TRANSIT
COSTS
PROJECT

The Sweden Case:

How Stockholm Builds Infrastructure Cheaply, and Why It's Becoming More Expensive?

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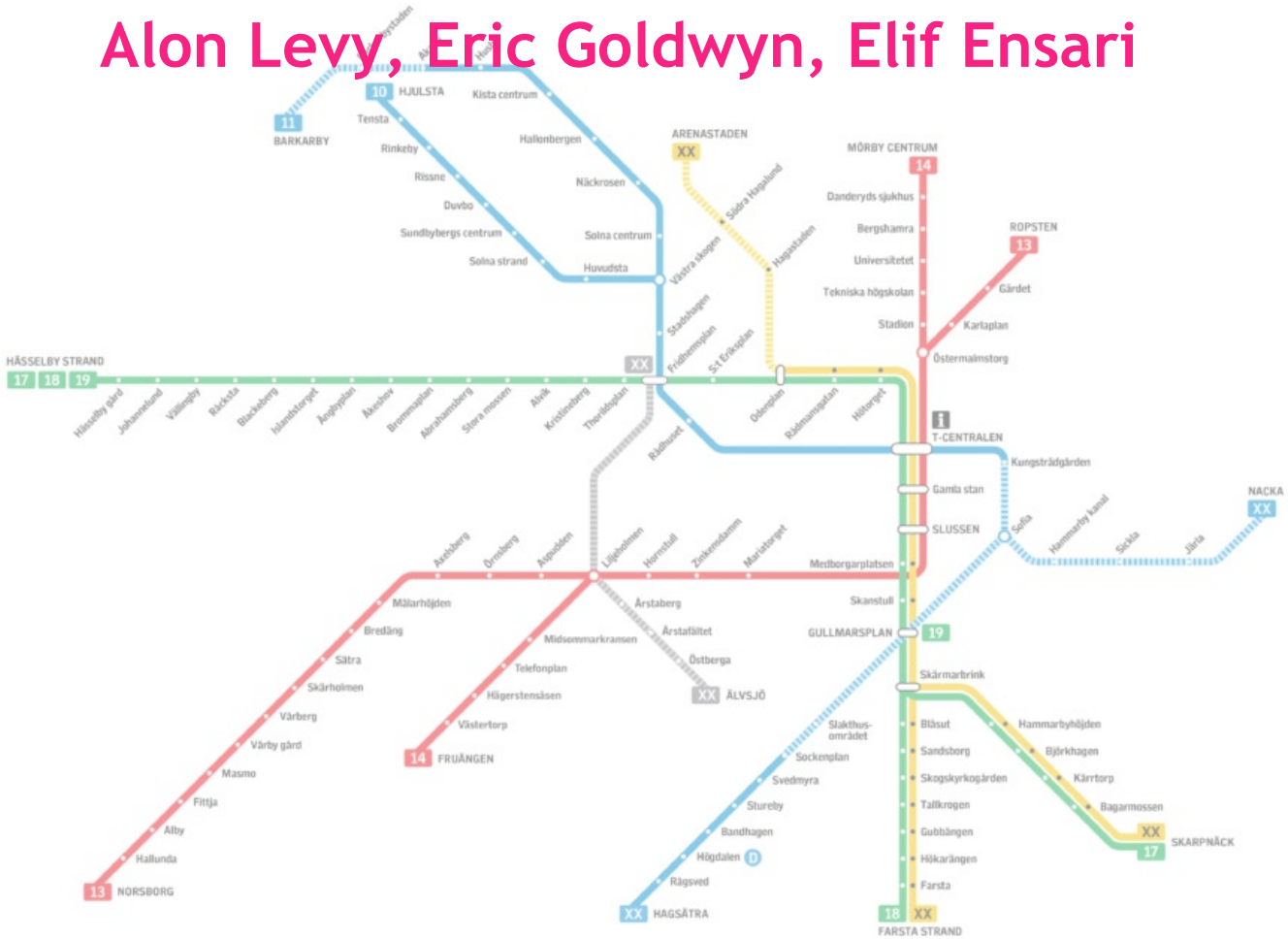

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1 Introduction

Stockholm County is a region of 2.5 million people. Despite its modest size, it has one of Europe's busiest urban rail networks: in 2019, on the eve of the corona crisis, the 104 km Stockholm Metro (Tunnelbana or T-bana) network carried 1,265,900 riders on an average weekday and including the region's commuter and light rail networks the system carried 1,892,300, representing comparable ridership per capita to large, established European transit cities like Paris and Berlin. The modal split for all trips in 2019 was 40% car, 30% public transport, 28% biking and walking (SL Annual Report 2019), representing one of the highest shares for public transport in Europe. The system is currently in the middle of a large expansion wave: the commuter rail tunnel Citybana opened in 2016 and the system is currently carrying 410,300 passengers a day, while the T-bana is currently building about 19 kilometers' worth of extensions, collectively called Nya Tunnelbanan.

The urban rail expansion program in Stockholm is an instructive case. The construction costs remain fairly low. Citybanan cost SEK 16.8 billion in 2007 terms, or about $2.4 billion in 2020 purchasing power parity (PPP) terms, averaging $320 million/kilometer; this is slightly more expensive than the global median, but Citybanan was an unusually complex project, built entirely underneath city center, with two large station caverns mined under older T-bana platforms. Nya Tunnelbanan is currently projected to cost SEK 32 billion, about $190 million/km, well under the global median. Alongside the other Nordic countries and perhaps Switzerland, Sweden is the only country among the world's very wealthiest with construction costs this low: other low-cost countries such as those detailed in the reports about Italy and Turkey are on the economic periphery of the developed world.

The quality of in-house designs under the civil service system is high. The Swedish Traffic Administration, or Trafikverket, has a generations-long tradition of apolitical engineering, and decisions about the construction of small road projects are undertaken on the basis of benefit-cost analysis. Rail megaprojects like Citybanan and Nya Tunnelbanan cannot be so reduced – they cost so much that the elected national government must approve the

final plans, and yet it has not politicized those plans. The in-house expertise of Trafikverket cascades down to the regional level and incorporates a procurement strategy that centers public-sector expertise; designs are traditionally done by the public sector, with the assistance of private consulting firms, and are subsequently owned publicly and bid out to private construction firms.

And yet, there is danger that the low Nordic costs are rising. Nya Tunnelbanan has had a large cost overrun, from SEK 23 to 32 billion. The cost of Helsinki's West Metro (or Länsimetro), opened 2017, was only $130 million/km in 2020 terms, but this was more than double the cost when the project was approved in 2007, and the second phase of the West Metro is costing $230 million/km. Oslo's under-construction Fornebubanen with its deep-mined stations is projected to cost $300 million/km (2020 PPP terms), triple the cost of Lørenbanen, which opened 2016.

Moreover, the Nordic civil service is showing long-term interest in changes in procurement in a direction more akin to what is found in the English-speaking world. Academic and gray literature within the Nordic world, and not just Sweden, speaks favorably of reforms that reduce public-sector involvement; Trafikverket's new strategy is that it should become “a pure client” and implement a system that centers private-sector expertise and innovation.

The long-term changes are unlikely to be positive. The one-time increase in cost of Nya Tunnelbanan appears permanent: future metro expansion is likely to have similar per-km cost to Nya Tunnelbanan, Fornebubanen, and the second phase of the West Metro, rather than to the original budget for Nya Tunnelbanan or the actual cost of Lørenbanen or the first phase of the West Metro. The English-speaking world has high construction costs, and yet the academic and gray literature out of the Nordic world looks up to it and ignores low-cost construction within Southern Europe, which Northern Europe looks down on.

Nonetheless, construction costs in Sweden, Norway, and Finland, remain well below the world average; nowhere else in Northern Europe are construction costs so low save perhaps Switzerland, and costs in Germany, the Netherlands, and the United Kingdom are a multiple of those of Sweden.

2 Sweden and the Nordic Region

The Nordic countries are expanding their urban and intercity rail offerings, including metro extensions in their capitals, investments in regional rail, and intercity rail that in some cases includes high-speed rail.

Those countries are institutionally similar: their legal and political systems are all similar to one another, and they make efforts to learn from one another. Nordic or Scandinavian law is based on collaboration among Denmark, Sweden, and Norway going back to the 1880s, with Finland joining after independence in 1917; Nordic contract law was harmonized in 1915 (Bernitz 2007), and when reforms were needed in the late 20th century, they largely happened in parallel across all Nordic states. In comparative law, Nordic law is treated as a primary global category, alongside French civil law, German civil law, and English common law (Siems 2022).

Politically, too, there are strong parallels among the four mainland Nordic states, and early intergovernmental cooperation under the Nordic Council. The party systems in Sweden, Norway, and Denmark are similar, and to some extent so are those of Finland and Iceland, with extensive ties between each Nordic party and its counterparts in other Nordic states.

It is common in each Nordic country to compare its performance on topical issues to the other Nordic states. For examples:

- Norwegian politicians comment on immigration to Denmark (Moe and Kagge 2021) and the media comments on immigration to Sweden (Andreassen 2014).
- Critiques of education in Sweden heavily employ comparisons to Finland with its higher PISA test scores – see for example Boman (2022) but also multiple personal conversations with Swedes in academia and political advocacy.

– Sweden's approach to corona drew comparisons to the rest of the Nordic world above all; within Sweden, defenders of the approach, including public health chief Anders Tegnell, compared Sweden's death toll with that of the United States or the European average, in which case Sweden would come out above average, whereas critics would compare it with that of Norway, Denmark, and Finland, all of which had far lower death rates.

