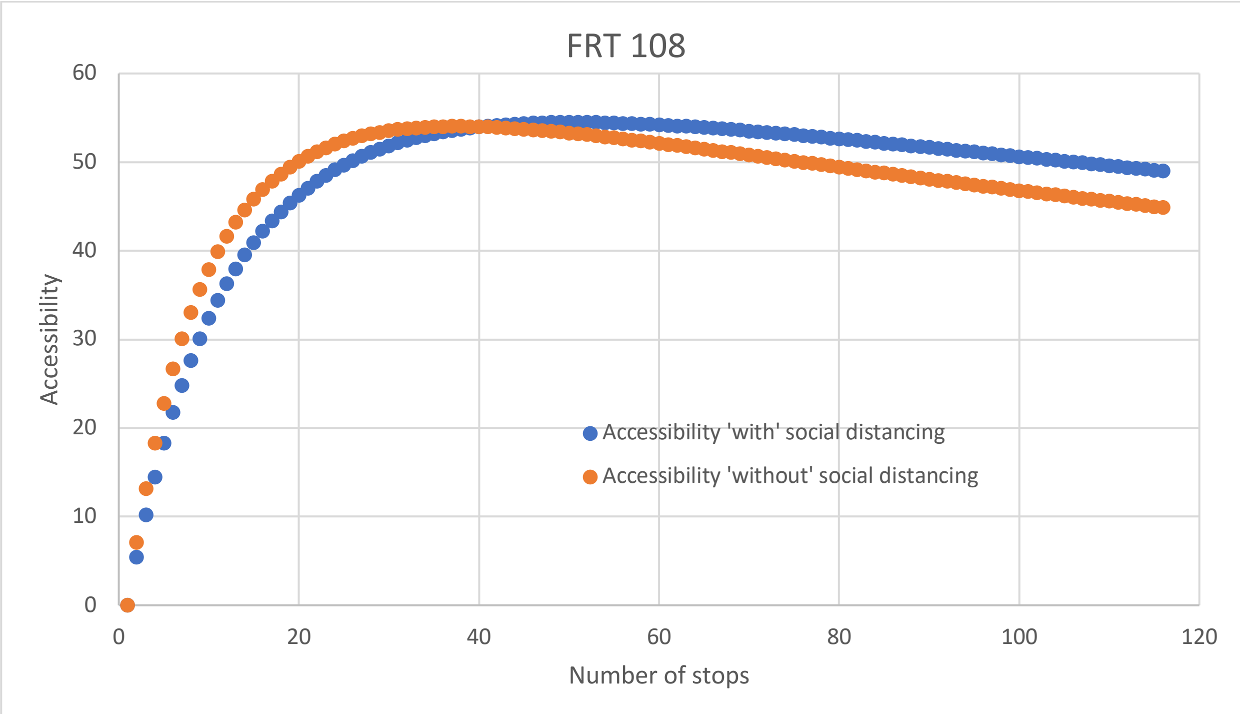


Figure 1. Accessibility Variation with Number of Stops for FRT 111

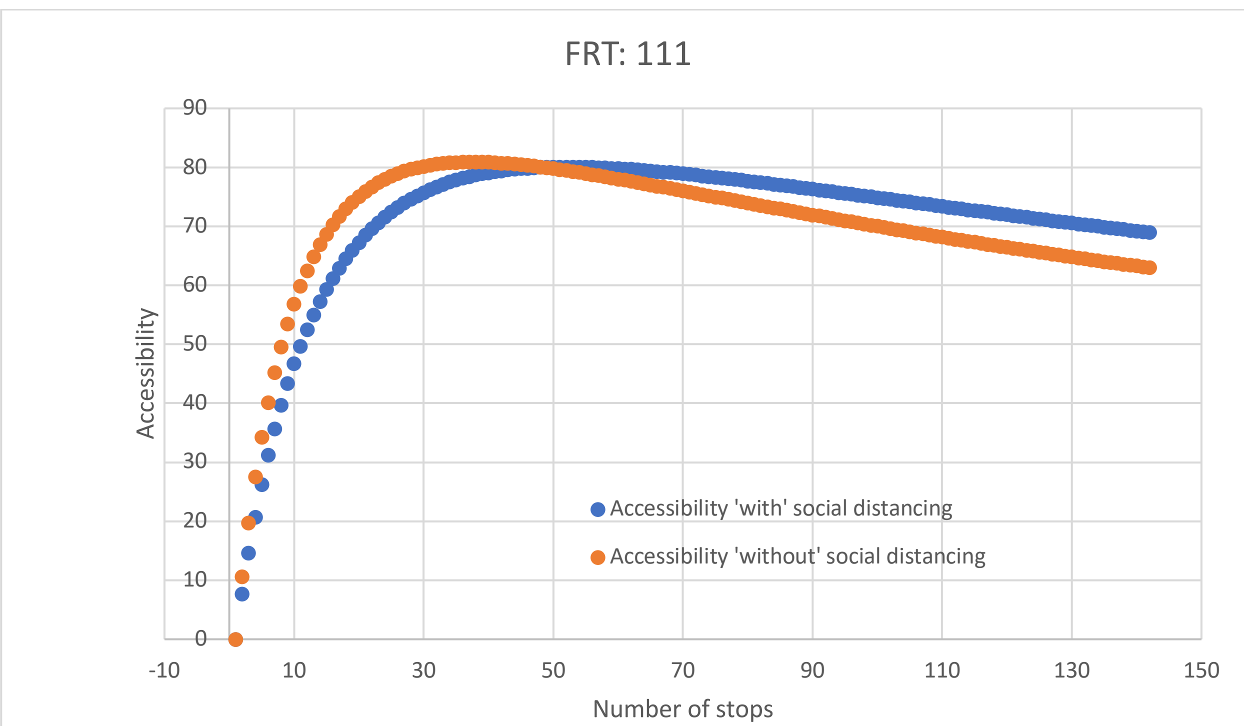
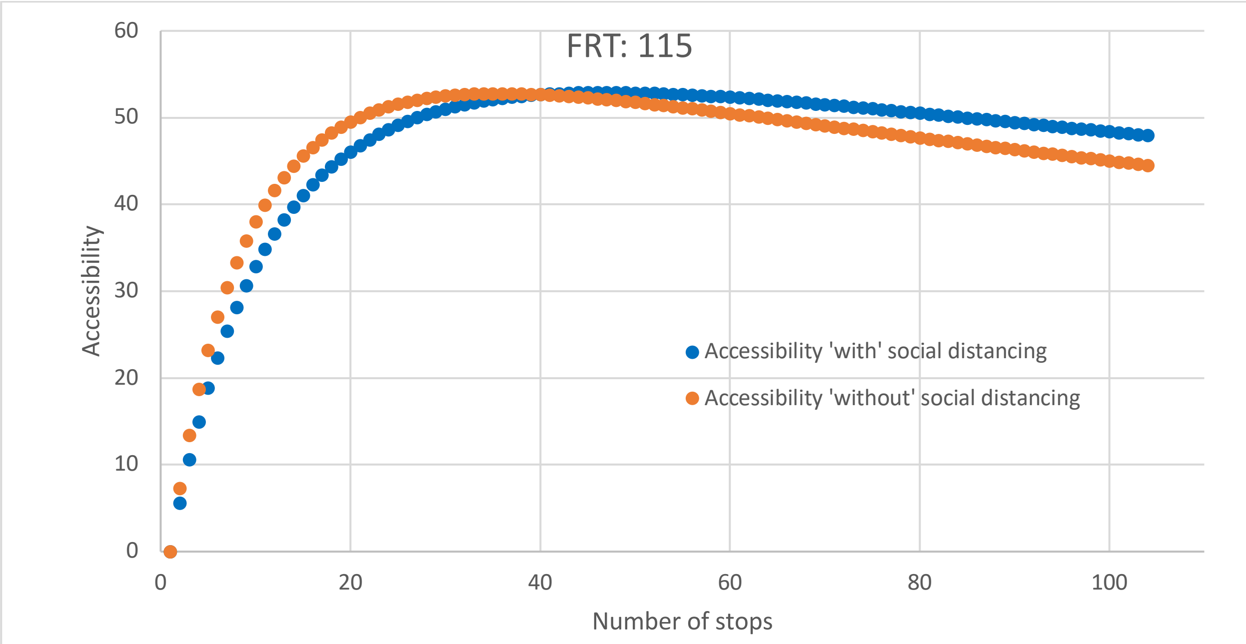


Figure 9. Accessibility Variation with Number of Stops for FRT 115



The findings presented in Figures 6 through 9 suggest that FRT accessibility with social distancing is initially lower than without social distancing. However, as the number of stops served increases, the accessibility for the case with social distancing is greater than the accessibility for the case without social distancing for all four FRT routes.

Figures 6 through 9 also show that the FRT accessibility can be almost equal for the cases with and without social distancing. The equality is noted for routes 105, 108, 111, and 115 if the number of stops served is 65, 52, 52, and 50, respectively.

Although the application focused on FRT accessibility when servicing the rail line, it was assumed that the single vehicle served a route. Multiple vehicles used for service could lower the demand at a stop for one vehicle and thus, dwell time at a stop would reduce. In effect, If the number of vehicles is increased to such that only one passenger gets to board a vehicle at a stop, there will not be a need to consider any social distancing. But this may not be practical as it would incur very operating costs for the transit agencies.

Results also indicate that the as the demand for FRT by low-income commuters would go up there Is an Increase In accessibility of FRT as well. , We notice this for FRT 105. The other three routes had a lower demand per stop per square mile relative to FRT 105.

6. Summary and Conclusions

The recent pandemic has compelled transit agencies to ensure safe travel for passengers. Promoting social distancing among transit riders is one of the most significant measures that has been implemented. It is intuitive to believe that increasing the fleet by reducing the headway or increasing the frequency of transit buses could offset the overall increase in passenger travel time caused due to social distancing. However, adding another fleet to service could also increase the costs for transit agencies.

This research shows that social distancing impacts the accessibility of FRT routes 105, 108, 111, and 115 to the LA Metro A Line stations, which are quite popular among low-income commuters in Los Angeles County. The findings indicate that the maximum FRT accessibility is achieved only for a certain number of stops served. For the case with social distancing, FRT routes 105, 108, 111, and 115 have maximum accessibility when 65, 52, 52, and 50 stops are served, respectively. Therefore, if the goal of the transit agencies is to provide first-/last-mile FRT accessibility to a major transit line, the model developed in this research could help determine the optimal number of stops that the FRT should serve to maximize accessibility. This might require further increasing the FRT service frequencies.

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