Trends in transit accessibility and network performance in four North American cities during the 2010s

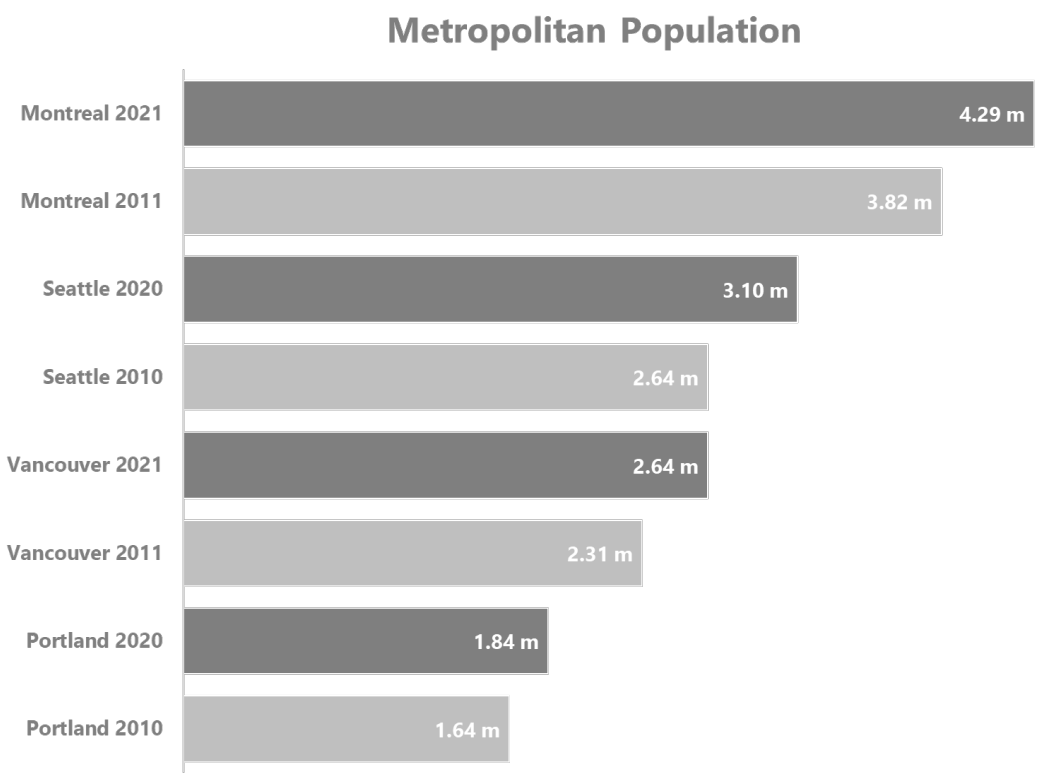
by Jan Scheurer, June 2025
with Craig Townsend

The Spatial Network Analysis for Multimodal Urban Transport Systems (SNAMUTS) team conducted field research in North American cities twice: In 2012, we first analysed two Canadian (Montreal, Vancouver) and two US cities' (Seattle, Portland) land use-transit systems, to form part of the 30-city global SNAMUTS suite and documented in our 2016 book, Planning for Public Transport Accessibility. In 2024 as part of an informal collaboration of RMIT University (Melbourne/Barcelona) and Concordia University (Montreal), we returned to update our network analyses to include recent changes to public transit infrastructure and service configurations in these four cities, incorporate more recent spatial data on the distribution of residents and jobs from the 2020 (USA) and 2021 (Canada) census, and also expand the North American SNAMUTS sample to Toronto. Simultaneously, the existing 2012 analysis was updated to reflect the latest methodological adjustments to the SNAMUTS tool for better year-on-year and international comparability. Findings presented in the following may thus differ from those published on previous occasions in some cases.

This blog post will present the longitudinal results (2012-2024) for Montreal, Portland, Seattle and Vancouver, highlighting how public transit accessibility, understood as the interplay of transit service levels, network configuration and the land use system, evolved in the four cities over the intervening 12 years. At a later stage, we also plan to publish a specific blog post on Toronto, where a large-scale program of transit infrastructure expansion is under way and might see its first substantial openings in 2025.

Population size and growth trends

The four North American case study cities are of different sizes, but each subject to significant population growth over the decade of the 2010s (12% in Montreal and Portland, 14% in Vancouver and 17% in Seattle). The metropolitan area definitions used for the SNAMUTS analysis are as follows: in Montreal and Vancouver, they refer to the extent of Statistics Canada's census metropolitan areas (note, however, that this definition expanded slightly between the 2011 and 2021 census years in Montreal after the inclusion of the town of Saint Jean sur Richelieu). In Portland, the metropolitan area extends to the counties of Clackamas, Multnomah and Washington; in Seattle, to the counties of King and Snohomish. It is acknowledged that significant commuting relationships to and from counties beyond these defined limits exist in the US cities; however, the associated links were not served by public transit that meets the SNAMUTS minimum service standard (see below) in either 2012 or 2024.



Urban intensification around transit

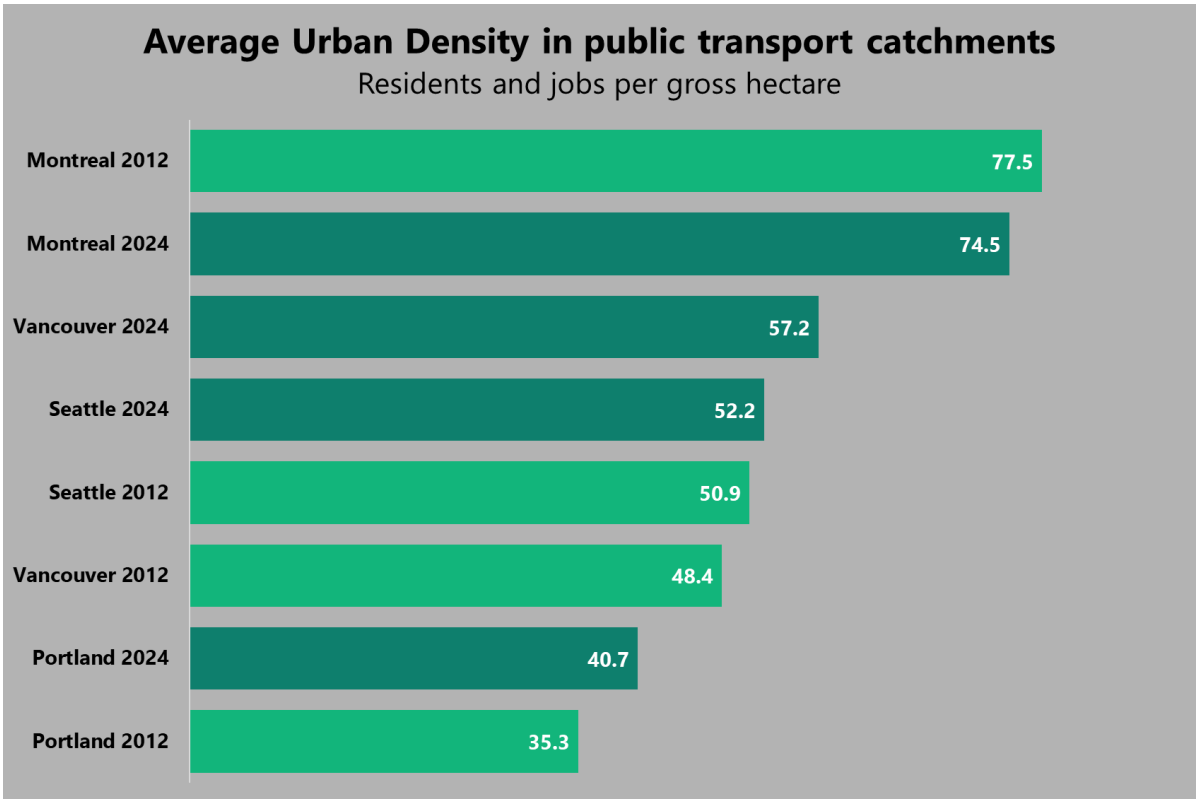
The four North American cities do not only differ in size, but also in urban form and its evolutionary trajectory around public transit. In Montreal, those parts of the settlement area that are within walking distance to public transit (defined as an 800-metre/½-mile radius around rail stations and ferry terminals, and a 400-metre/¼-mile corridor along bus and streetcar lines) are typically characterised by a much higher urban density (residents and jobs per hectare) than their counterparts in the three western cities. However, between 2012 and 2024 average densities around transit declined in Montreal, not necessarily because of net losses of population and jobs in specific areas but because transit service levels changed: in some higher-density neighbourhoods in the core city, bus service frequencies were cut below the SNAMUTS minimum standard while in some lower-density suburban areas, it was improved to now meet this standard (more on this effect in the next section).

In Vancouver, a substantial increase in average urban densities around public transit is on record for the 2012-24 period, alongside smaller similar trends in Portland and Seattle. Seattle's small increment in average densities is influenced by a quite generous expansion of the transit network at the SNAMUTS minimum standard into lower-density suburban areas during those years (see below), though in more modest terms, the same is also true for Portland and Vancouver.