Diplomatically, there is greater divergence – Norway and Iceland are not in the EU, and Sweden and Finland had no interest in joining NATO until the Russian invasion of Ukraine – but there is enough of a concept of Nordicity that all five Nordic states built their post-unification embassies to Germany in the same complex.

The concept of Nordicity applies throughout the social, economic, and political spheres, and so it should not be a surprise that public transport planning follows similar broad trend across Scandinavia. In the interviews we have conducted with Norwegian and Finnish planners, their descriptions of project procurement, management, and construction techniques are similar to the ones we have in Sweden. Therefore, we expect that this report has bearing not just on the case study from Stockholm but also on how the rest of Scandinavia engages in planning.

The similarities across Scandinavia also lead to extensive comparisons between the different Nordic countries, focusing on differences between them. The academic literature compares the impact of benefit-cost analysis in Sweden and in Norway, finding it is much more significant in Sweden (Eliasson et al. 2015). Other examples may compare countries with non-Nordic countries, but usually several Nordic countries will be included as well, for example in the Finnish Ministry of Transport's review of rail transport in Finland (Ministry of Transport and Communications 2003) or in Smith et al. (2018) on Mobility as a Service developments.

Although the *social* context of metro rail investment across Scandinavia is parallel, many of the *physical* characteristics of public transport across the four main Nordic capitals (omitting Reykjavík as it is far smaller) differ, as do their histories:

– Stockholm has a metro system consisting on three lines (Red, Blue, and Green) each with two to three branches; it has removed its historic tram network, converting some lines to metro branches. Its metro system has always been supplemented by various commuter rail lines, of which those using mainline rail service are called Pendeltåg and those operating as isolated systems, generally connecting to an outlying metro station, are called Lokalbana if longer-distance or Spårväg or tram is shorter-distance. The Pendeltåg system ran through the same two-track tunnel through Central Stockholm until Citybanan opened, giving it a dedicated tunnel to permit for more commuter rail as well as longer-distance regional and intercity rail capacity.

- Copenhagen has a metro system with two main lines with branches, of which one forms a circle, but the system only opened in 2002, later than in nearly all other European cities of comparable size. The Copenhagen Metro is driverless and runs short trains at high frequency, as is common in some smaller Italian cities. In contrast, Copenhagen has long had a dedicated commuter rail tunnel, opening in 1917 and running high-frequency urban electric rail service since 1934 under the name S-tog, borrowed from the German S-Bahn. The city also makes extensive use of bikes: within the city proper, consisting of about a quarter of the metro area, bikes have a 62% modal split (City of Copenhagen 2019).

- Helsinki has a metro system consisting of one line branching in two in the east, together with a large urban tramway network and a regional rail system running from suburbs and secondary cities to the north of Helsinki to a stub-end city center terminal. The region is expanding all three modes, with a western extension of the metro (West Metro), a large expansion program for the tramways, and a proposed loop tunnel under city center to permit commuter trains to run in and out without reversing direction.

- Oslo combines a subway system, a tramway network, and commuter rail, like Helsinki. Its subway system consists of a Common Tunnel with four to five branches on each side, generally on the surface but with some tunneled urban sections. Its commuter rail system has a common trunk carrying mostly commuter traffic but also some longer-distance trains and is oriented toward farther-away suburbs than in the other Nordic capitals.

Despite the differences in characteristics and modal choice within public transport, all four Nordic capitals maintain a high modal split for non-automobile traffic; in Copenhagen this comprises high usage of both bikes and trains, whereas in the other capitals, public transport predominates, and bikes have a secondary role.

The construction costs in Sweden, Norway, and Finland look broadly similar. This includes *ex ante* and *ex post* costs for metro tunnels, regional rail tunnels, proposed high-speed rail, and conventional rail upgrades. Danish costs are somewhat higher, but the costs in Sweden, Norway, and Finland are converging to Danish levels. A report on the Copenhagen Metro is in preparation for the construction costs project at the Eno Center (Aevaz et al. 2021) and is beyond the scope of this case study, but it appears from Eno's existing work that Copenhagen has always used the procurement and regulation package that the other Nordic countries are moving to.

3 Case Selection

In preparing this report, both urban rail extensions in Stockholm – Citybanan (built 2007-16) and Nya Tunnelbanan (built 2020-30) – are considered. In the same period in question, going back to the early 2000s, Sweden has had two additional urban rail megaprojects: Malmö's Citytunneln, and Gothenburg's under-construction West Link, or Västlänken.

Citytunneln, built 2005-10 for SEK 8.45 billion ($1.37 billion in 2021 PPP terms), is outside the scope of this analysis. It is a connecting railway on the Malmö side of the Öresund Bridge, with new stations including under city center, but much of the planning was done in the 1990s, and most of the length of the 17 km project is surface connections, not an urban tunnel.

The West Link, in contrast, is a valuable sanity check for the analysis of this report. It is contemporary with Nya Tunnelbanan, with construction expected to take place over 2018-26. It is a regional rail tunnel for Gothenburg, more akin to Citybanan than to Nya Tunnelbanan albeit without the need for deep-mined city center stations, and like Citybanan the lead agency is state transport administration Trafikverket as it is a mainline rail project; Nya Tunnelbanan is led by Stockholm County, often still abbreviated by its old name SLL, and its transport arm SL (*Storstockholms Lokaltrafik*).

4 Stockholm Metro History

The system to the 1990s

In the 1940s, Stockholm was a small city; the county's population in 1940 was 880,000, rising to 1.1 million by 1950. At the time, the city's tramway network already included grade-separated segments, including a tunnel running north-south through Södermalm, called Södertunneln, opened 1933. When the city made the decision to build the metro in 1941, it was the smallest in Europe with such plans; Rome opened its metro a few years later than Stockholm, with a municipal population of 2 million.

Construction began in 1944, and the first section, an upgrade of Södertunneln to metro standards, opened in 1950. By 1965, there were two lines, the Green and Red Lines, and a plan was proposed for further expansion including the construction of what is now the Blue Line and further extensions, and some of those extensions are now being built as part of Nya Tunnelbanan.

Throughout this construction scheme, the T-bana took over peripheral radial lines constructed as tramways or local trains, converting them to metro standards in the process. At some places, such takeovers did not happen, creating the modern Spårväg and Lokalbana lines terminating at a T-bana station with a transfer for onward trips to city center.

The Green and Red Lines were designed as a coordinated system from the start. They meet in city center at three stations: T-Centralen, Gamla Stan, and Slussen; each of the two lines has dedicated tracks through this shared segment. Moreover, all three stations are set up for cross-platform interchanges, between same-direction (northbound or southbound) trains at Gamla Stan and Slussen and opposite-direction trains at T-Centralen. This way, same-direction transfers can be done cross-platform, and opposite-direction transfers between the Red Line to the northeast and the Green Line to the northwest can be done cross-platform at T-Centralen; only opposite-direction transfers between the Red Line to the southwest and the Green Line to the south require the

inconvenience of walking between platforms at Slussen, or else staying on the train two extra stops for the interchange at T-Centralen.

The T-bana was integrated with urban planning from shortly after opening. While the 1946 city plan centered auto-centric development and city center urban renewal, the 1952 city plan took a different route. It took inspiration from Copenhagen's contemporary Finger Plan, for what would today be called transit-oriented development around the branches of the S-tog; with a just-opened subway system, the plan called for the construction of modernist neighborhoods facing the stations, with neighborhood centers and high-density housing close to the stations and lower-density housing at greater distance.

The first major suburb based on this plan, Vällingby, grew rapidly in the 1950s. Soon thereafter, the nationwide Million Program constructed a million units of social housing in 1965-75; in the Stockholm region, those projects tended to be oriented around the T-bana like Vällingby before them. The 1952 plan envisioned a polycentric region with communities with both housing and jobs ("ABC," where A stands for jobs, B for housing, and C for center), but in practice they turned into bedroom communities for Stockholm jobs. To this day, urban studies literature considers Stockholm an example of monocentric transit city development (Söderström et al. 2015; Cats et al. 2015; Spasov 2017); where there is polycentricity, it is often radial along the rail lines, with high modal split (Cervero 1995).

A recent study by Börjesson et al. (2014) finds that the benefit-cost ratio for the system built so far is 6 without taking agglomeration and labor market benefits into account; if they are taken into account, the ratio rises to 8.5. This comes from a combination of high ridership and low construction costs: the 104 km system cost SEK 5 billion in 1975 prices, corresponding to $3.3 billion in PPP 2021 dollars, or $2,600 per workday trip;[1] even taking into account that only 57 km of this system is underground, this is an extraordinarily low cost, not achieved on contemporary lines such as those of London, Milan, or Rome.

But then expansion cooled. The Million Program was over by 1975. The Blue Line opened in the same year, and T-bana growth thereafter was slow; the most recent expansion, a short extension of the Green Line Skarpnäck branch, opened in 1994.

[1]Imputed from 1,265,900 daily riders on a winter workday, from SL 2019, pp. 51, 67.

