
Back on Track: How Sound Transit Can Deliver its Vision

A detailed analysis of an alternate approach to delivering the most expensive project in ST3

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V1.3

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Version 1.1: Updated to include a discussion of redundancy and resilience (page 37)

Version 1.2: Corrected minor typographical error

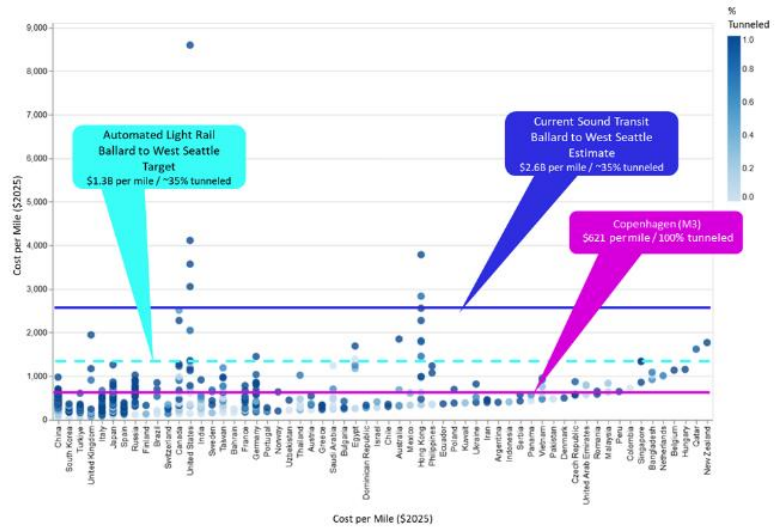
Version 1.3: Included a brief acknowledgement of interviewees in Executive Summary, minor typographical error, updated Figure 29 to correct math error.

Executive Summary

Sound Transit can reduce the cost of light rail to Ballard and West Seattle by at least \$15B by adopting international best practices and building Automated Light Metro / Automated Light Rail¹ from Ballard to West Seattle.

Reducing the cost of Ballard and West Seattle is essential. Sound Transit faces a \$35B shortfall and is unable to deliver the full Sound Transit 3 plan within the 20-year time horizon of their current financial plan. The full shortfall is driven by a combination of extremely high project costs, conservative operating and fare revenue assumptions, and statutory finance limitations. Sound Transit’s current cost estimate of \$2.3B to \$2.5B per mile for Ballard and West Seattle is surpassed globally only by much more complex projects in New York and Hong Kong. Copenhagen, a peer city of Seattle, built its most recent rail extension in 2019 for ¼ of the cost of Sound Transit’s proposed West Seattle and Ballard project.

Figure 1. Sound Transit’s cost estimates are among the highest in the world



Source: Transit Costs Project, Sound Transit 2026 Proposed Budget

Following the example of Copenhagen and building an Automated Light Rail (ALR) is feasible, will reduce the cost of construction, reduce construction-related disruption, and deliver a better rider experience.

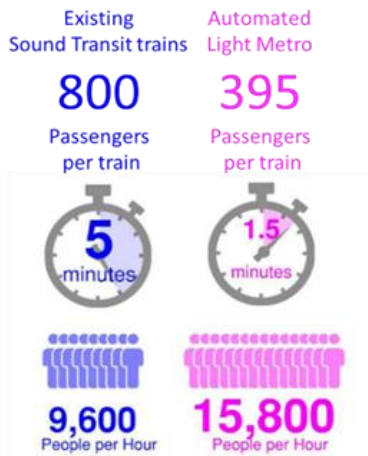
The key to this proposal lies in questioning long-held assumptions and an uncompromising drive to deliver the ST3 plan approved by voters. **Achieving these outcomes requires a return to first principles: Is there a better way to meet Ballard and West Seattle’s transit needs?** To be considered, any alternative must meet five criteria:

- **No delay in project delivery** – this must not “reopen planning”
- **Better rider experience** – more frequent and just as comfortable
- **Equal or greater capacity** –at least 9,600 passengers per hour
- **Less disruptive** –faster while impacting fewer blocks and intersections
- **Lower cost** –a viable pathway to reducing capital cost by at least 50%

¹ US transit modal terms are applied inconsistently, with similar systems variably classified due to legacy definitions. To avoid confusion, this paper uses Automated Light Rail (ALR) as a clear functional descriptor. In Europe and Asia this mode is referred to as Automated Light Metro.

Step 1. Make the spine work: In 2012 Sound Transit produced an [operating plan](#) that showed how to split the Regional Spine without routing trains to Ballard and West Seattle. The infrastructure to operate this plan exists today. Using that infrastructure allows Ballard and West Seattle to operate as a standalone line in a dedicated second tunnel.

Figure 3. Smaller more frequent trains deliver more capacity.



Step 2. Automate Ballard and West Seattle: An Automated metro operating in a 2nd tunnel can exceed ST3's capacity assumptions through higher frequency and more efficient use of space.

Step 3. Shorter trains unlock smaller stations, less disruption and lower costs: Stations built to fit in a city - 210 feet long NOT 680. resulting in 69% less excavation). Smaller stations can fit within a single block face and avoid intersections, reducing cost, construction time, and neighborhood disruption.

Figure 2. A small change in train routing unlocks capacity and the opportunity to save billions of dollars.

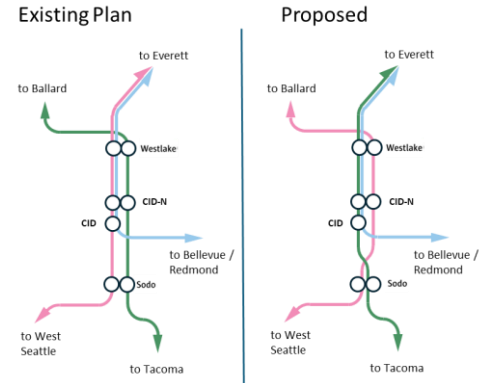
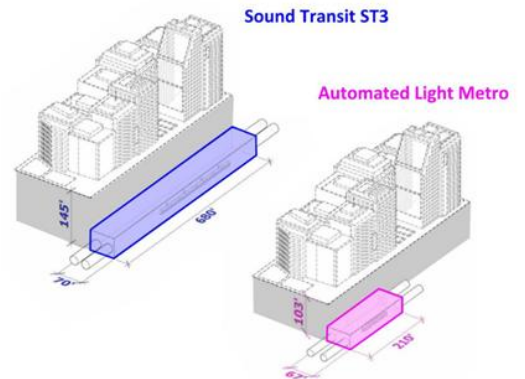


Figure 4. Smaller trains yield smaller stations, leading to lower cost and less construction related disruption.



This paper is informed by interviews with dozens of national and international experts, including transit CEOs, project delivery experts, A/E consulting leaders, current and former government officials, and community stakeholders. The paper also acknowledges that pursuing automation presents real challenges related to implementing new technology and vehicle types, conformance with ballot language, possible schedule and NEPA risks, uncertainty around operations and maintenance facility strategy. We do not argue these challenges are trivial, but that they are manageable and should be compared against certainty of the current approach, most notably decade-scale delay, escalating cost, and the possibility that the region delivers substantially less than voters were promised.

For that reason, our principal recommendation is procedural rather than prescriptive: Sound Transit should issue a focused Request for Information to determine whether internationally proven delivery models, vehicle platforms, and project strategies could deliver Ballard and West Seattle faster, cheaper, and with better service than the current approach. The paper recommends that this work proceed in parallel with ongoing planning and engineering, minimizing downside risk while preserving the upside of identifying a credible lower-cost alternative. In short, the paper calls on Sound Transit to return to first principles. If the region can deliver the promised connections to Ballard and West Seattle with higher

frequency, lower cost, and less disruption through a different operating concept, that option merits serious and immediate evaluation before the agency locks in decades of delay and expense.

We propose a simple framework for assessing the feasibility of this approach.

Technical Approach: What is the recommended approach to deliver a 100% grade separated transit line with stations located within Sound Transit's proposed station envelopes? How will they meet or exceed Sound Transit's planned capacity of 9,600 riders per hour, minimize lifecycle cost, minimize construction related disruption, and maximize project delivery speed?

NEPA / Federal Funding Strategy: Given Sound Transit's current level of environmental approvals and analysis on the Ballard and West Seattle line, how would the respondent minimize the risk of schedule delay from additional NEPA analysis and how would their proposed approach impact Sound Transit's ability to secure federal funding (TIFIA or New Starts)?

State / Local Regulatory and Permitting Changes: What state and local regulatory practices will enable Sound to deliver Ballard to West Seattle with a schedule and budget consistent with international best practices? What procurement strategies and methods are needed to deliver an ALR effectively?

Integration with Existing ST Facilities: Under what circumstances is it feasible to utilize existing Sound Transit infrastructure to reduce project delivery cost and risk?

Sound Transit should convene a Technical Advisory Group with expertise in automated rail planning, design, construction, and automation. It should contain individuals with project delivery and project finance expertise in the US and internationally. International experts should come from countries with a demonstrated expertise in delivering high-capacity transit at much lower costs than the US. The issuance and evaluation of the RFI responses should take no longer than 6 months. During that time, Sound Transit should continue advancing planning and engineering. In the event that industry returns with a credible path to cutting capital cost by 50% or more, the \$15B savings will more than offset the sunk cost of planning and engineering.

Concept of Paper

Sound Transit faces a \$35B shortfall to complete the system it promised to voters in the 2016 Sound Transit 3 (ST3) package. The shortfall is based on a myriad of factors, some outside of and some within the agency's control. Sound Transit has not proposed a solution yet as it continues to review options under the [Enterprise Initiative](#) and its four 'levers': Project Level (design optimization), Interdepartmental Collaboration (permitting, regulations, etc.), External Coordination (Scope changes), and Phasing (Minimum Operable Segments). Based on preliminary results presented to the board, the agency does not have a viable path to reduce project costs enough to deliver all of ST3 as promised to voters. Specifically, it does not have a viable path to complete a Link extension to Ballard prior to 2050 under any scenario. Sound Transit is planning and engineering the Ballard and West Seattle alignment under a false constraint: the need to split the spine and route Tacoma trains to Ballard and Everett trains to West Seattle. As a result, Sound Transit only evaluated Light Rail Transit (LRT) alternatives for the Ballard and West Seattle extensions. LRT is the ideal mode for the Regional Spine because its flexibility allows for the reuse of the Metro bus tunnel and at grade operations. However, this flexibility comes at a cost of heavier and longer trains operating at lower frequencies. LRT as conceived imposes massive additional costs when delivering a line with extensive tunneling and close spaces in an urban environment.

Failing to deliver the full ST3 vision would betray the commitment made to voters. Worse, this choice will burden the region with debt for a generation and baseline costs at a level that makes future expansion fiscally and politically impractical. In this paper, we go back to first principles and ask, ***"if there were no prior assumptions on Ballard and West Seattle extensions, what would we build?"***

Before evaluating any alternative, we established five criteria that the proposal must meet or exceed:

- **No delay in project delivery** – this must not “reopen planning” of station and alignment decisions
- **Better rider experience** – more frequent and just as comfortable
- **Equal or greater capacity** – at least 9,600 passengers per hour
- **Less disruptive** – construction should be faster and disrupted fewer blocks and intersections
- **Lower cost** – a clear path to reduce project cost by 50% to match currently available funding

The United States is a case of reverse exceptionalism when it comes to transit. US projects are among the most expensive in the world. Delivering beyond expectations to meet our five criteria requires looking outside of the United States. We interviewed dozens of local, national, and international experts developing this white paper, including former transit CEOs, delivery experts, government officials, and academics to develop this paper and our recommendations.

In this paper we look to Copenhagen as an example for Sound Transit and the Puget Sound region to follow. Copenhagen has a transportation system that is emulated globally due to the quality of service it provides relative to cost. Its central city is a reasonable peer for Seattle: it is dense, old, and surrounded by water. Lastly, it has a comparable cost of living and is a democratic society with high transparency, public engagement, social, and environmental protections. Their success is not through top-down

authority at the expense of democratic norms or individual liberties. Most importantly, it has recent experience building world class transit.

Copenhagen revolutionized global transport via the development of Automated Light Metros (ALM) or Automated Light Rail (or ALR),² delivering the first of its four lines in 2002. The system has since expanded, with their most recent lines, the Copenhagen Metro Circle Line (M3) and Line 4 (M4), opened in 2019 and 2020, respectively. ALM / ALR's low cost and high quality is now the global standard for new metro projects globally.

Copenhagen's insight was deceptively simple. Automating trains allows much more frequent service. More frequent service meant that shorter trains could deliver the same capacity as longer, less frequent trains. Shorter trains meant they could build small stations with less disruption at the service. Identical, modular stations reduced the amount of time and money spent on engineering and design. The end result is a system with more capacity than Sound Transit delivered at ¼ of the cost.

Adopting an Automated Light Rail operating concept (as shown in Copenhagen) meets all five criteria.

- **No Delay:** Delivery can occur within existing planning framework and financial resources. Copenhagen's design allows it to build 25% faster per mile than Sound Transit's current schedule.
- **Better Rider Experience:** Trains arrive every 90 seconds (ALM) versus every 5 minutes with LRT
- **Equal or Greater Capacity:** 65% more capacity than current Sound Transit proposal
- **Less Disruptive:** Station construction limited to 1 block / 0 intersections per station (ALM) versus 2 to 3 blocks / 1 to 2 intersections per station (LRT)
- **Lower Cost:** Construction costs are an estimated 77% lower than Sound Transit LRT, faster construction, less disruption and more capacity.