The metropolitan average figures conceal some underlying trends in urban form that become clearer when looking at different parts of the settlement areas, or pinpointing neighbourhoods with particular density characteristics. All four North American cities can be divided into a core municipality and the outer metropolitan region surrounding it, though at varying proportions: the core municipality of Montreal contains 41% of the total metropolitan population and that of Portland 34%, while those of Vancouver and Seattle only contain about 25%. We would expect the core municipality to have higher average densities than suburban areas, but how did these figures evolve in each city between 2012 and 2024 and when looking only at those neighbourhoods that are

within walking distance from transit at the SNAMUTS minimum standard? In Portland, average core municipality density around transit grew from 37 to 46 residents and jobs per hectare (15 to 19 per acre) during this period; for areas outside the core municipality, the figures are 30 and 33 per hectare (12 and 14 per acre) respectively. In Seattle, average core municipality density increased at a much higher level, from 63 to 68 residents and jobs per hectare (26 to 28 per acre), while outside the core municipality values shifted within a range closer to that known from Portland (37 to 41 per hectare or 15 to 17 per acre). In Vancouver, transit catchments grew from 77 to 84 residents and jobs per hectare in the core municipality and from 36 to 47 outside of it. Montreal recorded a density increase from 91 to 99 residents and jobs per hectare in transit catchments in the core municipality, and a slight drop from 40 to 39 in suburban areas.

There is thus a clear intensification trend around transit in all four cities, but there is also a significant difference in typical urban form between core municipality and suburbs in Seattle, Vancouver and Montreal. In Portland, average densities associated with outer metropolitan areas in the three other cities appear to also prevail in the core municipality. This contrast becomes even clearer by using another metric: how many residents and jobs per metropolitan area are located in transit catchments above a specific threshold density, such as 100 activities per hectare (40 per acre) which could be considered a rough minimum for an urban precinct that generates a critical mass of both transit usage and all-day pedestrian activity at the local scale? In Portland, this share grew at a quite marginal level from 5.4% of all metropolitan residents and jobs in 2012 to 6.0% in 2024. In Seattle, it surged from 10% to 17% during this period, reaching similar levels to Vancouver (where it grew more modestly from 15% to 17%) and Montreal (where it hovered around the 19% mark in both years).



[Note that these comparisons, both at metropolitan and local catchment level, are based on shifting network configurations and statistical boundaries and thus do not necessarily contrast identical land areas for the different base years.]

Download SNAMUTS network diagrams: Urban Density			
Montreal 2012	Portland 2012	Seattle 2012	Vancouver 2012
Montreal 2024	Portland 2024	Seattle 2024	Vancouver 2024

[Note that density maps for Portland and Seattle are also available in residents and jobs per acre on the SNAMUTS website]

Service intensity: What resources are provided for transit operation?

The service intensity indicator measures the extent of operational input into the transit system at the SNAMUTS minimum standard (every 20 minutes during the day on weekdays, every 30 minutes on both Saturdays and Sundays for buses and streetcars, every 30 minutes on weekdays with 7-day service for light or heavy rail and ferries), and hence the disposition of transit agencies and decision makers to supply it with resources. However, high service intensity figures can also represent inefficiencies in operation, such as the deployment of many smaller vehicles at slow speeds (such as buses in congested traffic) rather than that of fewer larger vehicles at faster speeds (such as trains or metros on segregated rights-or-way).

On this indicator, trends in the four North American case study cities have been far from uniform during the 2012-2024 period. The two US cities record solid growth in service intensity in both absolute figures and relative to population. To some extent, their 2012 results were affected by temporary service cuts necessitated by funding challenges in the aftermath of the 2008 Global Financial Crisis (for example, Snohomish county in the Seattle region ran no transit service at all on Sundays for several years, thus failing to meet the SNAMUTS minimum standard for inclusion in this analysis), hence the 2024 results can be seen as a measure of normalisation.

Portland opened a dedicated transit bridge across the Willamette River (Tilikum Crossing) in 2015, which allowed for the extension of one of its streetcar lines into a full inner-city circle, and the extension of the MAX light rail system from PSU Urban Center to Milwaukie in the southeastern suburbs. Numerous bus services saw frequency improvements, which lifted several of them above the SNAMUTS minimum service standard for the first time, especially in Washington County in the western part of the metropolitan area. There have, however, also been some service cuts on lesser-used bus routes in the core city.

In *Seattle*, the sole light rail line in existence in 2012 was extended in several stages from SeaTac Airport to Angle Lake (2016) and from Westlake in the CBD to University of Washington (2016), Northgate (2019) and Lynnwood (2024). A thus far geographically isolated second line in the Bellevue-Redmond area also opened in 2024 (and is expected to be connected to central Seattle in 2026). A second inner urban streetcar line (First Hill Streetcar) between Occidental Mall at the waterfront and Capitol Hill LRT station on Broadway opened in 2016. Simultaneously, the length of the high-frequency RapidRide express bus network in King County was doubled. In neighbouring Snohomish County, 7-day transit service was restored and a frequent bus network similar to RapidRide established along the main corridors. In both counties, bus feeder services to the strengthened LRT spine were improved; however, the previous mixed operation of LRT and express

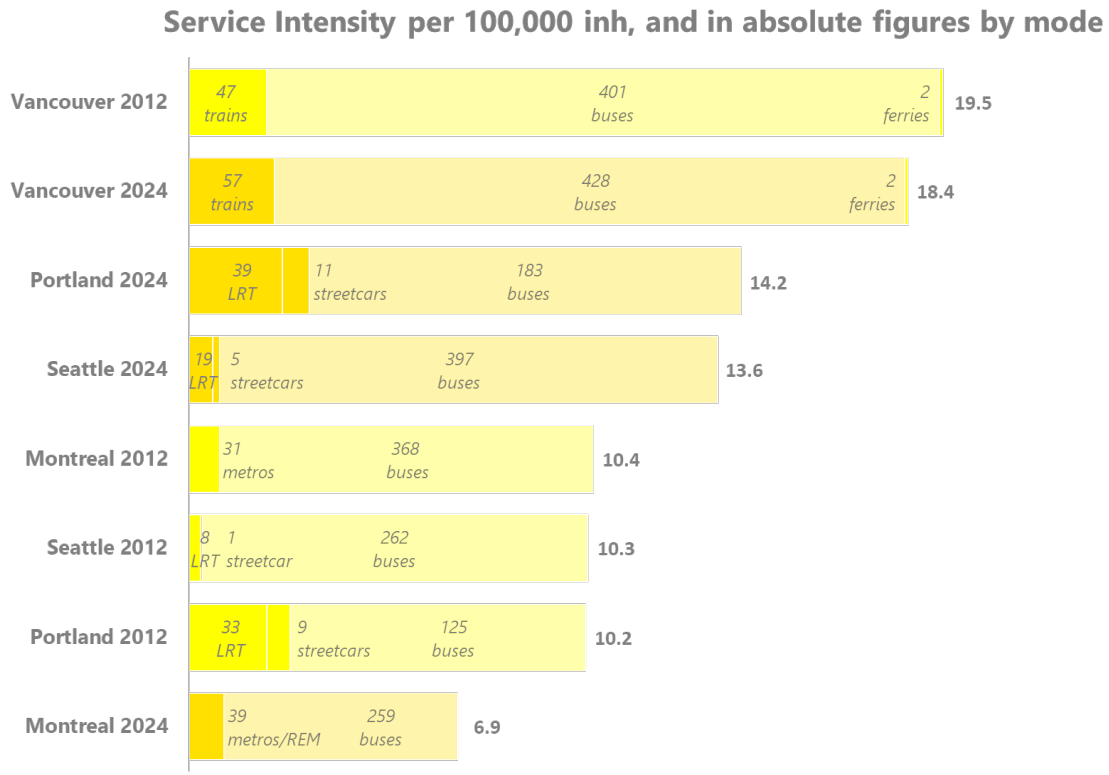
buses in Seattle's downtown transit tunnel was discontinued in 2019 and all bus routes relocated to the surface.

The two Canadian cities present a rather different picture on this index. In both Vancouver and Montreal, service intensity relative to population declined between 2012 and 2024, though at starkly different levels. While Vancouver's service offer continued to grow (modestly) in absolute figures during this period and continues to be significantly higher on a per-capita basis than that of its US neighbours in Seattle and Portland, in Montreal an already low level of service intensity in 2012 declined further in both relative and absolute terms to reach the bottom in the ranking of all 30 global SNAMUTS cities in every base year investigated.

What happened there?

In *Vancouver,* an extension (11 km, 7 stations) of the SkyTrain system from Lougheed Town Centre to Lafarge Lake-Douglas in Coquitlam (Evergreen Line) was opened in 2017, alongside a reconfiguration of the bus network in the same corridor to integrate with rail that led to some frequency improvements and new lines at the SNAMUTS minimum standard. Significant bus service improvements between 2012 and 2024 are also on record for other outer suburban areas, particularly in the Surrey-Langley region in the city's southeast. Conversely, within the core municipality there is a long-standing tendency to concentrate high-frequency services on a number of selected corridors (RapidBus) while gradually reducing frequencies towards a uniform 15-minute daytime standard across the remainder of the bus and trolleybus network.

In *Montreal,* 2023 saw the opening of the first stage (16 km, 5 stations) of a new, driverless and mostly above-ground urban rail system named Réseau express métropolitain (REM) to link central Montreal with destinations in the eastern suburb of Brossard (with further extensions to the western suburbs and the airport scheduled between 2025 and 2027). In 2022, a middle suburban bus corridor (route 439 along Boulevard Pie IX) was upgraded to bus rapid transit standards. However, elsewhere in the core municipality bus network, frequency and service cuts were widespread between 2012 and 2024 and led to a number of lines no longer meeting the SNAMUTS minimum standard for inclusion in this analysis. Conversely, in some suburban municipalities, notably Laval, Longueuil and Brossard, bus services were improved and the network at the SNAMUTS minimum standard grew, though in most cases at daytime frequencies no higher than every 15-20 minutes.



Ease of movement: How are travel times and frequencies evolving?

