Bang For The Buck: Toward A Rapid Assessment Of Urban Public Transit From Multiple Perspectives In North America

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ABSTRACT

Urban public transit must fulfill many criteria in order to be successful. In addition to being attractive and convenient from a rider's point of view, public transit agencies also require a level of financial viability, as well as providing a necessary public good in the form of transport, particularly for individuals without automobile access. Nevertheless, whether transit agencies are able to provide good quality service from multiple perspectives that is also affordable is an underexplored topic. In this study, we investigate the ability of public transit agencies in large North American cities to provide quality transit service from different perspectives and whether this service is affordable to minimum wage earners. To ascertain how transit agencies are performing, we construct key indices to capture the perspectives of transit riders, society at large, and transit agencies themselves. Moreover, we assess the level of affordability for the different agencies by determining the number of minimum wage hours required to earn a monthly transit fare. We find that agencies vary widely in terms of affordability and service levels. In particular, there is a key trade-off between service quality and affordability, so that agencies in Montreal and San Francisco, provide relatively good service at an affordable level, while some agencies, such as those in Toronto and New York, while providing excellent service, are more expensive for minimum wage earners. Our assessment provides a useful framework for transport planners to evaluate and compare transit performance.

Keywords: Public transit; performance evaluation; rapid assessment; affordability

THE ROLE OF PUBLIC TRANSIT, FROM MULTIPLE PERSPECTIVES

Urban public transit plays a vital role in society. In addition to providing an important service to commuters, particularly those who do not own personal vehicles, by enabling them to access employment and other essential services on a daily basis, public transit contributes to public goods, which benefit urban populations as a whole. There are important objectives and outcomes related to urban public transit from the perspective of transit riders, society at large, and the transit agencies themselves. Further, there can potentially be important interdependencies, conflicts and trade-offs between these objectives, both from the perspective of each of these groups, as well as across them.

As far as transit users are concerned, the outcomes that are crucially important are, on the one hand, service availability and accessibility; service frequency and reliability; security and safety; and comfort and convenience; and on the other hand, and just as importantly, affordability. In other words, transit riders desire high levels of service quality, in terms of the first three sets of outcomes, but that is also affordable. Whereas service availability depends on the frequency of service, on the hours of available service or service span, and on the accessibility to transit stops or stations (*1*), transit accessibility is essentially the ease of reaching desired destinations where commuters can access jobs, health services, education, and so on, and depends both on transit service quality as well as land use planning, and how well land use is integrated with transit. And while transit riders may be choice riders, who use transit instead of driving a private vehicle, or transit-dependent riders who have no other option but to use transit (*2*), comfort and convenience are important (*3; 4*), and can affect satisfaction and usage for both types of riders (*5; 6*). Comfort can result from the seating (and standing space) availability, which in turn depend on passenger loading and service frequency. Also important in this regard are factors such as waiting and journey time, driver helpfulness, and reliability of the service. Indeed, a large body of evidence based on customer satisfaction surveys reiterates the importance of all of these factors for transit riders (*1; 4; 7; 8*). Finally, affordability of transit fares is crucial, particularly for riders who depend on transit. Indeed, a recent report on the working poor in New York found that fare affordability was the “biggest problem” of the subway system, ahead of delays and crowding (*9*). While studies have examined equity related to fare subsidies (*10; 11*), little research has focused on the financial affordability of public transit, which is an important aspect of public transit accessibility.

From a societal point of view, an important outcome is the extent to which public transit is able to carry people (*12*), and more particularly, the extent to which it is able to replace car trips, thereby contributing to reduced motor vehicular activity, air pollution, energy consumption, and improved road safety. Finally, from the viewpoint of transit agencies, it is important that transit contributes to the outcomes of importance to commuters and society at large, while also being financially viable. This is particularly important since public transit agencies in North America typically face significant funding shortages (*13*). Operating revenue for transit service is derived from a variety of sources, such as government funding, advertisement and other revenues, and importantly, fare revenues. Transit agencies rely a great deal on fares to maintain financial viability; fare revenues contribute up to a third of operating expenses in regions with populations greater than 200,000 people (*14*). Besides, fares have outpaced inflation in the United States between 1989–1994 (*15*). In Canada, limited federal funding means that for transit agencies, operating expenses are mostly covered through provincial funding and locally generated revenues and fares. For example, in Montreal, 41% of the 2016 operating budget of the Société de transport de Montréal (STM) comes from fares, while 34% comes from local and regional governments, and nearly 23% is provided by the provincial government (*16*).

Indeed, urban transit agencies face what might be considered a coverage-service quality-affordability-viability dilemma—that is, a tension exists between the ability of public transit agencies to, on the one hand, provide the coverage and level of service riders expect, and on the other hand, to maintain fares at an affordable level for them, while also being financially viable (*17*). Note in this regard that, because of their significant dependence on transit fares, coupled with their increasing expenditures, transit agencies might face intense pressure to increase fares, but fare increases may particularly burden low-income groups as they rely on public transit as their main mode of transport (*9; 18*).

To summarize, multiple, inter-dependent, and often conflicting objectives and perspectives are involved in relation to public transit, and an intricate balance is needed to reconcile these objectives and perspectives.

Rationale, Objectives and Outline

It would be useful to assess how effectively public transit agencies, and more generally, urban transport systems, address and reconcile the various objectives that we have discussed, that are important to transit users, society and the agencies themselves. Our objective in this paper is to show how a rapid assessment may be conducted in this regard, based on publicly and freely available data reported by public transit agencies, for the largest 14 metropolitan areas in North America with a population of more than three million inhabitants. In particular, we seek to investigate how effectively the public transit systems in our selected cities reconcile the trade-off between accessibility, service frequency, and comfort on the one hand, with affordability of fares on the other, which is important from the transit rider's perspective; and the trade-off between affordability of fares on the one hand, and financial viability on the other, which is important from the transit agency perspective.