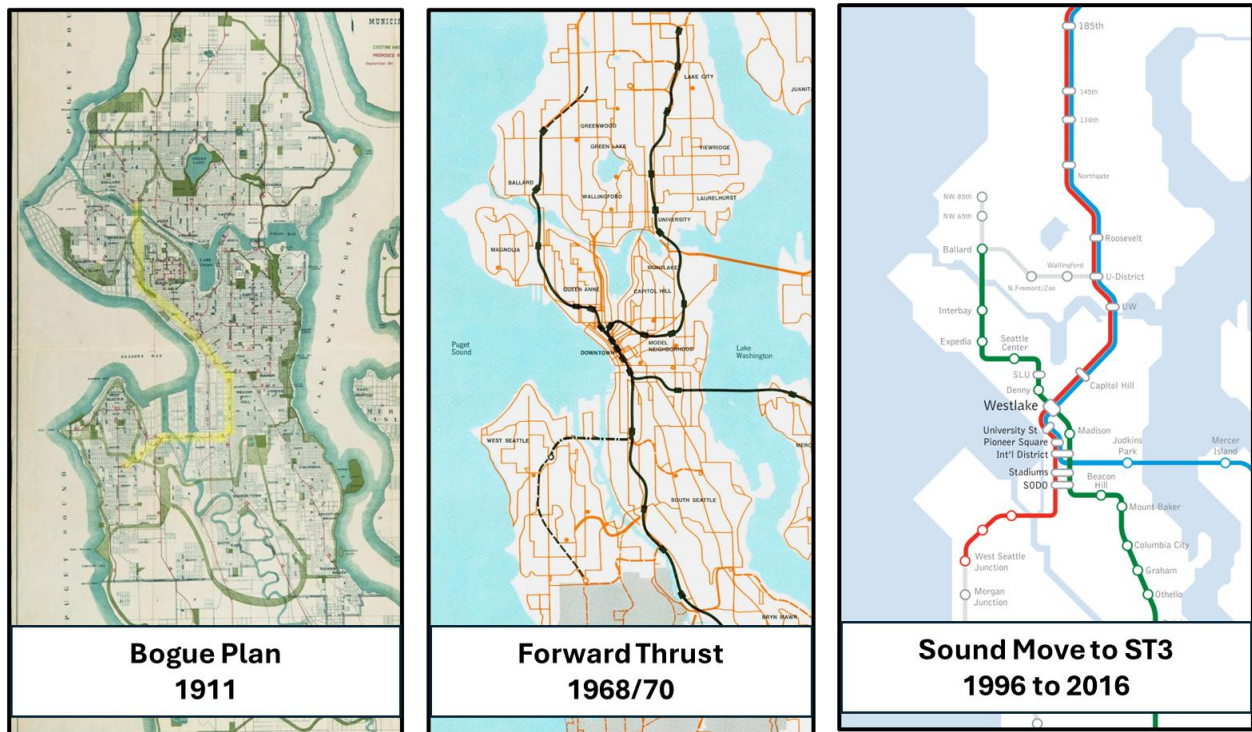
Our proposal is about the means and methods of delivering world class transit, not re-litigating planning decisions. This paper will show the technical consequences of regionalizing the 2nd tunnel more than doubled the cost of the Ballard and West Seattle extensions - exceeding the regional contribution, leaving North King no better and the region worse off.

² US transit modal terms are applied inconsistently, with similar systems variably classified due to legacy definitions. To avoid confusion, this paper uses Automated Light Rail (ALR) as a clear functional descriptor. In Europe and Asia this mode is referred to as Automated Light Metro.

How We Got Here – A Historical Account in Three Acts

The story of how Seattle arrived at this moment occurs in three acts. These three acts built on one another and created the perceived constraints that led Sound Transit, during the Ballard and West Seattle design process, to fail to seriously examine alternatives to operator controlled light rail. These early decisions were simultaneously visionary and pragmatic in the moment, and their success makes it hard to recognize when this lock-in shifted from benefit to burden. Critically, these decisions fall against the backdrop of the 115-year-old dream to build rail to Ballard and West Seattle.

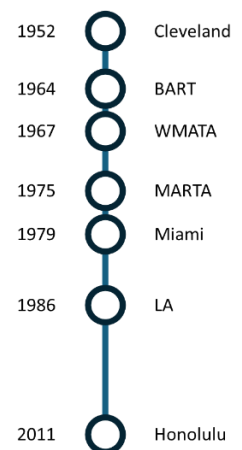
Figure 5. Plans for rail to West Seattle and Ballard since 1911



Act 1: Light Rail’s Emergence in a Moment of Scarcity

Starting in the 1960’s the US started a Heavy Rail (e.g. Washington Metro and Bay Area Rapid Transit) building boom. Seattle missed its opportunity to ride the wave of construction, rejecting Forward Thrust in 1968 and 1970. By the late 1970’s and early 1980’s [high costs](#) and a collapse in political support under Reagan then Bush eroded the US’ capacity to deliver metro/heavy rail (broadly defined as fully grade separated systems). Light Rail emerged as a lower cost alternative, viable absent generous Federal support by avoiding heavy rail’s high costs through smaller stations, mixed traffic operations, and repurposing existing right of way while leveraging dedicated right of way and grade separations at critical points.

Figure 6. US Heavy Rail Construction Starts



Act 2: Metro’s Ballot Success, and Building the Bus Tunnel

Cities across the country started building light rail based on promising results in San Diego, Portland, and St. Louis that showed how the opportunistic repurposing of freight rail and strategic grade separations could deliver high-quality transit for cheap. Seattle, confronting a legacy of failed rail measures, brought a bus-only measure in 1980 that funded the Downtown Seattle Transit Tunnel (DSTT), 1.3 miles for \$1.3B (\$2025), which included track. While the rail was structurally inadequate, its inclusion in the bus tunnel established expectations for future light rail use. The deeply pragmatic ‘dual use’ design of the tunnel reflected the visionary intent to assemble a system opportunistically. Light rail’s flexibility renders it a jack of all trades but a master of none. It made sense because in an environment with tenuous political support, light rail could adapt to a wide variety of operating environments. Since the public had demonstrated their unwillingness to build a visionary system at once, piecing it together incrementally became the path forward to build regional connections.

Act 3: The “Regional Spine”

Voters rejected the creation of a Regional Transit Authority in 1995 before passing the less ambitious Sound Move in 1996. Finally, after decades of false starts, voters approved the creation of a regional transit system. Sound Move created the vision for a Regional Spine, by funding the first light rail segment stretching from University District (with plans to reach Northgate) to Angle Lake - Central Link. The assumption being that once people experienced light rail, they would endorse its expansion.

Cost minimization was foremost of mind, resulting in mixed operations in SODO and the Rainier Valley while sharing the bus tunnel with bus services. LRT made these cost saving measures possible via its operational flexibility.

Sound Move encountered incredible cost overruns that nearly killed the program. The initial segment was three years late, opening in 2009, and deferred connections to the University District and Angle Lake until 2016. The much shorter line was 45% over the proposed budget for *the entire line*.

Two stations from the initial segment are still unbuilt - Graham Street and Boeing Access Road (both refunded in Sound Transit 3), while First Hill and Tukwila International Boulevard/South 144th Street

Figure 7. Sound Move plan



were deleted due to cost and local opposition. However, Sound Move firmly established the concept of a Spine, via the highly successful express bus program and Central Link.

When it came time for Sound Transit 2 (ST2) to extend the Spine south to Federal Way, North to Lynnwood, and East to Bellevue, using LRT to tie into the existing system was the only logical path. Learning from the experience of mixed operations in the Rainier Valley, fully separating services were increasingly prioritized with grade crossings only added on East Link. By ST3, no extensions featured at-grade crossings. The desire for higher quality transit led planners to reject at-grade operations, the design flexibility enabled by LRT that made it the technology of choice in the first place. Ironically, ST3 extensions in design and function closely resemble heavy rail systems and recreated the cost challenges LRT was developed to solve. Worse, the extensions also carry the design burdens of LRT in addition to heavy rail. For example, full separation unlocks lighter vehicle design standards because there is not the threat of car collisions. Effectively, Ballard/West Seattle extensions have all the baggage of both LRT and heavy rail with neither their advantages. Building to heavy rail standards to operate LRT makes no sense.

Challenging Assumptions

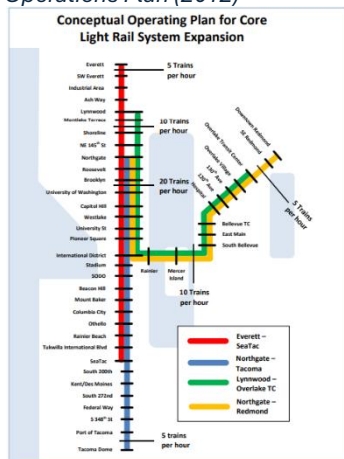
The premise behind Light Rail being the only choice for Ballard and West Seattle rests on a financing decision, not technical necessity.

Sound Transit and regional leaders concluded the region needed a second tunnel through downtown to handle service to Ballard and West Seattle. But the “North King” subarea did not have sufficient funds to pay for the extensions and the tunnel.

Sound Transit’s subarea equity rules constrain how locally generated funds can be spent, allowing cross-sub area spending only when a project serves a defined regional purpose (see map at right). By routing Northbound trains from Tacoma to Ballard through the new tunnel, Sound Transit was able to reach consensus that the Ballard and West Seattle project - now split in two - was regional, unlocking a 51% North King / 49% regional funding split. This essentially defines “regional” by where trains physically travel versus where people travel. Many regions use passenger origin and destination inclusive of transfers to measure access and regional benefits.

Regionalization was justified by the fact that continuous service between Everett and Tacoma is too long and is operationally inefficient. However, prior to the inclusion of Ballard and West Seattle in ST3, Sound Transit published [a conceptual operating plan](#)

Figure 10. 4-line Spine Operations Plan (2012)



[in 2012](#) for a completed spine that turned NB trains from Tacoma at Northgate and Lynnwood and SB trains from Everett at SeaTac. Pocket

tracks, the feature needed to perform these maneuvers, exist at Northgate, SODO and SeaTac. Pocket tracks were never built at Lynnwood due to value engineering³. Adding these pocket tracks, standalone or through Everett Link extension (at Alderwood or Mariner), would enhance resilience and enable the operating concept the Spine was designed to enable. The operating plan on the left does show lower frequencies to Everett and for East Link than planned, but that is flexible. The critical point is that the infrastructure exists to segment service on the spine without ‘breaking’ it, so transfers would occur seamlessly on the same platform.

Figure 8: Sub Area Boundaries



Figure 9. Current split of 2nd downtown tunnel (SODO to Seattle Center)

Downtown Seattle Tunnel Cost Split	
North King	51%
Regional	49%
East King	14%
South King	13%
Snohomish	13%
Pierce	8%

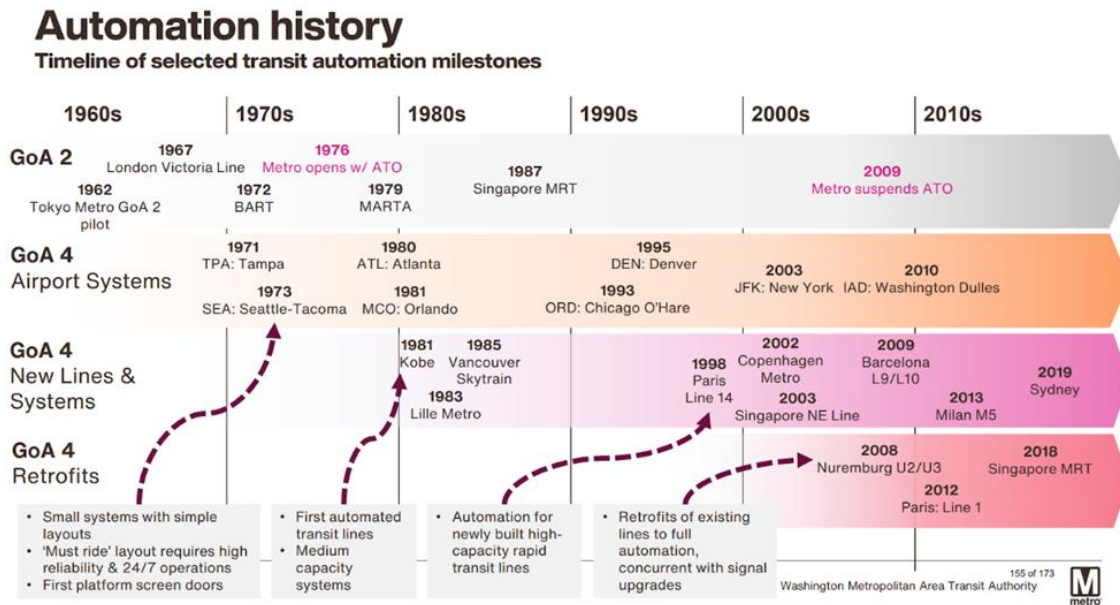
³ Creating crossover tracks at Lynnwood were identified in the system resiliency report as a contributing factor to system unreliability.