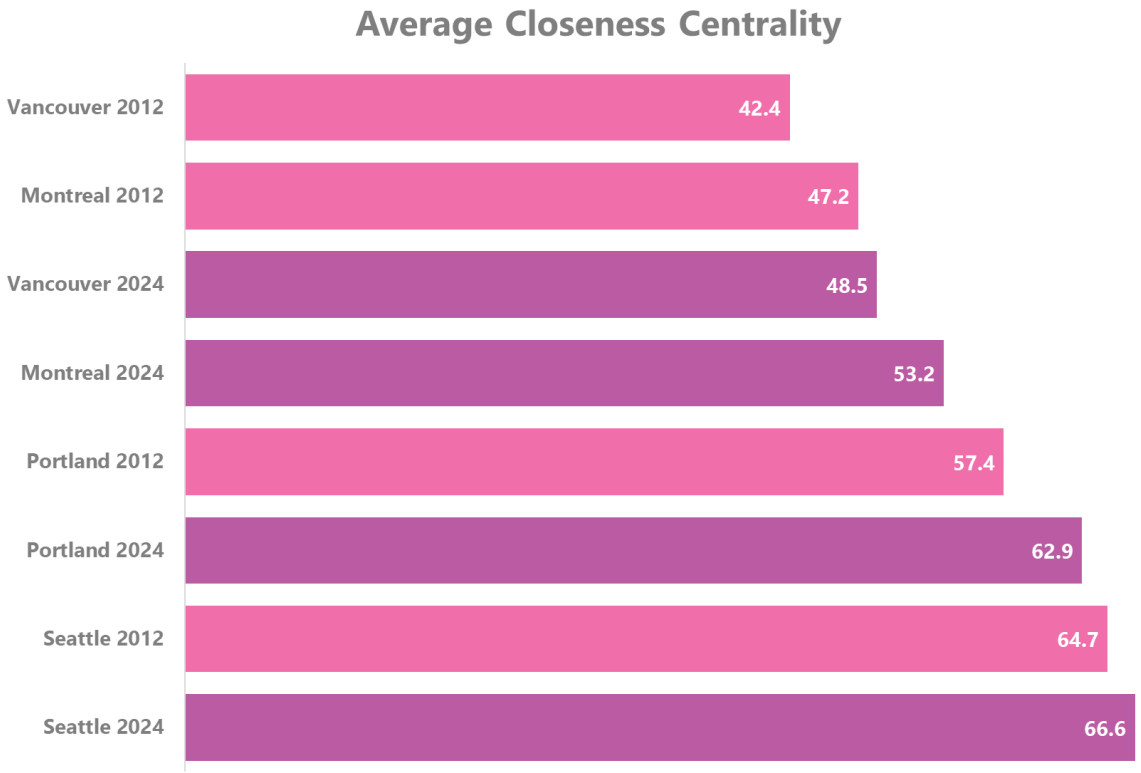
The closeness centrality index measures the ease of movement on a transit network, taking in travel time and service frequencies as factors of spatial separation. Lower figures indicate greater centrality. The geographical spread of the network influences the results on this index, with a greater share of far-flung, peripheral nodes tending to inflate average figures, and with smaller metropolitan areas tending to deliver better averages than larger ones.

Average closeness centrality deteriorated in all four North American cities over the 2012-2024 period, and roughly by a similar margin (5-6 points) except for Seattle, which recorded a more modest decline. The dominant explanation for this trend is the expansion of the networks into suburban areas, in other words places that are relatively remote to the more compact 2012 networks. In Vancouver and especially Montreal, this trend was exacerbated by frequency drops on a number of bus routes in the core cities or otherwise within the footprint of the previous network expansion. In Seattle, the trend was ameliorated by the completion of the fast and frequent light rail spine to Northgate and Lynnwood and the associated bus network adjustments, which had a transformative effect on public transport accessibility in the entire northern metropolitan region. In contrast, the rail extensions in Portland, Vancouver and Montreal, while significant, had a more localised impact on this indicator.

In Seattle, the network and service changes between 2012 and 2024 resulted in a convergence of closeness values across the metropolitan area: while results in the downtown area increased (deteriorated) slightly, they decreased (improved) almost consistently and often markedly in suburban areas. One could say that ease of movement on transit became more equitable across Seattle during this period. In Montreal, the opposite is the case: closeness results increased (deteriorated) slightly along the metro system but with few exceptions also increased (deteriorated), usually by greater margins, along the remaining higher-frequency bus routes and in suburban areas,

rendering ease of movement across the network less equitable in 2024 than it was in 2012. Portland and Vancouver deliver a mixed picture in this regard.

Vancouver continues to record the best average closeness performance in this sample, owing to its relatively compact urban form constrained by natural boundaries in the form of water bodies and mountain ranges. Montreal, ranked second, benefits from having the largest proportion of its SNAMUTS activity nodes (60 of a total of 134, or 45%) along the high-performing metro and REM system, whose speeds and service frequencies excel at reducing spatial separation or travel impediment (Vancouver has 44 of 125 activity nodes, or 35%, along the Skytrain system, while Portland has 41 out of 96 or 43% and Seattle 25 out of 119 activity nodes or 21% along their respective LRT systems – all figures are for 2024 and do not include the slower streetcar lines).



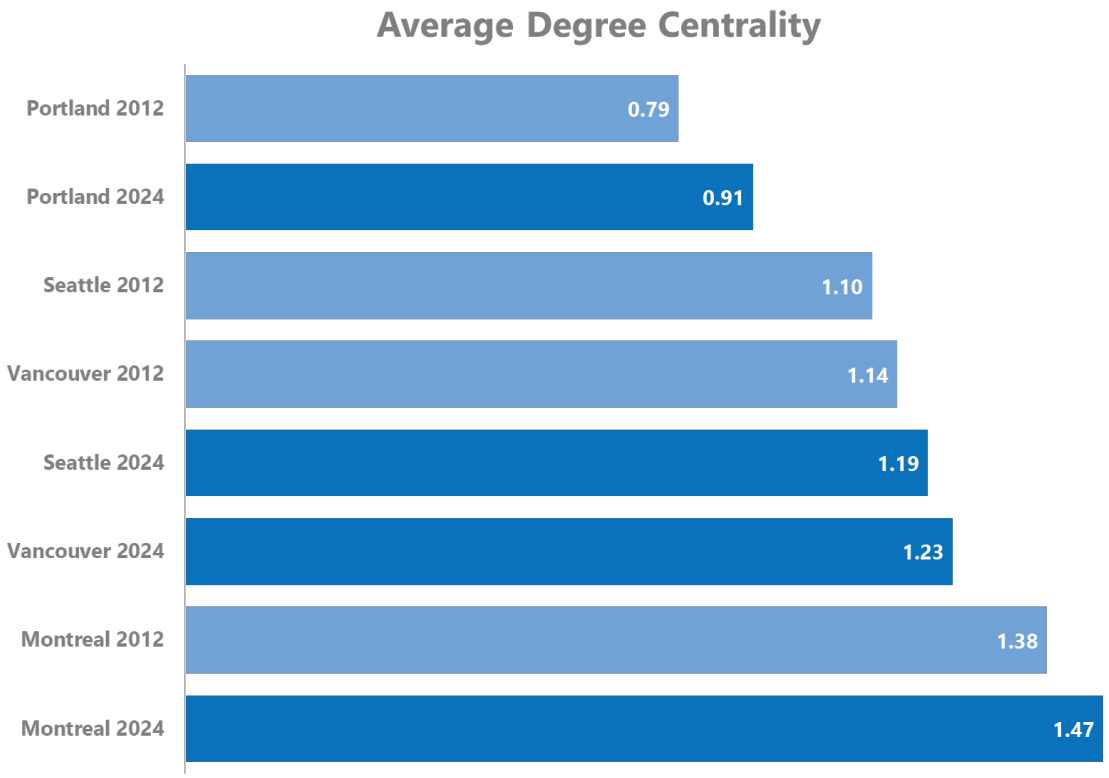
Download SNAMUTS network diagrams: Closeness Centrality			
Montreal 2012	Portland 2012	Seattle 2012	Vancouver 2012
Montreal 2024	Portland 2024	Seattle 2024	Vancouver 2024

Transfer intensity: Is the network making us change modes more often or less often?

Degree centrality measures the degrees of separation between origins and destinations; in a transit network, such degrees of separation are experienced as transfers. Lower figures indicate lower transfer intensity but are not without ambiguity: they can be read both as a successful quest for minimising the inconvenience of transfers for passengers, and as a sign of inefficiencies such as insufficient integration between modes or the failure to channel as much transit movement as possible along the fastest and highest-capacity services.

Transfer intensity increased in all four North American case study cities between 2012 and 2024, though at different levels. Portland, the smallest city in the sample, is the least dependent on transfers owing to a downtown area with multiple transit connections between all light rail and radial bus and streetcar lines, complemented by several well-placed orbital bus routes in the middle suburbs to the east. In the outer western and southern suburbs, however (Washington and Clackamas Counties), light rail feeder services prevail and did in fact increase in number during the study period.

In Vancouver and Seattle, the rail networks are less connected (not all routes connect to all others) and the prevalence of sub-regional feeder bus networks is greater. The same is true for Montreal's suburban areas (particularly Laval and Longueuil, where transfer-dependent metro feeder bus networks were expanded during 2012 and 2024). However, Montreal's transfer dependency is further exacerbated by the dominant network design feature of the metro and bus systems forming a rectangular grid where there is a relative absence of nodes that act as 'super-connectors' – a situation that deteriorated further between 2012 and 2024 when bus frequency cuts made a number of routes drop out of the SNAMUTS minimum service standard and thus leave behind an even patchier transit network.