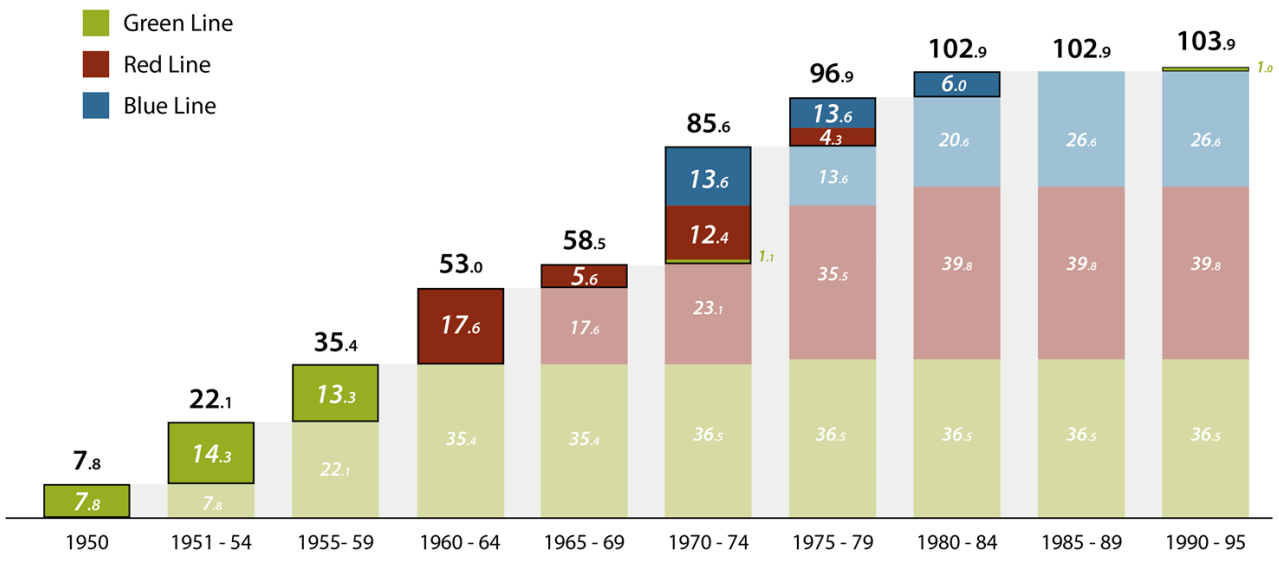

figure 1. Stockholm Metro kilometers built per five-year period per year

Between the 1980s and 2000s, Stockholm was characterized by stability. Population growth slowed down, as the working class had already settled in in the Million Program projects. Swedish economic growth was weak, culminating in the financial crisis of the early 1990s, also affecting the rest of Scandinavia. Most of the T-bana lines planned in 1965 had been built already, and the metro region had already shaped itself along what had been built.

Planning since the 2000s

Stockholm has continued growing in the last 30 years. Recovery from the financial crisis has been rapid: from 1990, the earliest year with current World Bank PPP (2017) calculations, to 2019, the eve of the corona crisis, Sweden's GDP per capita grew a cumulative total of 55%; in the developed world as conceived at the time, without newer entrants like South Korea, only two countries have posted faster growth, Australia at 59% and the Netherlands at 56%, and the US near-tied Sweden. This growth has attracted immigrants, and, moreover, Sweden has maintained long-term openness to labor and humanitarian migration, leading to high population growth.

The monocentric character of the city and its population and economic growth led to escalating urban rail ridership. Long-term growth in Stockholm commuter rail traffic led to concerns about capacity saturation; there were only two railway tracks through Stockholm, which had to carry both the county's commuter rail system and intercity rail to points south and west, where the vast majority of the rest of Sweden's population lives. On the

eve of the opening of Citybanan, those two tracks, called the *wasp's waist*, carried 24 trains per hour at the peak, including 16 commuter trains and 8 regional and intercity trains.

Moreover, all projections called for further growth. In the 1990s and 2000s, Stockholm County's population averaged 1.1% annual growth; this rate accelerated in the 2010s as immigration levels have increased, raising the county's annual growth rate to 1.5% over the decade. In 2005-6, Trafikverket contracted with the consultancy Transek, now owned by WSP, to project future demand through 2060 and perform a benefit-cost analysis (Transek 2006).

The Transek report projected a rapid exhaustion of capacity. Under a high-growth assumption, a no-build option would have traffic reaching the wasp's waist's capacity by 2011, before any project could be completed. A surface track option investing in the system without a new tunnel could raise capacity in the limit to 32 trains per hour of which 18 were commuter trains, but traffic would reach that level by 2014. Citybanan would suffice through 2020, and even a second step for Citybanan, with a theoretical capacity of 30 trains per hour in the tunnel rather than the current 24, would only last until 2032. A more conservative assumption of low growth had the no-build option lasting until 2018, the surface option until 2021, Citybanan until 2043, and a second-step Citybanan until 2075.

At the same time, the benefit-cost analysis was unfavorable. All investment options had negative social rate of return, but the surface option had a more negative rate of return than the Citybanan options, which cost more but were far more beneficial for the region. The project was decided then because of the need for further increases in capacity in the Stockholm region; wider benefits are not always directly measured,[2] and official analyses can omit them, making projects that by broad consensus are beneficial look weak.

Nya Tunnelbanan comes out of similar plans for long-term capacity. The population growth projections in Stockholm require large quantities of new housing, to be developed on greenfield and brownfield sites outside city center; in Stockholm, as is typical for growing European cities, housing redevelopment is done on non-residential sites, with no replacement of historic low-rise apartment buildings with bigger ones.

To permit this growth, SLL concentrates on three growth regions: Nacka, Barkarby, and the Arenastaden area in Solna. Planning for all three extensions was done in coordination with local and regional growth plans.

The Nacka extension plan was explicitly done with a housing growth target in mind for the municipalities served (SLL 2018a); a branch of the same extension is to take over a Green Line branch, to reduce the Green Line's

[2]This point is also made in the retrospective analysis in Börjesson et al. (2014).

southern section from three branches to two in order to both increase frequency on all branches and permit redevelopment of brownfield industrial sites.

Once the overall direction was decided, SLL looked at many different options for alignments:

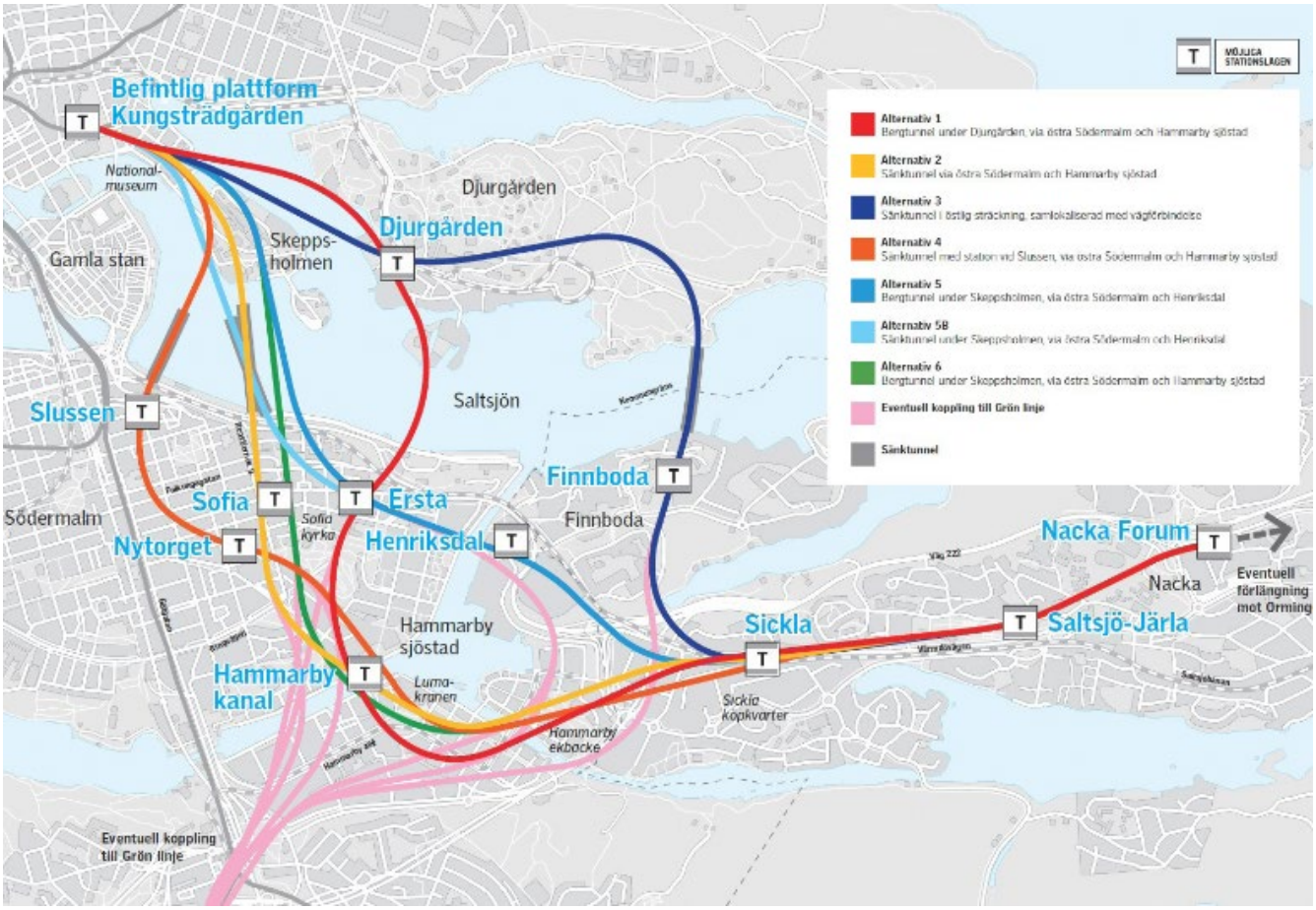

figure 2. Studied deep-mined routes for the Nacka extension

Plans for the extension to Barkarby followed a standard four-step process, to ascertain such a high-cost megaproject is truly necessary for the region (SLL 2014):

1. "What if?": this includes measures that manage transportation demand, such as reducing parking.
2. Optimization: this includes using existing infrastructure more efficiently, for example encouraging carpooling to use road lanes more efficiently, increasing public transport frequency to effect modal shift, and improving the bus network.