Automated Light Metros (Automated Light Rail)

Overview: History and Concept of Operations

Automated Light Metro (ALM) technology traces its roots to convergent innovation in Kobe, Japan and Lille, France followed by Vancouver, Canada in the 1980s.

Figure 11. Rail Automation History



Source: WMATA Rail Modernization Program

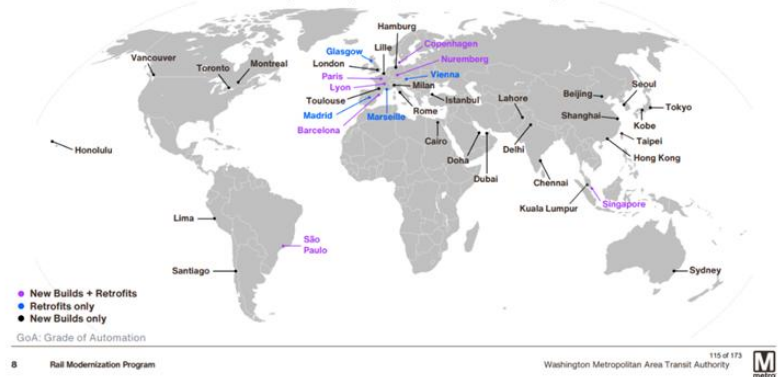
Copenhagen opened its first line in 2002. Since then, the number of cities with fully automated metros has exploded globally (image below). The presence of GoA3⁴ systems is a byproduct of upgrading existing systems and operational constraints that require a human onboard. For example, while some GoA4 systems operate without screen doors, like Vancouver's SkyTrain, other operators will not fully automate service in their absence.

Rail systems globally are aggressively upgrading existing systems to fully autonomous operations. Paris has upgraded Lines 1 and 4, dating to 1900 and 1908 respectively, while they operate

Figure 12. Automated Metros Globally

Metros are automating across the world

Selection of Grade of Automation 3/4 (GoA 3/4) lines, current and in development



Source: WMATA Rail Modernization Program

⁴ In a GoA3 system the train operates fully on its own, but with human oversight.

numerous fully automated new lines. Paris opened their first fully automated line in 1998 and plans to open four new fully automated lines over the next two years.

Copenhagen

In the 1990's Copenhagen was facing a fiscal crisis⁵. The Orestad Development Corporation was created in 1993 to redevelop a former military training site and disused industrial sites in central Copenhagen. Financing the metro, one of the pillars of the redevelopment, came from borrowing against the land with obligations to be met from an increase in land values created by the metro. Copenhagen considered three modes: an expansion of their S-Tog regional rail (similar to Link), a tram (like Tacoma Link), and an Automated Light Rail. The strict funding cap set by the value of the land they could borrow against meant each additional dollar spent resulted in less service and coverage.⁶ The Copenhagen metro had to pay for itself, and every choice was made to maximize value through service that they could then capture via land value increases.⁷ Copenhagen recognized automation would reduce capital and operating costs through delivering capacity via small, high frequency trains instead of long, low-frequency trains. The critical driver of cost savings was dramatically smaller stations, less than half the size of similar capacity heavy metro system. They traded physical capacity (longer trains) for operational capacity (higher frequency). Operational innovation was then complemented with design innovations, like platform screen doors, to deliver better service and greater capacity than heavy metros at a fraction the cost. In solving their financial challenge, Copenhagen invented a new kind of rail transit.

Figure 13. Copenhagen Regional Transit System (2026) Figure 14. The standard Copenhagen Metro station



⁵ <https://www.linkedin.com/pulse/how-dying-city-transformed-one-wealthiest-world-bruce-katz/>

⁶ This constraint is analogous to Sound Transit statutory debt limit

⁷ The Orestad Development Corporation was eventually split into two enterprises: The Copenhagen City Port Development Company and the Copenhagen Metro. The Copenhagen Metro continues to generate revenues via land taxes dependent upon proximity to the metro. The Orestad Development Corporation was eventually split into two enterprises: The Copenhagen City Port Development Company and the Copenhagen Metro. The Copenhagen Metro continues to generate revenues via land taxes dependent upon proximity to the metro.

Delivering twice the service in half the space reduces costs by more than just halving the inputs. Safety codes are a function of size. A smaller station means less onerous emergency escape requirements because riders are closer to exits on a short platform than a long platform. Since trains are more frequent, the loads to/from the platform are less, reducing crowding and smoothing flows. Most of all, smaller stations enable standardization, better locations, and less construction impact mitigation.

Underground stations are [64m in length and 20m wide](#)⁸ or approximately 210' by 65' and employ a 'kit-of-parts' approach, meaning all station elements are standardized and assembled, much like LEGOs. The connection between Danish LEGOs and the kit-of-parts approach is no coincidence. [Per Als](#), the Copenhagen project lead and former CEO of Copenhagen Metro, and [Bent Flyvbjerg](#), the world's foremost scholar on megaprojects, were classmates. Two of Flyvbjerg's maxims, "find your LEGO" then "build big from small," were referenced by Per as guiding principles in our conversations with him. Another Flyvbjerg principle of working right to left - identify your performance goals then work to solve them - also infuses the Copenhagen approach. A local example that follows a similar philosophy is Amazon's emphasis on creating "work backwards" plans. Decision making is driven by performance, customer experience, and safety outcomes, not how they are attained. This focus on results versus tradition enables innovation by allowing flexibility in solving problems. An example of how deep this problem-solving approach runs, Copenhagen operates 24 hours per day through strategically located crossover tracks to allow it to run 15-minute headways on a single track. This makes Copenhagen one of a handful of cities globally that can operate 24-hour per day rail⁹ and allows them to provide late night service without sacrificing long-term maintenance and repair windows.¹⁰

Copenhagen's magic can be summarized as: higher frequency → shorter trains → smaller stations → standardization → less design complexity → less impacts = faster, cheaper, and a better rider experience.

A core insight of Copenhagen is that ***maximizing the rider experience and delivering at the lowest cost are achieved with the same strategy.***

⁸ <https://www.railway-technology.com/projects/cityringen-metro-copenhagen/?cf-view>

⁹ <https://www.zicla.com/en/blog/which-cities-have-24-hours-public-transport/>

¹⁰ During our interview with Per Als he also described how 1 day per year the entire system shuts down for a 1-day maintenance blitz.

Operations: Automation and Train Design

A Copenhagen-style automated metro exceeds the capacity of the planned Sound Transit light rail service, but it takes a radically different approach to achieving this capacity. Copenhagen uses 127' trains, about *one third the length of a 380 foot 4-car Sound Transit train*.

Seat Configuration

Copenhagen uses a 127' long Hitachi Italy Rail Driverless Metro trainset¹¹ with a mix of longitudinal and limited transverse seating. Longitudinal seating reduces the number of seats and increases standing capacity, a tradeoff that is appropriate for a high-capacity line with short trips. Sound Transit uses the Siemens 700 Light Rail Vehicle, which is 95 feet long. However, couplers (the joint between trains) and driver cabins reduce the passenger cabin to ~78 feet. Sound Transit has a mix of transverse seating and longitudinal seating, with a higher ratio of transverse to longitudinal seating. A higher share of transverse seating makes sense for the Regional Spine where the average trip is longer than shorter trips between neighborhoods in a city. Copenhagen's platforms are 167' long, which is long enough to fit the 162.5' version of the Hitachi vehicle that is operated in Milan. Therefore, we use the Milan car (162.5') for capacity calculations and operations and maintenance facility design requirements.

Figure 15. Interior of Copenhagen Metro Vehicle



Open Gangway

The Hitachi vehicle has an open gangway for the entire car (a feature of all new ALR trains). Continuous gangways increase capacity and reduce dwell times (the time it takes for passengers to board and alight the train) by increasing room for more doors and allowing passengers to move to less congested parts of the train.

In traditional systems with separated cars, like Sound Transit's, passengers are not evenly distributed. Passengers cluster in the center of the platform and board cars in the middle of the train. This makes the cars in the middle of the train more crowded than cars at the front and rear, reducing the effective capacity of the train. Additionally, the Hitachi is a single flat boarding compartment, while the Siemens has a stepped-up section at the end of each car to accommodate the "bogies" - train speak for the wheel assemblies, which impedes flow and limits the number of doors. More doors and flat floors paired with no wasted space for couplings and operator cabins means automated metros use every inch of the

¹¹ The Hitachi train is technically a 3-car trainset. However, because it is an open gangway design it looks like a single car. For the purposes of this paper, we refer to this as a single car.

vehicle to move passengers. Traditional Light rail vehicles sacrifice about a sixth of their length to dead space.

Train Frequency

Copenhagen’s Cityringen operates trains at a frequency of 80 seconds to 100 seconds (35 to 45 trains per hour), but Copenhagen is not the only city operating extremely high frequency automated light rail.

Milan, Montreal, and Vancouver offer a sampling of other cities that have deployed ALR systems.

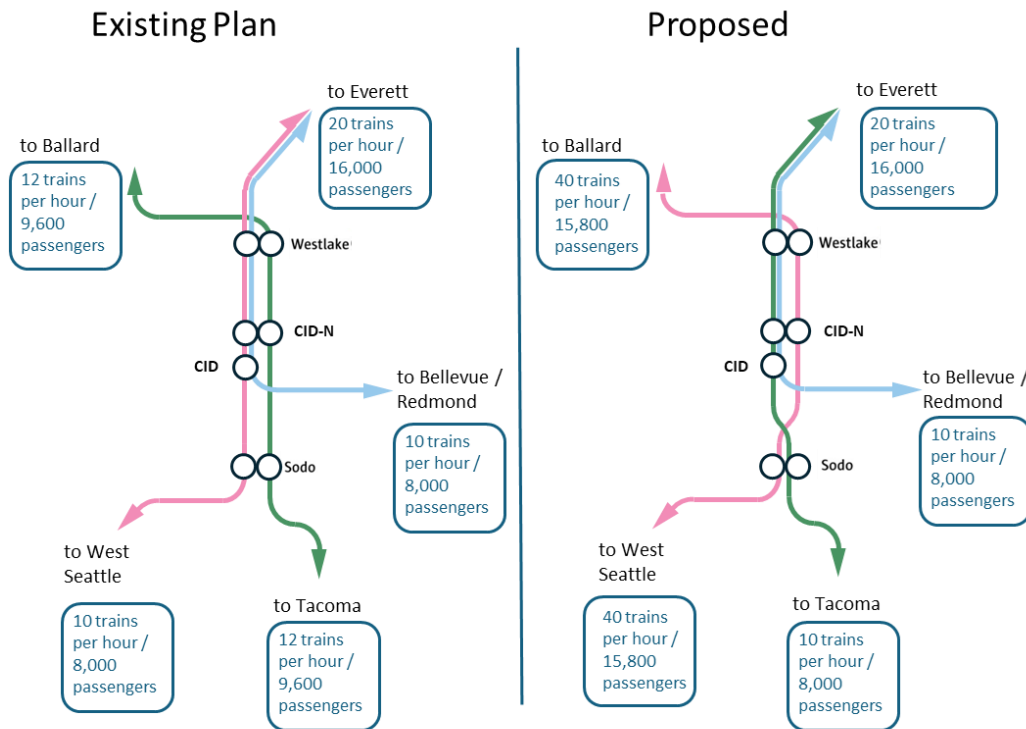
Figure 16. Sample frequencies from Automated Light Rail lines around the world

System	Car Manufacturer	Maximum Allowable Frequency		Maximum Operated Frequency	
		Seconds	Trains per Hour	Seconds	Trains per Hour
Sound Transit		5 to 6 minute headways			
Copenhagen	Hitachi	80	45	90	40
Milan	Hitachi	75	48	180	20
REM (Montreal)	Alstom	90	40	150	24
Vancouver	Hyundai Rotem	90	40	120	30

Sources:
 Copenhagen <https://www.webuildgroup.com/en/media/press->
 Milan https://www.railjournal.com/in_depth/milan-completes-first-of-two-automatic-metro-lines/
 Montreal <https://rem.info/en/rolling-stock>
 Vancouver <https://dailyhive.com/vancouver/canada-line-maximum-frequency-skytrain>

In comparison, Sound Transit’s current operating assumptions are 5 to 6-minute headways across the three lines, 30 to 32 trains per hour split between the two tunnels (see image below).

Figure 17. Existing and proposed operating plan, frequencies and capacity



Note: The planned ST frequencies vary across agency documents. For the purposes of this document we assume that Tacoma and Ballard operate on 5-minute frequencies.

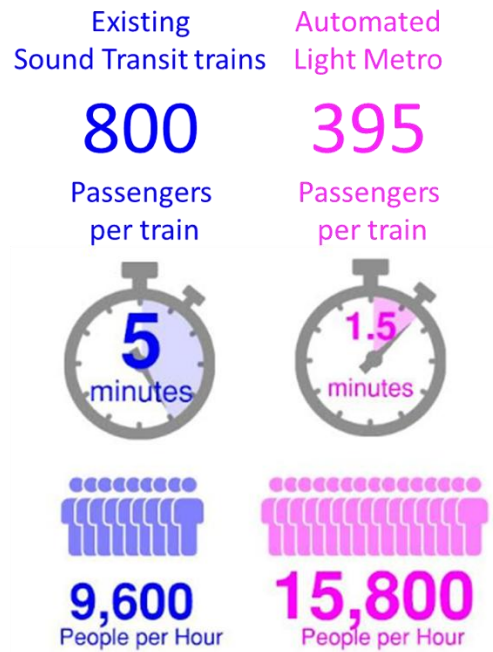
Capacity

A Copenhagen-style ALR running extremely frequent trains (40 trains per hour) through a dedicated, automated second tunnel increases the capacity coming into downtown from 51,200 to 63,600, a 24% increase over the current plan and a 65% increase in capacity from Ballard to West Seattle.