Our study has the potential to allow transport planners, researchers, practitioners and interested members of civil society to assess and compare the performance of public transit agencies along multiple dimensions, and from multiple perspectives without the need for costly and proprietary surveys (*19*). However, it should be noted that this paper does not offer a comprehensive evaluation or benchmarking study of transit agencies per se.

In the following section, we discuss our methodology, including how we selected our peer cities and transit agencies for our study; how we constructed our measures to capture key outcomes from the perspective of transit riders, society, and transit agencies; and our data sources, and related issues and challenges. In the third section of the paper, we present and critically discuss our analysis of our results; this section includes a discussion of how we assessed trade-offs between key transit objectives from the above perspectives, in terms of our measures. In the final section, we discuss the implications of our findings, and how our assessment may be improved upon and expanded in future work.

METHODOLOGY, DATA AND ISSUES

First, we limited our analysis to the largest North American cities, with metropolitan populations greater than three million inhabitants, and the main transit service providers in these cities. It is important to note that the population of the core cities themselves may be smaller. We also restricted our analysis to transit agencies that operate at least two modes, namely bus and rail, including light rail, heavy rail (metro or subway), and/or street rail (cable car, streetcar, etc.). Since the main concern of this study is urban transit, we excluded agencies providing commuter rail service only, and therefore, data pertaining to commuter rail for the agencies included in this study. In total, we analyzed data from 14 transit agencies, including two from Canada and 12 from the United States. Table 1 lists, in order of decreasing metropolitan population, the cities and transit agencies examined in this paper.

TABLE 1 Cities and Transit Agencies

Metropolitan area	Core city	Metropolitan population	Transit Agency	Modes
New York-Northern New Jersey-Long Island, NY-NJ-PA	New York	18,351,295	MTA New York City Transit (NYCT)	Heavy rail, bus
Los Angeles-Long Beach-Santa Ana, CA	Los Angeles	12,150,996	Los Angeles County Metropolitan Transportation Authority (LACMTA)	Heavy rail, light rail, bus
Chicago-Joliet-Naperville, IL-IN-WI	Chicago	8,608,208	Chicago Transit Authority (CTA)	Heavy rail, bus
Toronto (Mississauga), ON	Toronto	5,521,235	Toronto Transit Commission (TTC)	Heavy rail, light rail, street rail, bus

Metropolitan area	Core city	Metropolitan population	Transit Agency	Modes
Miami-Ft. Lauderdale-Pompano Beach, FL	Miami	5,502,379	Miami-Dade Transit (MDT)	Heavy rail, bus
Philadelphia-Camden-Wilmington, PA-NJ-DE-MD	Philadelphia	5,441,567	Southeastern Pennsylvania Transportation Authority (SEPTA)	Heavy rail, street rail, bus
Dallas-Fort Worth-Arlington, TX	Dallas	5,121,892	Dallas Area Rapid Transit (DART)	Light rail, bus
Houston-Sugar Land-Baytown, TX	Houston	4,944,332	Metropolitan Transit Authority of Harris County (Metro)	Light rail, bus
Washington-Arlington-Alexandria, DC-VA-MD-WV	Washington	4,586,770	Washington Metropolitan Area Transit Authority (WMATA)	Heavy rail, bus
Atlanta-Sandy Springs-Marietta, GA	Atlanta	4,515,419	Metropolitan Atlanta Rapid Transit Authority (MARTA)	Heavy rail, bus
Boston-Cambridge-Quincy, MA-NH-RI	Boston	4,181,019	Massachusetts Bay Transportation Authority (MBTA)	Heavy rail, light rail, bus
Montreal (Laval), QC	Montreal	3,752,475	Société de transport de Montreal (STM)	Heavy rail, bus
San Francisco-Oakland-Fremont, CA	San Francisco	3,281,212	San Francisco Municipal Railway (SFMTA)	Light rail, street rail, bus
Seattle-Tacoma-Bellevue, WA	Seattle	3,059,393	King County Department of Transportation (King County Metro)	Street rail, bus

Sources: CUTA (*20*); NTD (*21*)

After selecting peer agencies, we next turned to choosing measures to capture the key outcomes from the perspective of transit riders, transit agencies and society. In this regard, note that the multi-criteria decision making (MCDM) approach, which has been used to address a range of complex decision problems in a number of policy contexts, is ideally suited for characterizing and reconciling trade-offs and conflicts among multiple conflicting objectives from the perspective of multiple groups in society that are differentially affected by policy impacts. Particular attention is paid in MCDM to carefully developing measures by means of which to reflect, and to evaluate policy alternatives in terms of, key objectives and outcomes from the perspective of various groups (*22*-*25*). Measures are specified as precisely as possible, to capture the meaning of the related objectives; this task is especially challenging for social impacts as in the present case. Further, note that different measures for the same objective reflect different perspectives, convey different pictures of a given situation, and importantly, have different implications for policy choices and outcomes. While measures should precisely capture the meaning of related objectives, they should at the same time be easily operationalizable, and should be capable of being easily understood by and communicated to decision makers and the general public. Besides, rapid assessments, based on readily available data, as we are attempting in this paper, are very useful for enabling speedy action. In view of these considerations, we now discuss how we constructed our measures to capture key outcomes from the perspective of transit riders, society, and transit agencies, and our data sources, and related issues and challenges.

First, we consider the important outcomes for transit riders—availability and accessibility; frequency and reliability; comfort and convenience; and affordability (p. 9, RPA (*26*)). Unfortunately, reliable and comparable data to capture accessibility, and frequency and reliability, are extremely difficult to obtain or to generate for all of the metropolitan areas that we have chosen for this paper; these measures will need to be developed in the future. For instance, while frequency and reliability (related to waiting time) are two chief concerns of transit riders (*3*), and are tracked by many agencies (*27*-*29*), transit agencies do not use an uniform measure of reliability, thus making comparisons across agencies difficult. For our analysis, we have therefore used publicly available data to estimate accessibility, service frequency, comfort, and affordability, as best as possible.