3. Rebuilding: this includes minor infrastructure improvements in conjunction, such as running more surface commuter rail service to non-city center destinations (since city center is already full, hence Citybanan and long-term plans for Citybanan step 2) and rearranging bus infrastructure for higher priority, including transit signal priority.

4. New construction: only after steps 1-3 are exhausted is fully new infrastructure to be considered. The report looks at many modes of public transport, such as BRT and a gondola, but finds that they are not as good as a subway extension, and further finds that the best place for an extension to Barkarby is from Akalla.

Arenastaden had the most complex history of planning (SLL 2018b). It originates in plans for expanding public transport capacity to Karolinska, located in Solna just to the north of the present-day Green Line. Multiple options were considered, including bus service expansion, a tram, a branch of the Green Line, and an entirely new subway line.

The metro option was deprecated at first due to its cost and complexity; some of the early plans called for rebuilding Odenplan, which proved too difficult. Eventually it was bundled with parallel plans for Nacka and Barkarby to form what is now Nya Tunnelbanan.

The choice of brand even recalls this history of the Arenastaden branch: it is called the Yellow Line and portrayed as such on maps, even though it is still a branch of the Green Line. Thus, maps show the Yellow and Green Lines as two separate branches to the north and northwest, but then as a single line from Odenplan south, with the southern branches carrying both Green and Yellow Line trains.

5 Project decision process

As in most of the Nordic world, Swedish politics is traditionally bipolar between two blocs, with regular alternation between them, albeit with more frequent left governments and less frequent center-right ones than elsewhere. The party situation in Sweden is important for understanding budget priorities, and Sweden displays large variations in broad policy according to which bloc is in power, but little in the way of political influence over technical matters or over alignments. This is in contrast with frequent interference in North America – for example, as we explain in more detail in the New York case, there was partisan politics in the decision to build Second Avenue Subway, which in the late 1990s was seen as a Democratic city project in opposition to commuter rail to Republican suburbs.

Politics and priorities

The center-left bloc is led by the Social Democrats (S), who were dominant in the middle of the 20th century, and consists also of the Green Party (Mp) and the farther-left Left Party (V); it is currently called Red-Green, and is dominated by S, with Mp as a minor partner and V at most an outside supporter of the coalition, mainstream enough to participate in some political institutions but not enough to enter the government. S and Mp are aligned on practically all issues; a joke among S members is that Mp exists as a thinktank for S's environmental policies, and with little daylight between them, Mp support has dwindled in recent years.

The other bloc, formed by the center and center-right parties and known since 2004 as the Alliance for Sweden, is a four-party bloc consisting of the mainline center-right Moderates (M), the Liberals (L or Fp), the historically agrarian Center (C), and the Christian Democrats (KD). Its situation is in flux, and the Alliance proper was dissolved in 2019, due to differences over the role of the far-right Sweden Democrats (SD), who supported the Alliance from outside in 2010-4 but grew more vocal subsequently; currently, C and L support the S-led government with

tensions with V over budgetary and regulatory issues such as rent control (Steensig 2021) while M and KD do not and are willing to govern with the support of SD. The future of this system is in flux, but the entire history of planning in Sweden so far has been with the traditional two-bloc system, long before the center-right called itself the Alliance.

On transport-related issues, there are large differences between the two blocs over priorities, owing to the role of public transport as a green alternative to the car. There was intense disagreement over the issue of congestion pricing in Stockholm in the 2000s, and right now, there is debate over a high-speed railway connecting Stockholm with Gothenburg and Malmö, which the Red-Greens support and the Alliance does not, preferring investment in electric cars instead (Eliasson 2014; Hårsman and Quigley 2011; Personal Interview B 2021; Personal Interview G 2021).

Both Citybanan and Nya Tunnelbanan faced some Alliance opposition, both on fiscally conservative grounds: as explained above in the section on Stockholm Metro history, the alternatives analyses for both programs projected negative rates of return. Nonetheless, the plans for growth and extra capacity required the construction of those projects, and so they were not canceled, and the Alliance assented to both in its 2006-14 coalition.

A culture of consensus

The guiding principle within Swedish culture is consensus (Personal Interview E 2021). This occurs at the levels of politics (Bengtsson 2013), office culture (Altinkaya 2006; Salminen-Karlsson 2013; Ullman 2017), and local empowerment.

Whereas in business, consensus means slowing down process until everyone agrees, in politics it means accepting a large interpartisan difference in political agendas. There is little sniping involved: Alliance governments do not cancel projects begun under the Social Democrats, and vice versa, and projects that are so controversial there is risk of such sniping are not chosen for going through (Personal Interview E 2021).

This has implications for the use of Stockholm's congestion pricing revenues. In the 2000s, the Social Democrats and Greens called for using them to fund investments in public transport, whereas the Alliance, having formerly opposed the scheme, promised to instead divert the money to roads. The compromise under the Alliance government of 2006-14 under Frederik Reinfeldt was that congestion pricing money would go toward building new motorway tunnels in and around Stockholm, but also to some extent Nya Tunnelbanan, which was planned in the same era.

The same culture of consensus applies to labor and to other conflicts. Swedish and other Nordic unions go on strike often if their demands for higher wages, benefits, or labor standards are not met. Consensus may be achieved at tripartite meetings between the government, union representatives, and business-group representatives, but there is recognition that there is conflict between workers and bosses and overall the system does not empower groups to act as veto points.

There is likewise a right to sue within Sweden, which interview subjects who discussed this issue treat as a normal part of the democratic process (Personal Interview F 2021). However, in practice, lawsuits are rare, and no group chose to sue Citybanan or Nya Tunnelbanan. Informally, there is great effort made not just at community level but also at the level of conflict between public agencies and private contractors to avoid going to court; see below on procurement.

Local-national interface

Sweden's unitary state is tempered by a large degree of devolution of planning to county and municipal governments. Rail megaprojects come from regional growth plans: Citytunneln was planned locally and likewise the West Link in Gothenburg is planned by the county, Västra Götaland, which comprises the entire metropolitan area plus additional rural hinterland.

This devolution applies not just to megaprojects but also local transit planning. In Gotland, an island of 59,000 whose main city is Visby, a county-level civil servant handling public transport is connected to all other important officials within the county, enabling rapid coordination, in contrast with top-down unitary systems such as that of the United Kingdom (Personal Interview C 2021).

The Swedish state has extensive fiscal devolution: local and county taxes are 16% of Swedish GDP, the second highest figure in the OECD after Australia's, and among the highest figures as a proportion of total government revenue; moreover, there is near-complete discretion by local governments about how much to charge, as opposed to central taxation at a uniform rate that is then distributed to localities by formula (OECD 2020). However, megaprojects remain beyond the capability of a county, even one as big and urbanized as Västra Götaland, and therefore project funding comes from a combination of regional and state sources. The West Link is funded about 50% by the Swedish state, 41% by Gothenburg congestion pricing revenues, 7% by city and county funds, and 2% by land sales (Personal Interview E 2021).

To resolve the issue of multiple funding sources for one project, Sweden employs competitive grants given by Trafikverket to regions that have the strongest proposals. If a county or municipality has demands in excess of the

minimum required to execute a project, such as additional tunneling to avoid the impact of above-ground intercity rail service, the local government is required to fund the excess costs; this prevents local areas from treating state infrastructure money as a free lunch for unrelated priorities.

Stockholm is nationally unique in the size and importance of the city and its projects. As a result, state involvement is unavoidable, and both Citybanan and Nya Tunnelbanan are planned and funded jointly between the state and county budgets. Citybanan may be a mainline rail project planned primarily by Trafikverket and SL, but funding came from multiple sources (Tihinen 2017)[i]:

SEK 10.3 billion: state loans.

SEK 5.1 billion: Stockholm County and the municipality.

SEK 2.3 billion: municipalities in adjoining counties benefiting from regional rail service.

SEK 1.6 billion: state appropriations.

In this way, Stockholm and Gothenburg are similar: megaprojects are funded by negotiation between the state, the county, and municipalities. However, unlike in Gothenburg, the planning for the need for Citybanan came not from the county, but from Trafikverket, which projected both regional and national rail traffic trends; Citybanan was deemed a project of national importance, and therefore the county was less involved in its planning and municipalities even less so.

Civil service role

Interviewees from the civil service as well as external organizations confirm that decisions on planning originate in the civil service, and not in politics. In the 1950s, Sweden imitated the American road planning system that produced the Interstates (Personal Interview B 2021), which was insulated from political interference through strong civil service norms under Thomas MacDonald and a lockbox on road funding such that federal funding was not subject to regular congressional control. Unlike in the United States, in Sweden the system was also designed to remove local infighting and prevent regions for jockeying for funding; competition between different regions for funding is handled through apolitical mechanisms.

This system has persisted through changes in the organizational chart. Swedish Railways (SJ), nationalized in 1888, developed internal planning capacity, and modernized throughout the postwar era, running both commuter and intercity rail. In 1988, SJ was split, and the responsibility for infrastructure was transferred to the new Swedish

Rail Administration, which through mergers in the 2000s combined with the Road Administration to form modern Trafikverket in 2010.