Running trains every 90 seconds instead of every 5 minutes saves the average rider 1.75 minutes per trip, improving the rider experience.

Most importantly, smaller trains allow Sound Transit to revisit the primary cost driver of the system – station design

Figure 18. Extremely frequent, smaller trains have more capacity than less frequent, larger trains

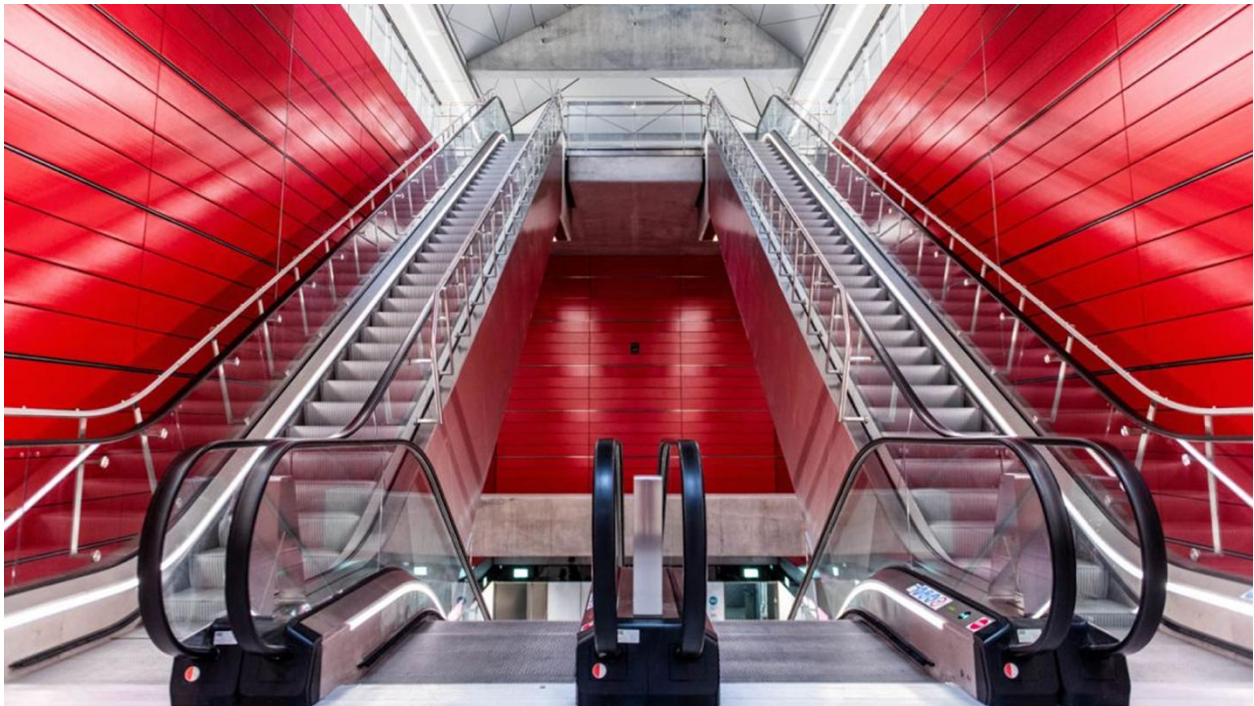


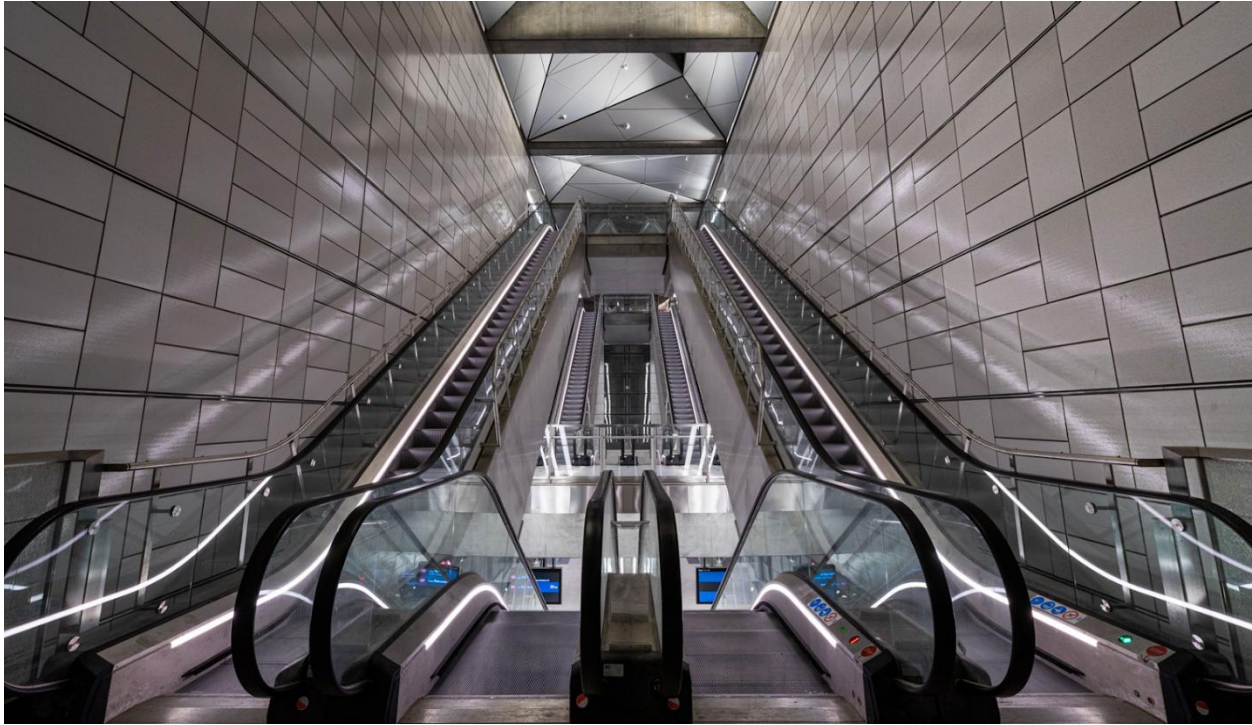
Capital: System Design

Copenhagen's approach to operating strategy (small trains at very high frequencies) was developed in direct response to a need to reduce capital cost. Transportation has high fixed costs but comparatively low operating costs. It functions like a utility - the expensive part is building the capacity, not providing the service, particularly for an automated system.

The Copenhagen approach of using shorter, more frequent trains to build capacity **yields smaller, shallower stations**, and it standardizes station design using a modular kit of parts to lower the cost of construction and maintenance. Per Als, Copenhagen's former Director of Finance and the Copenhagen Metro's first Director of Operation and Development (and later CEO) describes stations as "no frills." The station was viewed as a "transport machine" and not an architectural statement. Stations are simple and functional with standardized approaches to placemaking, like colored panel inserts.

Figure 19. Standard Copenhagen stations with modular approach to place making





Source: CNN

The standard Copenhagen-style station is 210 feet long and 65 feet wide, compared to a typical Sound Transit station that is 680 feet long and 70 feet wide. Smaller tunnels lead to shallower stations, which means that the standard Copenhagen station requires 90% less excavation and a comparable reduction in the amount of concrete.

Figure 20. Comparison of size and depth of typical Sound Transit station to a typical Copenhagen station.

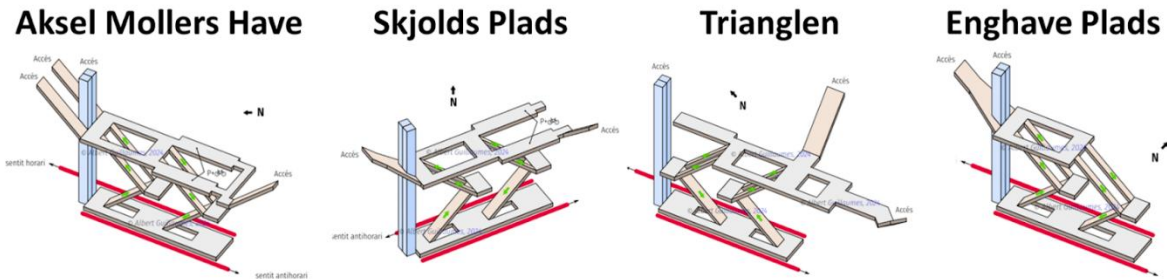
	Sound Transit 3	Copenhagen Cityringen	% Difference
Station Length (feet)	680	210	-69%
Station Width: Platform + Tracks (feet)	70	65	-7%
Station Depth (feet) ¹	108	62	-43%
Volume of Earth Excavated (cubic feet)	5,140,800	516,000	-90%

Note: These volumes are illustrative due to difference in station design and construction. Sound Transit stations are mined and excavate large headhouses and station access points. Copenhagen stations are dug in the ROW via an open excavation pit.

1. <https://www.railway-technology.com/projects/cityringen-metro-copenhagen/?cf-view>

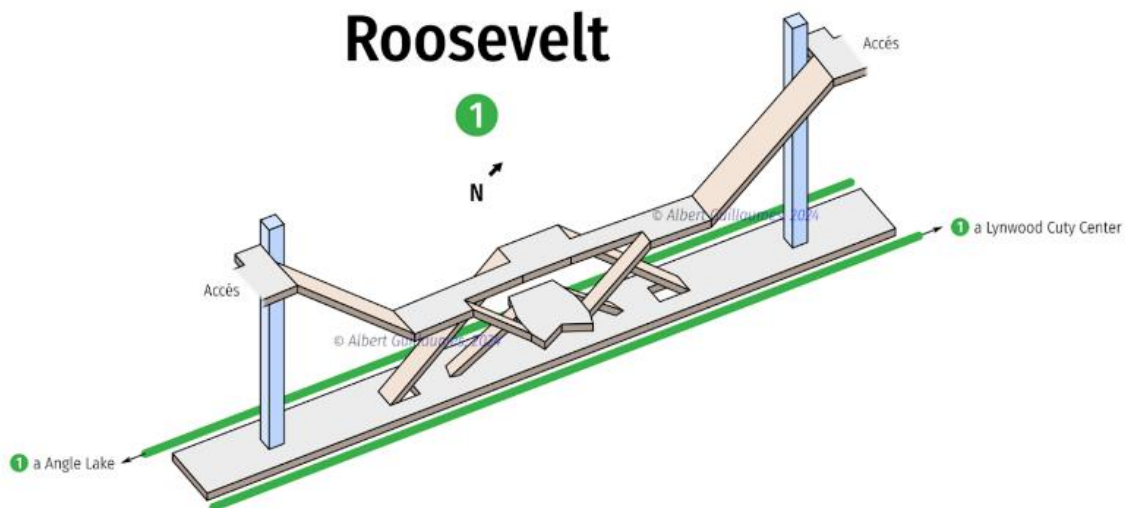
This does not include mezzanines. Copenhagen is very efficient in its use of space. Vertical circulation (elevators and escalators) takes place directly above the platform versus expansive mezzanines, further reducing the amount of earth excavated and concrete used. And the narrower smaller stations means that entrances and exits fit within existing public Right of Way, reducing acquisition costs and delays.

Figure 21. Modular stations with near identical design and efficient vertical circulation



Sound Transit stations in contrast are palatial, requiring massive excavation and property takings. To illustrate design inefficiencies, two deconstructed fighter jets could fit in the excess space at the Capitol Hill Station.

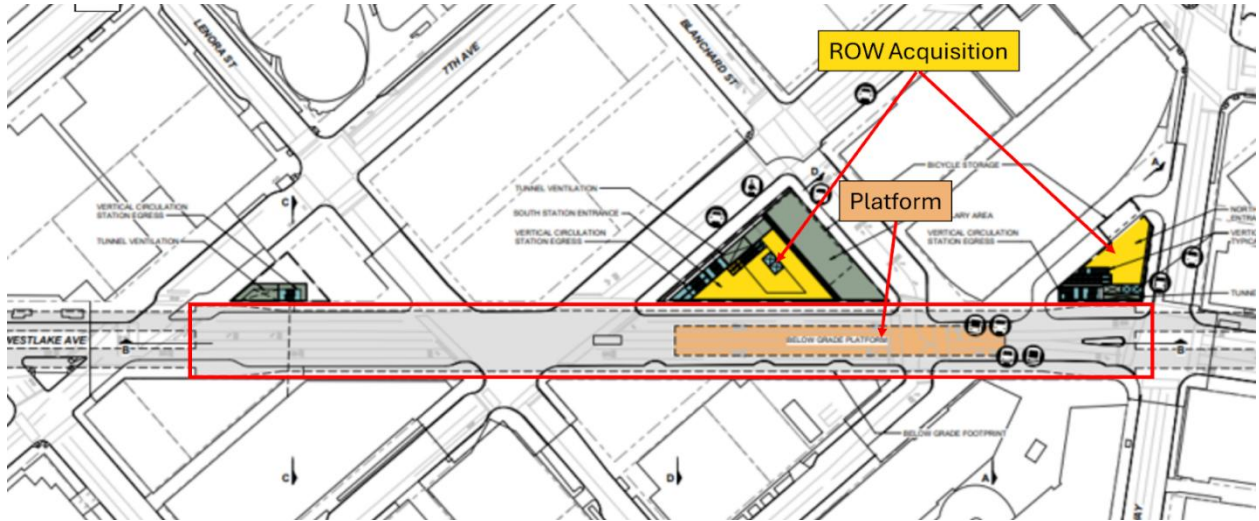
Figure 22. Roosevelt Station features excess depth and inefficient vertical circulation



Smaller shallower stations require less excavation and less construction. Reducing the scale and scope of construction allows work to be completed faster, at lower cost, and with dramatically lower impacts. For example, the standard city block in Seattle is between 300 and 400 feet, far exceeded by the average Sound Transit 3 station, but comfortably larger than a new Copenhagen Cityringen station. Since a station can fit within a city block, this means intersections can go unimpeded, dramatically reducing local impacts while the impacts themselves are of shorter duration.

