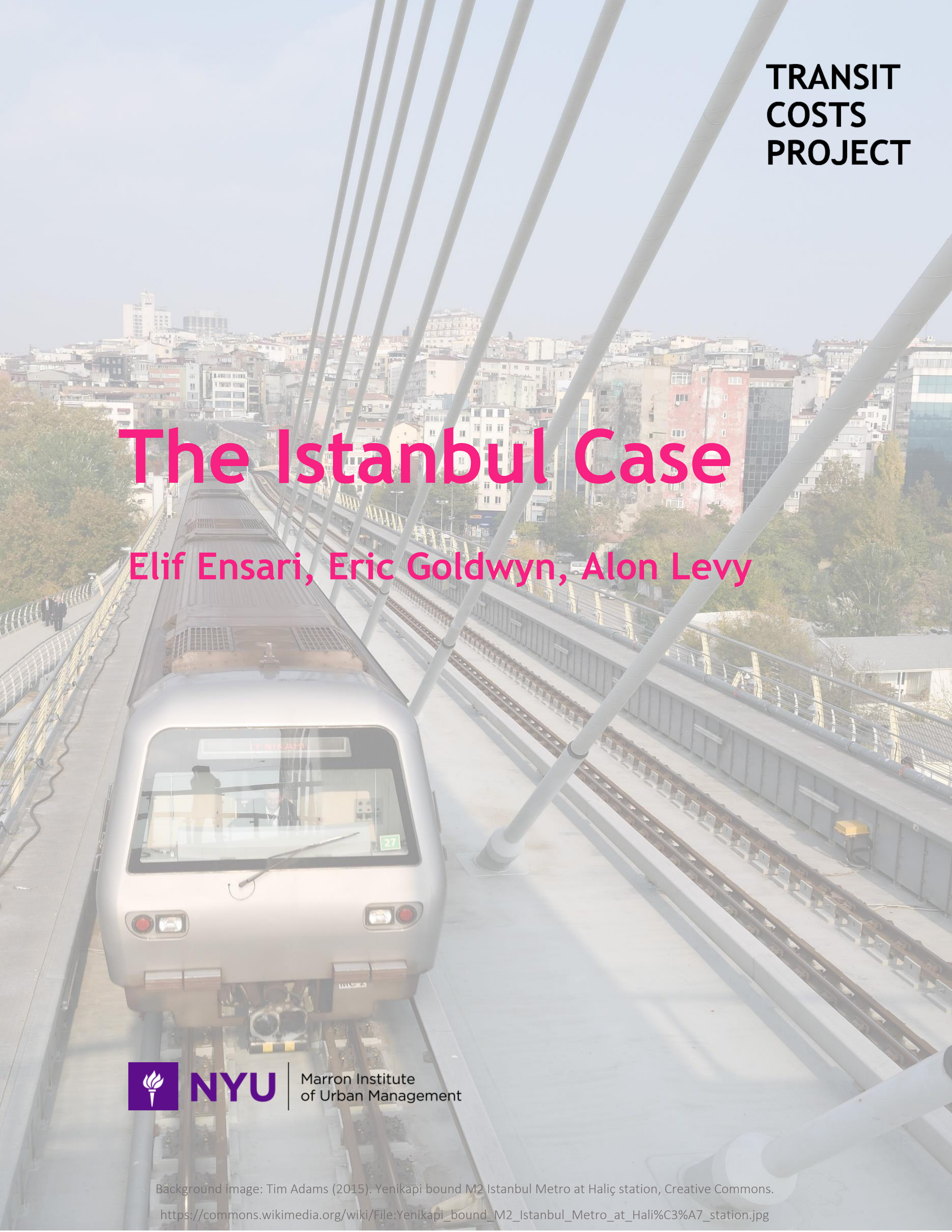

TRANSIT
COSTS
PROJECT

The Istanbul Case

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1 Introduction

In 2019, the International Public Transport Association (UITP) named Istanbul the world's leading city in the total length of urban heavy rail under construction (İstanbul Büyükşehir Belediyesi [İBB] 2019). Within less than two decades, Istanbul went from commissioning its first metro line to managing 17 projects with a total length of 222 kilometers under construction. How had a city with little experience building subways become a leader in the global transit construction arena? This study explores rapid rail construction in the Turkish city of Istanbul, pinpointing the best practices that facilitate its efficiency in project delivery and how these processes developed over the years so that Turkish experts now design and engineer rail projects abroad.

In 1989, İstanbul Ulaşım,[1] under the Istanbul Metropolitan Municipality (IMM) commissioned Turkey's first light rail transit (LRT) line. Now known as M1A, the line was 8.5 kilometers,[2] and from September when it opened until the end of the year, it carried almost 1 million passengers (Metro İstanbul n.d.-a). The construction of the first phase of M2, which was 7 kilometers long, took 8 years to build. It was the city's first heavy rail line and connected some of the most important commercial, touristic, business and residential centers on the European side of Istanbul. The line started service in 2000. M1B has Istanbul's first rapid rail tunnels mined by a Tunnel Boring Machine (TBM). The 5.5-kilometer light rail line features 4.35 kilometers of tunnels and began operations in 2013.

During these early years of building metros, there were only a handful of Turkish firms which were qualified to undertake heavy rail contracts that involved extensive tunneling. Track systems were imported and European experts were brought in to operate TBMs and train crews. As the city rapidly expanded its rail network over the following decades, the IMM, local contractors and consultants gained extensive experience. They adopted or

[1] The transit agency "Istanbul Ulaşım [Istanbul Transit]" under the Municipality was established in 1988 and was responsible for the rapid rail system of the city. It was renamed "Metro İstanbul" in 2016.
[2] The 6.5 kilometers section was commissioned in September and an additional 2 kilometers, in December of 1989.

developed new methods and technologies in construction, design and management; streamlined their project delivery processes; and raised the standards of occupational health and safety as well as environmental mitigation measures implemented. Today, Turkish agencies and contractors carry out metro projects from conception to construction of lines much larger than the M1B.

Since the 1950s, Turkey's population grew from 21 million to 85 million, and from only 25% of the population living in its urban centers to over 75% today. The country was able to leverage urbanization to boost economic growth, through a number of economic and urban management policies (The World Bank 2015). A metropolitan municipality regime was adopted, which consolidated regions’ infrastructure and investment functions as well as granting greater power to cities over their planning decisions. The informal land rights were legalized, leading to household and public investment in dwellings and neighborhoods (Karpat 1976; Uzun, Çete, and Palancıoğlu 2010). Housing stock was expanded and demand was instigated through mortgage-based financing. National programs were adopted to support access to water, sanitation and other municipal services, the financial burden of which was shared between the municipal government and the private sector through Public-Private Partnerships (PPPs) (The World Bank 2015). The economic and urban management policies Turkey adopted to encourage urbanization attracted domestic and foreign investment into cities and eventually led to a construction boom starting in the early 2000s (Balaban 2011; Yeşilbağ 2016). Along with an explosion in the construction of new housing, many megaprojects have been realized through PPPs paid for by domestic and international loans through the guarantorship of the Turkish state.

Among the thousands of contractors that the country’s construction boom produced, a number of firms have gained global experience in projects of significant size and complexity; they employ experienced teams of architects, engineers and construction workers; and are able to mobilize quickly. With over 300 kilometers of rail tunnels including those that are under construction and a steady stream of urban rail projects built within the last decade, the city cultivated a rapidly growing, competitive rail construction market. This experience has enabled Turkish contractors to compete on a global scale: Doğuş has rail projects in Bulgaria, Georgia, Saudi Arabia and India; Gülermak builds in Sweden, Poland, India, and UAE; Yapı Merkezi in Qatar and Saudi Arabia; Prota has designed rail projects in Germany and Poland.

We selected Istanbul as one of our six cases because the lessons learned through years and several kilometers of rail building can help inform practices in other cities around the world. This report is the second in a series of case studies the Transit Costs Project research team has undertaken in an effort to understand how various urban centers and regions tackle building urban rapid rail infrastructure from planning, design, financing and procurement to construction and commissioning (Transit Costs Project n.d.). We highlight practices that help cities save money and time while delivering quality infrastructure to communities and ensuring high standards for health, safety, and environmental (HSE) impact policies throughout construction. Our research involves studying academic publications; government, trade and media documents; and conducting interviews with professionals from government agencies, contractor firms and consultants.

1.1 A Global Leader in Building Rapid Rail

Istanbul is the economic, financial, industrial and cultural activity center of modern Turkey. It has grown rapidly in the last three decades with its population doubling during that period to exceed 15 million inhabitants. Striving to meet its increasing travel demand, the city built a large network of public transit that includes buses, metros, trams, funiculars, bus rapid transit (BRT), ferries, sea buses, aerial trams as well as paratransit.[3] Nonetheless, as was the case with many urban centers globally, rapid urbanization brought rapid motorization and public transit planning fell short in providing widely accessible, sustainable mobility options to Istanbulites (Batur and Koç 2017).

Istanbul ranks as the fifth most congested city in the world (Tomtom n.d.) and to address this, IMM has committed to increasing the share of public transit ridership,[4] decreasing private car use and prioritizing the expansion of its rail network as one of its main transportation strategies.[5] The 2011 Transportation Master Plan outlined a maximum rail system network of 749 kilometers of which 227 kilometers were already in service, under construction or in the process of being tendered. The additional 522 kilometers of proposed lines were evaluated and 388 kilometers of these new lines were selected to be completed with a target of 37 lines in operation by 2023, including funiculars, trams, light rail, the Marmaray commuter line and metros.

Since the completion of the 2011 Transportation Master Plan, Istanbul commissioned the commuter rail line Marmaray with a submerged tunnel crossing the Bosphorus Strait, M6, the first phases of M3, M5, M7 and multiple phases of M2 and M4 along with new trams, funiculars and cable car lines. As of 2021, Istanbul has 17 rail lines measuring 253 kilometers; four of which are trams, two are aerial trams, two are funiculars, one is Marmaray and seven are heavy rail lines totaling 135 kilometers in length (See Figures 1-3 for the heavy rail lines). There are 15 ongoing heavy rail projects measuring 193 kilometers, and an additional 10 kilometers of trams (See Figure 4 for the heavy rail network targeted to be completed by 2024).

[3] Consisting of mini buses and dolmuş which are 8 passenger mini buses.
[4] See Appendix A for ridership numbers.
[5] According to a recent study based on interviews with officials from the Istanbul Metropolitan Municipality (IMM) officials and surveyed 21 reports and plans, 10 of which were approved by the IMM Council, expanding the railway network is stated as a main priority for IMM in "IMM's Strategic Plan for 2020-2024", "Istanbul Climate Action Plan, 2018", "Istanbul Metropolitan Municipality Transportation Master Plan, 2011" and "Istanbul Development of Public Transport Strategies Master Plan Report, 2019" (Beyazit-Ince et al. 2020).

Within all modes of transportation in Istanbul, the share of private car use is 20%, public transit ridership is 28% and the remaining share of trips is split between walking and private shuttles (Beyazit-İnce et al. 2020). 18.6% of the public transit ridership is by rail, 77% is by rubber-tired vehicles and 4.3% by sea transport (İstanbul Elektrik Tramvay ve Tünel İşletmeleri [İETT] n.d.). With the addition of approximately 200 kilometers of rail including commuter lines, trams and funiculars, the city anticipates that the share of rail ridership within public transit will increase from 18.6% to 30% by 2024.[6] By 2029, the total length of the rail network is planned to reach 622 kilometers (Emlak Kulisi 2021). Figure 5 shows the timeline of Istanbul's heavy rail construction.

figure 1. Map of M1A metro line.

6 The initial target of 388 kilometers for he year 2023 in the 2011 Master Plan was revised.

figure 2. Map of M1A-B, M2, M3 and M4 metro lines and Marmaray's commuter line's BC1 Bosphorus crossing section.