Accessibility measures provide a good indication of the potential ability to reach desired destinations, like jobs, health services, or schools, based on the service characteristics of the mode in question, and land use (*30; 31*). For our study, we used employment-related accessibility measures to jobs by computing the average number of jobs reachable by public transit within a 30-minute travel time threshold (weighted by the number of workers in each census tract or block), and averaged over the metropolitan region. These measures were drawn from the *Access Across America* report (*32*) for the American cities, and from previous work (*33; 34*) for the Canadian cities. Note that, because of different geographical scales and methods (average accessibility over 7–9 a.m. for American cities vs. accessibility at 7 a.m. for Canadian cities), and since these measures encompass all transit modes (including commuter rail), the accessibility measures likely overestimate the accessibility of the particular agencies examined here. Regardless, they provide a useful comparison. Note also that accessibility data from Owen and Levinson (*32)* were calculated using all the public transit agencies in their respective regions; we assume that the agencies analyzed in our study, being the main agencies in each of our selected cities, likely contribute the greatest to the accessibility measures used.

To approximate service frequency, we downloaded General Transit Feed Specification (GFTS) data for all agencies for a date in fall 2014 in order to avoid summer or winter holiday scheduling, and then calculated scheduled headways. Headways for all modes operated (≥60 s) were calculated at the stop-level for stops scheduled from 8:00 a.m. to 8:59 a.m. and from 9:00 p.m. to 9:59 p.m. for weekdays. Next, 500 random headways (or fewer if 500 stops were not made) were extracted for the two time periods and the average headway was calculated for each city. While the headway values are approximations of actual headways, they nevertheless may provide an indication of service frequency (and indeed, service availability) at two different times of the day. Also, note that, while we have averaged the headways for the two time periods, one could apply different relative weights to them, to reflect the importance to be attached to service frequency during these two time periods.

As for comfort and convenience, load factor—the ratio of passenger kilometres to carrying capacity kilometres, expressed as a percentage, with capacity kilometres being obtained by multiplying the total seating and standee capacity of all buses by the kilometres operated—would be a good measure for this purpose. Unfortunately, load factor data, or even the total capacity on the transit fleet, is not available for the various agencies in North America. So we chose to estimate a proxy measure of crowding (and thus, the space available, and comfort and convenience for commuters) on transit, by means of the ratio of passenger kilometres to revenue kilometres, taking into account all relevant transit modes. Note that, while from a rider perspective, a greater value of this ratio is undesirable since it indicates less room on transit, a high figure might be good from the agency perspective.

Affordability studies of public transit have been scarce. In a Word Bank publication, Carruthers, Dick and Saurkar (*35)* derived a simple and useful metric to assess transit affordability. They assume 60 ten-kilometre trips (single fares) per month per person, and they then compute an "affordability index" as the percentage share accounted for by the total fare for these trips, relative to the average annual per capita income of a city. On this basis, they determined that residents of Latin American cities spend, on average, between 4–11% of annual income on transit, while residents of Western cities spend, on average, less than 5%. They also repeated this exercise for the bottom quintile earners and found that, whereas such residents in Western cities spend upwards of 10% of their annual income on transit, this share is higher than 25% for their counterparts in Latin American cities (*35*). Recent work has used Gini coefficients based on the cumulative distribution of transport benefits to determine how different groups, such as students or the elderly, benefit or lose based on different subsidy policies for transit fares (*10*). Nonetheless, deciding upon an acceptable level of income devoted to transport is not trivial (*36*).

Whereas the study by Carruthers et al. (*35*) provided a snapshot of the proportion of income dedicated to transit for the average residents (and residents in different income groups) of various cities, we are interested in determining the affordability for transit-dependent riders, in particular those who earn a minimum wage. These residents would likely rely on public transit (*18*), and we assumed that a monthly pass would be the most frugal fare to purchase, especially if they commuted daily, as well as to enable comparability between agencies. Thus, we used the monthly fare and minimum wage in local currency (in 2014), and developed an affordability measure to express the number of minimum wage hours needed to purchase a one-month unlimited fare (by dividing the fare by the hourly minimum wage). Taxes on the fare and on income were not included in the calculations.

For society as a whole, as discussed earlier, an important outcome is the extent to which transit agencies are able to carry people, as a proportion of the total population, but more particularly, the extent to which they are able to replace car trips. So, an ideal measure for this purpose would be total transit trips divided by the product of the population in the service area and the car ownership rate. However, since car ownership rate is not available for all of the cities in our analysis, we used total unlinked transit trips divided by the service area population as our measure. Finally, the measure we chose to capture the key outcome from the agency's perspective is the farebox recovery ratio (FRR)—that is, the share of operational costs recovered through farebox revenues.

All data except for headways were acquired through the National Transit Database (NTD) and the Canadian Urban Transit Association (CUTA) for the American and Canadian transit agencies, respectively (*20; 21*). Data were collected disaggregated by mode to avoid including statistics for modes other than bus, heavy rail (metro or subway), light rail, and/or street rail; data for these modes were then summed. Minimum wages for American cities were acquired through a website listing wages by city and state (*37*), and verified by checking with other sources, while Canadian minimum wages were acquired through a Canadian government website (*38*).

We normalized the values of each measure for each agency, by using the form of a single attribute utility function in MCDM and by assuming linearity of this function over its range (*39*), with the values of the resulting indices for the various agencies for each measure falling between zero (0) and one (1), for the worst and best performing agencies respectively on that measure. So, in the case of the *accessibility index*, the greater value between 0 and 1, the greater the number of jobs accessible by transit within a 30-minute travel time threshold. The *headway index* was generated by summing the normalized values of the headways at 8 a.m. and 9 p.m. for each city and agency, and then dividing by two and rescaling; a larger value of this indicator indicates shorter headways. Similarly, the larger the value of the *comfort index* between 0 and 1, the lower the passenger kilometres relative to revenue kilometres, and more space for riders on transit. A composite *service quality index* was constructed by summing the accessibility, headway and comfort indices, and dividing by three, and finally rescaling. We also computed an overall *rider satisfaction index*, which integrated the accessibility, headway, comfort and affordability indices, along the same lines. Note that in calculating these composite indices, the accessibility, headway, comfort and affordability indices were weighted equally; different relative weighting schemes could be applied, depending on the importance attached to each of these objectives from the perspective of riders. A higher value of the *society index* indicates a higher level of total unlinked transit ridership relative to the service area population, and therefore, a potentially larger substitution of car trips, with its attendant benefits in terms of, among other things, congestion, air pollution and safety. A higher value of the *agency index* indicates a higher FRR, and thus a greater level of the transit agency's financial viability.