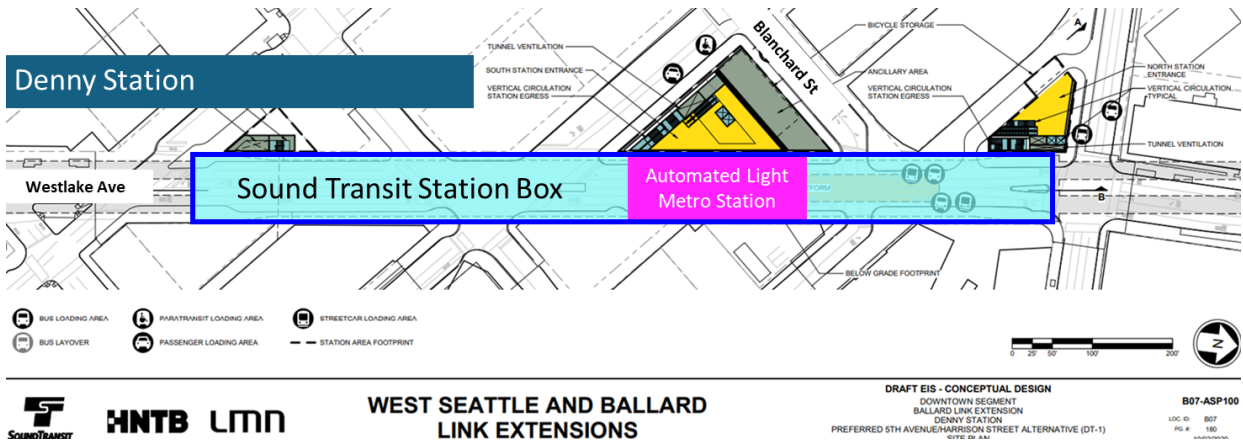
This is the proposed Sound Transit station at Westlake and Denny. It digs a station box covering three city blocks and disrupts 3 intersections, takes 2 parcels, and is 100' feet deep.

Figure 23. Proposed Sound Transit station at Denny and Westlake



This is an Automated Light Metro station within the same footprint as Sound Transit’s proposed station. Only 1 block is disrupted during construction. The footprint is so small that it could almost be accommodated in the parcel Sound Transit is acquiring for Station access.

Figure 24. Denny and Westlake Station built as an Automated Light Rail



In summary, smaller, shallower Stations = Less excavation + less concrete + faster construction + less property acquisition + less surface disruption less.

Project Cost

By delivering transit service and capacity through higher frequency and smaller stations, Copenhagen was able to deliver a 100% tunneled project with 1.7 stations per mile for ~\$621M per mile (\$2025). Sound Transit’s Ballard and West Seattle is approximately 35% tunneled with 1.2 stations per mile will cost an estimated \$2.3B to \$2.6B per mile (\$2025). Copenhagen’s project cost ¼ of what Sound Transit expects to spend.

Comparing apples to apples for big construction projects in different countries is challenging. A rail project is not built all in one year; design and construction can take 10 years or more with spending occurring throughout the project. Agencies may report “hard” (materials and labor) and “soft” (Design and Engineering and Project and Construction Management) costs differently. Additionally, some project costs are not included in the headline cost number. For example, Sound Transit does not include the cost of rail cars or the incremental space needed in their Operations and Maintenance Facility (OMF) as a project cost for Ballard and West Seattle. Rail car costs are included in the Series 3 LRV budget and the OMF requirements are included in the Everett Extension and the OMF South project. The change in Peak Car requirement for the Regional Spine does not appreciably change if Sound Transit shifts to an ALR. Therefore, we did not adjust the Ballard and West Seattle cost per mile for our analysis. Rail cars and OMF are included in the ALR cost per mile.

Figure 25. Project data sheets from Sound Transit 2026 budget highlighting that some Ballard and West Seattle project costs are included in other projects - understating the total project cost.

The figure displays three project data sheets from Sound Transit's 2026 budget. Each sheet provides financial and operational details for a specific project.

- SERIES 3 LRV (Project # T400037):** Managing Department: OPS, Project Type: SYSTEM EXPANSION. Authorized Allocation: Prior Year TIP \$33,000, Current Year TIP \$33,000. Project Details: Status 'In planning', In-Service Date 2044, Financial Plan Value \$2,091,936 (2044 in 000s).
- EVERETT LINK EXTENSION (Project # T400052):** Managing Department: PED, Project Type: SYSTEM EXPANSION. Authorized Allocation: Prior Year TIP \$196,942, Current Year TIP \$196,942. Project Details: Status 'In planning', In-Service Date 2037, Financial Plan Value \$7,934,587 (2044 in 000s).
- O&M FACILITY-SOUTH (Project # T400054):** Managing Department: PED, Project Type: SYSTEM EXPANSION. Authorized Allocation: Prior Year TIP \$394,360, Current Year TIP \$403,729. Project Details: Status 'In planning', In-Service Date 2029, Financial Plan Value \$1,967,169 (2044 in 000s).

Simply reading a headline article about the cost of US infrastructure vs. European infrastructure is not sufficient to evaluate the potential cost savings of moving to an ALR. To ensure we were not inadvertently presenting overly favorable cost estimates for Copenhagen, we estimated Copenhagen’s s-curve (the rate at which it spent money over the course of the project).

Figure 26. Estimated S-Curve of Copenhagen spending on the Cityringen project.

	2012	2013	2014	2015	2016	2017	2018	2019	Total
% of Project Spend Per Year	4%	8%	12%	16%	18%	18%	14%	10%	
Spending Per Year (\$YOE)	\$128,000,000	\$256,000,000	\$384,000,000	\$512,000,000	\$576,000,000	\$576,000,000	\$448,000,000	\$320,000,000	\$3,200,000,000
NHCCI Inflation	1.577	1.591	1.628	1.72	1.631	1.617	1.675	1.849	
Spending Per Year (\$2025)	\$256,568,167	\$508,620,993	\$745,592,138	\$940,948,837	\$1,116,331,085	\$1,125,996,289	\$845,449,552	\$547,063,277	\$6,086,570,340
Cost per Mile (Flat) - \$2025	\$603,755,102								
Cost Per Mile (S-Curve) - \$2025	\$621,078,606								

Notes: Q1 2003 = 1 / Q1 2025 = 3.161

The most recent Copenhagen Metro project, the Cityringen (M3) is 100% tunneled and cost [\\$3.2B in 2019](#) to build 9.3 miles and 17 stations. Inflated to 2025 using the US National Highway Construction Cost Index brings Cityringen’s cost to an estimated \$6.1BB or \$621M per mile.

We took Sound Transit’s existing \$2025 cost estimates as a given. We have not incorporated any savings identified in the ongoing Enterprise Initiative. The Ballard and West Seattle’s cost estimate \$27.1B to \$30.5B for 11.8 miles (\$2025).

Figure 27. Current cost estimates of the Ballard and West Seattle extensions (\$2025)

Project name	Current Finance Plan value (2025\$ in millions)	Updated estimate (2025\$ in millions)	Current Finance Plan value (YOE\$ in millions)	Updated estimate (YOE\$ in millions)	Level of design development
West Seattle Link Extension	\$4,193	\$7,000 - \$7,900	\$4,791	\$8,700 - \$9,800	Preliminary engineering
Ballard Link Extension & Downtown Tunnel	\$11,907	\$20,100 - \$22,600	\$15,518	\$29,000 - \$32,700	Advanced conceptual engineering

Opportunities

Copenhagen’s cost is ~25% of the Seattle cost per mile. We set a target of 50% cost savings for a Seattle ALR based on reduced station size and excavation volumes. We believe this is a conservative approach. While both projects cross waterbodies and Copenhagen is 100% tunneled, we did not want to discount the complexity that comes with tunneling through the denser downtown of a North American city and the differing soil and seismic conditions in Seattle. However, there are opportunities that can further reduce costs from the 50% target and improve the rider experience. The sequence of these opportunities is:



Design Standards - NFPA 130

Fire code and design standard interpretations lead to oversized and engineered stations, increasing costs and complexity. Copenhagen’s Cityringen (M3) line is designed to the same fire code NFPA 130 standard used in Seattle, but complies based on minimum design outcomes, versus a checklist of compliance.

Copenhagen’s very efficient fire and safety design began with adopting the German BOStrab system for fire safety engineering and German consultants with deep experience designing subways. BOStrab applies a systematic approach to fire safety, which was then applied as a framework to inform NFPA 130 code interpretations. The comprehensive and more rigorous German standard therefore established the boundaries for compliance with NFPA 130.

In contrast, NFPA 130 compliance is *subject to the interpretation of the fire chiefs* where the infrastructure is built for Sound Transit. The chiefs’ latitude for interpretation means *each jurisdiction has differences despite the same code*. However, in Seattle, entire sections of NFPA 130 are replaced with **more stringent standards**. Seattle’s code is more stringent in the following ways:

Escalators and elevators cannot count toward egress capacity in any circumstance

~~5.3.5.10 Stopped escalators shall be permitted to be started in the direction of egress in accordance with the requirements for stopping of escalators described in 5.3.5.7(3), 5.3.5.7(4), and 5.3.5.7(5), provided that the escalators can be restarted in a fully loaded condition and that passengers are given warning.)~~

~~ISI4901.2.6.15 NFPA 130 Section 5.3.6 through 5.3.6.4. Delete NFPA 130 Section 5.3.6 through 5.3.6.4:~~

~~**((5.3.6 Elevators:**~~

~~5.3.6.1 Elevators meeting the requirements of 5.3.6.2 through 5.3.6.4 shall be permitted to account for part of the means of egress capacity in stations.~~

Enclosed emergency exits must provide 50% of egress capacity

5.3.3.6 Alternate Egress. At least two means of egress remote from each other shall be provided from each station platform as follows:

~~((1)* A means of egress used as a public circulation route shall be permitted to provide more than 50 percent of the required egress capacity from a station platform or other location.~~

Distance from any point of the platform to any exit is reduced from 100m to 76m

Expands areas requiring sprinklers to all enclosed areas in stations, exempting only areas with high voltage equipment

5.4.4.1* An automatic sprinkler (~~(protection)~~) system shall be provided (~~(in areas of stations used for concessions, in storage areas, in trash rooms, and other similar areas with combustible loadings, except trainways)~~) throughout enclosed stations.

EXCEPTIONS:

1. Traction power substation (TPSS) when located in a transformer vault designed in accordance with the NFPA 70.
2. Other high voltage equipment located in a transformer vault designed in accordance with the NFPA 70 when *approved* by the *fire code official*.

[S] ~~((4901.12))~~ **4901.2.6.9 NFPA 130 Section 5.3.3.4.** Modify NFPA 130 Section 5.3.3.4 as follows:

5.3.3.4 Travel distance. For open stations the maximum travel distance on the platform to a point at which a means of egress route leaves the platform shall not exceed 100 m (325 ft.). For enclosed stations the travel distance to an exit shall not exceed 76 m (250 ft.).

Reduces distance between emergency exits in tunnels from 2,500 ft to 800 ft

[S] **4901.7 NFPA 130 Section 6.3.1.4.** Modify NFPA 130 Section 6.3.1.4 as follows:

6.3.1.4* Within enclosed trainways, the maximum distance between exits shall not exceed ~~((762))~~ 244 m ~~((2500))~~ 800 ft.

Increases size of catwalks for emergency egress in tunnels

[S] **4901.7.1 NFPA 130 Section 6.3.2.1.** Modify NFPA 130 Section 6.3.2.1 as follows:

6.3.2.1* The means of egress within the trainway shall be provided with an unobstructed clear width graduating from ~~((610 mm (24 in.)))~~ 760 mm (30 in.) at the walking surface to ~~((760 mm (30 in.)))~~ 910 mm (36 in.) at 1575 mm (62 in.) above the walking surface to ~~((430 mm (17 in.)))~~ 760 mm (30 in.) at 2025 mm (80 in.) above the walking surface.

What is the basis for Seattle's divergence from industry standards?

Sound Transit is not responsible for code interpretation and approvals but bears the responsibility of delivering compliant designs. Lacking code authority, Sound Transit practices 'defensive design' to secure approval and prevent administrative delays.