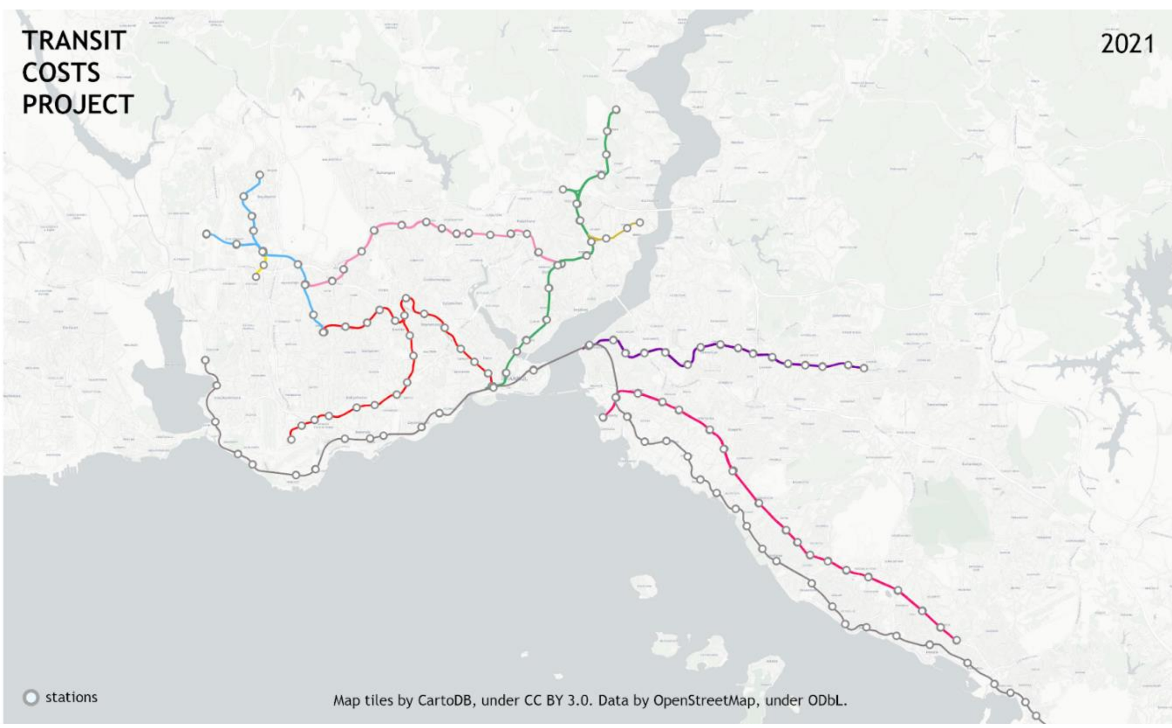

figure 3. Map of M1A-B, M2, M3, M4, M5, M6, M7, M9 metro lines and the Marmaray commuter line.

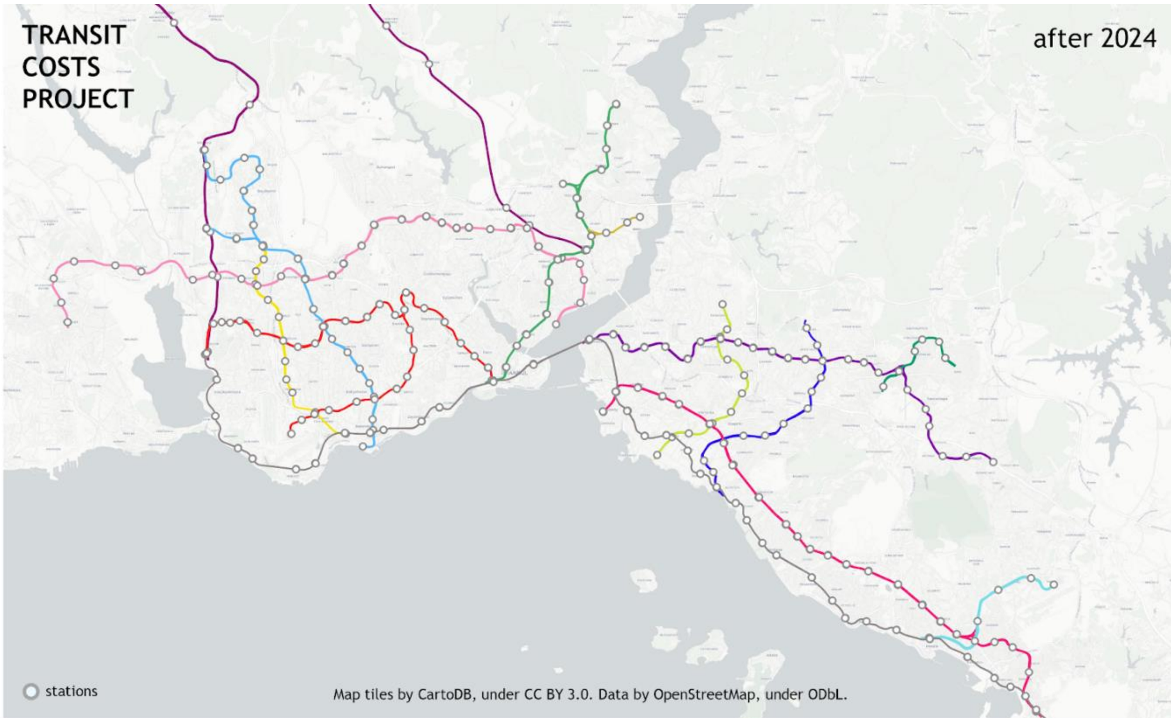

figure 4. Map of M1A-B, M2, M3, M4, M5, M6, M7, M8, M9, M10, M11, M12 metro lines and the Marmaray commuter line.

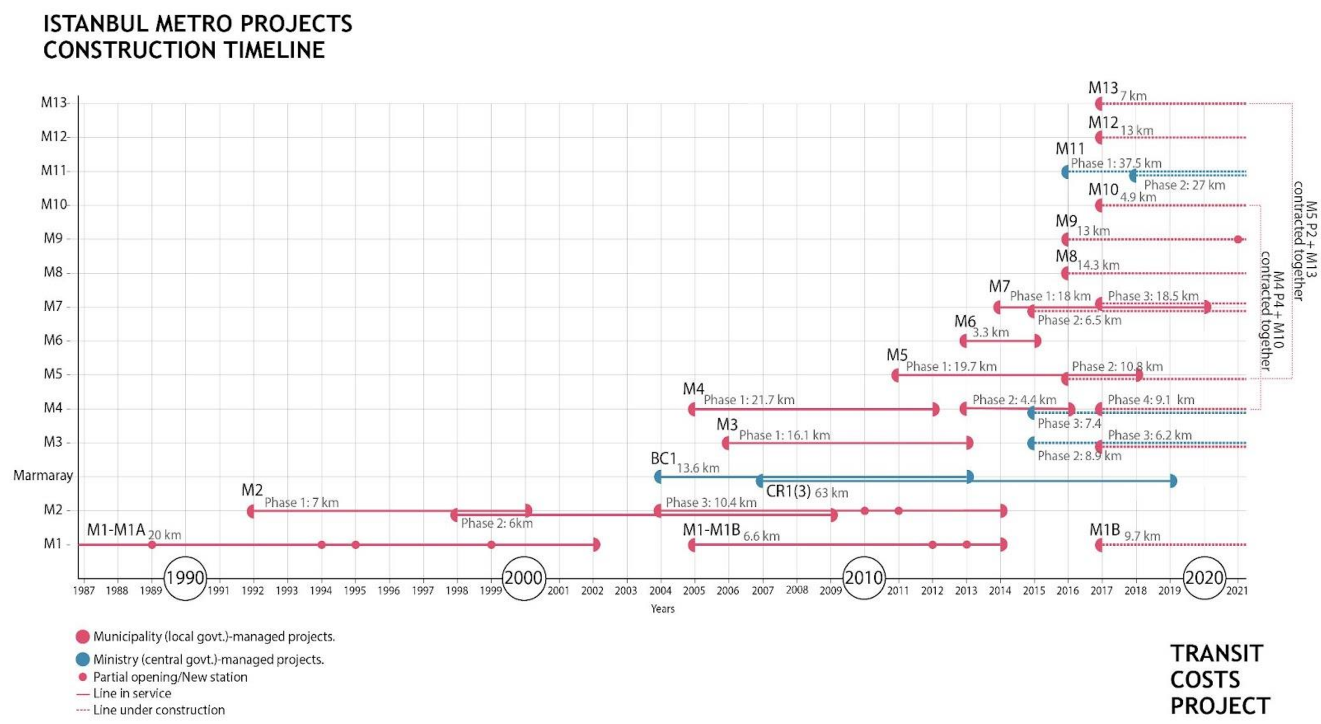

figure 5. Timeline of Istanbul rapid rail projects.

Among Istanbul's rapid rail lines, the average length per contract is 16 kilometers (9 miles), and the weighted average cost per kilometer of rail is $126 million PPP[7] (Figures 6 and 7). Even though a linear relationship does not exist between the length of a line and the duration of its construction, based on the total length of completed lines and the total time it took to build them, we can say that 1 kilometer of subway in Istanbul is built in 7 months on average.

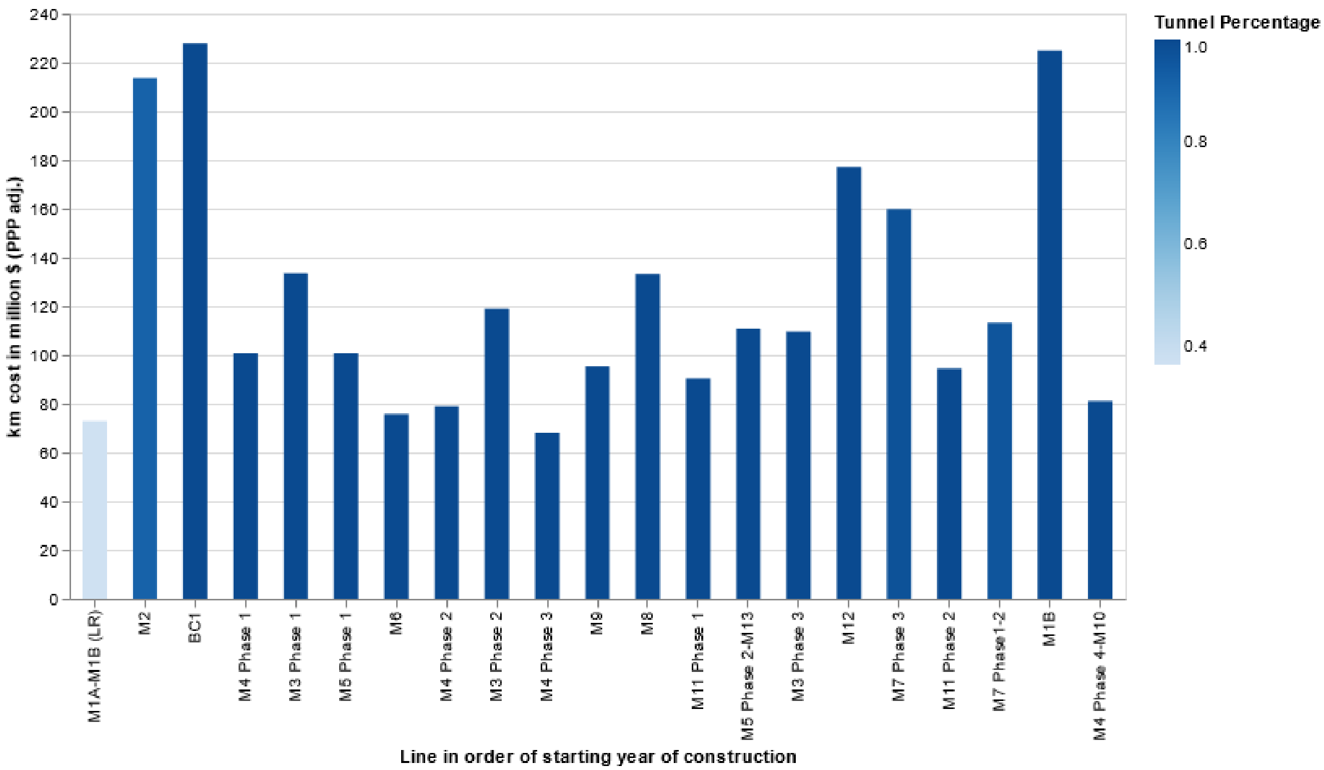

figure 6. Project cost/kilometer, in order of starting year of construction of lines in Istanbul. Colors show the percentage of tunnel. Project costs that include the construction of a yard, oftentimes to be shared with other lines are M1A-B (at grade yard), M2 (at grade yard and 3 large parking lots), M3-P1 (at grade yard), M4-P1 (underground yard), M5 P1 (at grade yard, +2,750m connection tracks), M7 P1-P2 (at grade yard), M8 (at grade yard).

[7] This average excludes the commuter line Marmaray's BC1 and CR3 contracts. We use Purchasing Power Parity adjustments based on data from the World Bank (World Bank n.d.)