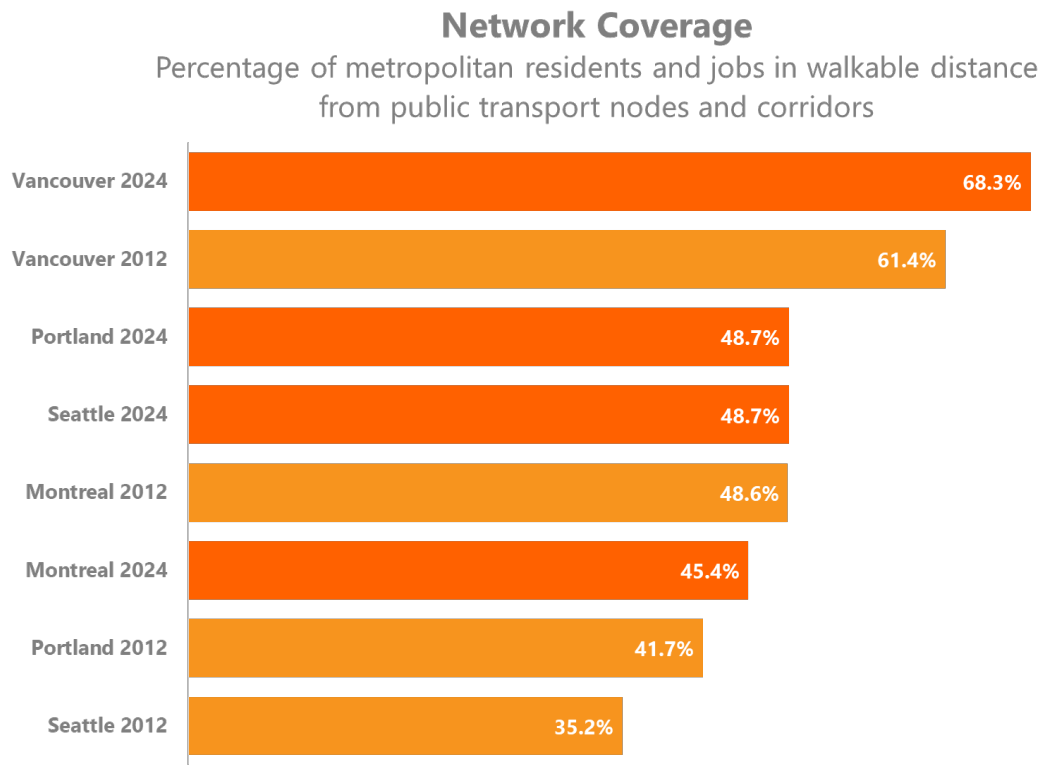
Download SNAMUTS network diagrams: Degree Centrality			
Montreal 2012	Portland 2012	Seattle 2012	Vancouver 2012
Montreal 2024	Portland 2024	Seattle 2024	Vancouver 2024

Network coverage and 30-minute contour catchments: Who gets access and can we travel further in less time?

Network coverage is a public transport endowment measure, asking a simple binary question: who in a metropolitan area lives or works within 400 metres/¼ mile (trams, buses) or 800 metres/½ mile (rail, ferries) of transit at the SNAMUTS minimum standard and who doesn't? Over time, network coverage can increase either by the geographical expansion of transit services, or by a higher rate of urban growth/intensification within transit-accessible areas than outside of them (or a combination of both).

Between 2012 and 2024, a net additional 7% of residents and jobs in Portland and Vancouver gained walking-distance access to the transit network at the SNAMUTS minimum standard. In Seattle, this was true for a whopping 13.5%, while in Montreal, there was a net loss of 3% of network coverage during this period. The numbers reflect varying rates of change in core cities and suburban areas. In Seattle, network coverage in the core municipality increased from 82% in 2012 to 94% in 2024, while in the remainder of the metropolitan region it more than doubled from 18% to 39% during this period. In Portland, network coverage in Multnomah County (containing and dominated by the core municipality of Portland) nudged slightly upwards from 66% in 2012 to 69% in 2024, but increased more markedly in the outer suburban counties of Clackamas and Washington (combined) from 19% to 31%. Across the border, Vancouver shows similar general trends: while the core municipality had practically 100% network coverage in both years, the outer suburban regions improved from 45% coverage in 2012 to 55% in 2024. Conversely, network coverage on the island of Montreal (containing and dominated by the core municipality of Montreal) contracted from 77% to 71% between 2012 and 2024, while in the remaining metropolitan area it expanded from 15% to 20%.

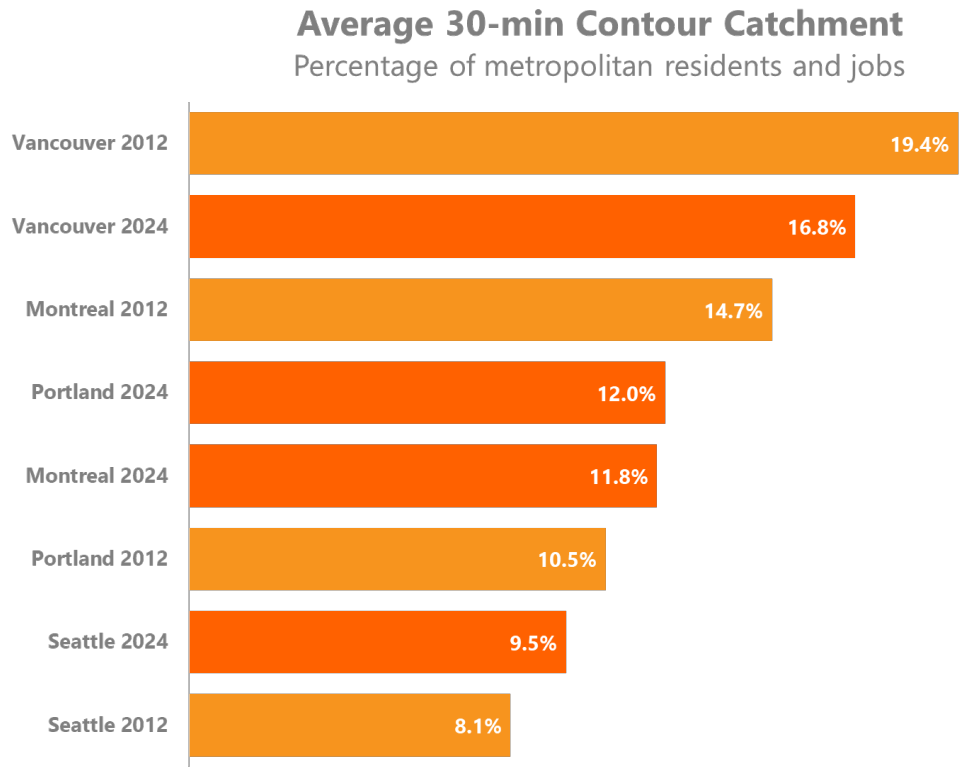
These figures illustrate the network changes pursued in the four cities outlined previously: there is a discernible focus on rolling out minimum-standard transit services to more outer suburban areas, though at different levels: Vancouver leads the group here while Montreal trails it, and it is Portland and particularly Seattle where this process currently proceeds most rapidly. Universal spatial coverage of the core municipality with minimum-standard transit services is a reality in Vancouver and not far off in Seattle, with Portland also making progress, while Montreal went backwards and now has the lowest overall network coverage in this four-city sample.



The 30-minute contour catchment measure adds a qualitative dimension to the network coverage index: besides transit endowment, we are now also examining the extent to which a metropolitan area is penetrated by useful transit travel opportunities. Useful in the sense of: achievable within a limited time frame (30 minutes) and accessing a high number of potential origins and destinations (catchment density). Travel speed, frequency (waiting and transfer times) and the geographical directness of journey paths (network configuration and geography) play a role here.

On average results for this index, the two Canadian cities, which led the ranking in 2012, deteriorated until 2024, while the two US cities improved their performance, with Portland now nudging into second place before Montreal. A greater prevalence of service frequencies of 15 minutes or better (which allow for transfer journeys to be counted as per the definition of this index) have likely expanded numerous 30-minute contours in Portland and Seattle, whereas in Montreal, the reverse is the case following frequency cuts on a number of core city bus routes. Typical service frequencies across the network also influence the average transfer delay, which enters this index and which improved between 2012 and 2024 in Portland (from 10.0 to 9.1 minutes) and Seattle (from 8.7 to 8.5 minutes) but deteriorated in Vancouver (from 7.3 to 8.2 minutes) and Montreal (from 7.8 to 8.0 minutes).

All things being equal, smaller metropolitan areas should find it easier to perform well on this index, which partly explains Portland's advantage over Seattle and Vancouver's over Montreal, but less so the difference between the US and Canadian cities. An expansion of the minimum-standard transit network towards the suburban periphery, as seen in all four cities between 2012 and 2024, depresses average contour catchments as a number of low-performing additional nodes in relatively remote locations enter the calculation, or (in the case of Seattle) partially neutralise the gains made by channelling movement onto new, faster and more frequent rail connections along critical corridors.



Download SNAMUTS network diagrams: 30-min Contour Catchments			
Montreal 2012	Portland 2012	Seattle 2012	Vancouver 2012
Montreal 2024	Portland 2024	Seattle 2024	Vancouver 2024

Betweenness centrality: How does the network channel transit journeys?

This index captures and visualises how travel opportunities flow across the network in geographical detail, and the volume they have, dependent on the ease of movement (closeness centrality, see above) and the spatial distribution of land use activities. A network-wide figure (global betweenness) aggregates all origin-destination values in relation to the number of metropolitan residents and jobs and thus attempts to quantify the overall presence of transit movement opportunities within a city. As the metropolitan-wide catchments of transit networks grow, in relative figures (network coverage index) and even more so in absolute ones (amplified by population growth), we can expect this index to go up. However, only in Portland and Seattle is this effect discernible, while in Vancouver and especially Montreal, the numbers deteriorated.