For some of our analysis, we combined the measures, in order to account for the multiple objectives represented by these measures in an integrated manner—so, for example, in the case of transit riders, measures related to accessibility, headway (frequency), comfort, and affordability were combined. In Tables 2 to 5 in the Results and Discussion section below, we show the individual measures computed for all the agencies in our study, and the related normalized indices. Also included are the combined indices that we constructed, which we discuss in that section. Finally, note that, in our graphs in the Results and Discussion section, we plot the normalized indices.

RESULTS AND DISCUSSION

Transit Rider Perspective

Table 2 lists the values of the accessibility, headway and comfort measures, and the related normalized indices, which we computed as discussed in the previous section, for the various cities and their transit agencies in our study. We also show the composite service quality index, which is a re-scaled unweighted average of the accessibility, headway and comfort indices, for each city and transit agency. Finally, note that we have listed the cities from best to worst performing in terms of the service quality index.

TABLE 2 Transit Rider Measures and Indices

City	Transit agency	Annual ridership (unlinked trips, '000)	Average accessibility (jobs)	Accessibility index (*a*)	Average 8 a.m. headway (min)	Average 9 p.m. headway (min)	Average headway (min)	Headway index (*b*)	Average pass. km/rev. km	Comfort index (*c*)	Service Quality Index -- Re-scaled value of (*a*+*b*+*c*/ 3)
New York	NYCT	3,631,168	210,186	1.00	8.55	13.86	11.20	0.73	28.53	0.00	1.00
Chicago	CTA	514,216	48,116	0.20	8.84	13.57	11.20	0.73	17.31	0.62	0.81
Toronto	TTC	534,815	60,676	0.26	5.80	7.48	6.64	1.00	23.48	0.28	0.81
San Francisco	SFMTA	155,317	65,246	0.29	9.06	13.77	11.42	0.71	21.94	0.36	0.61
Boston	MBTA	359,715	49,237	0.21	8.18	14.39	11.29	0.73	20.89	0.42	0.61
Philadelphia	SEPTA	301,146	35,317	0.14	8.99	19.57	14.28	0.56	16.85	0.65	0.60
Houston	Metro	72,694	15,166	0.04	15.24	21.85	18.55	0.28	10.47	1.00	0.57
Seattle	King County Metro	101,352	26,141	0.09	13.04	17.38	15.21	0.48	15.11	0.74	0.56
Montreal	STM	417,219	70,683	0.31	8.79	12.97	10.88	0.75	23.94	0.25	0.56
Miami	MDT	99,108	15,333	0.04	10.87	17.96	14.43	0.54	16.55	0.66	0.49
Washington, D.C.	WMATA	409,197	47,759	0.20	13.94	20.20	17.07	0.37	17.08	0.63	0.45
Dallas	DART	66,841	10,113	0.02	19.89	26.22	23.05	0.00	10.97	0.97	0.23
Los Angeles	LACMTA	466,659	43,430	0.18	12.72	18.86	15.79	0.45	22.26	0.35	0.22
Atlanta	MARTA	128,539	6,995	0.00	20.90	20.77	20.84	0.12	16.72	0.65	0.00
Average		–	50,307	–	11.78	17.06	14.42	–	18.72	–	–
Standard deviation		–	50,480	–	4.48	4.72	4.43	–	5.05	–	–
Coefficient of variation		–	1.00	–	0.38	0.29	0.31	–	0.27	–	–

Sources: GTFS; CUTA (*20*); NTD (*21*)

Transit accessibility to jobs, as we discussed in our introduction, depends on transit service quality as well as land use planning (in terms of the population and employment densities in the service area, and where people live relative to where they work), and how well land use is integrated with transit. New York offers by far the highest transit accessibility to jobs of all the cities, with Montreal a distant second, with an accessibility index of 0.31 relative to New York's 1.0. All the other cities in our study have accessibility indices lower than Montreal's, with Atlanta offering the lowest accessibility to jobs in the cohort. As for headways, they are unsurprisingly shorter in the morning peak than in the evening hours. However, note that the TTC in Toronto offers the shortest headways during both time periods, as well as the smallest variation between the headways in these time periods, of all the transit agencies. MARTA in Atlanta and DART in Dallas have the longest headways during the morning peak and the off-peak evening hours respectively (Table 2), and these agencies have the lowest headway indices. Short headways have the potential to contribute to space availability and comfort for riders on transit; however, and interestingly, most of the agencies with short headways perform poorly in terms of passenger comfort, measured in terms of the ratio of passenger-kilometres to revenue kilometres, because of the high ridership levels carried by these agencies. Indeed, while NYCT, STM and TTC (in New York, Montreal and Toronto) offered the shortest headways (and had the highest headway indices), they had the highest levels of passenger kilometres per revenue kilometres (and correspondingly, the lowest comfort indices). Meanwhile, Metro, DART, and MARTA, which have the longest average headways, also carry—along with MDT in Miami—the fewest passenger kilometres relative to revenue kilometres, and have the highest comfort indices. This situation is likely due to the fact that, because of their poor service frequency (and accessibility), the service provided by these agencies is not popular with commuters, as reflected in the fact that the same agencies have the lowest ridership levels per capita (Table 5); and so, the few commuters who do use their service have a high level of space available (and comfort) on transit.