Trafikverket retains extensive planning power, even with growing privatization of operations, such as the contracting out of Stockholm commuter rail to the MTR. At the regional and local levels, there are parallel civil service systems, and there is porosity between Trafikverket and SL: many of the planners responsible for Nya Tunnelbanan worked on Citybanan previously.

Swedish norms of civil service independence are such that it's fair for civil servants to frankly criticize common wisdom. As detailed below in the section on functional procurement, a growing trend in Nordic procurement is to have loosely-specified functional contracts, with support from Trafikverket and independent research, but a civil servant with experience in both Citybanan and Nya Tunnelbanan openly criticized this trend in an interview (Personal Interview 2021), in much more straightforward language than observed in interviews with American, Canadian, or British civil servants.

Nonetheless, politicians remain the top authority when it comes to the biggest investment decisions. While both Citybanan and Nya Tunnelbanan were *planned* by civil servants, the decision to proceed was political. The budgets for both projects are so large relative to the size of Sweden that it was unavoidable that they should be debated as part of the national budget.

While road investment decisions in Sweden are decided by benefit-cost analysis whereas those in Norway are not, in neither country is there politicization of route choice (Eliasson et al. 2015). Political influence boils down to a yes-no decision, perhaps with loose guidelines over the level of investment. To the extent there is any evidence of politicization of priorities, it is again loose, consisting only of decisions of whether to prioritize urban or rural infrastructure, or, in the Stockholm region, modal conflict between road and public transport investments.

Cost and ridership

Predicting the ridership of an urban rail project *ex ante* is imperfect. Nonetheless, we can look at the ridership of recently-opened lines to gauge whether the value proposition of Nordic urban rail construction is positive.

Citybanan provides a ready example: ridership in 2019 was 410,300 on a winter workday (SL 2019). The project's overall cost, SEK 16.8 billion in 2007 terms or $2.4 billion in PPP 2020 dollars, is $5,850 per weekday trip, among the lowest costs for urban rail lines in the Transit Costs Project for which there are definitive ridership figures and not just costs. Recently-opened and under-construction lines in Europe usually cost $15,000-40,000 per weekday

trip. This is especially positive for Citybanan as its business case relies on estimates of continued growth in the coming decades, whereas the ridership figure is only two years after it opened.

Even if the ridership of Citybanan nets out the previous commuter rail ridership, 324,800 per weekday in 2016 (SL 2016), the case remains solid: it would mean that Citybanan generated enough ridership to lower the cost per *new* rider to $28,000 within two years, and will lower it further in coming years due to continued growth in this region, where typically metro and commuter rail tunnel projects cost within this range when considering all riders and not just new riders.

The $5,850/rider figure is especially extraordinary when compared with the existing T-bana network. Its construction costs over the decades amount to $3.3 billion in 2020 dollars, for a total of $2,600 per trip, a cost figure that like the $5,850 figure does not net out the ridership of older lines, such as the now-closed historic tramway system. But Sweden today has 2.6 times the GDP per capita that it had in the early 1960s (Maddison 2020)[3], midway through the opening of the T-bana; the affordability of Citybanan relative to ridership is higher than that of the T-bana.

The combination of benefit-cost ratios for the original T-bana and Citybanan is a puzzle. The benefits of the T-bana scale with ridership, and practically all of them come from the value of time, which scales with income; some analyses even disaggregate the value of time by class or income (Teulings et al. 2018). If $2,600 per trip results in a benefit-cost ratio of 6 in a Sweden with a GDP per capita of $17,239, then, in a Sweden with a GDP per capita of $45,193, a $5,850/rider project should have a benefit-cost ratio of about 7, and even netting out the entire 2016 ridership of Stockholm commuter trains, the resulting $28,000/rider project should have a benefit-cost ratio of 1.46 without taking into account future ridership growth. And yet, the projected benefit-cost ratio was lower than 1.

Elsewhere in Scandinavia, costs per rider for recently-opened lines have not been high either:

- Helsinki had 92.6 million metro trips in 2019 (HKL 2019), compared with 64.1 million in 2016 (HKL 2016), on the eve of the opening of West Metro. The difference, 28.5 million annual trips, is about comparable

[3]In 2017, the year that Citybanan opened, Sweden's GDP per capita was $45,193 in 2011 PPP dollars. The most comparable year for the analysis in Börjesson, Jonsson, and Lundberg is 1965, the year of opening of the midpoint of the present T-bana network by length, when Sweden's GDP per capita was $17,239.

to 95,000 on an average weekday, in line with the projection of 100,000/weekday (*Railway Gazette* 2017), which makes the project cost about $18,000 per new weekday trip, only two years after opening.

– Lørenbanen has 8,000 boardings at the single station that opened (Sporveien 2016), which corresponds to 16,000 trips; this makes the cost of the project $10,000 per weekday trip, new or diverted from other lines.

It is likely that the contrast between low or medium costs per rider and low benefit-cost ratios reported in prior analysis is why the decision to build Citybanan was undertaken, even in a fiscally conservative Alliance government.

Transit-Oriented Development

Historically, the T-bana was built together with suburban social housing, from Vällingby to the Million Program. The connection between housing construction and public transport infrastructure remains strong with Nya Tunnelbanan, and so the extensions to both Nacka and Barkarby are bundled with regional housing growth plans.

This is because housing is sorely needed in the Stockholm region. In 1987, as an environmental and anti-sprawl measure, Sweden passed the Plans and Constructions Act (Plan- och Bygglag, or PBL), requiring community consultation for development. Housing growth remained healthy in the run up to the financial crisis of the early 1990s, but after the crisis it crashed to a minimum of about 12,000 units a year in a country of 9 million people, compared with 110,000 in the peak years of the Million Program (Statistics Sweden 2022b).

Weak housing growth even as the economy was recovering from the crisis and growing fast led to rapidly rising housing costs; the rise in rents in the late-1980s bubble was not erased after the bubble popped but instead became permanent, and rents kept rising further (Statistics Sweden 2021). By the 2010s, the housing bubble returned (Dermani et al. 2016; Asal 2019), as on the eve of the global financial crisis house prices were 60% above 1990 levels and by 2015 they had risen to twice 1990 levels. Apartment prices, for which the index only goes back to 2005, rose even faster over the period with available data, a nominal rise of 138% compared with 71% for detached houses.

Starting in the 2000s, plans for housing growth became part of the Stockholm region's growth projections. In 2007, the advocate group YIMBY was founded in Stockholm, calling for a repeal of the PBL and acceleration of housing construction in urban areas, where there is the most demand; YIMBY asserts that it wants Stockholm to grow

"both in width and in height," that is through taller construction in or near city center but also the construction of new high-density neighborhoods on urban rail lines to be built (YIMBY Stockholm 2022; Personal Interview J 2022).

The further-reaching demands of YIMBY are far from met. However, in the 2014 election, the political parties competed by promising to build more housing, as both rents and prices reached record levels, and waitlists for rent-controlled apartments in Stockholm reached decades. Prices are now high enough that even with extensive local role in development, municipalities are more likely to approve new housing as they expect the new residents to be wealthy enough to be net contributors to local taxes. In the mid-2010s, the rate of construction of housing accelerated to about 55,000 annual completions Sweden-wide (Statistics Sweden 2022b), with 15,000 net completions in Stockholm County, or about 6 per 1,000 people. The municipality where Barkarby is located, Järfälla, built 780 net new dwellings a year over the same period, or 10 per 1,000 people (Statistics Sweden 2022a).

The coordination between housing construction plans and urban rail infrastructure is one of the contributing factors to high public transport usage in Stockholm. The main threat to this model is that there is substantial lag between housing demand and housing supply: the infrastructure development plans of the 2000s were designed for a population not much higher than that of the 2000s, but thanks to economic growth and immigration Stockholm has surpassed the projections, leading to a state of permanent housing crisis; the delays in the opening of Nya Tunnelbanan are likely to magnify this crisis.

6 Project delivery

Project scoring

When receiving bids, Sweden uses a combination of the lowest-bid and best-value methods for picking the contractor.

Lowest-bid contracts, awarded purely on the basis of price, are used for less complex public procurement, for example access tunnels. In addition, Swedish contracts may be decided on the basis of cost rather than price (Swedish Public Procurement Act 2016), in which case the entire lifecycle cost can be considered, including in the case of public transport operations and maintenance.

However, complex projects are awarded on the basis of best value. The main contracts of Nya Tunnelbanan and Citybanan were both best-value, with Nya Tunnelbanan using the ratio of 75% price to 25% quality and Citybanan using a 50-50 ratio. Going forward, the 50-50 ratio is the most common for the most complex project, whereas 25% quality is intended for intermediate projects, which Nya Tunnelbanan was not.

Benefits for technical purposes are assessed based on a pre-published schedule of monetary values, collecting in the ASEK manual, of which the current version is 7.0 (Personal Interview G 2021); the external costs and benefits are compared across the Nordic countries, and there is substantial variation, but also interest in sensitivity analysis to ensure that project selection does not hinge on arbitrary values (Nordic Council of Ministers 2021).

Competition

Sweden has a large and growing ecosystem of engineering and construction firms. Some are international in scope and well-known for getting contracts abroad, most notably Skanska; others are more regional, such as NCC, the Finnish conglomerate YIT, the Swiss tunneling firm Implenia, and the Czech firm Subterra/SBT.