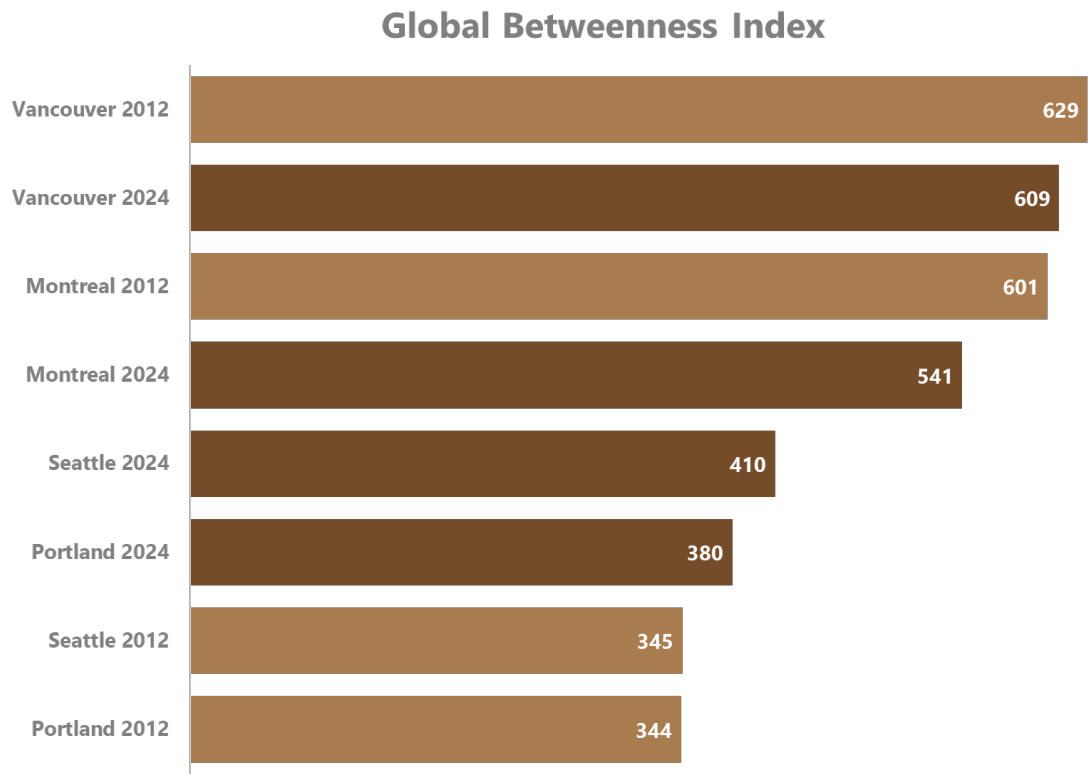
In Portland, the betweenness results suggest both a centralisation and decentralisation effect for travel opportunities operating in parallel. An expansion of the network in the outer suburban counties of Clackamas and Washington increased the share of these areas out of all total metropolitan travel opportunities from 6.2% to 10.5% between 2012 and 2024. Simultaneously, the share of travel opportunities channelled through Portland's downtown area went up from 28.4% to 29.5%, where extensions and frequency improvements to the radial LRT system make themselves felt particularly on the western (Hillsboro-Beaverton) and southern (Milwaukie) approaches. Conversely, the areas east of the Willamette River in Multnomah County remained relatively stable in terms of network significance, with the exception of the Division Street corridor which was

upgraded to a higher standard bus service (Frequent Express) and consequently attracts a greater number of travel opportunities.

In Seattle, the newly opened northern LRT corridor promptly acquired the dominant share of network significance outside the CBD area, suggesting it is well-placed to mobilise tremendous amounts of latent travel demand for transit in its catchment. Network improvements in suburban King County and in Snohomish County resulted in these areas capturing a share of 17.2% of metropolitan transit travel opportunities in 2024, up from 9.5% in 2012 (Snohomish County increased from a very marginal 0.2% to 4.9% on this measure, as most of its bus network was not counted in 2012 due to its lack of 7-day service). In southern King County, feeder and express bus improvements distributed relatively evenly onto the LRT line and direct bus links to central Seattle; nonetheless, the CBD share of travel opportunities fell (or should we say normalised) from a high 43.3% in 2012 to 36.2% in 2024. Urban intensification and network improvements around Seattle's two streetcar lines (and their connecting bus services) contributed to creating a more transit-friendly experience in their inner urban catchments. Conversely, the network significance of the isolated first stage of LRT line 2 east of Lake Washington remains relatively small, but this can be expected to change when the line is connected into central Seattle in 2026.

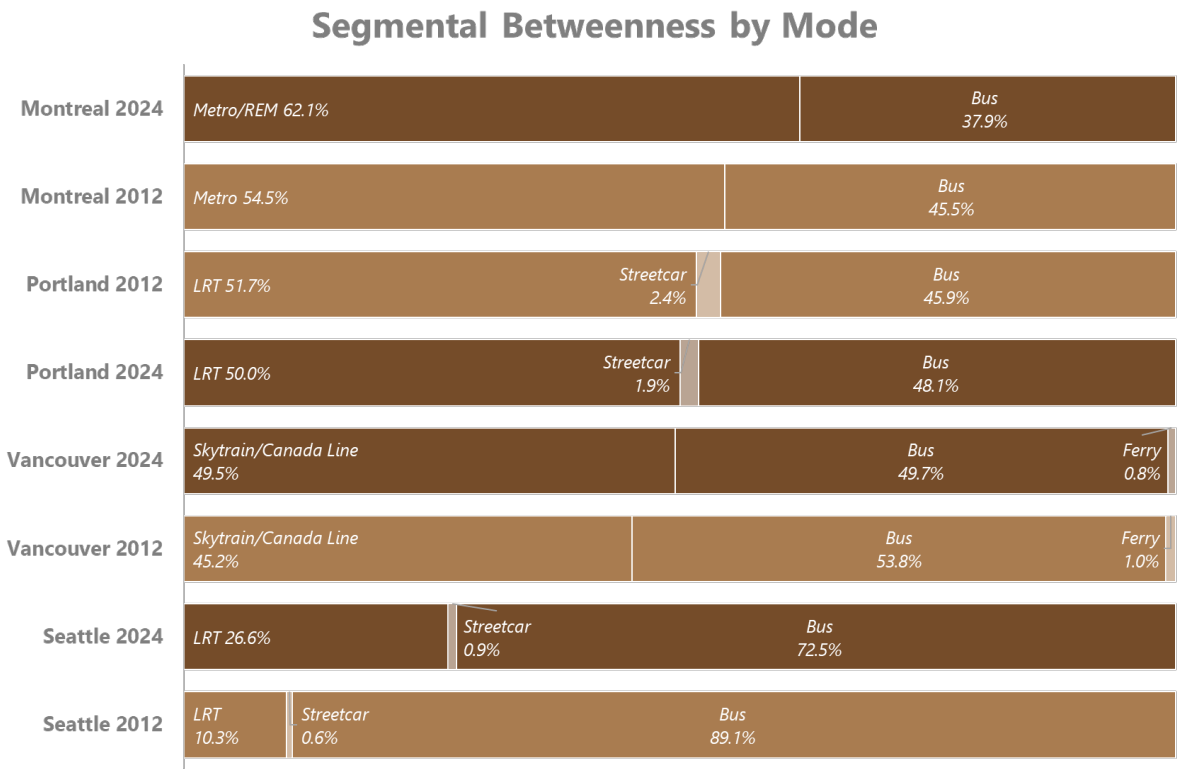
In Vancouver, the transit network's gravity (so to speak) seems to have shifted eastward from the Skytrain CBD approach (Expo Line) to the rail corridors east of Commercial-Broadway in Vancouver and adjacent Burnaby between 2012 and 2024. This effect was primarily caused by the network expansions in the outer east: the Skytrain extension to Coquitlam (Millennium Line) and the significant improvements to bus services in the Surrey and Langley areas. Conversely, a number of bus and trolleybus services in the core city were subject to (minor) frequency cuts, which led to a decline in their attraction of travel opportunities. An exception are the orbital corridors on 41st and 49th Avenue where bus services were improved, and which connect well to the Skytrain stations at Joyce-Collingwood and Metrotown along the much-strengthened Expo Line between downtown Vancouver and Surrey Central/King George. All up, the concentration of travel opportunities in Vancouver's (peninsular) CBD declined from 23% to 19%, and in the core municipality as a whole from 70% to 62% of the metropolitan total between 2012 and 2024, while the outer metropolitan region accordingly gained in significance from 30% to 38% of all transit travel opportunities.

Montreal recorded a tangible drop on the global betweenness index between 2012 and 2024, but this effect is not evenly distributed across the metropolitan area. In fact, bus network improvements in the neighbouring municipalities of Laval, Longueuil and Brossard strengthened the metro lines into Montreal's core municipality that these bus routes feed. The same is true, at even higher levels of travel opportunities, for the REM starter line which reversed the order of importance of Montreal's two diametrical metro lines in the CBD area between Berri-UQAM and Lionel Groulx (in 2024, the REM only connected to the orange line at Bonaventure-Gare Centrale). Conversely, the service cuts on the bus network in the core municipality led to a spatial contraction of feeder bus catchment areas with useful service and hence weakened some of the metro spines – particularly the Côte Vertu branch of the orange line, the Honoré Beaugrand branch of the green line and the entire length of the blue line. At a metropolitan scale, service improvements in the suburban municipalities do not make up for the impact of the thinned-out bus network in the core municipality: the share of metropolitan travel opportunities attracted by network segments outside the island of Montreal shifted only slightly from a marginal 1.7% in 2012 to a still very modest 4.1% in 2024.