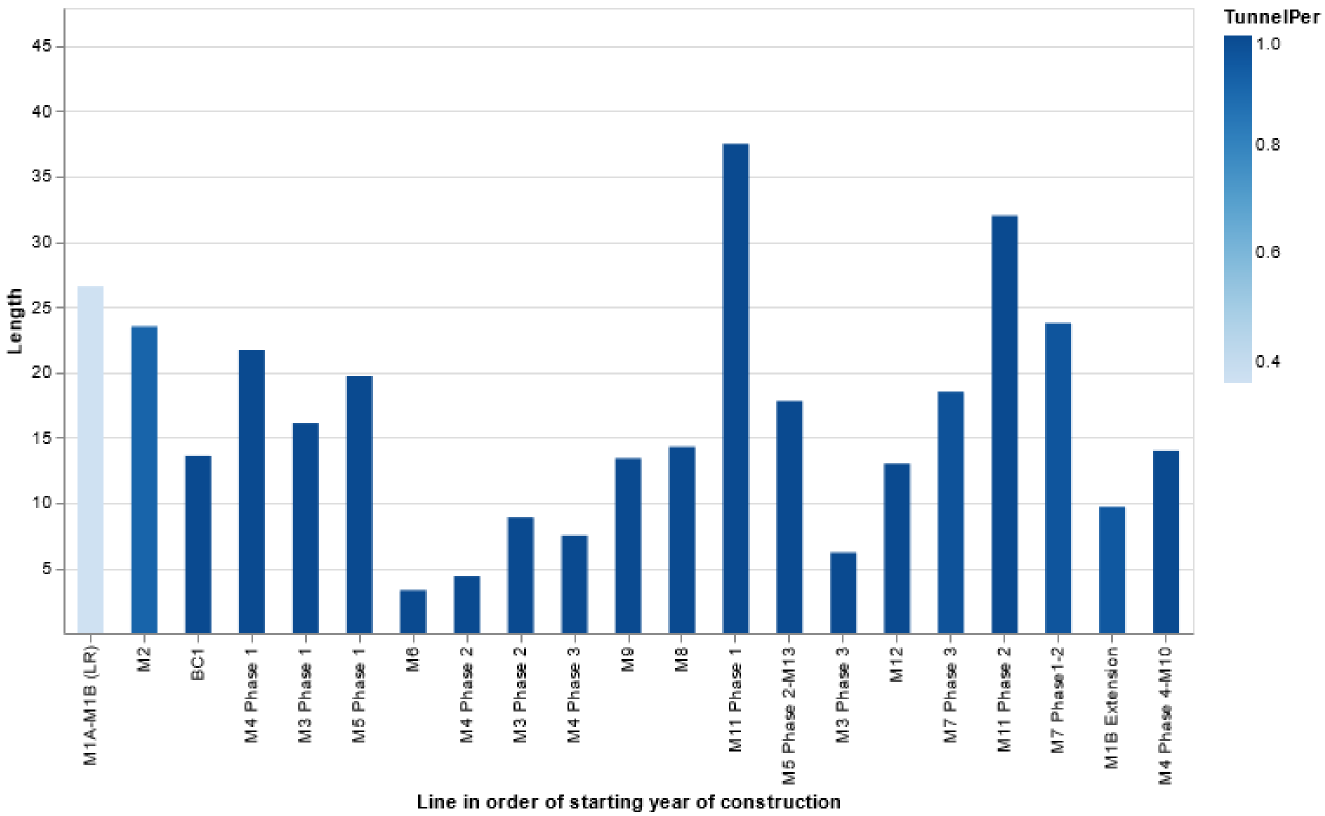

figure 7. Project length, in order of construction starting year of rapid rail lines in Istanbul. Colors show the percentage of tunnel.

1.2 Politics of Urban Rail Construction in Istanbul

Building urban rail in Istanbul is difficult due to the city's unique geography, geology, rich archeological heritage and old building stock; yet, politics often breed the greatest challenges against rail construction in the city. Situated between the Black Sea in the north, the Marmara Sea in the south and the Bosphorus Strait bisecting the city, many construction sites are close to the water or under the water table, and often require diaphragm walls for structural stability and to keep water out. Thicker walls and heavier reinforcements are also necessary because the city is in an earthquake zone. Multiple archaeologically significant sites, some as old as eight thousand years have been unearthed while building the Istanbul Metro over the last two decades. The existing city is dense and the majority of the building stock is old, poorly reinforced or made of low-quality materials. On top of these challenges, the local and central governments might disagree on rail projects' financing plans dependent on international loans, meddle in tenders and put pressure on the contractor to finish construction earlier for better publicity opportunities. All of these factors impact the construction processes, inevitably elevating project costs.

Politics play a major role in deciding what gets built, who builds it and how fast it is built. Until 2019, the IMM was run by the same political party as the central government, Justice and Development Party (AKP). Following the election of the current mayor Ekrem İmamoğlu from Republican People's Party (CHP), the municipality and the central government have been in competition over building and commissioning rail projects (See Figure 8 for the timeline of key events and rail construction in Istanbul).[8] Even though such a race can seem to be a positive influence on the construction of metros in the city, the conflict between the two parties' impacts metro projects negatively. Since the opposition party took over the Istanbul Municipality, not only did the central government refuse to guarantee international loans; but the public banks that were on good terms with AKP failed to provide loans to the municipality (Altaylı and Erkoyun 2019; Savaşkan 2020). Istanbul turned to European banks for loans to restart their rapid rail construction. The treasury under the central government still needed to approve these loans, which it delayed until Mayor İmamoğlu's complaints were amplified by some left-wing media outlets (Güvemli 2020a, Cumhuriyet 2020a).

Local politics also influence construction processes and can create roadblocks in different stages of planning and building subways. Istanbul's municipal parliament consists of members from both CHP and AKP, with the latter holding a majority of the seats. After the new mayor was elected, AKP members delayed the decision permitting new muck yards,[9] which became critical with the increasing number of underground metros being built in the city (Güvemli 2020b). Similarly, land acquisition is easier for the central government both because they have access to more disposable funds and can expedite legal processes which they are unwilling to do for the current municipal government. Hence IMM under İmamoğlu prefers utilizing municipally owned land when building surface structures, rather than waiting for approvals.

Central and local governments have undermined competition in Istanbul's rail construction market by interfering with tender processes. The construction tenders of five heavy rail lines in the city were carried out on the same day in March 2017, in which the same group of contractors submitted separate bids to all five and each was awarded one project.[10] The resulting contract values were uncharacteristically higher than the estimated costs by the Rail Systems Department. Furthermore, the 21b law intended for extraordinary circumstances, that eliminates the request for qualifications (RFQ) stage in tenders started being used, through which the municipality could

[8] AKP is the right wing, conservative and populist political party that has been in power in Turkey since 2003. CHP is left wing and the main opposition in the parliament.

[9] Muck yard refers to the land that the city designates for the unloading of excavated earth.

[10] Public consensus is that this was facilitated through each bidder submitting the lowest bid for a different line, bringing to mind a possible pre-arrangement among bidders, possibly in coordination with the agency. In Istanbul, construction tenders are awarded based on the lowest bid criterion at the end of a two-staged tender process involving a Request for Qualifications and a Request for Proposals.

award tenders to contractors without public notices or following open tender procedures. Based on 21b, two airport connector metro lines were awarded to contractors known to be favored by the central government. Before the election of the new mayor, the local government also lowered the track record requirements to bid on rail construction tenders, which led to less experienced contractors with government connections winning some contracts.

Political pressure sometimes accelerates the construction of projects, which can facilitate earlier access to new transit lines for the public. There is always pressure on the local and central governments to complete projects within their terms. Opening rail projects are valuable publicity events for mayors and presidents, so towards the end of construction, usually after the initial deadline has already been extended due to delays, it is common for agencies to ask that opening dates of lines be rescheduled to coincide with a national or religious holiday. This requires rushing construction programs and often means a phased opening or completion of part of the work after revenue service starts. The Turkish contractors are accustomed to such rescheduling and often bear the risks and share the extra costs of an earlier opening with the agency. On the other hand, such changes in the program can raise costs and risk the quality of construction. Three senior level engineers with international experience in rail construction mentioned in our interviews that it is for this reason that such a concession would be unthinkable for a European contractor (Personal Interviews G, I 2020 and N 2021).

Despite these issues, there is sustained political will to build urban rail, a certain level of streamlining is built into the system, and agencies ease processes which allow Istanbul to build rapid rail cheaper than most cities in our database (Transit Costs Project n.d.). Below we present a summary of our takeaways from this study. In the next section, we provide an overview of how the agencies, contractors and consultants work together to bring down construction costs together with a detailed overview of cost information. Chapter 3 presents three projects studied in more detail. Our conclusion highlights the lessons that can be learned from Istanbul's approach to building heavy rail infrastructure, and lays out the challenges the city still needs to overcome to improve its project delivery processes and quality of construction.

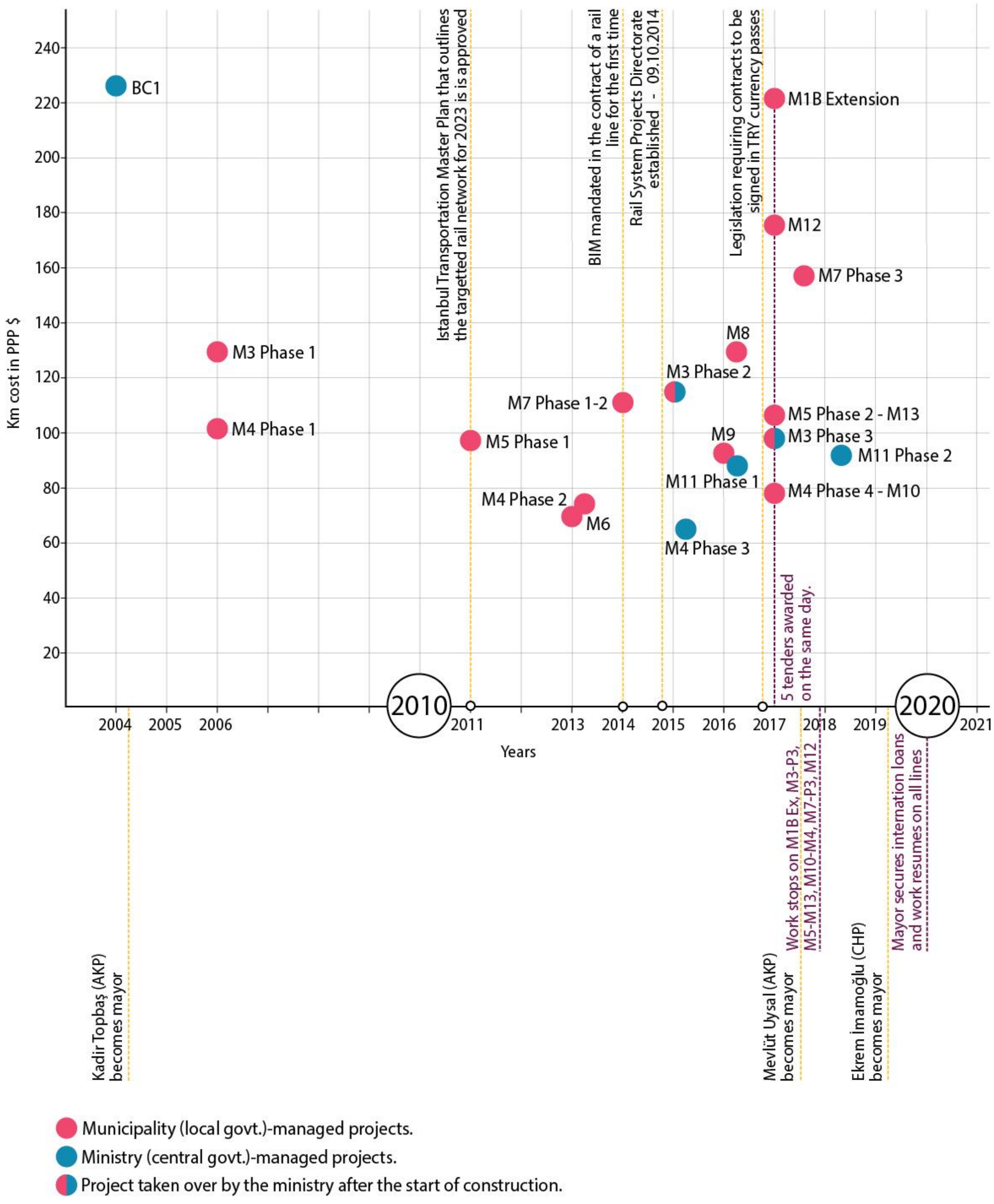

figure 8. Timeline and costs of Istanbul projects, changes in administration and legislation.

1.3 Main Takeaways

Over the course of 36 interviews and a review of numerous documents, we identified four main factors that contribute to lowering costs and speeding up the construction of urban rapid rail projects in Istanbul. These are:

- The cultivation of a rail construction ecosystem through the completion of 15 urban rail projects[11] within the last 3.5 decades which facilitate competition in the market as well as an increased know-how. Political will, being partly responsible for this steady stream of projects.
- The established processes of project delivery that have been refined over the years.
- The flexibility of the agency and the contractors in collaborating to overcome obstacles by accommodating design changes during the building process, stemming from the understanding that speed saves money.
- The adoption of technology in design, management and construction through investment in software tools such as Building Information Modeling and expansion of equipment pools that involve purchasing new TBMs.