Tunnel Code Compliance and Design

Overly prescriptive design standards limit the ability to design for a context by eliminating entire design typologies. These arbitrary additions *are on top of the already overly conservative interpretations of NFPA 130* found in North America.

The impacts of overly stringent interpretation *before accounting for Seattle's uniquely stringent standards*, is illustrated in an analysis of the Sepulveda Line's single bore tunnel design versus single bore tunnels for the Grand Paris Express. Single bore tunnels are when one large tunnel is dug for both directions of travel versus two tunnels.

The Grand Paris Express is a 120 mile and 68 station addition to the Paris Metro featuring four entirely new lines and extensions to two lines. 90 percent of the extension is underground, and the majority is in a single bore tunnel. [27 boring machines](#) will deliver the project.

The proposed tunnel diameter for the Sepulveda Line is 43.5 ft, compared to the largest diameter on the Grand Paris Express - 32 ft, an 85% difference in excavation of 804 sq/ft vs. 1,485 sq/ft. However, *single bore is not allowed* under Seattle’s existing code because of the cross-passage fire requirements.

This is not an endorsement of single bore, but an illustration of the rigidity imposed by code interpretations and standards. The primary drivers for differences in tunnel diameter are the requirements for a fire separation wall with egress in the middle. Whereas in Europe it is common practice to have no fire separation wall and using the track space for egress is an option.

Why does the interpretation of similar or identical standards vary so greatly between America and Europe?

Tunnel Size Impact on Delivery Cost and Time

Tunnel size has several outcomes: the cost of tunnelling, the speed of tunneling, and the depth of tunneling. Sound Transit’s tunnels are 21.5’ in diameter whereas Copenhagen’s Cityringen features 18.8’ diameter tunnels. This seemingly minor difference has major impacts. The diagram below shows how a small reduction in the diameter of the tunnel reduces the amount of earth excavated by 18%.

Figure 28. Comparison of tunnel cross section in Paris and Los Angeles

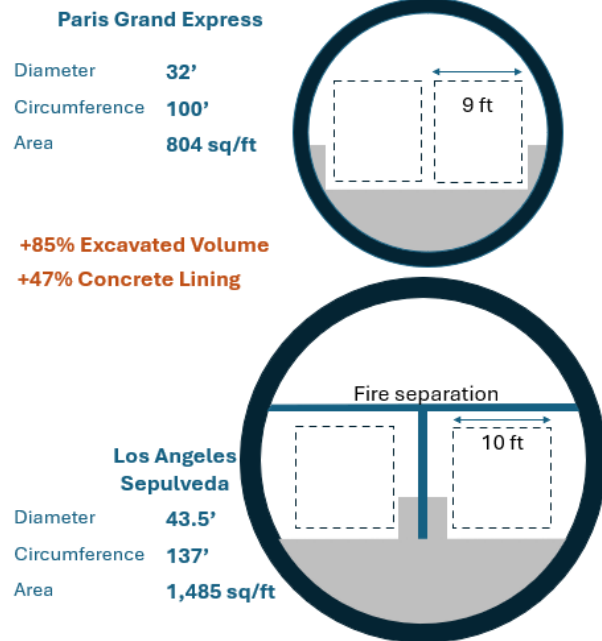


Figure 29. Impact of tunnel diameter on excavation volume

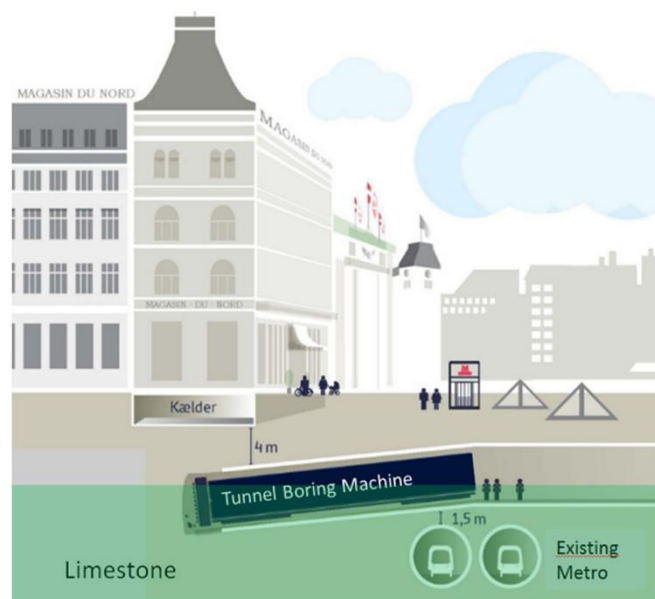
	Sound Transit	Copenhagen	Difference	% Reduction
Diameter (ft.)	21.5	18.9	2.7	12.3%
Earth Excavated (sq.ft.)	363.2	279.2	84.0	23.1%

Notes

[https://www.soundtransit.org/get-to-know-us/news-events/news-releases/sound-transit-finishes-](https://www.soundtransit.org/get-to-know-us/news-events/news-releases/sound-transit-finishes)
<https://www.wbuildgroup.com/en/projects/metros/copenhagen-cityringen-metro/>

Smaller tunnels can also be built closer to the surface and disturb far less ground because excavation volume scales with the square of the radius, which greatly reduces settlement risk near the surface. Because of this, smaller tunnels need much less cover above them, while large tunnels must be placed deeper to safely distribute loads. Smaller tunnels can also fit between utilities and foundations instead of going beneath them, avoiding the need to dive deep under the entire urban subsurface. For context, the Cityringen features a section that passes only 4m below a historical building's foundations and passes [1.5m above active metro tunnels](#). Seattle has different geological conditions than Copenhagen which will impact how and where tunnels can get built. However, we also know that building smaller tunnels presents an opportunity to reexamine the depth at which we need to build them.

Figure 30. Illustration of Copenhagen metro threading through complex subterranean, urban environment



Source:
https://www.researchgate.net/publication/319102161_Mitigation_works_prior_to_soft_ground_tunnelling_with_low_cover_for_the_Copenhagen_Cityringen_Metro

Station Depth

The average station depth for Copenhagen is 65 feet¹² vs. 108 feet for Sound Transit 3 stations. As reported in *The Urbanist*, there are a myriad of reasons for station depths. “The primary drivers include the existing terrain in the Downtown area; soil properties and underground utilities; light rail operational requirements such as how steep light rail can climb, and special track work; high-rise buildings with underground tiebacks; and other underground infrastructure such as the existing light rail tunnel, and SR-99 north tunnel portal.”¹³ Not mentioned is the construction-related disruption and impacts. A key question to revisit is, with smaller stations and construction disruption limited to a single block face, can Sound Transit revisit the depth of stations? We interviewed several SDCI staff who indicated that “underground tiebacks” can be removed after a building is constructed. [SPU’s current tunnel project in Ballard and Fremont](#) and the [DSTT](#) are local examples of the feasibility removing tiebacks during tunneling. Lastly, smaller tunnels open the possibility of avoiding previously unavoidable utilities. With the dramatic reduction in station size and the feasibility of a smaller tunnel diameter, Sound Transit could revisit the need for extremely deep stations, creating the opportunity for additional savings.

In summary, smaller tunnels = Less excavation + less concrete + faster to build + closer to the surface

¹² <https://www.railway-technology.com/projects/cityringen-metro-copenhagen/?cf-view>

¹³ <https://www.theurbanist.org/2022/01/14/deep-seattle-light-rail-stations-other-st3-details-emerging-ahead-of-january-28-draft-plan-release/>

Rider Experience

Train frequency and station depth have a profound impact on the rider experience. Moving to an Automated Light Rail with more frequent trains and shallower stations dramatically reduces travel time for riders.

Shorter trains and shorter stations allow Copenhagen to build shallower stations using open pits. Sound Transit’s longer stations (680’ on average) force it to choose between disrupting multiple blocks with cut and cover construction or exorbitantly expensive mined stations. Sound Transit is choosing deeper, mined stations. As a result, Copenhagen’s tunnels are 30 to 40 feet shallower than Sound Transit stations.

The typical pedestrian descends on an escalator at 4 to 10 vertical feet per second (depending on walking speed), so the difference between a 108-foot-deep Sound Transit station (ST3 average) and a 40-foot-deep station is 40 to 80 seconds at the beginning and end of the trip (depending on if the passenger is walking). Since trains arrive every 1.5 minutes instead of every 5 minutes this will save the average rider 1.75 minutes waiting for their train.

Figure 31. Travel time savings from shallower stations and more frequent trains.

	Sound Transit (sec)	Automated Light Rail (sec)	Time Saved (sec)	Time Saving from ALR
Station Entrance to Platform ¹	38	33	-5	-13%
Waiting for a Train ²	150	45	-105	-70%
Riding on the Train ³	900	729	-171	-19%
Platform to Station Exit	68	33	-35	-52%
Total Travel Time (seconds)	1,155	839	-316	-27%
Travel Time (minutes)	19.3	14	-5.27	-27%

Note:

1. Assumes 5 seconds of travel time for every 10 feet of elevation change via escalator (assumes walking up and down vs. standing stationary). Assumes Ballard station is 75' deep and Westlake is 135 feet. Assumes ALR is 65' (Copenhagen depth). This is to illustrate the impact of station depth on travel time. It is not asserting these would be the actual station depths with ALR.
2. Assumes 5-minute frequency for Ballard and 90 seconds for ALR
3. Sound Transit travel time based on Ballard DEIS. ALR assumes a speed of 25.2 mph, which is based on time table of a representative trip from Vestamager to Islands Brygge St (comparable distance and number of stations) and then applied to the distance from Ballard to Westlake.

Project Finance

A portion of Sound Transit’s financial shortfall is related to a statutory cap on the agencies’ debt service. Separating Ballard and West Seattle into a separate second tunnel and segregating operations from the legacy LRT system opens the door to new project delivery and project finance possibilities. Outside of the US, Public-Private Partnerships are much more common. A common approach to PPPs is to structure a procurement as a Design Build Finance Operate and Maintain (DBFOM). In a DBFOM the public entity outlines the scope of services to be delivered, and the project and services are delivered by a private sector entity. The public agency pays an “availability payment” to the DBFOM entity. Depending on the structure of payments and allocation of risk, it may be possible Sound Transit to deliver the Ballard and West Seattle line without impacting Sound Transit’s statutory debt limit. There are tradeoffs to this approach- an availability payment may be higher than a project financed by public debt. Some may have concerns about labor rights and organizing under a PPP. Labor rights can be negotiated into the PPP terms to ensure that workers are still organized or have the right to organize. Sound Transit has limited experience with this method of project delivery, and bringing in outside expertise to advise the agency would be essential.

Challenges

Pursuing an Automated Light Metro presents several unknowns, and in major capital projects unknowns represent risk. This section identifies the primary risks that came up during stakeholder conversations and industry outreach.

Introducing Automated Light Rail Technology / New Vehicle Type

Introducing automated train operations is not as simple as removing an operator. ALR will require a different systems architecture with tighter integration among signaling, communications, SCADA, vehicles, control-center functions, yard procedures, and safety certification. The US transit industry has limited experience with high-frequency, high-capacity automated transit. This creates added risk around scope definition and the agency's institutional capacity to procure and manage a more software-intensive rail system.

These risks can be mitigated, though not eliminated, by selecting a proven automation concept, minimizing bespoke solutions, and minimizing interfaces with legacy Link infrastructure. The agency should seek guidance from international experts with experience building and operating automated light rail systems.

Some stakeholders expressed concern with inefficiency created by operating a new mode versus moving forward with the existing rail vehicle. Specifically, their concerns related to the need to train a different workforce and stock different parts for a unique system. The inefficiencies associated with multiple vehicle types generally diminish as a new fleet grows large enough to support its own dedicated maintenance, training, and spare-parts ecosystem. Copenhagen offers an instructive example here as well. Prior to building the Metro, it evaluated expanding the S-Tog (Link equivalent and at the time a 7-line system) or building a new Tram (streetcar equivalent). They analyzed the total lifecycle cost and elected to introduce a new 42-vehicle Automated Light Metro fleet rather than expanding the S-Tog or building a new Tram.

Ballot Language

Moving to an automated light rail raises the question of whether this approach is compliant with the ballot language approved by voters:

The Sound Transit Board passed Resolution No. R2016-17 concerning expansion of mass transit in King, Pierce, and Snohomish counties. This measure would expand light-rail, commuter-rail, and bus rapid transit service to connect population and growth centers, and authorize Sound Transit to levy or impose: an additional 0.5% sales and use tax; a property tax of \$0.25 or less per \$1,000 of assessed valuation; and additional 0.8% motor-vehicle excise tax; and use existing taxes to fund the local share of the \$53.8 billion estimated cost (including inflation), with

continuing independent audits, as described in the Mass Transit Guide and Resolution No. R2016-17.

The first question one needs to ask is, what is the legal definition of “Light Rail”? There is no legal definition of “light rail” in the RCW or federal statute. Transit modes exist on a continuum and represent a cluster of features. For every term like “light rail” that seems to have a clear cut definition of features, there is an exception. FTA uses 4 categories for reporting transit data.