Contracts are awarded on a competitive basis. In an analysis of 41 contracts let between 2018 and 2021 for Nya Tunnelbanan, only two received just a single bid, both small contracts for work access tunnels, and eight more received just two bids. The median number of bidders is four. In Gothenburg, a major contract worth SEK 820 million had to be rebid because the first tender received only one bid and it was over budget (Reynolds 2018); it is a general rule in Sweden that if there's only one bid and its price is not as expected, the contract must be relet (Interview D 2021).

Moreover, the market is large enough that it is not the same four firms bidding on all contracts. An analysis of both the winning bids and all bids on some contracts (Siljevall 2021) shows the following list of contractors for tunneling projects:

- Skanska
- NCC
- YIT
- Implenia
- Subterra
- Obrascón Huarte Lain
- China Railway Tunnel Group
- Gülermak
- Itinera
- Sacyr Construcción/Serneke
- Comsa/Soner Temel Mühendislik (STM)
- Züblin

– Peab

The Swedish market is open to international entrants, such as CRTG and multiple Turkish contractors.

However, Turkish contractors report that they are informally required to partner with longstanding Swedish or otherwise European firms. The above list includes one such partnership: STM is a Turkish firm bidding on Nya Tunnelbanan contracts together with the Spanish contractor Comsa. Such partnerships are not restricted to Turkish groups – Sacyr is Spanish and bids together with Swedish Serneke. But Turkish contractors who were interviewed for this project say that Swedes are culturally more comfortable with a partnership than with hiring a purely Turkish firm. In one interview, a Turkish contracting manager held up an Android phone and said, "If a Swede says this is an iPhone, then this is an iPhone, and if I say this is an iPhone, they will check" (Personal Interview 2021).

While openness to Turkey remains uncertain, openness across Europe is much more complete. The list of contractors includes multiple from Southern and Eastern Europe, and some of the firms are relatively new entrants to the market (Serneke was founded in 2002).

Build contracts

The typical contract for infrastructure in Sweden is done as design-bid-build. The design is done in-house with the assistance of private consultants, and is owned by the lead agency, for example SLL; the construction contractors only bid for the build contract, and as a result, in domestic Swedish parlance, design-bid-build contracts are called build contracts (Personal Interview D 2021; SLL 2021).

There has been a long-term shift in the Nordic countries toward the design-build method, which is viewed as more modern and efficient (Andersen 2018). At the same time, Osipova (2008) finds that the design-build method's attractiveness in offloading cost escalation risk to the private sector means that bidders increase the price to compensate, leading overall to higher profit margins. It is notable that the method that is viewed as more modern and cooperative between the client and contractor nonetheless is associated with higher costs and higher uncertainty.

Part of the issue concerns familiarity to the contractors. Although design-build is not yet common in the countries the contractors come from, the separation between design and construction works differently. In particular, the Nordic build contract has relatively little flexibility for the contractor to suggest changes.

An interview in Oslo (Personal Interview A 2020) revealed that in this model, the standard for risk allocation is that the designer bears all risk in case the builder follows the exact specification, but otherwise the builder and the client bear the risk. As a result, builders do not deviate from the design based on meter-scale geology, and designers compensate with defensive design, including more options than is required to avoid liability. The Oslo case is that of the Fornebu Line, built for about $300 million per km (in 2020 PPP terms) with underwater tunneling and deep-mined stations in imperfect geology; to avoid water intrusion, the designers recommended waterproof concrete throughout the project, whereas a building contractor with more flexibility would decide whether to use such concrete based on local conditions as discovered while tunneling.

The Nordic style of design-bid-build then contrasts with other styles. Turkey uses two contracts, but splits them differently: one contract goes up to 60% design, another combines going up to 100% design with construction; this provides builders with the flexibility needed to make small changes, and even then, builders can redo some of the work in the 60% design contract if they need to. The Spanish system of design-bid-build emphasizes the flexibility to make small changes based on conditions as well, as detailed by former Madrid Metro CEO Manuel Melis Maynar (Melis 2003).

Because of this difference, Turkish and other international contractors in Sweden find the local design-bid-build system cumbersome. This has led to a tendency to use design-build more often, but so far the contracts for Nya Tunnelbanan remain largely build contracts, as was the case for Citybanan.

Fixed price, but with itemization

Contracts in Stockholm, as in the rest of Scandinavia, vary between contracts let on the basis of fixed price (lump sum), and itemized contracts. Itemized contracts come in multiple flavors; for the most complex projects, including Nya Tunnelbanan and Citybanan, they tend to use the cost-plus model, as recommended by Nilsson (2011). In this model, instead of a single price for the contract, the contractor and client compute the total itemized costs in the contractor's proposal and apply a fixed rate of profit; this is a common method in low-cost countries, and Melis (2003) credits it with Madrid's easy process of change orders, which contrasts with the contentious process in fixed-price American cities.

Nya Tunnelbanan uses some fixed-price contracts in addition, but more common is a hybrid method based on fixed prices but still with itemization, in case modifications are needed; this is called *fixed-price with adjustable quantities*, or *fixed-price with bill of quantity*, which begins with a fixed price but itemizes a portion of the budget to shift some of the risk from the contractor to the client.

Under the Swedish Public Procurement Act (2016), change orders do not require redoing the bid if the cost overrun is less than 50% and the change is necessary for the completion of the contract, or if the overrun is less than 15%.

Interviews with civil servants involved with procurement did not reveal any contentious process for change orders (Personal Interview D 2021). If the modifications are itemized in the contract already then it is easier, but even if they are not and renegotiation is required, both sides aim to avoid litigation, and the courts prevent the contractor from walking away from risk that it assumed.

In contrast, contractor interviews portray a more complex process (Personal Interview I 2021). There are pre-agreed itemized rates, but not for everything, and sometimes there is conflict, leading to a back-and-forth in which the client rejects a design multiple times due to disagreements about quality control, although even then there is no litigation so far for Nya Tunnelbanan or the West Link. For change orders, the builder can propose modifications but needs the approval of checkers, who are external consultants and are insulated from civil service pressure; only the general manager of Trafikverket can overrule them, and otherwise the builders have to communicate with the checkers via the client.

Within the Nordic countries there is demand from the private contractors to be given more control, in the form of not just design-build contracts but also a transition to lump-sum contracts, as investigated by senior civil servants at not just Trafikverket but also peer agencies in the entire region (Andersen 2018). This is justified on the grounds of private-sector innovation, in which fixed-price contracts permit contractors to do what they know best.

Functional procurement

Sweden is transitioning to a new form of procurement aiming at greater flexibility, called functional procurement (Personal Interview B 2021). Under functional procurement, the agency does not specify what it wants, but only the function of what it wants. If it needs a bridge, it only specifies the type of bridge (road or rail), the required capacity and speed, and operating and maintenance standards. This contrasts with the more conventional approach, retrospectively called product procurement, in which the agency gives more details about what product it wishes to buy.

The Swedish state's overall procurement strategy talks of transitioning from product to functional procurement in order to improve the competitiveness and dynamism of the market (Ministry of Finance 2016): “Requesting by function can promote competition in public procurements by enabling more companies and organizations to participate and submit tenders, to the benefit of small and medium-sized enterprises.”

Trafikverket participates fully in this transition to functional procurement, which is among the reforms with which it hopes to boost construction productivity – but see below on ongoing reforms.

However, in practice, the effect of functional procurement may be limited in the rail sector. A civil servant responsible for procurement (Personal Interview D, 2021) said they "can't say it makes it easier." In practice, a lot of technical detail has to be filled in to ensure backward compatibility with other systems, and railways must follow UIC and national regulations.

Ongoing reforms and the West Link

Trafikverket is slowly transitioning toward greater use of design-build. Its procurement strategy for the West Link (Trafikverket 2014) speaks favorably of the increase in the proportion of Swedish infrastructure contracts that use design-build, citing contractors who prefer it to design-bid-build. Trafikverket's slogan toward this is "pure client": Trafikverket, in this view, should not be doing designs by itself but rather outsourcing this aspect to the contractors.

The major theme in the strategy is internationalization. The Nordic market is too small, hence the invitation of international players. Trafikverket surveyed the contractors about their preferred contract size, and received answers ranging from SEK 500 million for national firms to SEK 3-4 billion for large multinationals:

Foreign contractors require sizable contracts since it is otherwise difficult for them to be competitive with smaller procurements. The specified size is needed in order for it to be worth them coming with their own construction vehicle fleets, own sub-contractors and designers, to move personnel and learn Swedish practice and Swedish regulations.

The West Link is accordingly divided into six contracts, of which four are in the SEK 3-4 billion range and two are smaller. In addition to sizing contracts for multinationals and using design-build, Sweden is putting out more information in English and proposing greater use of English as a business language for infrastructure.

The design-build variant proposed is called Early Contractor Involvement, or ECI. Under ECI, the client and contractor work together to define the project and its needs, so that the contractor and client jointly plan the scope and design. This is intended to increase flexibility as well as provide international contractors with a more familiar procurement environment.

However, while some of the literature in Scandinavia speaks favorably of lump sum contracts, justified on similar grounds as design-build, Trafikverket takes a more measured approach. It views the question of lump sum

contracts versus itemization as dependent on the complexity of the contract, and prefers to maintain itemization for the more complex West Link civil infrastructure contracts, using lump sum only for the systems contract and for the smallest civil contract.