Agencies most commonly use a Design-Build (DB) project delivery method, but work with an initially procured, 60% design document that affords them a level of control over the project. While this design document is essential for estimating costs, conducting feasibility studies and evaluating construction bids; when working with the contractors, the agencies approach design change proposals with a level of flexibility that allows for innovation, which cuts down costs and saves time. In addition to this well-established practice of working with a design document while being adaptable to change, the city sustained a pipeline of rail projects within the last few decades (Figure 5) through which, the agencies, contractors and consultants gained experience and know-how. Availability of work encouraged an increase in the number of contractors in the city, and the competition soared. It became feasible for contractors to invest in technology and expand their capacities.

A streamlined procurement method that strengthens the agency's hand, a collaborative and adaptable approach to changes, developing capacity and know-how owing to a steady stream of projects, and the rise of the rail construction market constitute lessons to learn for other cities wanting to bring down their rapid rail construction costs. Some other components of construction that Turkish teams allocate smaller budgets and time for, compared to the North American and European teams are more questionable. Low labor and professional service costs in Turkey bring with them substandard working conditions; HSE mitigation is well-enforced with legislation

[11] 7 metro lines, 4 trams, 3 funiculars and the Marmaray commuter line.

but lacks in execution resulting in higher numbers of fatal occupational accidents[12] and more disruptive environmental impact; and perfunctory community engagement along with minimal land acquisition can prevent conflict in order to save time and money, but the alignment of lines end up being suboptimal for the transportation of the city (Personal Interview C 2020).

Labor conditions, HSE and stakeholder management are critical issues that require control mechanisms, good planning and proper execution. However, it is worth taking a critical look at the resources allocated to deal with them both in Istanbul and other parts of the world. How much time and money cities spend on managing different aspects of construction should be considered in accordance with what is achieved, and the negative consequences when they are poorly executed.

[12] Some senior managers of contractor firms pointed out that restricted timelines demanded by the agencies in Turkey compromise HSE mitigation standards; Turkey has a higher rate of occupational fatal accidents than Europe and the US. According to the International Labor Organization's statistics, Turkey had 7.4 occupational fatalities per 100,000 workers (in 2016) while the US had 5.3 (in 2018), Italy, 2.4 (in 2015), Sweden, 1 (2016) and the U.K, 0.8 (in 2015) (International Labor Organization [ILO] n.d.). However, it is hard to draw a direct link between the speed of construction and the quality of HSE.

2 Process Overview

In this section we present a process overview of how urban rail gets built in Istanbul. By examining Istanbul's processes and how they have been refined over more than 30 years and the construction of more than 200 kilometers of urban rail, we can learn from Istanbul's struggles and successes to develop best practices for subway construction. At the end of this section, we present cost information for labor, material and tunneling equipment as well as general cost estimates for metro lines in Istanbul.

2.1 Planning and the Internal Capacity

IMM and its agencies are responsible for transit planning and building the majority of rail infrastructure in Istanbul. They are bound by larger scale plans developed by the central government and need approvals from the central government at various points during the course of the planning of a rail project. The Ministry of Transit under the central government also builds rail infrastructure in the city, but only assumes projects of national significance such as the airport connectors and the commuter rail, Marmaray. As an exception, two additional urban rapid rail projects were taken on by the central government due to the financial difficulties IMM faced and the project's contractor connections with the central government before the change of mayors in 2019. Thus, some projects in Istanbul are built by the IMM and others, by the Ministry of Transit, and each agency is responsible for securing funding for their own projects. The local and the central governments do not collaborate on projects.

The Transit Planning Branch Office (TPBO) under IMM appoints a team of 10 people to work on the transit demand and planning, together with coordination of intermodal transportation. Under IMM, the Rail Systems Department develops the preliminary rail projects in coordination with the TPBO and works on route designs based on the Integrated Urban Transportation Master Plan for Istanbul Metropolitan Area which is based on the City of Istanbul Environmental Plan developed by the Ministry of Environment and Urban Planning under the central government.

This plan is dependent on the Strategic development plan prepared by the Presidency of Strategy and Budget (Figure 9).

The Integrated Urban Transportation Master Plan for Istanbul Metropolitan Area, the latest of which was issued in 2011, outlines the planned rail transit routes in Istanbul (İBB). The timeline for any project in the masterplan starts with the Rail System Projects Directorate under the IMM, or the General Directorate of Infrastructure Investments under the central government's Ministry of Transit picking up the project. A group within a 35–40-person team carries out an alternatives analysis for the line internally (Personal Interview V 2021). The next step is to procure a final design document[13] at 60% design and a feasibility report. With these documents, the agency acquires a thorough understanding of the project prior to the construction tender, and, according to a project manager of an independent design firm that has completed several final designs and feasibility studies for the Istanbul metros, estimates costs with 90% confidence (Personal Interview A 2020).

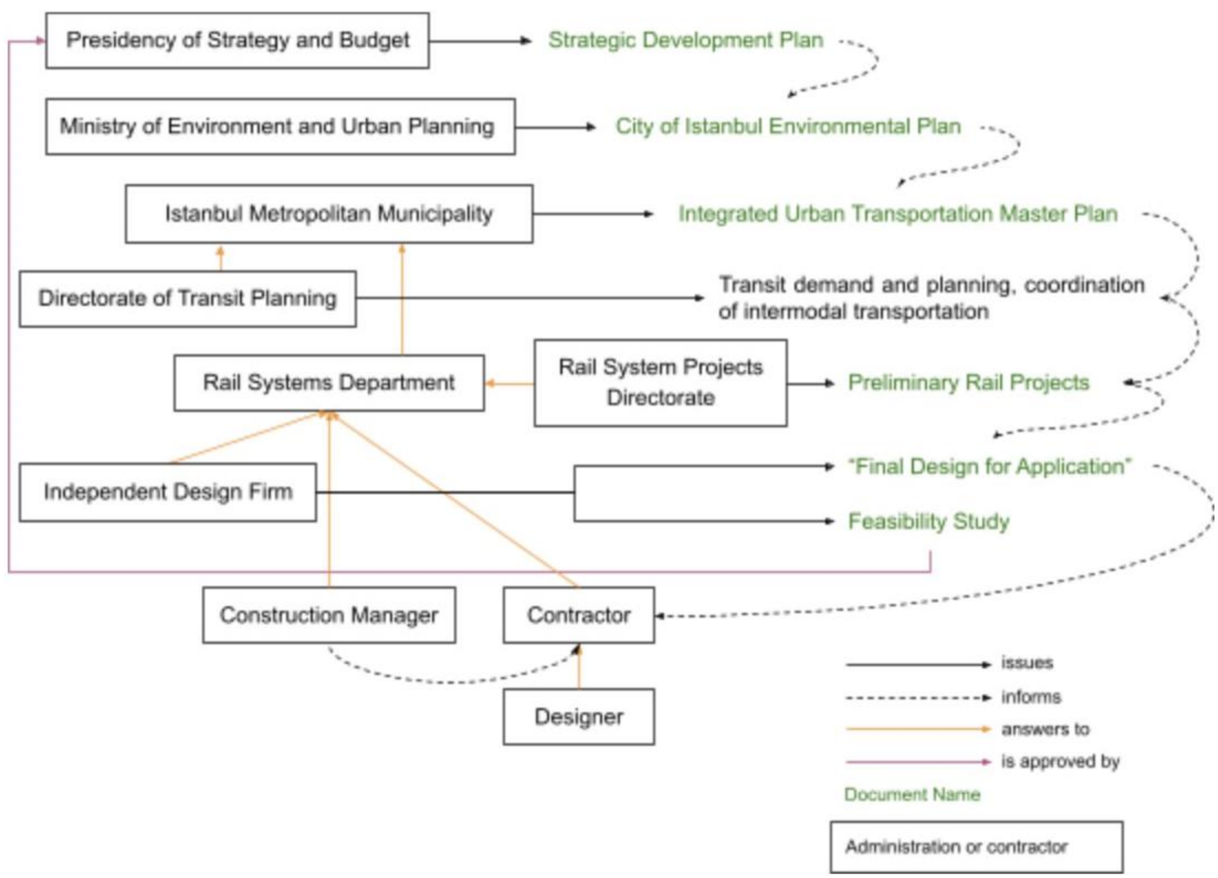

figure 9. Rail planning and procurement flowchart

[13] The direct translation of the title of this document would be "final design for application project".

Next, a Project Promotion Document is prepared and the Environmental Impact Assessment (EIA) process is initiated. Metro projects are not directly subject to EIA (EIA or "ÇED Report" in Turkish), but fall in "the List of Projects Subject to Selection and Elimination Criteria", hence, the owner agency applies to the Ministry of Environment and Urbanization, and upon evaluation, an "EIA Not Required" decision is issued. To obtain this waiver, a Project Promotion Document is prepared and an application is submitted to the Ministry of Environment and Urbanization. The preparation of this document takes about a month, and its approval process takes approximately two months.[14] This process has been streamlined in consideration of the net-positive environmental effects of urban rail projects. Compared to the US, where the average time it takes to obtain an Environmental Impact Statement is 4.5 years (Council on Environmental Quality [CEQ] 2018, 2020), the process in Turkey is extremely rapid.

The Rail System Projects Directorate under the Rail Systems Department of IMM was established in 2014, and is responsible for the preliminary planning phases of rail projects in Istanbul. Beside procuring the 60% design document before launching the construction tender, the responsibilities of the department include the initiation of land acquisition processes for the lines approved by the municipality's Transportation Directorate; preparation or procurement of the feasibility analysis and tender documents for the design, construction management, construction and rolling stock tenders; conducting the EIA process; evaluation of the design revisions during construction; supervision of the operating agency's technical and maintenance work for lines in revenue service; specifying the architectural materials to be utilized in rail projects; developing strategies that encourage the use of local resources in procurement; enforcing the use of Building Information Modeling (BIM) technology; coordination with utility companies during construction and keeping record of the communications among all parties throughout the construction of rail projects.

The directorate typically carries out three more tenders after obtaining the EIA waiver, one for the construction management (CM), one for the construction work and one for the rolling stock. In the early years of metro construction, the tender package for construction used to include the rolling stock procurement as well. The agency did not have the capacity to procure the rolling stock on their own, however, transferring the risk to the contractor consequently increased the costs of procurement. Today, the agency carries out procurement tenders for rolling stock on their own.

The operating agency Metro İstanbul is consulted during the design process, but IMM's Rail System Projects Directorate is more influential so Metro İstanbul does not demand significant changes. During construction, an 8–

[14] To learn more about what the EIA process entails for projects subject to EIA, see Appendix D.

10-person team from the Rail Systems Department supervises the project on site. It is common to have 10 people on the agency side while a team of 60 people work on the project from the CM, which the agency considers their representative.

2.2 Financing

As part of the planning stage, the owner agency submits the feasibility report to the Presidency of Strategy and Budget for approval, in order for the project to go into the National Investment Program. This step is crucial when seeking financing options; once a project is included in the National Investment Program, the central government can act as a guarantor for the agency to obtain international loans with low interest rates; and even if not, the central government's approval is still required for loan agreements or the issuance of bonds to finance projects. The construction cost estimates on the feasibility study reports are kept 10-20% higher than the actual estimated costs in order to account for possible overruns (Personal Interview C 2020).

Different financing options are evaluated in the feasibility reports. These include scenarios of 100% self funding, 75% self funding with 25% funding by commercial or export loans, 50% self funding with 50% funding by commercial or export loans, 25% self funding with 75% commercial or export loans, and also, 100% funding by commercial and/or export loans. Export loans indicate loans obtained from Turkish banks and commercial loans are those that are granted by international institutions such as the European Investment Bank, the European Bank for Reconstruction and Development, the World Bank, the Islamic Bank and Japanese International Cooperation Agency. In the feasibility reports, financial analyses explore different payment plans for the loans, interest rates and fees over specified payback periods as well as expected fare and advertising revenues.

Typically, the feasibility studies find a combination of 55-60% commercial and 40-45% export loans to fund 100% of a project's costs to be the most advantageous. The interest rates are calculated based on the EURIBOR or LIBOR[15] rates, with an added 0.75 - 3.5%. A 0.6% commitment fee for both types of loans and a 1.27% commission fee for the commercial loans also apply. Grace periods of 1-4 years after the starting date of construction, payback periods of 10-14 years for the commercial loans and 20-24 years for the export loans are considered.