As noted, Table 2 lists the transit agencies from the best to the worst performing in terms of the composite service quality index, which is a re-scaled unweighted average of the accessibility, headway and comfort indices. NYCT, the CTA, and TTC (in New York, Chicago and Toronto) are the top performing agencies, while MARTA, LACMTA, and DART (in Atlanta, Los Angeles and Dallas) are the worst performing ones, in terms of this index.

TABLE 3 Transit Agencies, Fares, Minimum Wages, and Affordability

City	Transit agency	Monthly fare ($) (*a*)	Hourly minimum wage ($) (*b*)	Hours to purchase fare (*a*/*b*)	Affordability index
San Francisco	SFMTA	68.00	10.74	6.33	1.00
Montreal	STM	79.50	10.35	7.68	0.93
Los Angeles	LACMTA	75.00	9.00	8.33	0.89
Seattle	King County Metro	81.00	9.32	8.69	0.87
Boston	MBTA	75.00	8.00	9.38	0.84
Dallas	DART	80.00	7.25	11.03	0.75
Chicago	CTA	100.00	8.25	12.12	0.69
Toronto	TTC	133.75	11.00	12.16	0.69
Houston	Metro	90.00[a]	7.25	12.41	0.67
Philadelphia	SEPTA	91.00	7.25	12.55	0.67
Atlanta	MARTA	95.00	7.25	13.10	0.64
New York	NYCT	112.00	8.00	14.00	0.59
Miami	MDT	112.50	7.93	14.19	0.58
Washington	WMATA	237.00[b]	9.50	24.95	0.00
			Average	11.92	
			Standard deviation	4.48	
			Coefficient of variation	0.388	

[a] The Houston transit agency does not have a monthly fare, so the maximum daily unlimited fare ($3.00) was simply multiplied by 30 days. [b] While WMATA has an array of monthly fares available by mode, maximum price of a trip, etc., this fare was chosen to be comparable with other agencies, i.e., offering unlimited travel for a 30-day period. Sources: APTA (*40)*; Canada (*38)*; Dolye (*37)*

Next, in Table 3, we report, for each agency, the cost of a monthly transit fare, the hourly minimum wage, the number of hours of minimum wage work needed to purchase the monthly transit fare, and finally, a normalized affordability index (the agency with the fewest hours needed to afford its monthly fare has an index of 1, and the agency with the highest hours for this purpose an index of 0). The transit agencies that are the most affordable for minimum wage earners (and therefore have the highest affordability indices) are the SFMTA, the STM, and the LACMTA (in San Francisco, Montreal and Los Angeles). The least affordable agencies—those with fares that require most hours of minimum wage work—and therefore the agencies with the lowest affordability indices, are WMATA, MDT, and NYCT (in Washington, DC, Miami and New York).

TABLE 4 Ranking of Agencies on Service Quality Index versus Rider Satisfaction Index

City	Transit agency	Rider Satisfaction Index	Service Quality Index
San Francisco	SFMTA	1.00	0.61
New York	NYCT	0.97	1.00
Montreal	STM	0.90	0.56
Chicago	CTA	0.90	0.81
Toronto	TTC	0.89	0.81
Boston	MBTA	0.86	0.61
Seattle	King County Metro	0.84	0.56
Philadelphia	SEPTA	0.71	0.60
Houston	Metro	0.68	0.57
Los Angeles	LACMTA	0.58	0.22
Miami	MDT	0.53	0.49
Dallas	DART	0.47	0.23
Atlanta	MARTA	0.18	0.00
Washington, D.C.	WMATA	0.00	0.45

Next, we constructed, in addition to the service quality index, which incorporates the accessibility, headway and comfort indices, an overall rider satisfaction index, which integrates the affordability index in addition to the accessibility, headway and comfort indices. Whereas Table 2 lists the agencies in the order of decreasing service quality index, Table 4 shows both the service quality and rider satisfaction indices for all the agencies, and lists them in terms of decreasing overall rider satisfaction index. The rankings of the agencies changes, in some cases significantly, when affordability is also accounted for, relative to their rankings in terms of only the service quality index. The rider satisfaction index shown in Table 4 was computed with the accessibility, headway, comfort and affordability indices weighted equally; we also computed the rider satisfaction index as the re-scaled average of the service quality index and the affordability index. In the latter case, the relative weight accorded to affordability in the rider satisfaction index is ½, as opposed to ¼ in the previous case; but the rider satisfaction indices—and the relative rankings—for the various agencies remain essentially the same. For this reason, we show only the rider satisfaction index computed as the re-scaled average of the accessibility, headway, comfort and affordability indices in Table 4.

Society Perspective

An important outcome from a societal perspective, as we discussed, is the extent to which public transit carries people, and more particularly, replaces car trips, thereby contributing to reduced motor vehicular activity, air pollution, energy consumption, and improved road safety. As we explained in our methodology section, we used total unlinked transit trips divided by the service area population as our measure to assess this outcome. Table 5 (left) lists the various transit agencies in decreasing order of ridership per capita and the related normalized society index. The highest ranked agencies are NYCT, STM and TTC, in New York, Montreal and Toronto, and the lowest ranked are in Houston, Dallas, Miami, Seattle and Los Angeles, historically car-dependent cities. Transit in Los Angeles has low per capita usage though it is the third most affordable agency for minimum wage earners, and despite transit investment and rail expansion (*41; 42*). This situation is likely related to the city's poor transit accessibility to jobs, and LACMTA's long headways. Indeed, there appears to be a strong correlation between ridership per capita on the one hand, and job accessibility and headways on the other, and to a much lesser extent, with affordability, and passenger comfort (note that, as we discussed earlier, the agencies with the highest ridership levels are generally also the least comfortable in terms of space availability on transit). Finally, it is worth noting that high transit ridership per capita is dependent not only on high accessibility and transit service features such as short headways and affordability, but also importantly on transport demand management policies such as, for example, parking control and pricing.