Download SNAMUTS network diagrams: Betweenness Centrality			
Montreal 2012	Portland 2012	Seattle 2012	Vancouver 2012
Montreal 2024	Portland 2024	Seattle 2024	Vancouver 2024

Already in 2012, Montreal was the most rail-oriented city among our North American sample of four, and this position has consolidated since, owing both to the opening of the first REM line and the contraction of bus services in the core municipality while the metro network remained unchanged. In Seattle, the light rail system more than doubled in length between 2012 and 2024 and this is evident from the segmental betweenness figures; however, in 2024 the city remained the most bus-dependent of its regional peers. In Vancouver, the share of travel opportunities on rail modes grew between 2012 and 2024, partly as expected given the Millennium line extension to Coquitlam, but also as a result of improved local bus networks there and in Surrey/Langley whose additional travel opportunities invariably flow on to the rail trunk lines they feed. In Portland, a slight drop in the (otherwise quite high) rail share of the segmental betweenness score is on record for the study period, suggesting that the bus network improvements in the core municipality and in the neighbouring counties had a greater cumulative effect on the modal distribution of travel opportunities than the light rail extension to Milwaukie. In both Portland and Seattle, the relatively small streetcar operations only occupy a niche position in the modal mix when it comes to their importance for the network as a whole.



Network Resilience:
Can the transit service offer cope with the role the land use system assigns to it?

This index can be understood as a troubleshooting tool for transit networks. By calculating a ratio between segmental betweenness results and the actual passenger capacity offered on each route segment, and to and from each activity node, we can determine whether the service level on a particular network element is well-matched to its significance for metropolitan-wide movement, or whether (and to what extent) it falls short. Positive values, shown in green on the diagrams, indicate a good match. Smaller negative values (between 0 and -12, shown in yellow and orange) indicate a measure of underperformance. Larger negative values (beyond -12, shown in red and maroon) indicate a more severe capacity constraint.

Average nodal resilience performance in all four North American case study cities deteriorated within already negative territory between 2012 and 2024: in Montreal by 0.9 points, in Portland by 2.7 points, in Seattle by 2.9 points and in Vancouver by 3.9 points (each colour bracket on the maps represents 4 points). This suggests that none of the four cities succeeded in developing its transit infrastructure and service levels to an extent commensurate with the pace of population and job growth between 2012 and 2024 – but there are also a number of details that qualify the picture.

Montreal in 2012 already had two metro sections that appeared to be struggling with the network significance (segmental betweenness) assigned to them by the land use system: the green line section in the CBD (McGill-Berri UQAM) and the orange line section through Plateau de Mont Royal (Berri UQAM-Jean Talon). The latter section had, if anything, deteriorated further until 2024 while the problematic CBD section had also shifted to the orange line (Lucien l'Allier-Berri UQAM), most likely because of the elevation of Bonaventure-Gare Centrale along this route as the sole transfer point between metro and the new REM system (subsequent REM extensions will also establish transfer points to the green and blue metro lines and thus alleviate this situation). But while average resilience across Montreal's metro system dropped only slightly (from +1.7 to +1.5 points), resilience

on the bus system recorded a more drastic decline (from +0.1 to -3.6 points). The loss of useful (minimum frequency) services on many core city bus routes added pressure to the remaining ones and may have resulted in either overcrowding or patronage losses (or a combination of both). Additionally, many of the added useful bus routes in suburban Laval and Longueuil/Brossard display poor resilience values as they serve corridors with land use intensities that suggest higher levels of service could be warranted, but where a generous provision of road and parking infrastructure may also depress transit usage in favour of the private car.

Average resilience in Portland fell by roughly similar margins across the light rail and bus networks between 2012 and 2024, while dropping more severely in the downtown area. Only the relatively small streetcar system held up on this index. The outer western suburbs in Washington County, where a number of useful bus feeder services were added during the study period, add significant pressure to the Hillsboro-Beaverton light rail line and the SW Barbur Boulevard bus corridor, while urban intensification in the core municipality led to deteriorating resilience performance along some bus corridors such as 11th/12th and 82nd Avenue. The MAX light rail system might be showing signs of becoming a victim of its own success here – its predominant alignments at street level and along former heavy rail lines may have allowed for a fast pace of expansion, but they also limit its capacity particularly in combination with the small block sizes of Portland's downtown street grid, which cannot accommodate LRT stops longer than two coupled vehicles (while Seattle's mostly independent or underground LRT alignments allow for train sets consisting of up to four vehicles).

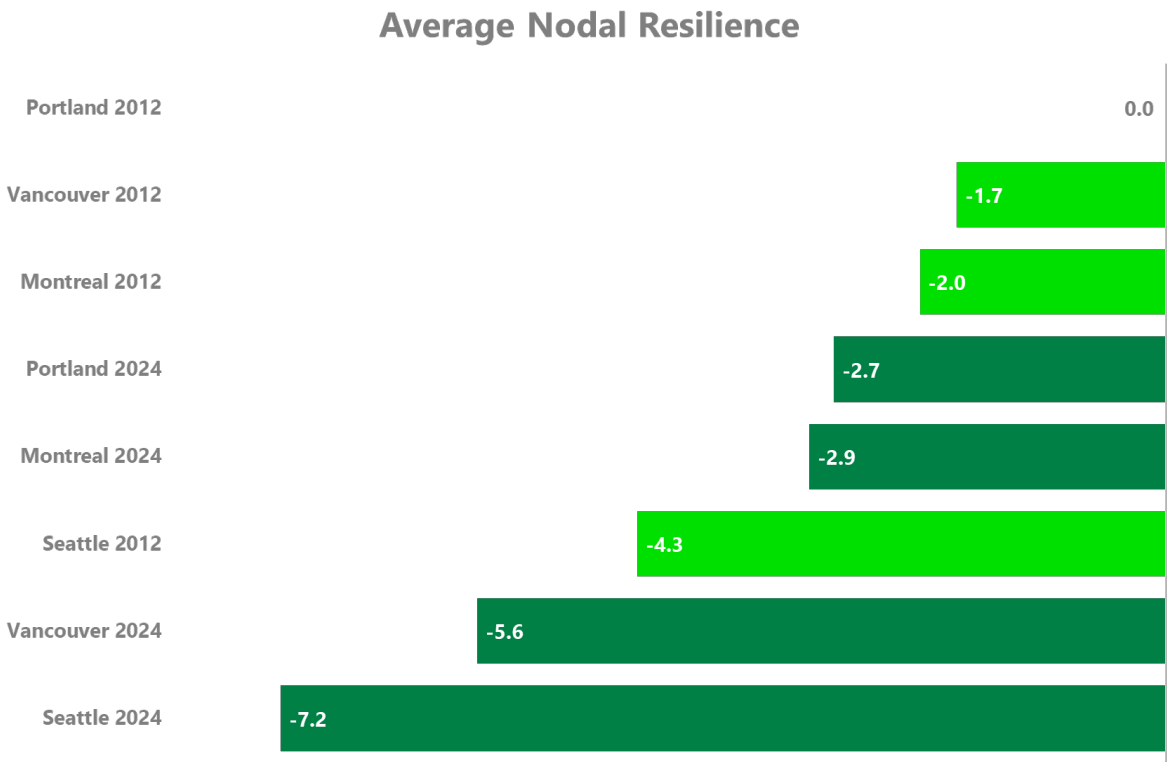
Seattle, in 2012, experienced severe resilience shortfalls chiefly along its rambling express bus network, linking disparate suburban centres and employment hotspots with the downtown area and each other at low capacity. By 2024, some of these express bus routes had made way for light rail extensions or been converted to light rail feeders (particularly through the new interchange at University of Washington). However, the new northern Light Rail line between Westlake and Northgate itself already appears to be struggling with the role of dominant transit spine assigned to it; this might find some relief if and when its frequency is improved from the current, relatively modest 10-minute daytime intervals. Elsewhere, Seattle's high rate of urban growth and even higher rate of transit network expansion at the SNAMUTS minimum standard have increased the pressure on a multitude of feeder bus lines as well as on the approaches to and within the downtown area. Here, the cessation of joint bus-light rail operation in the transit tunnel created imbalances between an intensely serviced bus surface corridor along 3rd Avenue and a less intensely serviced light rail tunnel underneath, resulting in a massive 10-point drop in CBD resilience performance between 2012 and 2024. The completion of the light rail link across Lake Washington in 2026 and the associated higher frequencies on the LRT trunk route should to some extent reverse this situation.