Even though projected ridership numbers and therefore the expected fare revenues utilized in the feasibility studies are considered to be optimistic, the projects are found to be financially infeasible (Personal Interviews F, I and J 2020). On the other hand, the economic feasibility analyses that take into account the travel time saved by

[15] EURIBOR (Euro Interbank Offered Rate), LIBOR (London Interbank Offered Rate) are average interest rates which leading Eurozone and London banks estimate that they would be charged when borrowing from other banks. These rates are updated daily.

commuters switching from different modes of transit; the savings realized by the reduction in crashes, maintenance and operating costs of rubber-tired vehicles and the upkeep and expansion of road infrastructure; as well as the environmental impact benefits show that the economic benefits of rail projects outweigh the financial costs. Hence these studies generally conclude that the projects are feasible to build when considered in terms of their economic benefits.

Foreign entities make decisions to grant loans for rail projects based on the credit rating of the owner agency (the municipality or the central government). Once major international investment agencies agree to provide loans, smaller banks also get involved through consortia. A single loan granting institution rarely finances 100% of the projects, their loans usually cover 20% or 30% of the costs. When foreign investors finance a project, they demand that the agency works with prominent designers and CMs, and also require reports to guarantee that stakeholder engagement plans are made; occupational health, safety and environmental impact standards are high. They visit the site and do quality control every six months.

There is a political side to the foreign financing mechanisms. When a financing institution agrees to provide a loan, it is common that they require a percentage (i.e., 30%) of the budget to be spent on procurement from the loan granting institution's country of origin. For example, for the Marmaray Commuter Rail's Bosphorus Crossing Phase, the Japanese Investment Bank which financed the project allowed for only a specific group of countries to bid on the construction tender, and the Japanese-Turkish consortium Taisei-Gama&Nurol (TGN) was awarded the contract.[16]

Politics between the local and central governments play an important role in the financing of rail projects as well. Most of the rapid rail lines in Istanbul are built by the local government, however, construction of some including the airport connectors M11 and M4's airport extension as well as M3's phases two and three are conducted by the Ministry of Transit under the central government. Due to congestion and a dire need for public transit infrastructure in the city, it is a matter of pride and prestige for both administrations to build rapid rail lines, and now that the local government has been run by the main opposition party since 2019, the two administrations race over who builds more rail infrastructure. Thus, the central government does not provide funding for municipally run projects; the municipalities find funding on their own. Among the rail projects that are owned by

[16] For the line M5+M13, Deutsche Bank provided a loan covering 15% of the costs and did not have such a requirement, however an executive level engineer of a contractor stated that if the financing was to be extended, it would very likely require the procurement of the catenary system, electrification and telecommunication systems from Siemens (Personal Interview J 2020). This credit agreement was arranged by the IMM.

the Ministry, those from cities run by the same political party as the central government receive disproportionately more funding (Savaşkan 2020).[17]

2.3 Procurement

For the procurement of urban rail infrastructure, IMM utilizes a method that was modeled after the FIDIC Red Book Design-Bid-Build contract template, but evolved into what resembles a Design-Build method over the years.[18] The agency adopted a working relationship with its contractors, which meant that it was open to revisions coming from the contractor's designer, if it found them to be reasonable and believed that they would save time and money. Examples include changes in the tunneling method, i.e., from using TBMs to building by NATM, the conditions of which are predefined in the contracts, or modifications in structural design, as was done in one case by replacing diaphragm walls with bored pile walls to make use of the contractor's abundantly available piling machines (Personal Interview E 2020). The Public-Private Partnership (PPP) scheme is not preferred for the procurement of rapid rail lines in Istanbul due to the projects' feasibility mainly being dependent on their economic rather than the financial benefits.

The pricing model of the construction contract is based on an itemized list of quantities for the civil and finishing works, which constitute about 65% of the items. The rest of the work such as tunnel ventilation system design, drainage system design, power and traction power design, training services and station common spaces environmental control systems or station sewer system for each station are also added to the itemized list but are priced as lump sum "sets." The cost estimate, not announced before the bidding is complete, is carried out by compiling the list of quantities, quotes for services and lump sum items, then adding 25% on top of the total to amount for overheads, profit and contingency. Prepared by the Rail System Projects Directorate, the list of quantities for each project is provided to the tender applicants together with the final design documents, and is required to be filled out and submitted as part of the bids. The proposed prices are expected to be based on a standardized unit cost schedule that is annually issued by the Ministry of Environment and Urbanization for labor, equipment and materials, but can vary across bids.[19]

Usually, the procurement of construction works is carried out through a restricted procedure which is a two-phased tendering process; first an RFQ is issued to shortlist applicants, who submit offers to the later announced

[17] 5 billion and ₺7 billion was spent on projects in Istanbul and Ankara but only ₺30,000 on projects in Izmir (Savaşkan 2020).

[18] FIDIC (the International Federation of Consulting Engineers) is a standards institution best known for their contract templates. FIDIC Red Book Design-Bid-Build contract template recommends a balanced division of risk between the contractor and the agency.

[19] Issued in Turkish and recently also in English and Russian (Turkish Ministry of Environment and Urbanization [TMEU] n.d.)

request for proposals (RFP). Construction tenders are evaluated based on the lowest bid, however, a minimum limit value is calculated dependent on the estimated value and the average of the proposed bids. Any bids under this limit are disqualified. A minimum of three and a maximum of ten bidders are shortlisted and invited to the second stage. If the number of qualifying firms is fewer than three, the tender is canceled. As opposed to the construction tender, the design and CM bids are evaluated based 70-90% (usually 80%) on the technical score and 10-30% (usually 20%) on the bid price (Directorate of Presidential Administrative Affairs, General Directorate of Law and Legislation [DPA] 2009).[20]

The scope of the construction contract generally includes tunneling, the civil and the finishing works of the stations and support facilities, the procurement and installation of the electromechanical systems, training of the operating staff and commissioning of the metro line.[21] This is a turnkey project delivery method; however, the agency and the contractor collaborate regularly throughout construction. The agency approves design and implementation decisions at several stages but also provides assistance to the contractor in third party relationships. For example, the electromechanical systems that make up approximately 25% of the contractor's direct costs are often subcontracted to foreign firms such as Siemens, Thales and Alstom over which the agency has some leverage as a long-term customer when negotiating on prices. The agency helps the contractor in these negotiations and they both benefit (Personal Interview J 2020). The agency also aids the contractor regarding utility replacements by providing excavation permits and utility blueprints.[22]

Some construction tenders require the contractor to partner with a credit granting institution and their credit offer is evaluated as part of their bid. The contractor doesn't owe or guarantee the money but, in those cases, arranges for the financing.

Landscaping design at the site of the cut and cover stations, station entrances and exits are within the scope of construction contracts. Sidewalks, signage, vegetation, water drainage are included but the designs are kept at minimum. Bridges, over and underpasses are built or renovated within the scopes of the contracts.[23] Contracts also include maintenance of the whole system for 2 years (or other predefined duration), including all elevators,

[20] 80%-20% ratio have been utilized in the tenders of: M5 Üsküdar-Ümraniye-Çekmeköy, M4 P2 Kartal Kaynarca, M7 Mecidiyeköy-Mahmutbey, M8 Dudullu-Bostancı, M5-P2-M13 Çekmeköy-Sancaktepe-Sultanbeyli and Sarıgazi (Hastane)-Taşdelen-Yenidoğan lines.

[21] Electromechanical systems include: power supply & traction power system, signaling, communication and control system, environmental control systems and supplementary station facilities.

[22] See Appendix C for more detail on utility replacement work in Istanbul projects.

[23] Most metro lines in Istanbul are 100% underground, with the exception of short sections and the at grade commuter line CR3, thus they don't require a lot of superstructures.

escalators, pumps, vents and other systems. The contractor procures the maintenance work from the suppliers and subcontractors.

The electromechanics systems of extension projects are usually purchased from the same provider that installed the systems of the initial phase and hence are expected to be a little costlier. However, in some instances as was the case for M2, the agency may choose to go with a completely new system, requiring for the first section to be re-wired. In M2, the initial phase was built by Alstom, but because the agency found their offer for the second phase overpriced, the agency decided to switch the whole system to Siemens.

Agencies building rapid rail in Istanbul specify very short timelines for projects when compared to average durations of construction globally,[24] but multiply the number of TBMs required in the contracts, specifying schedules for mining different sections of lines simultaneously. Despite the implementation of these work programs, such timelines play out to be unrealistic and the contractors almost always negotiate for time extensions.

2.4 Average Cost Breakdowns

In this section, we summarize cost information from 17 rail projects in Istanbul between 2012-2018 (Figure 10). We examined government presentations, public procurement results, feasibility studies and trade news. A majority of this information is based on early estimates that are likely to change over the course of construction of a project and interviews with multiple engineers and project managers working in Istanbul, who are comfortable making estimates for projects based on a few inputs like length of a line and tunnel percentage. We also provide a walk through of a cost estimator's process of estimating the costs of a project in Istanbul. It is important to note that these estimates do not account for ground conditions, archeology and financial difficulties hindering timely payments which also change the real costs and their breakdowns.

Excluding rolling stock, the majority of a project's budget is spent on construction; and since agencies in Turkey prefer contracting infrastructure projects in a single package rather than breaking them up into several contracts, this 65-70% of the budget goes directly to the contractor. Soft costs, the majority of which are the financing charges, but also include the preliminary design, construction management and the preconstruction costs that are expenses related to obtaining the environmental assessment report, make up an average of 25-30% of the total budget. Utility replacements, remedial work, and mitigation costs are usually less than 5%.

[24] The average timeline specified in the contracts of seven recent rapid rail lines with an average of 14.85 kilometers in length is 1063 days, which means that one kilometer of rail is expected to be completed in 2.5 months. The actual duration of completion for one kilometer of rail line in Istanbul is 7 months on average.

When we look at the general breakdown of the contractor's expenses for Istanbul rapid rail lines, we see 65 to 75% is spent on the direct costs (Table 1), which comprise all labor, material and equipment utilized in the construction. 3 to 5% is allocated to professional services such as the design and construction documentation; 5% to setting up and maintaining the construction sites; 2% to contract fees, insurance and securities; 1 to 2% to the head office costs; up to 7% to contingencies and the remaining 5 to 15% to profit.

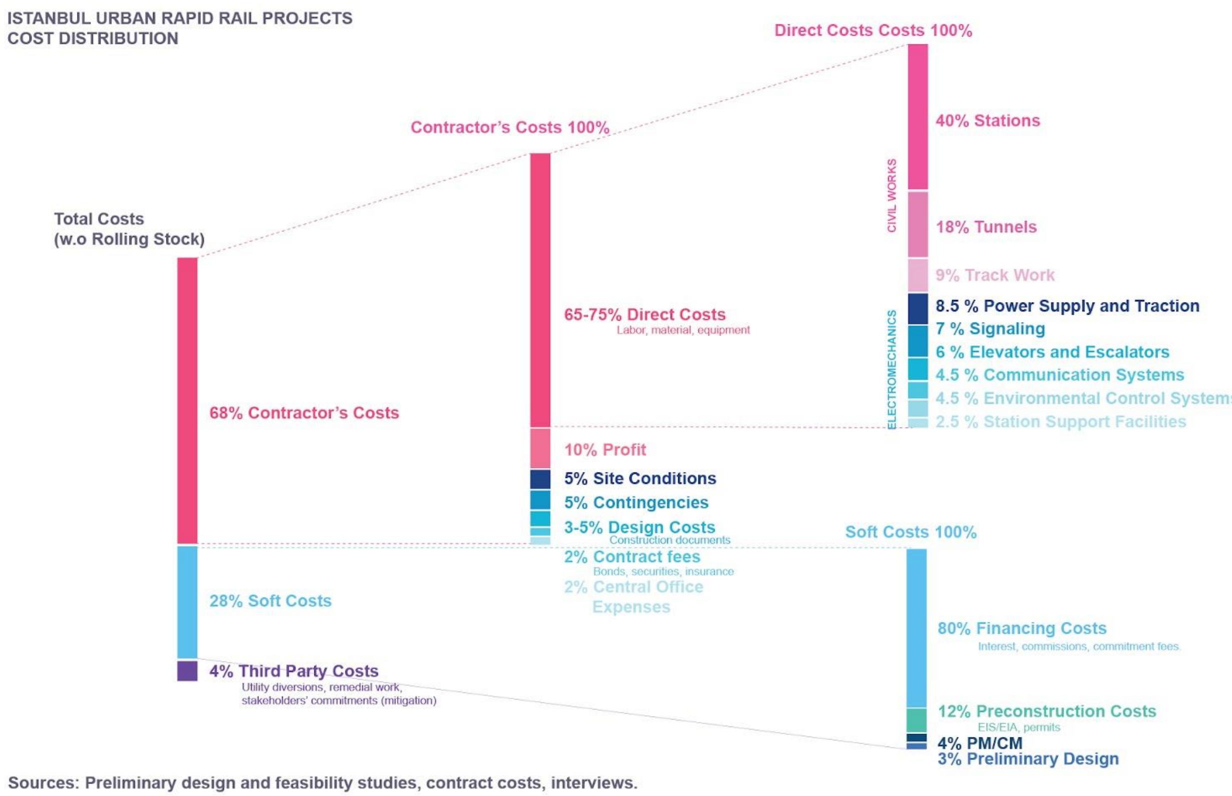

figure 10. Breakdown of average capital costs of a heavy rail line in Istanbul.