TABLE 5 Ridership per capita, Society Index, FRR and Agency Index

City	Transit agency	Ridership per capita	Society Index	Transit agency	FRR	Agency Index
New York	NYCT	427.65	1.00	TTC	0.71	1.00
Montreal	STM	215.28	0.48	STM	0.56	0.75
San Francisco	SFMTA	192.88	0.42	NYCT	0.51	0.67
Toronto	TTC	190.43	0.42	WMATA	0.48	0.62
Chicago	CTA	150.09	0.32	CTA	0.44	0.55
Washington	WMATA	110.01	0.22	MBTA	0.40	0.49
Philadelphia	SEPTA	89.76	0.17	SEPTA	0.36	0.41
Boston	MBTA	86.04	0.16	King County Metro	0.33	0.36
Atlanta	MARTA	79.71	0.14	MARTA	0.31	0.33
Los Angeles	LACMTA	54.09	0.08	MDT	0.28	0.27
Seattle	King County Metro	49.57	0.07	SFMTA	0.26	0.25
Miami	MDT	39.70	0.05	LACMTA	0.25	0.23
Dallas	DART	27.42	0.02	DART	0.15	0.06
Houston	Metro	19.67	0.00	Metro	0.12	0.00
	Average	123.74	–		0.37	–
	Standard deviation	108.45	–		0.16	–
	Coefficient of variation	0.88	–		0.44	–

Sources: CUTA (*20*); NTD (*21*)

Transit Agency Perspective

We used the farebox recovery ratio (FRR)—the share of operational costs recovered through farebox revenues—to assess the financial viability of transit agencies, which is of course an important objective from their perspective, but also from the point of view of its ability to continue to provide quality service to commuters, and to contribute to societal objectives over the long term. Table 5 (right) lists the transit agencies in decreasing order of FRR and the related normalized agency index. Interestingly, TTC and STM, the two Canadian agencies in our study, are the best performing in this regard, recovering 71 and 56% of their operational costs respectively through their fare box revenues. NYCT is close in third place at 51% recovery. The worst performing agencies are again in the southern American cities, including Houston, Dallas, Los Angeles, Miami and Atlanta. Indeed, funding for Metro (in Houston) comes largely through sales tax revenue (*43*). The agencies with high FRRs are those with high ridership, and in turn, as we saw earlier, good accessibility and short headways, but not necessarily the highest fares. While TTC is in the middle for affordability, STM, which has the second highest FRR, is also the second most affordable, while NYCT and WMATA, which have the third and fourth best FRRs, respectively, are among the most expensive agencies for minimum wage earners. So, while ridership and fares are important, FRR also depends on how well operational costs are managed, in which case a high FRR may be achieved even with affordable fares, as in the STM case. At the same time, an agency can have a poor FRR even with high ridership levels, if its fares are low, as in the case of San Francisco, which has the most affordable fares. Finally, if ridership is low, a high or reasonable FRR will need to depend on high fares; but there are agencies like Houston, Miami and Atlanta, which have low FRRs, even with high fares.

Key Trade-offs from the Rider, Society and Agency Perspectives

After having presented and discussed the measures that we have computed to capture the key outcomes from the perspective of riders, transit agencies, and society at large, we now consider how effectively the public transit systems in our selected cities reconcile the trade-offs between these objectives from these different perspectives. Specifically, we assess the trade-offs between service quality, incorporating accessibility, service frequency, and comfort on the one hand, with affordability of fares on the other, which is important for transit riders; between transit ridership per capita and fare affordability, which reflects the society perspective; and between financial viability and affordability of fares, which is important for transit agencies.

To this end, we first plot—in Figure 1a—the service quality index (which is the re-scaled average of the accessibility, headway and comfort indices—see Table 2) against the affordability index, which represents affordability of fares for minimum wage earners. In order to facilitate interpretation of this and all the other plots, we have clearly indicated the nature of the trade-offs in the corner of each quadrant of the plot. Note also that in all of the figures, the marker sizes represent unlinked passenger trips to provide an understanding of the volume of passengers handled by each transit system. Figure 1a represents in an integrated way the trade-off between all of the key outcomes for transit riders, who desire service quality that is also affordable. Figures 1b and 1c plot the society index (based on ridership per capita) versus the affordability index, and the agency index (based on FRR) against the affordability index, so that one may view and consider the trade-offs from the perspectives of riders, transit agencies, and society at large in a consolidated way in Figure 1.

While the bulk of the agencies are placed in the top right-hand quadrant of Figure 1a, indicating that they provide reasonably good service quality at affordable fares for minimum wage earners, the transit agency in San Francisco, being placed closest to the top right hand corner in the plot, offers the best "value for money" in terms of reconciling the trade-off between service quality (which incorporates accessibility, service frequency and passenger comfort) on the one hand, and affordability of fares on the other. It is followed in this regard by the agencies in Montreal, Boston, Seattle, Chicago, Toronto and New York. Note that, although NYCT in New York is the best on service quality (with a service quality index of 1.00), its affordability index is the third worst, after Washington, DC and Miami). Meanwhile, the agencies that offer the least "value for money"—in terms of reconciling the trade-off between service quality and affordability—are in Washington, DC (which is placed at the far left of Figure 1a), followed by Atlanta, Dallas, Los Angeles, Miami and Houston, all of them highly car-dependent cities.