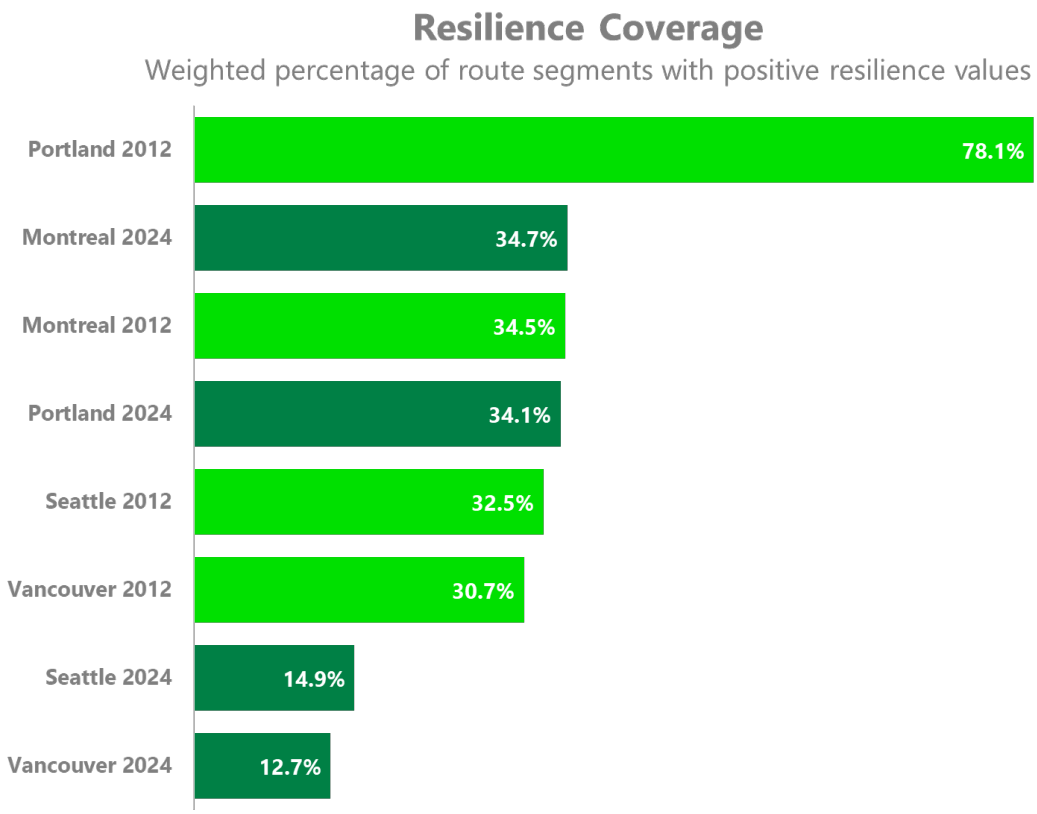
Of the four North American case study cities, Vancouver records the steepest decline in network resilience between 2012 and 2024, an effect that seems to be spread quite evenly across the metropolitan area with the exception of the Moody-Coquitlam-Pitt Meadows sub-region, which benefits from the Millennium Line Skytrain extension and the associated capacity and performance boost to transit. The reasons for the resilience drop can be found in the general population and job growth rate of the Vancouver region and the rate of expansion of the SNAMUTS minimum-service transit network (both second only to Seattle within this sample), and the stagnation or decline of average capacity per route or route segment. Vancouver's driverless Skytrain system allows for high service frequencies independently of staff costs, but these seem to have reached a practical limit at a (weekday daytime) network average of 14.5 trains per hour per direction in both 2012 and 2024. Simultaneously, the relatively short platform lengths particularly on the mostly underground Canada Line constrain increases in per-train capacity to serve a growing city. On the bus and trolleybus

network (to the extent it meets the SNAMUTS minimum standard), average weekday daytime service frequencies decreased from 7.2 per hour per direction in 2012 to 5.7 in 2024, both through the addition of more lower-frequency lines at the urban fringe and through frequency cuts on existing routes in the core municipality.

It appears as though Vancouver, as well as suburban Montreal, has been following a coverage-expanding approach towards transit supply during the study period while keeping patronage services in the core municipality stable at best (the Skytrain and metro systems), and declining in both frequency and coverage on the bus system (though with more pronounced effects in Montreal than in Vancouver).

It is also notable that transit resilience performance in all four North American case study cities trails quite markedly behind that of most European and some Australasian SNAMUTS cities, and that the gap seems to be widening. This may be associated with transit inherently serving a smaller segment of the total travel market in cities where road and parking space for private vehicles remain comparatively generous, enabling higher car mode shares than what is possible in much of urban Europe (though to the obvious detriment of transport sustainability objectives). But there are also significant differences between the Canadian and US cities in this respect. During the 2012 analysis, we found average metropolitan trip-making rates on transit of 157 per resident per year in Vancouver and 134 in Montreal, but only 64 in Portland and 59 in Seattle. By 2024, according to data compiled by the American Public Transportation Association (APTA), these rates had remained stable or deteriorated slightly in Vancouver and Montreal (there is a general trend across North America for transit ridership to not have fully recovered from the effects of the 2020-2022 COVID pandemic), but had fallen more drastically in Seattle (to 45) and particularly Portland (to 36). In such circumstances, transit networks can absorb resilience shortfalls of the magnitude documented here (the calibration of the index does not discriminate by overall levels of transit ridership) but will invariably run into difficulties when pursuing policy settings that seek to restore per-capita transit usage to pre-COVID levels or beyond.





Download SNAMUTS network diagrams: Network Resilience			
Montreal 2012	Portland 2012	Seattle 2012	Vancouver 2012
Montreal 2024	Portland 2024	Seattle 2024	Vancouver 2024

Nodal Connectivity: How freely can the transit-land use system be navigated?

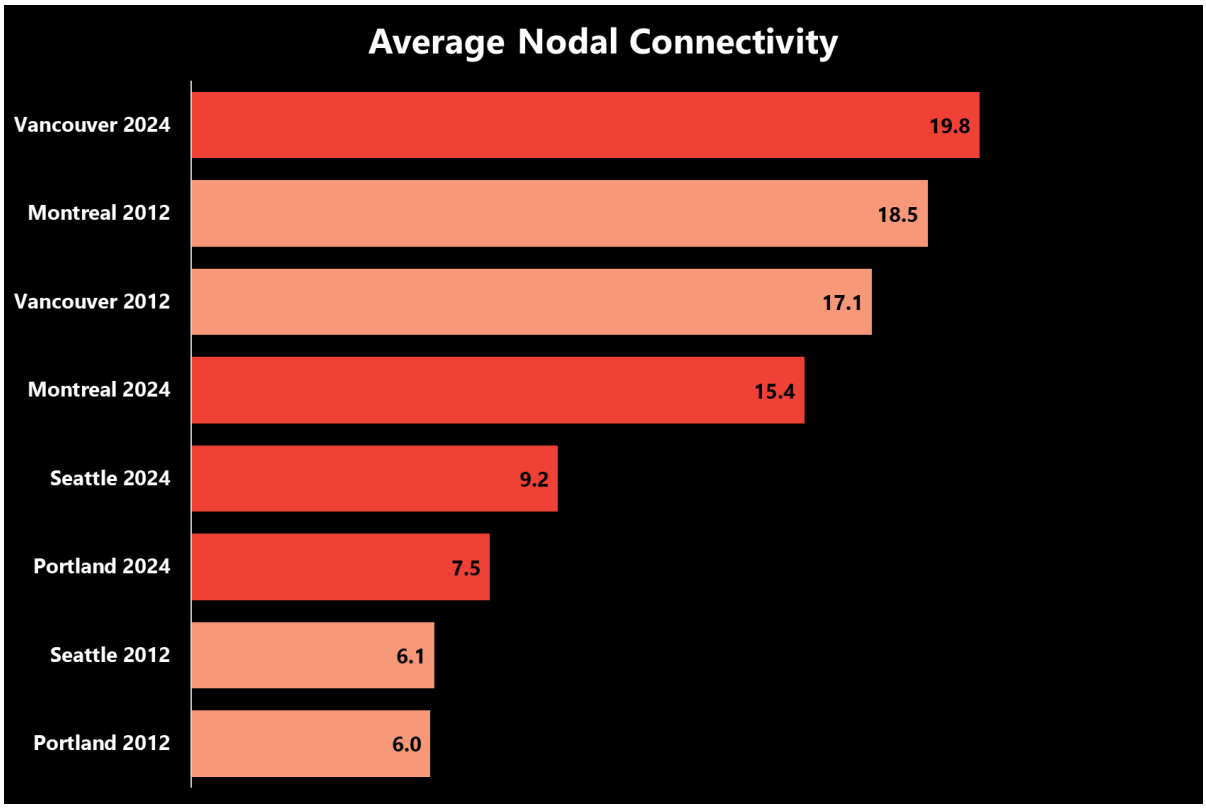
The nodal connectivity index conveys a sense of how flexibly users can move to and from a particular node on the network, by counting the number of directions one can travel in, the number of departures per hour, and the capacity (average occupancy) of the different modes that converge in each location. This has a bearing on the perception of a location to support transit-oriented lifestyles and business models, and in turn influences its attractiveness for transit-oriented development. 'Red dots' with a nodal connectivity score of 20 or above can be considered the hotspots of a network for these qualities. The prevalence of such hotspots is naturally greater in larger, more complex networks – however, the average occupancy of each mode also enters this index as a proxy for the number of people boarding, alighting or transferring at a node and is subject to change over time in relation to betweenness and resilience performance.