Broader reforms: discussion

There is extensive published literature in Sweden, some peer-reviewed and some gray, concerning procurement and construction productivity. The work done is largely on roads, because there are many road projects in the country of various sizes, permitting large-*n* studies, whereas rail megaprojects are rare, and the only four urban rail tunnel projects in Sweden in this century so far have been Malmö's Citytunneln, Citybanan, Nya Tunnelbanan, and the West Link. For example, the comparison of the use of benefit-cost analysis in Sweden and Norway concerns road projects (Eliasson et al. 2015), and Mandell and Nilsson (2010) compare different procurement mechanisms for roads as well. Trafikverket's document about the procurement strategy for the West Link suggests that some of this work is leading to changes in rail megaproject procurement as well.

Nilsson and Nyström (2014) additionally compare track maintenance, claiming 12% reductions in cost from Sweden's practice of contracting out maintenance to private firms. Nonetheless, they compare Sweden with Finland and the Netherlands, and explicitly say Sweden should imitate their practices of imposing more risk on the contractor relative to the client; the overall systems in Finland and Sweden are similar, but Finland's model of fixed price with adjustable quantities adjusts fewer quantities than Sweden's.

In this schema, there are two ways to do procurement, of which one is viewed as more traditional and the other as more globalized or modern:

Table 1.

Traditional	Globalized
Design-bid-build	Design-build
Itemized contracts (unit prices, cost-plus)	Lump sum contracts (fixed-price)
Smaller contracts (hundreds of millions of SEK)	Larger contracts (billions of SEK)
Product procurement	Functional procurement
Public client risk	Private contractor risk

In practice, the five items on the table can be mixed-and-matched. For example, American practice has long favored lump sum contracts with no itemization, but only recently have American transit agencies begun to transition from design-bid-build to design-build. The traditional Nordic system of risk assumption has also been a hybrid of public and private, as detailed in the section on build contracts, and coexists with design-bid-build.

The justification for moving from the so-called traditional to the so-called globalized system, which is most complete in the United Kingdom, is to permit more private-sector innovation. Thus, a European benchmarking survey by Trafikverket (2016) says,

One advantage of DBB contracts is that a competent and experienced client more easily can ensure that they get the quality they want by specifying the design in detail (Cheung et al., 2001). When a certain level of quality (or safety) is critical, DBB-contracts may be preferable if the client has sufficient expertise and experience to know what he wants and how to achieve this. A disadvantage is that the client's detailed specification reduces the contractors' opportunities for innovation; there are simply not that many technical aspects to develop.

In the 1980-2007 period, construction labor productivity in Sweden grew only 0.8% per year, whereas economy-wide the figure was 2.6%, rising to 4.7% in sectors subject to international competition (Mandell and Nilsson 2010); Trafikverket's procurement strategy as detailed for the West Link aims to boost annual construction productivity growth to the 2-3% range. However, in the United States, construction productivity over the same period fell per the work of Teicholz (2013)[4] and Stevens (2014), and Swedish infrastructure construction costs remain far below those of the target countries referenced positively by Trafikverket's benchmarking report, the UK and the Netherlands.

It is also notable that while the Swedish government's official procurement strategy speaks of openness to small- and medium-size enterprises, Trafikverket's procurement strategy in the context of the West Link justifies its decision about project size in the opposite way: the main West Link contracts are scaled at SEK 3-4 billion in order to be more open to large international firms, while it's the smaller domestic contractors that prefer smaller contract size.

It is equally notable that the academic and gray literature on infrastructure investment in Sweden is heavy on comparisons not just to the other Nordic countries but also to Germany, the Netherlands, and Britain, but never to Southern Europe, Turkey, or France. The way Scandinavia builds infrastructure – the traditional procurement procedure, some of the engineering decisions (such as the Copenhagen Metro technology), and the EU-wide labor

[4]See also the coverage of Teicholz's paper in Garcia 2014.

force – has similarities to the systems detailed in the chapters on Italy and even Turkey, much more so than to the high-cost American examples, and yet direct comparisons with Southern Europe appear very uncommon in Sweden as well as elsewhere in Northern Europe.

Finally, while the literature in Sweden recommends many practices that center private-sector innovation and aim to imitate British and American procurement, it does not oppose the use of best-value contracts. The literature on procurement is mostly silent on the issue of whether contracts should be decided by lowest bid or by a combination of lowest bid and a technical score. Trafikverket's benchmarking report treats the combined best-value system as the most modern, alongside early contractor involvement in bids, and the pan-Nordic report on design-build speaks favorably of best-value contracts too.

7 Engineering

Unlike the great majority of modern metro tunnels, the Stockholm Metro and commuter rail tunnels are built using drill-and-blast; no tunnel-boring machines (TBMs) are used, though there is discussion of using TBMs for the next tranche of construction in Stockholm after Nya Tunnelbanan, an extension to Älvsjö (Personal Interview F 2021). The West Link uses a combination of methods; through hard rock it uses drill-and-blast tunnels, but through softer ground it uses cut-and-cover, and the stations are cut-and-cover as well.

This choice of tunneling method comes from Stockholm's hard gneiss geology; Gothenburg is a combination of gneiss and granite. Stockholm's rock forms a natural arch, and therefore it is not necessary to line the tunnel with concrete as is done with a typical TBM. In most cases, there is no need for further sealing to prevent water intrusion, but in some it is necessary to use grout.

The upshot is that it is difficult to make direct engineering comparisons to urban rail projects that use the more conventional method of TBMs for the tunnels and cut-and-cover stations. It is also difficult to make direct comparisons with stations, because the dig volumes as mentioned in the reports for New York, Milan, and Istanbul can be given purely for stations, whereas in both Stockholm and Gothenburg it is common to combine stations and tunnels in citing volumes and even give contracts that do both at once.

Tunnel drilling

There are three kinds of tunnel used for Nya Tunnelbanan: access tunnels, single-track tunnels, and double-track tunnels.

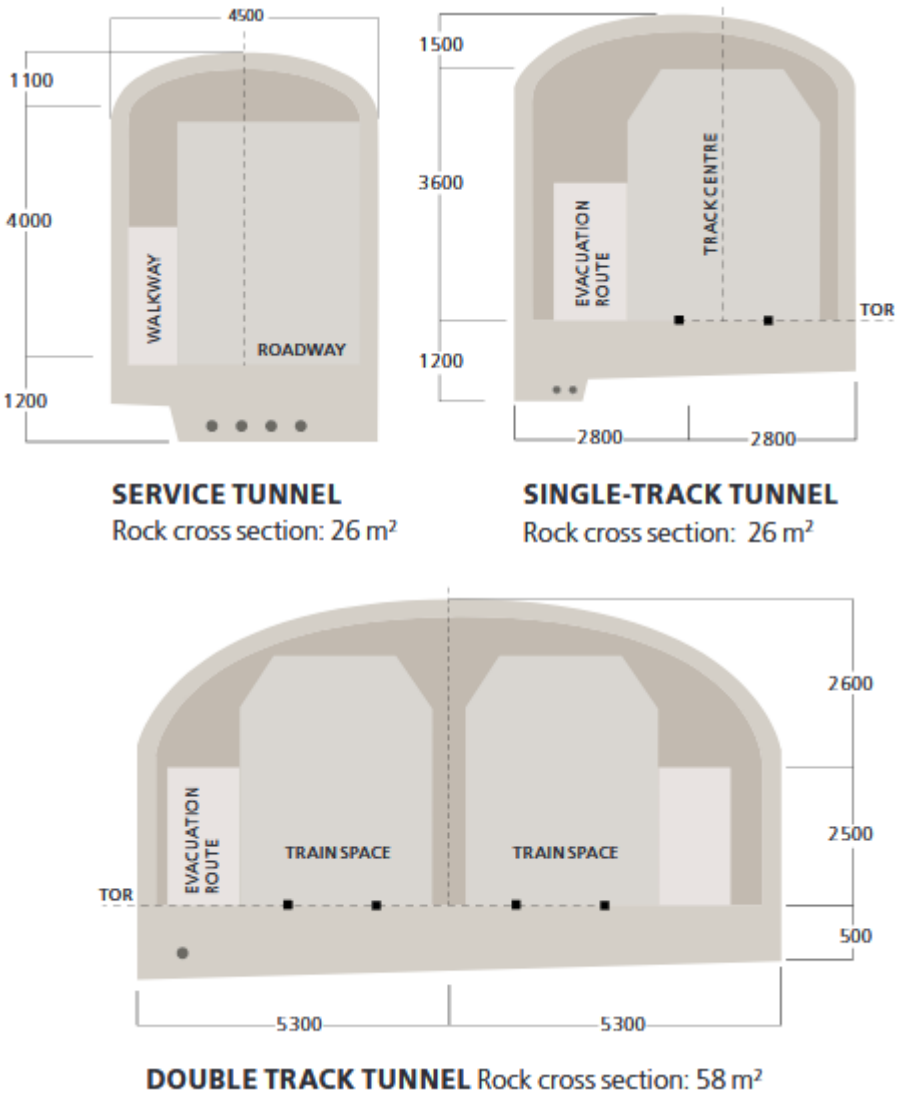

figure 3. Tunnel cross-sections

In practice, with access tunnels, the total length of single-track tunneling for Nya Tunnelbanan is far greater than 39 km, twice the route-length of the project. A service tunnel is required alongside all lines, regardless of whether they are built as twin single-track tunnels or as double-track tunnels; in addition, work tunnels for station access add to the dig volume, such that the planned tunnel between Söderstadion and Sockenplan allowing a connection from the Blue Line to take over the Green Line branch to Hagsätra, a distance of about 1.7 km, has 270,000 m^3 of total dig.

Station construction

Underground stations in Stockholm are mined. However, the entry halls may be built with cut-and-cover, with escalator and elevator connections to the main cavern.