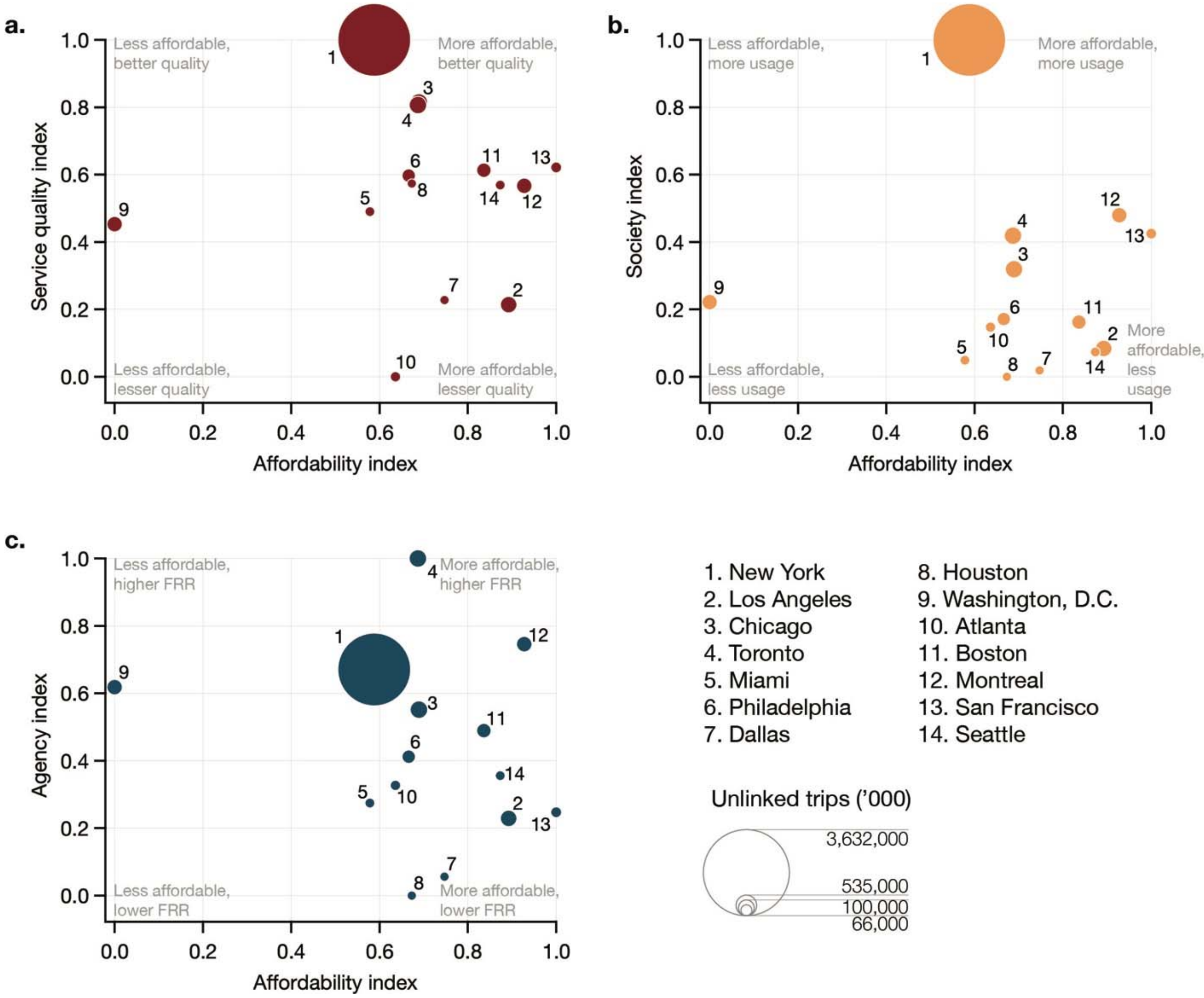

FIGURE 1 Service quality, society, and agency indices plotted against the affordability index.

From the societal viewpoint, as we discussed, it is important for transit to maximize ridership per capita, while keeping fares as affordable as possible, particularly for minimum wage earners. Figure 1b shows how effectively various transit agencies reconcile these objectives. First, note that most of the agencies are bunched together in the lower-right quadrant, indicating that, while they are reasonably affordable, they also attract a low ridership per capita. Although of course NYCT in New York has the highest ridership per capita and TTC in Toronto has the third highest ridership per capita, they also have high fares, as a result of which STM in Montreal—being the agency with the second-most affordable fares, and second highest in ridership per capita—is better than both, and is indeed the best agency, in reconciling the trade-off between ridership per capita and affordability. Following STM, TTC and NYCT in this regard is the agency in San Francisco, with Chicago being quite a bit behind these agencies. Yet again, the worst agencies in terms of providing "value for money" from the societal perspective are in Washington, DC, followed by those in Miami, Houston, Dallas and Atlanta.

Finally, Figure 1c shows how the various agencies performed in terms of achieving a high FRR while keeping fares as affordable as possible. The best agencies from this perspective, as judged by their proximity to the top right-hand corner of the plot, are STM in Montreal (which is the second best agency both in terms of FRR and fare affordability), followed by those in Toronto (which has the highest FRR but the eighth most affordable fare of all agencies), Boston, Chicago and New York. The worst agencies in reconciling this trade-off are those in Washington, DC (the least affordable agency), Houston, Dallas, Miami, and Atlanta. Whereas the STM in Montreal stands out as being financially viable even though it offers the second most affordable fare for minimum wage earners, the agencies in Houston, Dallas, Miami and Atlanta in particular, but also Washington, have low FRRs, despite charging high, unaffordable fares; TTC and NYCT in particular, but also CTA in Chicago charge high fares in order to maintain a relatively high FRR; and Los Angeles and San Francisco's agencies offer affordable fares, but also have low FRRs.

Overall, it appears that those cities and agencies that perform well in terms of providing transit accessibility to jobs—which in turn is a function of population and employment densities in the service area, and therefore the ability of public transit to serve a large number of commuters with a given fleet—are also those that can provide transit service with short headways. Together with other travel demand management policies that can be applied, renders transit attractive to commuters, and leads to high levels of rider satisfaction, and ridership, even though comfort levels may not be high, and in some cases, even with high fares. On the other hand, those cities and agencies that provide low transit accessibility to jobs—which in turn is a function of low population and employment densities in the service area, and therefore the inability of public transit to serve a large number of commuters with a given fleet—are also those that are unable to provide transit service with low headways, which renders transit unattractive to commuters, and leads to low levels of rider satisfaction (despite, as in the case of Houston, Dallas and Miami, high comfort levels), and ridership.