The most striking difference between the overall cost breakdowns of Istanbul rapid rail lines with those of an estimate recently made for the US subway projects, is the professional services costs constituting 15 to 20% or less, and the utility relocations, 5% or less within the overall budget in Istanbul. Instead, the construction costs make up 65 to 75%, which is 10 to 20% higher than in the US projects (Table 2). Within the direct costs, the US spends double to 2.5 times the proportion of the construction budget on labor, less than half the percentage on the permanent material, and 10-12% less of the budget on the equipment (Table 3).

Table 1. Turkey construction cost breakdowns.

Contractor's Fee: Total of construction and electromechanics contract values	Percentage within the total (based on Personal Interview B 2020, and consultation with colleagues)
Direct construction costs (labor, material, equipment)	65-75%
Design, construction documents etc.	3-5%
Contract, financing, securities, bonds	2%
Site spending	5%
Central office costs	1-2%
Contingencies	0-7%
Profit	5-15%

Table 2. US vs Turkey construction cost breakdowns. US values from "Why Tunnels in The US Cost Much More Than Anywhere Else in The World" (Tunnel Business 2020).

Overall Project Costs Breakdown	US	Istanbul (based on Personal Interview B 2020, and consultation with colleagues)
Soft costs (includes owner's costs, preconstruction costs including EIS/EA, feasibility studies, program management consultant, design consultant, construction management, right of way easement, permits, insurance, finance, bonding, etc.)	35%	25-35%
Third party costs (includes utility diversions, remedial work, and stakeholders' commitments)	10%	Up to 5%
Construction costs (excludes the rolling stock but includes the installation of all related systems and the commissioning.)	55%	65-75%

Table 3. Cost distribution of labor, material, equipment in Turkey vs the US. (Tunnel Business 2020).		
Breakdown of the Construction Costs	**US**	**TURKEY** (based on interviews)
Labor	40% to 50%	20%
Permanent material	15% to 18%	40%
Construction material, temporary works, consumables, etc.	10% to 12%	10%
Contractor construction equipment, TBM, etc.	18% to 20%	30%

According to a contractor's design director with experience working on urban rapid rail projects in Istanbul, the costs of a 10–12-kilometer twin bored tunnel project can be estimated as in Table 4 (Personal Interview G 2020). These costs include 10%-15% contractor's profit and contingency, 10% indirect costs which account for 2-3% design and 7-8% overheads, without issues regarding surface structures and with easy ground conditions. All values have been PPP adjusted for 2020.

Table 4. Turkey construction cost breakdowns.	
Work	**PPP $**
Tunnels and stations	$1,800-$2,070 million
Track	$70-$90 million
Power and traction	$145-$165 million
Signaling	$70-$90 million
CCTV, SCADA, ECS (communications, control, environmental control systems, support facilities)	$215-$250 million
Total	**$2,300-$2,665 million**
For the above estimate	
Number of stations	6-12
Tunnel cost per kilometer, including tracks and finishings	$18-$45 million
Per station cost with finishings	$120-$290 million

- $150-$200 million/kilometer can be estimated for tunnels + stations: deep, tube or cut and cover. If constructed closer to the surface, the price can go up 30-100%. A regular TBM tunnel of 6-meter diameter costs approximately $30 million PPP per kilometer. If tunnels are close to the surface as was in Marmaray, an additional 10-20% will be spent on mitigation for noise and vibration. The threshold is about 2x the tunnel radius below the basement level of buildings, so if the tunnel is twice its radius below the basement level, these costs will be minimal. The cost of an NATM tunnel of similar radius can go as low as 60% of a TBM tunnel, however, if the ground conditions are challenging, it can go up to 150% of the TBM costs. This is true even if the ground is hard rock that can be blast drilled, despite the excavation reinforcement requirements being less, since the permitted work hours and mitigation increases the costs.
- A cut-and-cover structure that is 30 meters deep is exponentially more expensive than a 15 meter deep cut and cover one. This is due to a change in the reinforcement design required.
- Signaling costs should be about $7-9 million PPP/kilometer for lines under 15 kilometers, unless it is a very complicated line. Change is rare in electromechanics costs across projects. The cost differences between projects are mostly due to the tunnel and civil works.
- Depot and maintenance areas cost roughly between one to two times that of one station's costs, depending on their size.

In Istanbul, even though project cost estimates are made by adding a 25% profit on top of the total costs, according to multiple sources, contractors give up a large part of this amount to be able to compete in tenders, and end up bidding with approximately a 3%-5% profit margin, that can go as low as 2% (Personal Interview P 2021). For the same reason, a minimum proportion of the budgets are allocated to contingency and risk management. As the majority of risk is on the contractor, this minimal profit margin strains the contractors more than it would in cities of other countries such as Germany where the larger proportion of the risk is taken on by the owner agencies.

2.5 Professional Services, Staffing, Labor, Equipment and Material

The budget breakdowns of rail projects differ significantly between Istanbul and the US. More importantly, the overall costs are much lower in Istanbul and that is because professional services, labor and equipment cost remarkably less. Material and consumable prices do not show significant differences across most countries, but the speed and duration of construction inevitably influence their dent in the project budgets. Here we give an overview of costs for each of these components in the Istanbul rail projects and comparisons with the US and other countries to provide a context for the case studies we present in the next section.

Professional services costs in Turkey are low due to small teams and low wages. White collar jobs are more than twice as expensive in the US as in Turkey (Personal Interview I 2020); a junior engineer in Turkey is paid a net amount of $2,000 to $2,500 PPP a month, whereas in the US, this number is closer to $5,500 (WPI 2020). The case is similar when Turkish white-collar wages are compared to those of Canada and a number of European countries. Below are the average costs for the most commonly outsourced professional services in metro construction in Turkey.

- The initially procured preliminary design contract which sometimes includes a feasibility study, on average, costs $26 million PPP or 1.2% of the total of construction and design costs. (Based on 5 projects).
- The average fee the contractor pays their own designer is $20 million PPP or 0.9% of the total costs (Based on 5 projects).
- The CM contracts cost, on average, is $49 million PPP or 2.3% of the total costs (Based on 14 projects).

Typically, professional service teams of Istanbul metro projects have the following staff numbers. A practice that keeps the teams smaller, is that the professional services and construction staff perform a variety of different tasks as part of their jobs, rather than being dedicated to a single task that is specified in their contracts. For example, it is possible to hire the same person as the head of technical office and the deputy project manager.

- Contractor's designer's team has 4-5 supervisors on the construction site, full time. 1 project manager and 7-8 team leaders work full time from the beginning to the end of the project. In addition to that, there are 15-20 people who jump on and off so in total, about 30 people are involved from the designer team's office throughout the construction, approximately 15 full time staff being dedicated to the project.
- The CM has about 10-12 people full time on the project and about 50 working on it on and off.
- On the agency side, 10-15 people work on one project full time.
- The contractor firm assigns 150-200 people for each project, excluding the laborers. 30 to 40 of these are management staff at the central office and 100-150 on the site all of which are white collar workers that are the full-time employees of the contractor. Additionally, 10-15 service staff are allocated on the construction sites. The construction workers and the rest of the service staff are employees of the subcontractors (Personal Interview M 2021).

One of the key factors that keep construction costs low in Istanbul is the low labor costs in Turkey. Tunneling staff are the highest paid workers in rail construction, and in the States or countries where labor costs are high, tunneling staff wages, benefits and fees can account for a considerable percentage of the construction costs. The size and efficiency of the teams are also influential. One way Turkey cuts down on labor costs is that skilled laborers perform a variety of different tasks on the construction site on top of the specific jobs they are hired to complete. The national social security system standardizes health benefits for all workers and costs an additional 30-35% of the net wages to the employer. 90% of workers are accommodated on the site in temporary structures. In total, accommodation, food and insurance add 40% to the wages as contractor's labor expenses.

The main reason for the low labor costs of Istanbul projects are the wages. If we compare the wages of tunnel workers in Istanbul and New York, a city that is known to have high labor costs and influential labor unions, the differences are astounding. In January 2021, Istanbul tunnel workers earned $100-$125 PPP per day working 12-hour shifts and had a gross compensation of $140 to $175 PPP when including social security and taxes bringing their hourly gross compensation to a range between $11.6-$14.6 PPP. In New York, in 2010, tunnel workers earned on average $350 per day, working 8-hour shifts and had a gross compensation of $700 dollars when including additional benefits (Personal Correspondence A 2021). So, their hourly gross compensation came to $87.5 exclusive of overtime. What is interesting is, the 6.7-fold difference is not parallel to the difference between wages in general. The minimum hourly wage in New York is slightly higher than twice the minimum hourly wage in Turkey and the minimum monthly wage, only 60% higher than in Turkey (Table 5).

Table 5. Turkey Minimum Wages

2021	Turkey (₺)	Turkey (PPP $)	US ($)
Monthly gross minimum wage	3,578	1,653	2,640
Daily gross minimum wage	120	55	120

Below we provide wages and costs of tunnel workers calculated based on four recent rapid rail projects in Istanbul and for two TBMs working simultaneously on site (Table 6). This team saves on staff and equipment through coordinating resources between the two TBMs.[25] Working in two twelve hour shifts per day, a total of 81 TBM personnel and 92 surface crew members are employed to run two TBMs simultaneously. The total cost of this team, including wages and benefits add up to $493,000 PPP per month.

[25] See Appendix B for a detailed list of wages for the TBM staff in Istanbul and New York.

Table 6. Summary of monthly wages of workers in a 2 TBM rail construction team in Istanbul

Summary Table	2 TBMs Tunnel Crew (total for 2x12 hour shifts, $)	2 TBMs Surface Crew (total for 2x12 hour shifts, $)	2 TBMs Tunnel and Surface TBM Crew Total (total for 2x12 hour shifts, $)	2 TBMs Tunnel and Surface TBM Crew Total (total for 2x12 hour shifts, PPP $)
Crew Size	81	92	173	173
Total Monthly Costs (wages *1.4: includes insurance, accommodation, food)	$75,460	$74,760	$149,380	**$492,954**

For comparison, a New York team working with a single TBM employs a total of 60 TBM workers, 78 support crew members and 44 management staff who split work in three shifts of 8 hours (Table 7). The labor costs of this team including wages, benefits and union fees total $593,000 per month. This number is higher than the monthly operating costs of a two-TBM operation in Istanbul with each TBM being expected to mine at a speed of up to 24 meters per day. In the construction of New York's Second Avenue Subway's first phase, the average speed was 12-15 meters per day. Based on these numbers, a conservative estimate says that Istanbul could build almost 18 times the length of TBM-mined tunnels that New York builds, with the money New York spends in a month:

$593,000 x 4.3 = $2,550,000 (NY team monthly cost)

13.5 meters x 22 (work days a month) = 297 meters/month (NY team mining speed)

$493,000 (Istanbul team monthly cost)

20 meters x 2 TBMs x 6 days x 4.3 weeks = 1,028 meters/month (Istanbul team mining speed)

($2,550,000/$493,000) x 1028 = 5,317 meters/month (Istanbul can build with NY money)

5,317/297 = 17.9 times (Istanbul builds 17.9 times as NY with the same money spent per month.)

Table 7. Summary of weekly wages of workers in a single TBM rail construction team in New York

Summary Table	1 TBM Tunnel Crew (total for 3x8 hour shifts, $)	1 TBM Support Gang (total for 3x8 hour shifts, $)	1 TBM Management Staff (total for 3x8 hour shifts, $)	1 TBM Tunnel and Surface TBM Crew Total (total for 3x8 hour shifts, $)
Crew Size	60	78	44	182
Total Weekly Costs	$221,000	$270,000	$102,000	**$593,000**

On the down side, labor conditions in Turkey, in general, are inferior when compared to those in the Western world. Most teams work 8-hour shifts and TBM teams operate 2x12 hour shifts which is comparable to the shifts in Europe, but workers only take one day off every 14 days, staggering their off days in order not to slow down construction. In comparison, tunnel workers in New York are not allowed to work more than eight hours a day, unless they work 10 hours x 4 days a week (State of New York Department of Labor [SNYDL] n.d.).

According to a contractor's engineer who has worked with French teams in Africa, the French and Turkish laborers, even when working on the same project, work under significantly different conditions. The French are hired by contracts that cover their travel expenses on top of insurance and accommodation (Personal Interview N 2021), cannot work more than six days in a row and 39 hours/week, they are paid 25% more than the base rate until the 43rd hour and 50% more after 44 hours, and can have extra days off in compensation (Personal Correspondence B 2021). The ratio of a Turkish laborer's versus a French laborer's monthly cost to the contractor, including food, benefits and accommodation is 11 to 18 (Personal Interview N 2021). Also, Turkish workers are rarely compensated for overtime (Personal Interview O 2021).