Station construction plans make an effort to reduce disruption. In residential areas, it is forbidden to truck muck out of the access tunnel overnight after 10 pm or before 7 am (Personal Interview F 2021); because the combination of drill-and-blast and mined stations does not rely on 24/7 construction, it is possible to pause the works overnight, and no additional infrastructure is needed to accommodate any overnight accumulation.

To further reduce disruption, stations are staged from off-street sites, to reduce street closures. When street closures are required, the priority is to keep the sidewalks open to the public and close the roadway, as part of Sweden's strategy of feminist planning: women walk more than men whereas men drive more than women, and so, in conjunction with sidewalk prioritization for snow removal in winter, sidewalks are prioritized during underground disruption.

But most of the time, no street closure is required. Entry halls in developed areas are staged in public plazas and parks or mined via sideways access tunnels. Most stations for Nya Tunnelbanan are located in outlying areas and therefore can be built more easily, in open land near land to be redeveloped or Million Program projects with suitable open space to be used for construction. However, some of Nya Tunnelbanan's stations are in the urban core of Central Stockholm, as are both of the stations of Citybanan, and yet their costs remain moderate.

The access tunnels are especially elaborate at Sofia, just outside city center. Sofia, built 100 meters below ground, is near the intersection of Folkungagatan, a 23 m wide street, and Renstirnas Gata, a 17 m wide street, but the station is offset to the east of the intersection and access for workers and materials is via service tunnels connecting the cavern to nearby arterial roads. Passenger entry is built in a park.

At Sofia, the access tunnels also double as evacuation routes. The station is so deep that it has no escalator access, only elevator access, but regulations still require timely evacuation of two full trains in an emergency (SLL 2016), to be provided by the elevators themselves in conjunction with emergency stairways and the access tunnels.

The cost of stations is not large. Sofia was a SEK 1 billion contract (*Tunnel* 2021), despite its depth. The stations for Citybanan, in more central areas underneath older T-bana stations, were not much more expensive; Implenia (2015) reports that a combined contract for the construction of Odenplan and a 2 km tunnel cost €147 million (about SEK 1.3 billion), and the cost of Stockholm City, built in city center beneath the surface intercity station and

the two-level T-Centralen metro stop, was estimated at SEK 1.5-2 billion, as was that of Odenplan (Personal Interview D 2021).

One possible explanation for the relatively low cost of complex central stations is the limited dig volume. Odenplan is 250 m long, 25 m wide, and 14 m tall from floor to roof (Mas Ivars et al. 2016), and Implenia (2015) reports the cross-sectional area as 337 m², a total of about 85,000 cubic meters. There is little spare volume: the longest Pendeltåg trains are 214 m. With no cut-and-cover, the total dig volume is substantially lower than it would be if construction had to be done top-down, which would increase the total depth of the dig by a factor of about 2.5. This is related to the hard gneiss rock of Stockholm, which permits cheap mined stations; in Oslo, in contrast, the switch from building Løren cut-and-cover to deep-mining the stations of Fornebubanen is one of the reasons for the higher cost per kilometer of the latter project (Personal Interview A 2020).

This volume is sufficient for future upgrade to four tracks. Currently, Odenplan is a two-track station, matching Citybanan's two-track capacity. However, in the future, there are plans to expand it to four tracks, so that each tunneled approach track splits into two station tracks, to permit higher capacity in case rush hour dwell times are too long; Stockholm City is already a four-track station.

It is notable that the two stations built for Citybanan only total about SEK 3 billion, less than a fifth of the total value of the project. Interviewees at Trafikverket and SLL instead explain the cost in terms of high additional design costs (2 billion) and a complex underwater tunnel built as an immersed tube in sections, also at 2 billion.

8 Labor and Wages

SEKO Tidingen, a newspaper published by the 72,000-strong union for railway, communications, and other service workers, profiled the tunnel workers building Nya Tunnelbanan (Lindgren Strömbäck 2021). The worker in focus, Micke Vilhelmsson, lives in Hagfors, an industrial town of 10,000 located 260 km from Stockholm; none of the tunnel workers building the system is a native Stockholmer, and it's common enough to work abroad that Vilhelmsson spent six years in Norway. EU migration rules are creating an EU-wide labor market, and contractors have explained in a private interview that there's a growing number of tunnel workers from Eastern European countries, who are subject to the same stringent labor laws as native Swedes when they come to work on Swedish projects. Slovakia and Poland are popular countries of origin for workers.

To house a mobile international and domestic migrant workforce, infrastructure builders provide temporary worker housing; this is also the case for maintenance workers, who are nationally mobile as they may work on track renewal projects anywhere within the country.

The difficult, skilled work leads to very high working-class wages. Stockholm tunnel workers earn SEK 70,000 a month before taxes (Personal Interview F 2021), or about $98,000 a year in PPP terms; the overall cost to the employer is twice that, including social security contributions (amounting to 31.42% of the payroll), temporary worker housing, overheads, and a profit margin on the cost-plus basis used for contracts.

The combination of high wages and a pan-European mobile workforce creates migrant labor dynamics that are not always healthy. A report by LO covering abuses in the 2000s on Citytunneln, Citybanan, and a road tunnel in Stockholm complains about regulatory arbitrage to suppress wages and avoid paying benefits (Jonsson et al. 2014). The report goes into the possibilities for bringing such migrant workers into the union, with a brief comparison to the situation in Oslo (where 40% of unionized building trades workers are Polish or Baltic) and Copenhagen (where it is only 3%).

And yet, the wages quoted are not low: in the 2000s, building workers in Stockholm averaged 190 SEK/hour; migrant workers building infrastructure, who are 45% of the workforce across those three projects, earn somewhat less, 100-150 SEK, but then specialists earn SEK 180-270/hour, the higher figure going to mining workers. Inflation over the last 15 years has not been high, but SEK 270/hour in 2007, when much of LO's data comes from, corresponds to 320/hour in 2021 price levels, and with economic growth since then, the figure is not far from the SEK 70,000/month quoted to us by a civil servant. LO goes over the quality of housing benefits, and those scale with the class of worker; one worker complained about housing quality and got better housing, and was only fired later after he wanted to join a union.

Doing an exact comparison of labor productivity is difficult because Stockholm uses drill-and-blast for tunnels rather than the globally more common TBMs. However, Sweden has high labor efficiency, as a way of saving money while still spending about $200,000 a year per mining worker. At a given time, there are about 6-8 workers inside the tunnel head in Sweden, and the ratio of white-collar supervisors to line workers is low (per LO, the workforce splits as 70% blue-collar, 30% white-collar); one contractor said that TBMs require more labor-intensive maintenance than drill-and-blast, at least in the context of Stockholm's rock (Personal Interview F, 2021; Personal Interview I, 2021). Overall, the LO report estimates that the share of labor costs in the contract for Citybanan is 23%, a comparable figure to what we have found in the reports on Istanbul and Italy despite much higher wages paid in Sweden.

9 The Nya Tunnelbanan cost overrun

While the absolute cost of Nya Tunnelbanan per kilometer is well below the global median for underground construction, there has been a substantial overrun from the budget. The current budget, SEK 32 billion, is higher than its original budget of 23 billion; this is not common in Sweden, where the retrospective lists of rail and road projects provided by Trafikverket (2017; 2019) show small or no overruns, even on big projects.

Unlike absolute costs of urban rail construction, cost overruns are well-studied in the literature. Flyvbjerg et al. (2003) identify strategic misrepresentation (that is, lying by civil servants and politicians) and optimism bias as underlying causes. Love et al. (2015; 2016; 2018) criticize Flyvbjerg, first arguing that cost overruns properly counted are much lower than Flyvbjerg finds, and second focusing on concrete causes in lieu of abstract issues of lying. Cantarelli et al. (2010; 2022) focus on the problem of early commitment, in which a political commitment to an incompletely designed project incentivizes overdesign and sticking with projects that turn out to be bad (high-cost or low-value) after further work. As a result, Sweden has taken great care to understanding its cost overruns for Nya Tunnelbana, much more so than the absolute costs.

As megaprojects are hotly politically debated, when we inquired regarding the ongoing cost overruns on the Nya Tunnelbana project, there was already a report explaining, written for EU reporting needs. A project progress report from 2021 lists the following changes in costs, in million SEK at 2016 price levels, between 2013 and 2021 (Personal Interview H 2021):

Table 2.

Section	Cost (2013)	Cost (2021)	Increase (based on interviews)
Kungsträdgården-Sofia	2308	3813	65.2%

Sofia-Sockenplan	4386	6857	56.3%
Sofia-Nacka.	7733	10214	32.1%
Odenplan-Hagastaden	2424	2705	11.6%
Hagastaden-Arenastaden	2308	2938	27.3%
Barkarby	3347	5286	57.9%
Total	22506	31813	41.4%

One reason is that the negotiations with stakeholders took longer than expected, leading to delays; in addition, two of the contracts went to court due to lawsuits by bidders, creating further delay.

However, much of the reason has to do with mid-project changes in environmental regulations. In SLL's report to the European Investment Bank and in interviews with experts and contractors, the following mid-project revisions were all mentioned as significant delay and cost factors:

- A regulation requiring contractors to dispose of waste rock, which they've had to truck to specific sites at high expense.
- A change in the maximum permitted level of water infiltration, which had direct and indirect impact on engineering, and was difficult to communicate with the client and is still leading to slowdowns in tunneling productivity.
- A safety requirement for a third service tunnel parallel to the two track tunnels, increasing the amount of tunneling work to be done by almost 50%.

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