Overall Transit Performance from Multiple Perspectives

In the previous section, we discussed how effectively the public transit systems in our selected cities reconcile trade-offs between the key outcomes from the perspective of riders, transit agencies, and society at large. In this last section of our paper, we present an assessment of the overall performance of transit in these cities, considering these different perspectives in an integrated manner. First we plot the re-scaled value of the average of the service quality, society and agency indices against the affordability index, representing affordability of fares for minimum wage earners in Figure 2. STM in Montreal—followed by TTC, NYCT, CTA (in Chicago) and SFMTA (in San Francisco)—offer the best compromise between service quality, society and agency indices taken together (on the y-axis) and affordability of fares for minimum-wage earners on the other hand. The agencies that perform the worst in this regard are those in Washington, DC, followed by those in Atlanta, Dallas, Houston and Miami.

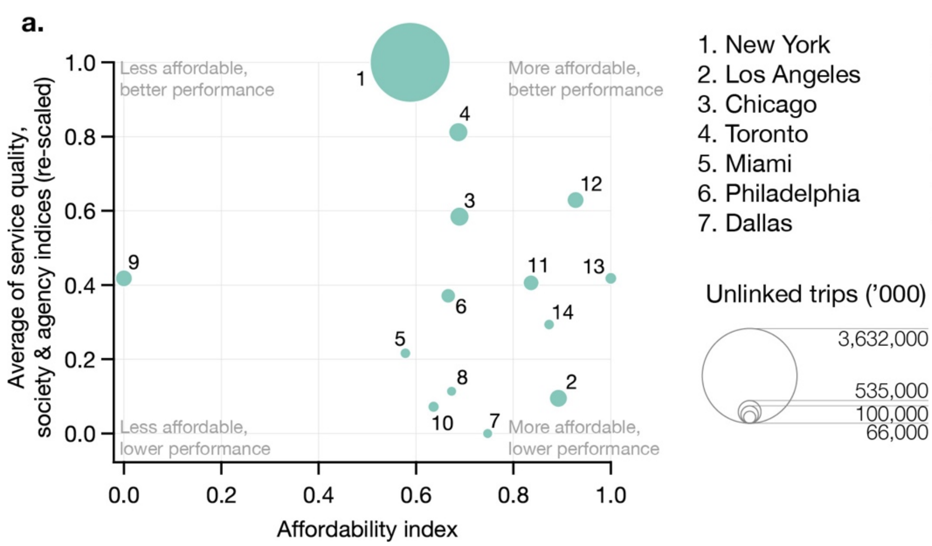

FIGURE 2 Average of service quality, society and agency indices plotted against the affordability index.

CONCLUSIONS AND RECOMMENDATIONS

We have demonstrated a rapid assessment of how public transit agencies achieve key outcomes, and reconcile trade-offs among these outcomes, from the perspective of transit users, society and the agencies themselves, for the largest 14 cities in North America with a population of more than three million inhabitants. This study will hopefully help transport planners, researchers and practitioners to build on our framework, to conduct such assessments without the need for expensive surveys.

While we employed simple metrics to capture key outcomes from the perspective of transit users, society and the agencies, based on publicly and readily available data, it would be desirable to develop better and more nuanced measures. So, for example, transit accessibility could be assessed not only to jobs but also to other essential services. While we used headways as a proxy measure for the purpose, frequency and reliability could be measured, taking into account the multiple dimensions of these factors. Load factor could be used as a measure of on-board comfort, as well as an indicator of agency viability. The ridership per capita measure we used to capture transit objectives from the societal perspective could be refined and expanded to better capture the car trips that are replaced, and the associated impacts, including those related to safety, congestion and pollution, that are avoided. Finally, equity objectives along multiple dimensions, in terms of, for example, service quality and affordability for different groups, could also be incorporated in the assessment.

As well, it would be desirable for metrics to be assessed uniformly and reported regularly across transit agencies, in order to enable their performance to be reliably tracked and compared over time. Unfortunately, metrics go unreported or are non-standard across the industry. Take, for example, reliability, which is defined by different agencies as on-time performance, excess wait time, or headway adherence, among others (*1; 44*). Clearly, standardization and regular reporting is essential for proper assessments of transit performance.

As for the key objective of affordability: using the hourly minimum wage and the cost of an unlimited monthly fare, we calculated the amount of work hours necessary to afford this fare, as a simple measure. Previous work has used single fares to estimate affordability, on the grounds that this fare is the most accessible to low-income individuals (*35*). Without knowing the total salary of minimum wage earners, it is hard to gauge what is an acceptable number of hours devoted to earning a transit fare. Nevertheless, transit fares are a chief concern of the working poor, particularly given the low minimum wages in many American cities. In some cities, such as Seattle and San Francisco, financial subsidies are available to low-income earners and may be a suitable strategy for improving public transit affordability (*9*).

We used data from a single year in our study. Building on the measures and indices we have developed, future studies could evaluate whether agencies are improving or worsening, and how these changes affect outcomes like service quality, affordability and overall transit performance over time. In 2015, Metro in Houston reviewed their bus network and are now running new bus routes with greater frequencies (*45*). Houston's ranking in our study could change depending on whether these new routes and service adjustments improve the accessibility and headway indices, among others. Such cases demonstrate the usefulness of our framework, and the need to study changes in transit performance over time.

Finally, it would be desirable to better understand how transit riders and decision makers weigh the relative importance of key objectives and sub-objectives, and to incorporate this understanding in assessments of transit performance. For example, while accessibility, service frequency, comfort and affordability are important from the perspective of riders, different riders value these objectives differently; transit-dependent or captive riders are influenced less by comfort (*2*), but affordability can be a major concern (*9*). Therefore, surveying transit riders can help weigh—and indeed, identify—objectives relevant to particular rider segments. Similarly, it would be useful to survey decision-makers and transit agency representatives to understand their objectives, and how they weigh them.

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