Tunnel excavations with a TBM costs $11-$12 million PPP/kilometer (Table 8) to the contractor, for which they will most likely bid for $13.5 to $15 million PPP/kilometer. The contractor's tunneling costs for a twin bore line with 7-kilometer tunnels (in total 14,000 meters) are presented in Table 8.

Table 8. TBM tunneling costs from two Istanbul metro projects in 2020

	Per Meter Cost (PPP $)	Depreciated Costs (due to equipment share with another project)
2 TBMs	$1,970	$1,280
Machinery Equipment (cranes, conveyor belts, concrete and welding stations)	$1,075	$690
TBM consumption (fuel, oil etc.)	$1,180	
TBM Staff	$1,130	
Concrete Segments	$3,735	
Grout	$195	
Customs and Delivery	$570	
Electrical Equipment	$60	$12
Power	$2,100	
TOTAL	**$12,015**	**$10,892**

Including contingency costs, shipping one cubic meter of excavated earth to a dumping ground costs $15 PPP. Based on the costs for four lines recently constructed, an average of 40.5 cubic meters of earth is excavated per meter length of TBM tunneling, the costs of which come to $600,000 PPP per kilometer of tunnel.

Turkey produces good quality cement for a low cost; January 2021 cost is $160 PPP per ton (Table 9). The cost of steel in Turkey is similar to other countries but these rates vary very little globally (Personal Interviews I and J 2020).

Unlike costs of labor and material, energy prices in Turkey are high. Electricity costs $0.5 PPP per kilowatt which is 40% more expensive than in Italy and almost 9 times more expensive than in the US. Diesel fuel, which is used for earth moving trucks, is also costly in Turkey. It is $3.08 PPP/liter, and gas (fuel) costs (as of November, 2020) $3 PPP/liter whereas it costs $0.6 PPP/liter in the US.

In Turkey, social security, income taxes, VAT and customs taxes do not constitute a serious burden on the contractor that results in a premium for project costs. The corporate taxes are 22.5%, and the VAT is 18%. For comparison, the corporate taxes in the US are 35%.

Table 9. Cement costs by country

	Cost per ton	Currency	Year	PPP	Real Cost (PPP $)	Source
Turkey	320	TRY	2020	0.5	160	Contractor's cost sheet
China	443	CNY	2021	0.24	106	(Sunsirs n.d.)
Korea	75,000	KRW	2019	0.001	75	(Tamotia 2019)
India	6307	INR	2019	0.047	296	(Directorate of Economics and Statistics Government of Andhra Pradesh [DESGAP] 2019)
Italy	108	EUR	2020	1.3	140	(Colacem 2016)
Spain	101	EUR	2020	1.6	161.6	(El Instituto Nacional de Estadística n.d.)
Sweden	800	SEK	2010	0.1	80	(Fagerlund 2011)
UK	124.8	GDP	2019	1.5	192.6	(Department for Business, Energy and Industrial Strategy (UK) [DBEIS] 2020)
USA	128	USD	2021	1	128	(IBISWorld n.d.)

2.6 Cost Overruns

The price of a project can increase based on the changes throughout its construction. This increase, however, is limited to 20% of the contract value by Turkish procurement law, otherwise it is required to be approved by the cabinet of ministers.[26] This is a lengthy process, therefore to avoid it, if a project is estimated not to be completed within the contract budget, or if the contractor foresees losing money, it finishes what it can submitting change orders totalling no more than 20% and terminates the contract in mutual understanding with the agency.[27] This usually happens gradually with the agency tracking costs through progress payments. Change orders are quickly assessed and approved because all contracts are based on itemized costs. Following the decision to terminate the initial contract, the agency opens a new completion tender. In some cases, as in the case for M4, subcontractors are rehired by the new contractor when a new company or consortium is awarded the completion tender.

In 2016, Turkey started mandating contracts and all business transactions to be carried out in the Turkish currency, TRY. This is counterproductive, because Turkey imports a significant amount of the material and equipment which make up 70-80% of the project construction costs, so the changes in exchange rates increase the costs drastically

[26] The 20% limit started to be applied in 2008 and excludes price adjustments based on inflation and the costs of CM consultants who charge based on man hours even after their initial contract value is overrun.

[27] There are examples of the ministers' granting approval for change orders exceeding 20%. For M2's 4. Levent - Darüşşafaka section, a 31% increase was approved in 2012.

in the Turkish currency. State issued yearly inflation rates remain below the currency exchange rate increases, therefore the price adjustments the contractors are permitted to make based on these yearly inflation rates do not cover the increased costs of material and equipment.[28] This is why there is almost always a 20% change order – even though contracts specify that the exchange rates cannot be shown as a reason for change orders.

Due to recent rapid devaluations of the Turkish Lira, it is difficult for a contractor to profit from a contract based in the currency and, according to a senior engineer with international and local experience in the field, the only reason contractors undertake projects in these conditions is to gain political favor (Personal Interview I 2020). Once a contractor completes a government owned project, it is likely to establish a positive relationship and get other, more profitable jobs in the future. But if a contractor's losses exceed 15% of the contract value due to inflation or currency exchange rate increases, because this percentage already exceeds the profit + contingency margin, the contractor will likely request the termination of the contract, finish the portion of the work they can within the budget and the 20% increase, and the remaining work will be re-tendered.

[28] Most of the recently built Istanbul metros are system-integration level 4, fully unattended (driverless) systems which are procured from foreign firms like Alstom (formerly Bombardier), Thales and Siemens. This means the increases in Dollar or Euro exchange rates have a great impact on the contractor's costs. Price adjustments allowed by the contracts used to pay for currency exchange rate increases before, but were unable to since 2018 as the Turkish Lira lost over 50% of its value against the dollar.

3 Cases

Through three case studies, we have explored existing practices and lessons learned by the Istanbul Metropolitan Municipality and the Turkish Ministry of Transportation and Infrastructure over 3.5 decades of building urban rapid rail in the city.

We selected the M4 Kadıköy-Kartal line to highlight how early projects in Istanbul struggled. M4 suffered from a chaotic preliminary design process conducted by an IMM that lacked internal capacity and experience. Major project scope revisions after the start of construction led to significant budget increases. Presenting the IMM with these challenges, the project laid the groundwork for better optimized planning phases and design outcomes in future projects.

BC1, the Bosphorus Crossing section of the 76-kilometer Marmaray commuter line, was chosen as a project with extraordinary risks which unlike other rail projects in Istanbul, was carried out with a contract based on the FIDIC Silver Book, built by an international consortium and completed after significant delays and cost overruns.[29] With capital costs only slightly higher than the average cost per kilometer among the 600+ projects in our database, Marmaray exemplifies a learning process within the lifetime of a project that steadily improved the productivity and collaboration between the multiple stakeholders involved.

M9 is a more recent line with lower rider capacity than M4 and BC1, but is considered better optimized in terms of design and construction by experts in the field, while falling within the cheapest 10% of rail projects in our database. By the time IMM started working on the line, it was armed with experience from decades of rail

[29] FIDIC (the International Federation of Consulting Engineers) Silver Book used for the Marmaray project is a template for a lump sum, turnkey, Engineering, Procurement and Construction contract which transfers the majority of the responsibility and risk onto the contractor.

construction and had streamlined its planning, procurement and management processes. IMM also benefited from the advantage of working within an efficient ecosystem of industry experts in the city.

Some overarching themes we explore within these three cases are, the improvement of the internal organization and know-how in the agencies, evolution of the procurement methods, optimization of the final designs, cultivation of the rail construction industry in the city, flexibility during the stages of construction as well as the use of technology in design, management and construction.

3.1 M4, an Early Example

Overview

M4 is a fully underground, double track urban rapid rail line on the Asian side of Istanbul, with Kadıköy as the western terminus, a residential and commercial district along the southern coast of the city that provides important transit connections to the European side via ferries, the Eurasia tunnel and an interchange station with the Marmaray commuter line (Figure 11). Once the line reaches Acıbadem, it follows the D100 (E5) highway and was planned to reduce the heavy motor vehicle traffic load of this busy transit route.[30] As part of its fourth phase of construction, the line is currently being extended to the Sabiha Gökçen Airport which is a hub for domestic flights on the east side of the city. Our study focuses on the first phase terminating at Kartal and includes 16 stations in the span of 21.7 kilometers. With 180m long platforms, the maximum capacity of the system was planned as 70,000 passengers per hour per direction.

We studied M4 to understand the planning and management processes during the early years of rapid rail construction in Istanbul. Additionally, M4 is unique in that it saw extensive changes to its project scope, normally a red flag. The agency and contractors, however, managed these changes and major technical challenges all while keeping the new budget below the 20% allowable cost increase limit following a second construction contract.

[30] See Ocak's 2006 paper for public and private motor vehicle passenger counts performed on the route in 2005.

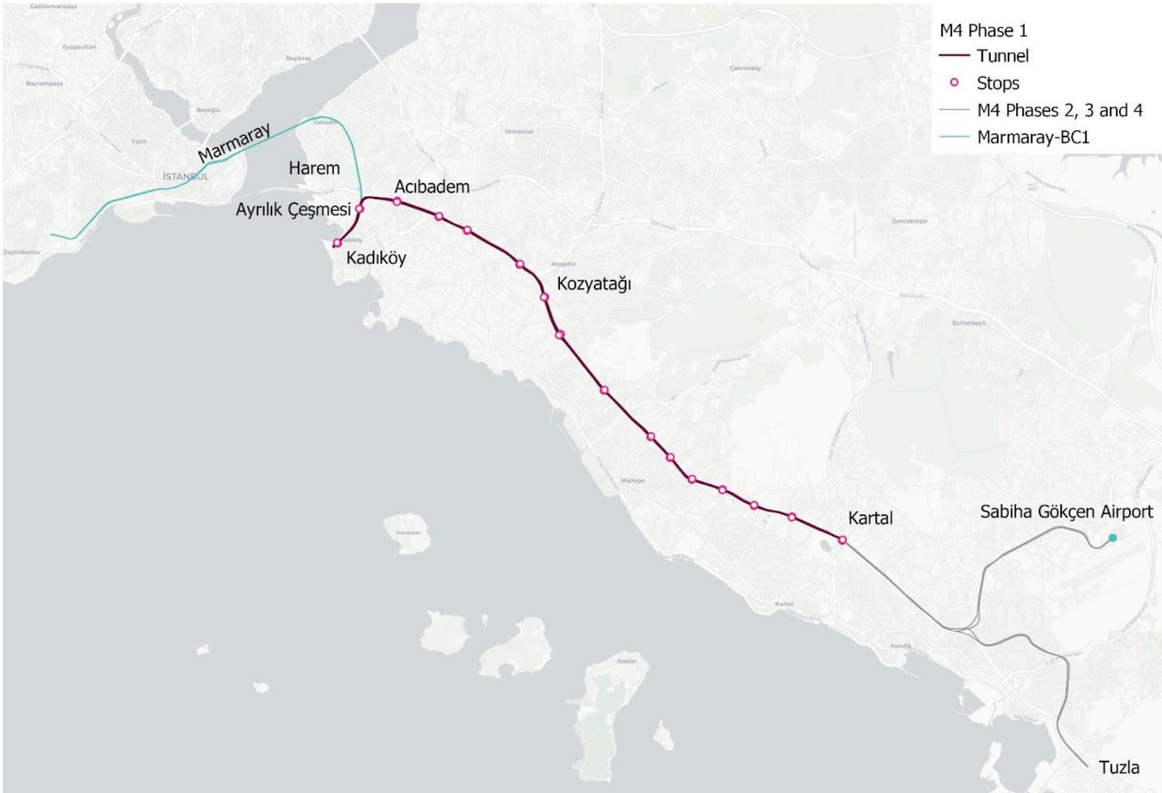

figure 11. M4 Phase 1, Kadıköy - Kartal Metro Line

The first of the key lessons from M4 is that, the role of the planning and design process preceding the construction tender is critical for equipping the agency with the necessary information to manage the project effectively throughout construction. Without a well-established preliminary design process that would allow the IMM in later projects to develop a thorough understanding of the design, produce a well specified construction tender package and keep contractors in check, M4 ended up with over-designed elements and a massive increase in its budget. We also saw that the later re-organization of the IMM through the establishment of the Rail System Projects Directorate, and the streamlining of the initial design process were pivotal in increasing the agency’s productivity in the many years of rail building to follow. Lastly, the flexibility and collaboration between the agency and contractor during construction, which for M4 facilitated the decision to drill and blast tunnels that were initially planned to be built by TBMs, are aspects that we would like to highlight as beneficial to Istanbul projects, as they speed up processes and consequently, reduce costs.