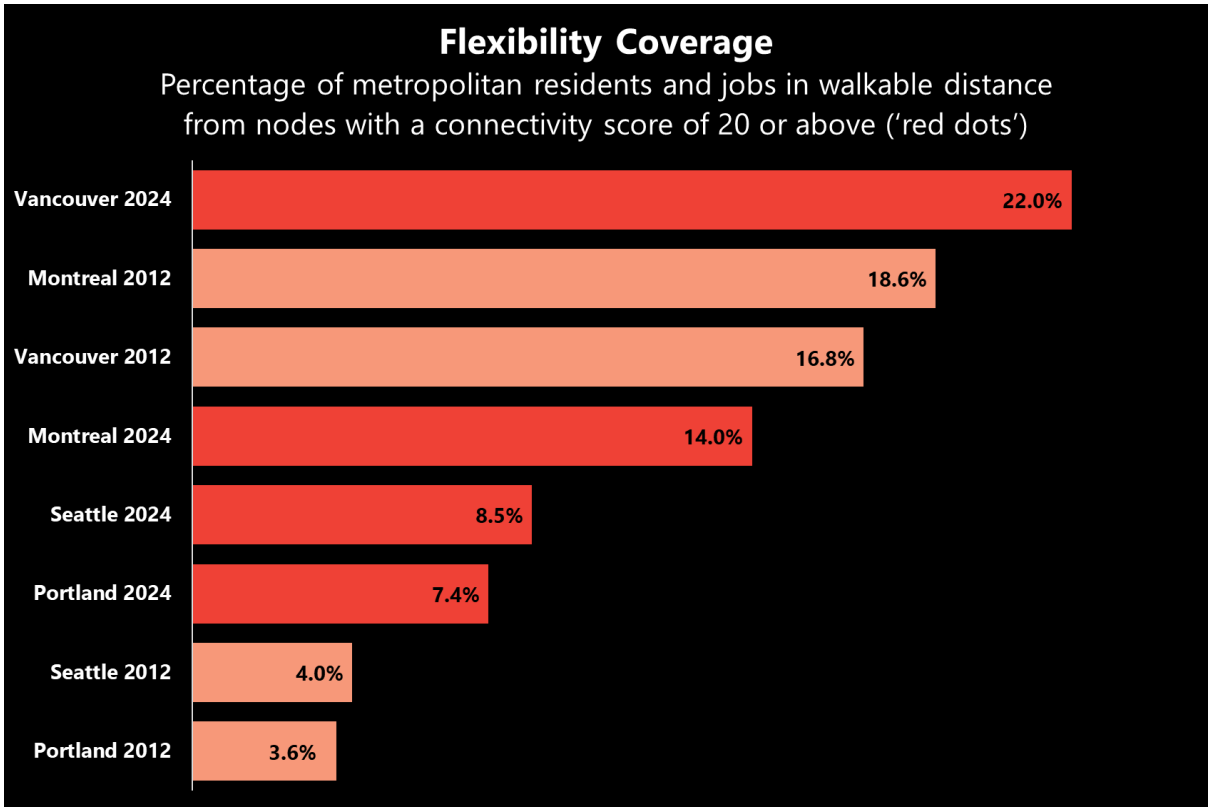
Average nodal connectivity grew in Portland, Seattle and Vancouver over the study period while these cities' transit networks became more complex and thus feature more nodes with connections in more directions in 2024 than in 2012. In Montreal, with the exception of the suburban municipalities of Laval, Longueuil and Brossard, the opposite is the case: many metro stations lost connecting bus services at the SNAMUTS minimum standard and thus ended up with fewer useful

movement options for travellers, reducing the scores on this index and making the city's overall performance slip below that of Vancouver.

A specific characteristic of North American cities is the relative absence of 'super-connected' nodes on this index, a circumstance that is likely owed to the dominant rectangular grid structure of the street network (and by extension the transit routes that share it), generally limiting the directions of travel available to a maximum of four. There are only a handful of exceptions to this pattern (Westlake in Seattle, Waterfront and Commercial-Broadway in Vancouver, Berri-UQAM and Lionel Groulx in Montreal). This paucity is also related to the absence of suburban rail routes with regular, frequent service in the North American cities, which form an integral part of the transit offer in Australasian (and most European) cities and tend to converge in those nodes with the best nodal connectivity results.

Overall, the percentage of residents and jobs located in walking distance from a transit hotspot ('red dot') expanded in Portland, Seattle and Vancouver (though at a much higher level in the latter than in its US neighbours), while in Montreal it contracted and made the city slip below Vancouver in the ranking.





Download SNAMUTS network diagrams: Nodal Connectivity			
Montreal 2012	Portland 2012	Seattle 2012	Vancouver 2012
Montreal 2024	Portland 2024	Seattle 2024	Vancouver 2024

SNAMUTS Benchmark Composite Index

The SNAMUTS composite index takes in results from the component indicators of closeness centrality, degree centrality, contour catchments, betweenness centrality, nodal connectivity and nodal resilience and calibrates them on a scale from 0-60 (maximum 12 points for each component indicator except resilience, where negative values lead to deductions). It is primarily conceptualised as a visualisation tool to quickly identify areas of good, average and poor transit accessibility on a metropolitan scale map, and to follow their evolution over time.

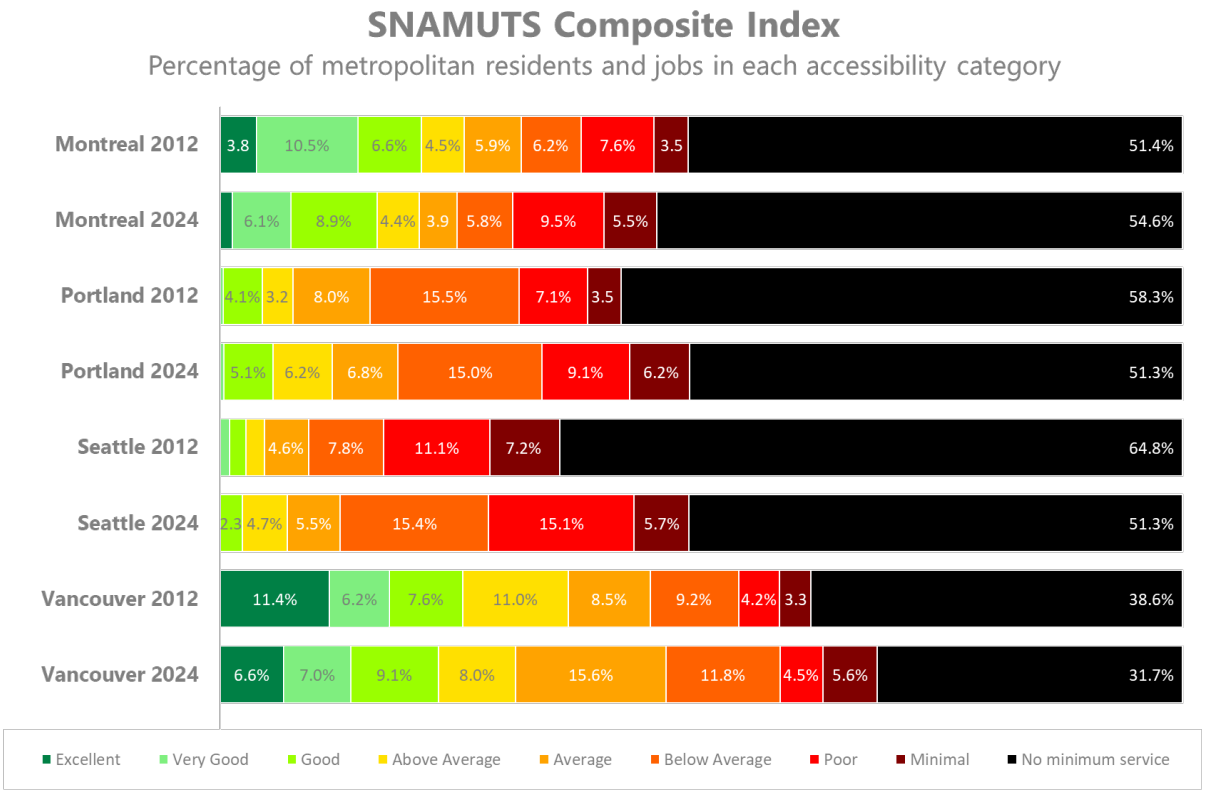
On a numerical scale, Vancouver continues to lead the four-city sample ahead of Montreal (though both cities suffered drops on this index between 2012 and 2024, mostly due to deductions for declining resilience performance in Vancouver and declining network coverage and nodal connectivity in Montreal). Portland remained steady on the composite index and continues to have a numerical edge over Seattle, which improved though also remains hampered by severe and further deteriorating resilience problems.

As discussed earlier under network coverage, Portland, Seattle and Vancouver expanded the percentage of residents and jobs within walkable access to transit at the SNAMUTS minimum standard between 2012 and 2024 while in Montreal, this share contracted. However, in both Canadian cities the share of residents and jobs in good transit accessibility categories fell during this period, while any gains (in Vancouver) occurred in parts of the metropolitan area where transit

access is average at best. This observation suggests that the policy focus of transit development in Vancouver (and in Montreal's outer suburbs) has primarily been on generating more geographical network coverage, but less on improving or even maintaining the quality of transit accessibility where coverage was already in place in 2012. As a consequence, many inner urban neighbourhoods dropped in overall accessibility performance after losing points from declining resilience.

In Seattle and Portland, areas with good transit accessibility have been more stable than in the Canadian cities, even expanding slightly, but overall they make up a much smaller share of the total than in Montreal and Vancouver. As a consequence, it is likely that there remains a more widespread urban 'transit culture' in Montreal and Vancouver than in their US peers, even though it may show signs of shrinking rather than growing (at least in relative terms) as bus service levels in the core municipalities are subject to reductions, and networks as a whole struggle with the pressure from population and employment growth around transit nodes and corridors.

By the early 2030s, when we hope to repeat the SNAMUTS analysis in these four cities, some major infrastructure projects currently under way are expected to be open in Seattle (light rail route 1 extension from Angle Lake to Federal Way, and the route 2 connection between South Bellevue and central Seattle), Vancouver (the Millennium Line extension along Broadway, and possibly the Expo line extension from King George to Langley Central), and Montreal (the REM routes to Deux Montagnes, Anse à l'Orme and the airport, and possibly the metro blue line extension from Saint Michel to Anjou). No light rail extensions in Portland are currently under construction or have committed funding.



Download SNAMUTS network diagrams: SNAMUTS Composite Index			
Montreal 2012	Portland 2012	Seattle 2012	Vancouver 2012
Montreal 2024	Portland 2024	Seattle 2024	Vancouver 2024