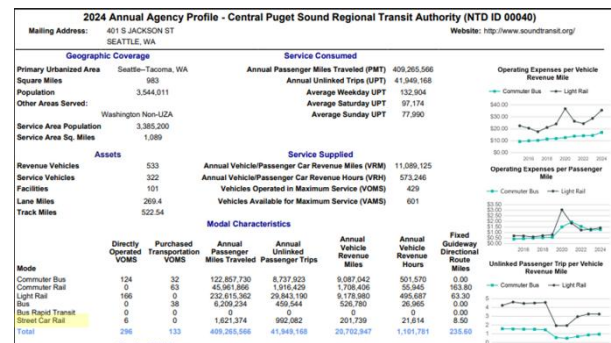
Figure 32. FTA modal definitions

Mode	FTA Definition
Light Rail	A transit mode that typically is an electric railway with a light volume traffic capacity compared to heavy rail (HR). It is characterized by: passenger rail cars operating singly (or in short, usually two car, trains) on fixed rails in shared or exclusive right-of-way (ROW); low or high platform loading; and vehicle power drawn from an overhead electric line via a trolley or a pantograph.
Heavy Rail	A transit mode that is an electric railway with the capacity for a heavy volume of traffic. It is characterized by: high speed and rapid acceleration passenger rail cars operating singly or in multi-car trains on fixed rails; separate rights-of-way (ROW) from which all other vehicular and foot traffic are excluded; sophisticated signaling, and high platform loading.
Commuter Rail	An electric or diesel propelled railway for urban passenger train service consisting of local travel which operates between a central city and outlying areas. Service must be operated on a regular basis by or under contract with a transit operator for the purpose of transporting passengers within urbanized areas (UZAs), or between urbanized areas and outlying areas. Commuter rail is generally characterized by multi-trip tickets, specific station-to-station fares, railroad employment practices, relatively long distance between stops, and only 1-2 stations in the central business district.
Streetcar	This mode is for rail transit systems operating entire routes predominantly on streets in mixed-traffic. This service typically operates with single-car trains powered by overhead catenaries and with frequent stops.

Source: <https://www.transit.dot.gov/mtd/national-transit-database-ntd-glossary#S>

The modal definitions reflect a cluster of features, with overlap across modes. For example, Sound Transit calls Tacoma Link “light rail” but for reporting purposes it is a streetcar. A light metro as described in this paper meets the characteristics of a light rail line.

Figure 33. NTD Agency Profile showing Sound Transit reporting Tacoma Link LRT as Streetcar



But the most important question is, IF someone chose to sue Sound Transit for not complying with the ballot language, what test would the court apply? We believe that the court would pose the question, does the automated light metro deliver the service that voters approved? This proposal delivers rail to and from the places promised at a frequency equal to or greater than Link “light rail.”

West Seattle Schedule

The schedule to the right is Sound Transit’s most current public schedule for the West Seattle extension from the March 2026 Board retreat. The biggest schedule risk is meeting a 2028 / 2029 groundbreaking on West Seattle. Given that station location and alignment are decided, if Sound Transit pursued an ALR it could likely be accommodated within the current timeline. However, moving to an automated light metro would allow the Ballard extension to avoid a decade of delay.

Figure 34. West Seattle Schedule (as of March 2026)

Milestones

- **ROD:** Completed April 2025
- **Start of Final Design:** Anticipated Q3 2026
- **Start of Construction:** Anticipated 2028 / 2029

Competitive Marketplace

Ensuring that there are multiple suppliers of GoA4 systems is critical to guarantee a competitive procurement. While we have used Copenhagen and Hitachi as an example Automated Light Metro, most major rolling stock manufacturers offer GoA4 systems. These systems are generally modular and can scale up or down to the specific system requirements. For example, Hitachi’s ALM scales from the 127-foot train in Copenhagen to 359 feet in Rome. However, Hitachi is not the only supplier of automated metro systems. Alstom; Stadler; CAF, and Siemens all offer driverless, fully automated metros capable of

exceptional frequencies and configurations. The table below summarizes light metro products delivered or planned for delivery in North America and other locations (this list is not comprehensive of automated metros globally).

Note: The discrepancy in number of 'Cities in Operation' is a product of Hitachi offering a more standardized, 'turnkey' product. Alstom, Siemens, Stadler, and CAF have all delivered multiple fully automated systems with multiple lines in single cities.

Figure 35. Fully Automated Light Metro / Automated Light Rail Manufacturers in North America

Manufacturer	Peak Speed	Peak Frequency (headway)	Length	Cities in Operation (North America)
Hitachi	50mph (80km/h)	40tph (90-seconds)	2-6 cars (~127'-359')	Copenhagen, Honolulu , Lima, Milan, Riyadh, Rome, Taipei, Toronto (under construction) , Vancouver*
Alstom	62mph (100km/h)	40tph (90-seconds)	3-6 cars (154'-354')	Montreal , Paris, Vancouver*
Siemens/Stadler	70mph	40tph (90 seconds)**	3-4 (~216'-280')	Los Angeles (Sepulveda Line)
CAF	No North American operations, supplier of GoA4 systems in Spain, Italy, Colombia, Netherlands, Turkey, Brazil, and Chile			

*SkyTrain is unique, legacy induction powered systems were acquired by Bombardier, then Alstom. The Canada Line's delivery partners have since been acquired by Hyundai
 **2:30 initial operations, capable of 90 second headways with future rollingstock purchases

Operations & Maintenance Facility (OMF)

Sound Transit's current and planned Operations and Maintenance Facilities (OMF) are built to service its current and planned fleet of light rail vehicles.

Building a second tunnel that utilizes a different vehicle than the Regional Spine would require building a new Operations and Maintenance Facility or adapting the OMF Central to serve the new fleet and adding capacity to the planned OMF North or OMF South to house LRT vehicles currently stored at OMF Central. A Ballard to West Seattle ALM operating at 90-second headways will require 48 trains (including spares). Adapting the service plan on for the spine would increase the number of LRT cars by 10. This increases the storage needs of the system from an estimated 515 cars to 573.

Figure 36. Estimated car requirements with a ALR operating on 90-second headways.

	Travel Time (1-way)	Layover	Peak Frequency (min)	Peak Car Requirement	Total Cars
Current Plan					
Tacoma to Ballard	93	3	5	156	188
Everett to West Seattle	79	3	6	112	135
Redmond to Mariner	86	3	6	120	144
Issaquah to South Kirkland	25	3	6	40	48
Total				428	515
Automated Light Metro Proposal					
Ballard to West Seattle ALR	28	1	1.5	156	188
Tacoma to Northgate LRT	96	3	6	132	159
Redmond to Everett LRT	108	3	6	148	178
Issaquah to South Kirkland LRT	25	3	6	40	48
Total				476	573

Notes:
 Travel time for ST routes based on ST timetables and environmental documents
 technology.com/projects/cityringen-metro-copenhagen/)
 Assumes a 20% spare ratio
 Requires an additional 10 light rail vehicles and 48 ALR vehicles

We suggest the following approach to address OMF requirements:

Step 1. Does Sound Transit have adequate space in its other facilities to store and service vehicles currently housed and serviced by OMF Central?

Figure 37. Storage capacity at current and planned Sound Transit Operations and

	Total Storage Capacity	Acres	Cars per Acre
South	144	64	2.3
Central	112	23	4.9
East	104	22	4.7
North	152	80 to 100	1.5 to 1.9
Total Storage	512		

Note:
 OMF North and South Capacity based on storage capacity presented in Sound Transit environmental documents

Based on current and planned yard designs, Sound Transit does not have sufficient storage capacity across the network to accommodate 48 ALR vehicles and the fleet required to run its long-term service plan. Sound Transit would need to increase storage capacity by at least 58 vehicles. This can be accomplished by a modest increase in the site efficiency at the OMF North and / or OMF South. Both are at an early enough stage of design (OMF-S = 30% design / OMF-N = 5% design) that adding additional capacity is feasible without significant delay). Based on current schedules, OMF South’s advantage is it will open before the Ballard and West Seattle line is set to open while OMF North’s advantage is it is larger and earlier in design. Both are feasible alternatives, identifying a preferred approach will require further study.

Figure 38. Incremental storage capacity at OMF North through improving site efficiency

	2 cars per acre	2.5 cars per acre	3 cars per acre
OMF South		8	40
OMF North			
80-acre Site	8	48	88
100-acre Site	48	98	148

Step 2. Can existing facilities be modified to serve Automated Light Rail, and if so, what if any changes need to be made to mitigate the impact of storing ALR cars at existing facilities?

The existing site currently has sufficient storage capacity. However, this would clearly require a deep technical analysis to examine feasibility of retrofitting the OMF Central to serve ALR. Primary considerations include but are not limited to the compatibility of the site layout, track geometry, shop layout and functionality, power requirements, and control systems. Those would need to be weighed against the retrofit cost, inherited design constraints from a legacy LRT facility, and the need to relocate or duplicate non-vehicle functions that OMF Central currently houses.

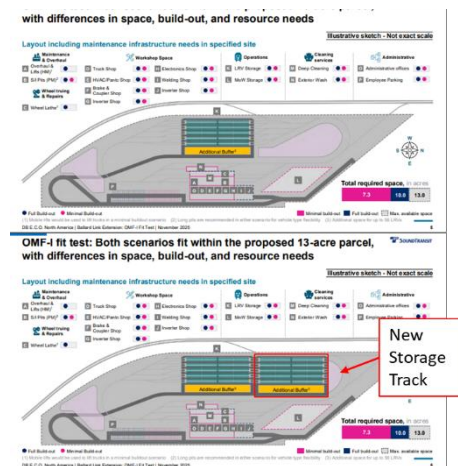
Figure 39. Turning radii at Sound Transit OMF Central



Step 3. If retrofitting OMF Central is infeasible or cost prohibitive, what are the requirements for a stand-alone OMF facility serving ALR?

A facility built to store a 48-car fleet is needed and would require a minimum of 8 to 10 acres. With an automated fleet, the fixed cost of serving train operators goes away and train sets can be stored in smaller, dispersed sites where the primary daily activity is light cleaning. Two smaller sites would cost more to develop but finding acceptable sites may be easier. Sound Transit has already identified a viable site: Interbay was studied under the [Ballard Spur alternative](#) and [the Armory site](#) was identified as a viable location to site an Operations and Maintenance Facility. This facility (as conceptualized by Sound Transit) stores 56 standard LRT or 32 162.5’ ALR vehicles. The design incorporates large balloon-loop circulation tracks, which increase land requirements. It prioritizes operational flexibility rather than rail car storage

Figure 40. Sound Transit illustrative site plan for Interbay OMF and an optional reconfiguration to store additional cars.



needs. Changing the balloon-loop tracks to a stub-end yard doubles storage capacity to at least sixty-four 162.5' ALR vehicles, enough to operate a Ballard and West Seattle line.

National Environmental Protection Act (NEPA)

Before diving into this risk, it is important to note the purpose of NEPA. NEPA requires that agencies analyze and document environmental impacts. It does not require agencies to select the least impactful alternative, and it does not require agencies to mitigate impacts. An inadequate NEPA process is frequently used as the basis of lawsuits designed to slow down or stop projects. We posed the following question to [Beth Osborne](#), former Assistant Secretary for Transportation Policy at USDOT about the impact on NEPA of changing technologies:

If a transit agency has a ROD and they decide to change from an overhead power supply to a 3rd rail and if they shrink the station size but stay within the original footprint of the station they analyzed. So, power supply changes and construction impacts are reduced but stay in the same location. What level of NEPA review would be triggered, if any?

Beth Osborne replied:

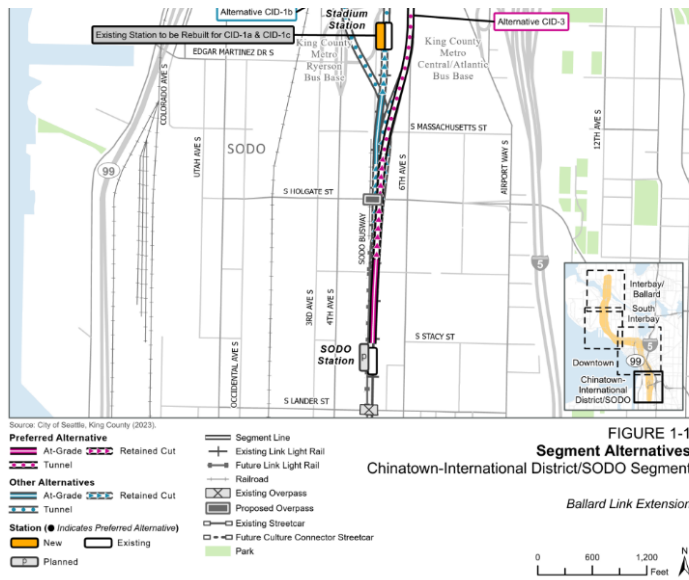
“That is a surprisingly hard question to answer. Shrinking the station size should have no impact on the NEPA review. Shifting from overhead wire to a 3rd rail shouldn't have an environmental or community impact (except to lessen the interruption of the view). But FTA applies NEPA overly-strictly and way more strictly than FHWA. Also transit agencies tend to freak out when their counsel says they could be sued. You can always be sued. The question is whether you can withstand the suit. And if you can show that the change would have no impact on the analysis then you should be fine. Sometimes that might require a quick refresh of the analysis to demonstrate and document, but that is not the same thing as reopening the EIS.

This also applies to the level of review. The number of times I see transit agencies do an EIS that should be an EA or an EA that should be a CE is mind-blowing. They think it will protect them from a lawsuit. It will not.”

- *Beth Osborne, CEO of SmartGrowth America, former Assistant Secretary for Transportation Policy, USDOT*

There are two primary risks related to environmental review. First, the Ballard and West Seattle environmental documents have not evaluated alternatives for an Operations and Maintenance Facility. It is possible that the Central OMF can be used by an ALR fleet, in which case the need for additional NEPA analysis is minimal. If a new OMF is needed, a more thorough NEPA evaluation will be required and may be a critical path risk. As noted above, Sound Transit has a solid basis to begin assessing alternatives.

Figure 41. Sodo station retained cut and TBM launch.



The second element that presents risk is a change needed just north of the SODO station. Sound Transit is proposing a section of retained cut from just north of Walker to just south of Massachusetts. North of this cut the TBM begins boring the second tunnel. The Tacoma to Ballard Link moves into this retained cut and the West Seattle line moves from track in the Sodo busway onto the existing track that ultimately enters the Downtown Seattle Travel Tunnel. An ALR from Ballard to West Seattle would have the retained cut in the SODO busway and the new tunnel would cross under the existing

track north of the retained cut. The primary challenge with the ALR proposal is that the retained cut would need to begin in the busway and then move under the existing rail lane once the TBM is launched. This construction would all take place in the same area as currently planned and should not increase the impact of construction on affected parties.

The second area is the crossover from West Seattle into the new tunnel. The current plan is a SODO tunnel portal / cross over. Current approach assumes Tacoma to Ballard diving into a retained cut and Ballard crossing over. This would require WSL going into a retained cut and cover tunnel / TBM launch pit and the Regional Spine crossing over the pit.

A critical note is that following the issuance of a ROD for West Seattle, significant change in alignment and the removal of the Avalon Station are likely to occur. The changes suggested in this report would not deviate from the current alignment and would decrease impacts while improving service.

Operating Cost Impact

Operating costs may increase under this proposal unless Sound Transit rationalizes service on the Spine.¹⁴ Any analysis should evaluate the total cost of ownership of the current plan and an ALR. Sound Transit cost of human operators is opaque as it is partially included in ST’s operating budget as Salary and Fringe and partly included in Purchased Transportation from King County Metro. Using 2024 numbers (most recent available), the cost per hour is \$664, assuming a typical operator wage of \$37 and a 42% fringe rate; the direct cost of operators is about 8%. The county budget is opaque and doesn’t transparently present salary, fringe benefits, and overhead costs (supervisors, HR, etc.). It is not clear

¹⁴ The current plan of 3-minute headways on the spine between CID and Mariner and 6-minute headways Between Everett and Mariner is far more capacity than is required to serve the projected demand. Rationalizing service levels to match demand would reduce overall operating expenses.

what overhead rate Metro applies. This [report](#) indicates that it is 40 to 50%, bringing the cost of human operators to about 11% to 12% before considering any ST operator-related costs.

Labor

Serving Ballard and West Seattle with Automated Light Rail will not reduce the number of future operator jobs. Based on the peak car requirements identified in the discussion of the Operations and Maintenance section, the number of operator jobs will stay the same or increase by a handful of jobs. The introduction of ALR will increase the total number of cars and car miles, which will likely increase the number of maintenance personnel.

Financial Impact of Delay

Delay is frequently cited as a major risk to large infrastructure projects, but it is often poorly quantified. Discussions of delay typically focus only on the effect of construction inflation, while overlooking the fact that the revenues used to pay for these projects also grow over time.

In principle, delay could also be measured in terms of lost mobility benefits to future riders. However, in the context of evaluating project delivery strategies, the most relevant impact is the financial effect of delay on the capital program.

When estimating delay impacts, project sponsors commonly report the increase in project costs due to inflation. This approach is incomplete. Inflation increases construction costs, but it also increases the tax revenues used to finance transit projects, including sales taxes and property-related revenues tied to economic growth.

$$\begin{array}{c} \text{\$}\text{\$}\text{\$} \\ \text{Impact of} \\ \text{Delay} \end{array} = \left(\begin{array}{c} \text{Construction} \\ \text{Inflation} \end{array} - \begin{array}{c} \text{Revenue} \\ \text{Growth} \end{array} \right) \times \begin{array}{c} \text{Project} \\ \text{Cost} \end{array}$$

According to Sound Transit's 2026¹⁵ financial plan, the agency forecasts a 4.0% per year increase in construction costs and 3.3% in revenue growth. The net financial impact of delay is therefore the difference between these two rates—approximately 0.7% per year.

For the Ballard and West Seattle extensions, with a current high-end estimate of \$30.5B, a one-year delay increases the effective cost of the project by approximately \$214M.

A decade-long delay therefore adds roughly **\$2B in effective cost** to a project of this scale.

The proposal outlined in this paper, issuing a **Request for Information (RFI)** to identify internationally proven cost-reduction strategies while continuing to advance engineering on the current plan, mitigates

¹⁵ <https://www.soundtransit.org/sites/default/files/documents/2026-Proposed-Budget-Financial-Plan.pdf>

both risks. This approach allows Sound Transit to explore whether a significantly lower-cost delivery strategy exists without incurring their current path of far larger financial consequences associated with delaying construction for a decade or more.

Pursuing a parallel evaluation of alternative delivery methods imposes **minimal financial risk**, while the potential upside - identifying a credible pathway to dramatically lower project costs - could be transformative for the ST3 program.

Federal Funds

Sound Transit’s capital program is estimated at \$121B (System Expansion + Service Delivery), of which 16% comes from federal grants. Going forward, \$100M per year is estimated to come from Federal Formula Funds, funding state of good repair. Therefore, grants for system expansion will account for 14% of the total.

Figure 42. Sound Transit 2026 Annual Financial Plan Sources and Uses

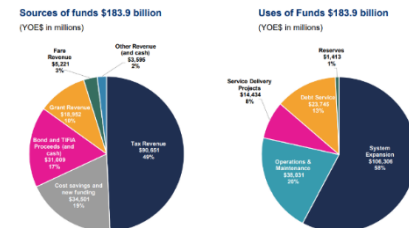
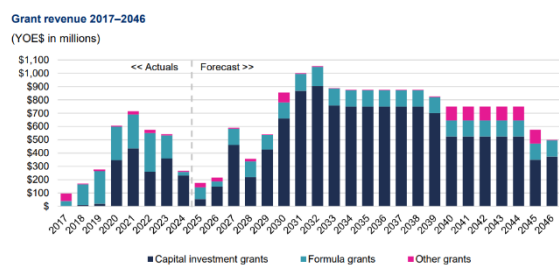


Figure 43. Estimated grant revenue by year



Federal Capital Investment Grants are competitive. To estimate the downside risk of losing federal grants, we evaluated the last 15 years of Federal Capital Improvements (aka New Starts and Core Capacity)¹⁶. Two clear patterns emerged. First, the number of grants per year is very small, and the amount granted is also heavily indexed to smaller projects. Second, Republican administrations tend to favor fewer, larger projects that are more cost effective while Democratic administrations favor more smaller projects, with less emphasis on cost effectiveness. At the current cost per rider, West Seattle and Ballard are not competitive and are less likely to perform well under Republican administrations. Their extreme cost means the smaller grant awards typical of Democratic administrations would do little to close project funding gaps.

Figure 44. Federal Full Funding Grant Agreements signed by year (2011 to 2025)

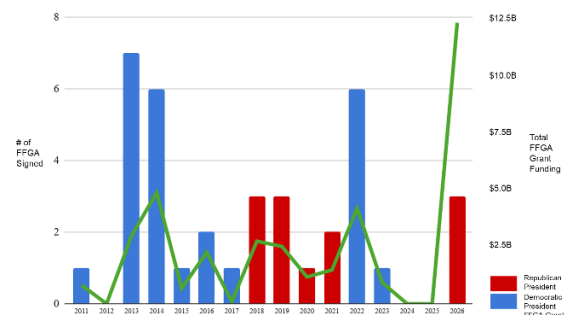
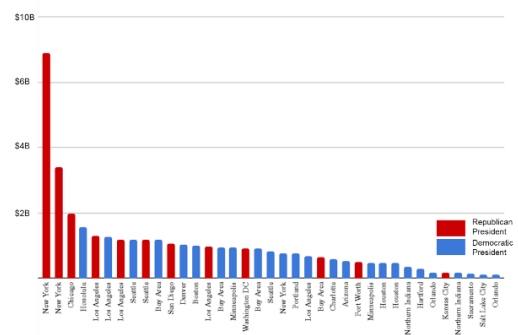


Figure 45. Full Funding Grant Agreement by Size (2011 to 2025)



¹⁶ <https://www.transit.dot.gov/funding/grants/grant-programs/capital-investments/annual-report-funding-recommendations-fiscal-0>

Ironically, two things happen when switching to ALR. It simultaneously makes the project more attractive to Republican administrations (cost effective) and makes Democratic grants more impactful (a larger percentage of project cost). Lastly, at a much lower project cost, it opens the question of whether using federal funds (grants or TIFIA loans) offsets the cost of meeting federal requirements (e.g. Buy America).

Redundancy and Resilience

One argument for a second downtown tunnel, as currently envisioned, is that it would improve system resilience and redundancy. Redundancy and resilience have two distinct dimensions: passenger resilience, meaning whether riders can still complete trips when service is disrupted, and operational redundancy, meaning whether trains can be rerouted through the network without materially degrading service elsewhere.

Under the current plan, the two-tunnel configuration appears to provide only limited redundancy. For riders, redundancy exists only where passengers can transfer between the two corridors, likely at Westlake and either Pioneer Square or Chinatown-International District, depending on final station location and track connections. For train operations, redundancy is narrower still. Only a limited set of service patterns could be rerouted between tunnels, and any such rerouting would likely require reducing service on other lines to create capacity. In practice, this is not full system redundancy, but a constrained form of partial redundancy over a short segment of the network.

From a rider perspective, passenger resilience is the more important measure. The current plan provides some ability for riders to transfer between tunnels, but that benefit is limited by station location, transfer conditions, and the service patterns that can actually be maintained during a disruption. Under the automated light rail concept proposed here, passenger resilience could improve because higher frequencies and greater corridor capacity would make transfers less punitive and recovery from disruptions easier.

If redundancy and resilience is a major justification for the current plan, it should be evaluated using a transparent cost-effectiveness metric. The most relevant measure is the incremental lifecycle cost per rider-hour of delay avoided under a defined set of disruption scenarios. That would allow the agency and the public to assess whether the additional capital and operating cost of the second tunnel produces resilience benefits commensurate with its price. Put differently, the question is not whether redundancy has value, but whether the specific form of redundancy provided by the current plan justifies its incremental lifecycle cost.

Conclusion

Sound Transit should issue an RFI seeking ideas on how to bring Sound Transit's practices in line with international best practices to speed delivery. Sound Transit needs to engage a Technical Advisory Group with expertise in autonomous operations, capital project delivery, NEPA, financial planning and procurement strategy, and international experience. The RFI must address the following:

Technical Approach: What is the recommended approach to deliver a 100% grade separated transit line with stations located within Sound Transit's proposed station envelopes? How will they meet or exceed Sound Transit's planned capacity of 9,600 riders per hour, minimize lifecycle cost, minimize construction related disruption, and maximize project delivery speed?

NEPA / Federal Funding Strategy: Given Sound Transit's current level of environmental approvals and analysis on the Ballard and West Seattle line, how would the respondent minimize the risk of schedule delay from additional NEPA analysis and how would their proposed approach impact Sound Transit's ability to secure federal funding (TIFIA or New Starts)?

State / Local Regulatory and Permitting Changes: What state and local regulatory practices will enable Sound to deliver Ballard to West Seattle with a schedule and budget consistent with international best practices? What procurement strategies and methods are needed to deliver an ALR effectively?

Integration with Existing ST Facilities: Under what circumstances is it feasible to utilize existing Sound Transit infrastructure to reduce project delivery cost and risk?

Sound Transit should convene a Technical Advisory Group with expertise in automated rail planning, design, construction, and automation. It should contain individuals with project delivery and project finance expertise in the US and internationally. International experts should come from countries with a demonstrated expertise in delivering high-capacity transit at much lower costs than the US. The issuance and evaluation of the RFI responses should take no longer than 6 months. During that time, Sound Transit should continue advancing planning and engineering. In the event that industry returns with a credible path to cutting capital cost by 50% or more, the \$15B savings will more than offset the sunk cost of planning and engineering.

Acknowledgements

This paper benefited from conversations with a wide range of experts and stakeholders. We spoke with former transit agency CEOs; senior project delivery experts at US transit agencies; many architecture, engineering, and project delivery consultants / practice leaders; former US Department of Transportation officials; global rail vehicle manufacturers; academic researchers; and two international project delivery and transportation experts. We also consulted with executive and staff-level personnel across four Seattle departments, Sound Transit staff, nonprofit leaders, and numerous Seattle stakeholders and advocacy organizations.

Several consulting experts requested anonymity due to ongoing contractual relationships with Sound Transit or the possibility of future work with the agency. These discussions informed the technical, regulatory, and financial perspectives presented in this paper; however, all conclusions and any errors remain the responsibility of the authors.