Timeline and Financing

M4 was initially conceived as a tram line during Erdoğan's term as mayor of Istanbul, between 1994 and 1998 (Table 10). A 22 kilometer right of way was planned which would run from Harem through Kadıköy, and follow the D100 (E5) highway all the way to Tuzla, a district in the southeast of Istanbul. The section between Acıbadem and Kartal was to be constructed at-grade in the highway's median. However, due to D100 being the only highway serving the international highways network in Istanbul until the TEM highway was built to relieve its traffic, D100's right of way belonged to the central government. In 2002, the General Directorate of Highways handed over the right of way to IMM, removing a key obstacle to building M4.

In 2004, Mayor Topbaş announced that the IMM had considered asking the Ministry of Transportation under the central government to run the project, but IMM changed its mind and decided to build it through a PPP in order to speed up the process, also mentioning that it was considering making it an elevated line (Türkiye Gazetesi 2004; Wowturkey n.d.). All major deviations from the initial conceptions regarding the line, no official plans were disclosed for any of these statements in the days to follow.

Plans changed again as M4's terminal was shifted from Harem to Kadıköy to integrate it with the Marmaray Commuter Rail line at Soğütlüçeşme. Following this decision, M4 was planned as a light rail with the Acıbadem-Kartal section at-grade, as was initially conceived, with 3.3 kilometers of bored and 2.5 kilometers of cut-and-cover tunnels from Kadıköy to Acıbadem (Ocak 2006). The tender was announced in December, 2004, and within one month, the contract was awarded to Yapı Merkezi-Doğuş-Yüksel-Yenigün-Belen İnşaat consortium (the "Anadoluray Group"), for $225 million PPP. Construction began in February 2005.

Construction projects move quickly in Istanbul. It's common for construction to begin within a couple of weeks to three months after awarding the contract, even as the contractor's design process is underway.[31] This overlapping process of design and construction can lead to missteps that require revisions during construction. During the construction of M5, the contractor had already bored the piles for one of the stations when the agency decided that the station needed to be one story smaller, so the station was built with deeper piles than necessary (Personal Interview G 2020). In the case of M4, the nature and number of changes that followed the start of construction were drastic.

[31] The contractor also orders TBMs soon after they sign the contract. A TBM is ready to be shipped in a minimum of 10 months, it is delivered in a month and tested on site for another, hence the contractor has at least 12 months to start TBM tunneling after they are awarded the construction contract. This is enough time to complete a station box that can double as a launch box for the TBM(s), and to start drilling the tunnels.

Table 10. M4 Timeline (Metro İstanbul n.d.). Contract values retrieved from various media

Date	Item
1994-1998	An early study of the route is carried out during the office of Mayor Erdoğan. The central government owning the right of way of the central traffic island between Acıbadem and Kartal poses a problem for the at-grade section to be constructed by the IMM.
2002	Protocol signed between IMM and the General Directorate of Highways handing over the central traffic island between Acıbadem and Kartal to IMM.
01-Apr-04	Kadir Topbaş becomes Mayor.
30-Dec-04	First tender with a scope of 5.6 kilometers underground and 16 kilometers at grade light-rail line.
28-Jan-05	Contract signed with Yapı Merkezi-Doğuş-Yüksel-Yenigün-Belen İnşaat consortium for $225 million PPP.
11-Feb-05	Construction works start.
14-Jan-08	Tender for the completion of Kadıköy-Kozyatağı section, the construction of Kozyatağı-Kartal section both fully underground and electromechanical works of the whole metro line. 3 offers received. Best offer by Astaldi–Makyol–Gülermak ($1.6 billion PPP).
06-Mar-08	New contract signed with Astaldi–Makyol–Gülermak. Deadline: 1460 days (4 years).
21-Mar-08	New contractor starts construction.
05-May-08	Tender for rolling stock of metro line. 30 sets, each with 4 cars, 120 cars in total. Delivery in 1200 days.
30-Jun-08	Agreement for the funding of the 1.6 billion PPP construction fee was finalized between the IMM and a group of local and international financial institutions led by Fortis, SACE, and WestLB.
14-Jul-09	2 offers to rolling stock tender, CAF and Alstom. Best offer by CAF ($330 million PPP).
09-Sep-09	CAF is awarded the rolling stock contract.
Mar-12	Signaling is completed on the line.
06-Apr-12	Total number of cars increased by 20%, reaching 144 in total.
08-May-12	Test runs start.
17-Aug-12	Service starts (the second construction contract was closed at $1.9 billion PPP, with a 20% increase).
31-Aug-12	The delivery of all 36 train sets completed.

After M4's construction began, the owner agency Istanbul Electric Tramway and Tunnel Establishments (İETT), made a decision to upgrade the line to a fully underground, heavy-rail line. IETT believed that managing D100's traffic during construction, an international freeway at the time, would cause congestion, create conflicts with local residents, and delay construction, and lead to major cost overruns. Once construction was completed, the planned LRT was slated to use one of the highway's travel lanes, which would reduce the road's vehicular capacity and exacerbate the already congested conditions. Additionally, a heavy-rail system which the travel demand analyses justified, would provide a capacity of 60,000 to 70,000 ppl/hr/direction, more than three times that of an LRT's 20,000 ppl/hr/direction (Ocak 2006).[32]

The scope of the first contract had involved a 21.6-kilometer LRT line with 16 kilometers of its length at grade, while the new plan was to build a fully underground, line with heavy-rail capacity. This enormous scope change meant that a considerable increase in the budget was inevitable. A law that had gone into effect in 2003 required that any cost overrun for public projects greater than 20% of the contract value would have to be approved by the central government. While the budget for the new project would far exceed the 20% limit, the central government's approval process was feared to be burdensome and lengthy. Instead, it was decided to keep the initial contractor doing part of the work while opening a new tender to complete the sections of the construction that would remain.

The initial contractor, Anadoluray Group re-submitted an estimate of $288 million PPP and redefined their scope; it would only cover the nine kilometers section of the tunnels from Kadıköy to Kozyatağı and the civil works for seven deep-tunnel stations. The work was completed slightly under budget in 2010. In the meantime, the new tender carried out in January 2008 for the remaining works was won by Astaldi–Makyol–Gülermak (the "Avrasya Consult"), for $1.6 billion PPP, in March.[33] The tunnels were completed in October 2011, the signaling system installation in March 2012, test runs were carried out in May 2012, and the line started service in August 2012. The second contractor completed their work with a cost increase that was just under the permitted 20%.

The IMM secured the funds to finance M4's second construction contract of 1.6 billion PPP through a funding package agreement finalized in June 2008. Led by the international financial institution Fortis, the Italian Export Agency SACE and the German Bank WestLB, the group of funders included Calyon, Dexia/Deniz Bank, Vakıfbank, Depfa Bank, ABN AMRO, Societe Generale, Unicredit Corporate Banking, Black Sea Trade and Development Bank, Mcc- Mediocredito Centrale (Globe Newswire 2008). $1.1 billion PPP of the sum was provided in the form of commercial credits (international loans) to be paid back with a 2.2 + Euribor interest rate in seven years after a

[32] Istanbul Technical University's Department of Transport Engineering was commissioned to carry out an analysis with results supporting the decision in April 2005 and later the Transportation Coordination Center (UKOME) was notified and issued their approval in June. UKOME is a municipal agency responsible for the coordination between the metropolitan municipality, national and local public institution's transportation departments and the district administrations under the city.

[33] Even though we were not able to uncover any details regarding the approval process of the new contract's budget that was almost 9 times that of the original one, Istanbul's mayor being a member of AKP, the ruling party of the central government, was likely an easing factor.

three-year grace period. The $490 million PPP was loaned as export credits (local) and would be paid back in 10 years following a grace period of four years (Arkitera 2008).[34]

The indecisions in the planning and management persisted until the second construction contract was signed in 2008, and extended the duration of the project by three years. The following four-year timeframe within which a majority of the construction was completed was a very fast-paced construction process.

Scope and Contracts

The two contracts involved the construction of a fully underground, 21.7-kilometer line from Kadıköy to Kartal with 16 stations, each having cut and cover mezzanines and tunneled platforms, as well as an underground maintenance and storage yard. A third tender was opened for the completion of the Ayrılıkçeşmesi station, part of which had been built within the scope of the connecting line, Marmaray's construction. The total cost of the line ended up $2.2 billion PPP or $102 million PPP/kilometer. Tables 11 and 12 show the details of the scope and contracts.

Table 11. M4 Scope. (İBB n.d.; Uysal 2016; Railway Gazette 2012; Rail Turkey En 2012; Indian Railway Stations Development Corporation Limited [IRSDC] N.D).

ELEMENT	SCOPE	FEATURES
Guideway	• M4 new rapid transit line	• Single line • Completely underground system
Track	• 21.7 kilometers double track + additional tracks for depot and maintenance area connections	• 54 kilo/meter UIC 54 (54E1) • 1,435 mm gauge • Switches: 42 main line, 12 depot and workshop, 3 rail crossings Switch Type: R: 300 m 1 / 9 type (Main line), R: 100 m 1 / 6 type (Workshop and Warehouse) • Gradient: 4% • Lucchini and Voestalpine rails • Pandol fastenings • ABB switchgear and transformers

[34] The EURIBOR value that was used in the financing fee estimates of more recent lines are 0.6, allowing for a 3.2% yearly interest rate. At the time of Kadıköy-Kartal's contract, EURIBOR values averaged around 4.4, taking up the interest rates to 6.6, more than double of what we calculate for more recent loans. This may be the reason for the more recent loans having longer payback periods such as 30 years; the lower interest rates make it feasible to extend the repayment schedules.

New Stations	• Kadıköy • Ayrılık Çeşmesi • Acıbadem (100% Deep tunnel) • Ünalan • Göztepe • Yenisahra • Kozyatağı • Bostancı • Küçükyalı • Maltepe • Huzurevi • Gülsuyu • Esenkent • Hastane-Adliye • Soğanlık • Kartal	• 16 new underground stations • All platforms are 180 meter long, for 8 car operation and built with side platforms. • Bostanci Station: Additional track with 2 side platforms • Maltepe Station: Depot and maintenance area constructed as two parallel tunnel structures. • Esenkent Station: Main control center • Total entrances: 52 • 264 escalators • 70 elevators • 315 turnstiles (29 wheelchair accessible) • A minimum of 90,000 cubic meter excavation was done for each station
Tunnels	• 21.7 kilometers main line twin tunnels and station tunnels constructed using TBM and NATM techniques	• 6.30-meter diameter, and 5.70-meter inner diameter (as in majority of lines in Istanbul). • Total Single Line Tunnel Length: 43,326 m • 2 EPB-TBMs: Kadıköy - Kozyatağı • 2 TBMs: Kozyatağı - Kartal • NATM: Station tunnels (2 or 3 x 240-meter platform tunnels), connection and crossover caverns of 13 kilometers length. • Max. Depth: 40 meters (Bostancı ve Huzurevi Stations) • Min. Depth: 28 meters (Ayrılıkçeşme ve Hastane – Adliye Stations)
Systems	• Overhead Catenary • CCTV • Thales SelTrac® CBTC (Communications-Based Train Control) and ICS (Integrated Communication and Control systems).	• 1,500 V DC • 1,281 camera system • Moving block system signalization • Driverless operation
	• The main control center (OCC)	• Includes traffic and storage, SCADA and ECS, communication, and supervisor sessions.
Support Facilities	• Maintenance and depot	• Maltepe Station (between Maltepe and Huzurevi stations): Heavy maintenance area capacity: 2 sets of 4 cars Maintenance area capacity: 2 sets of 4 cars Depot area capacity: 9 sets of 4 cars Additional depot area capacity: 4 sets of 4 cars Total: Capacity for 17 sets of 4 cars.
Vehicles	• (36) x 4	• DC Supply (Battery): 110 V DC • Traction Motors: 4 pole AC motors • Train Length: 90 meters (trains run as single sets of 4 cars or in double sets of 8) • Vehicle Height: 3.5 m • Vehicle Width: 3 m

Table 12. M4 Contract Costs

Contractor	Scope	Cost	Year	PPP $	Total with Overruns
Yapı Merkezi-Doğuş-Yüksel-Yenigün-Belen İnşaat	Kadıköy-Kozyatağı tunnels and civil works for the 7 deep tunnel station structures.	$140 M	2005	$225 M	$288 M
Astaldi–Makyol–Gülermak	Kadıköy-Kartal construction and electromechanics tender.	€750 M	2008	$1.6 B	$1.9 B
Haydar Sezer	Ayrılık Çeşmesi Station completion tender (Kadıköy-Kartal phase).	₺19.5 M	2012	$19 M	
CAF	Rolling Stock (30 sets of 4 cars)	€138 M	2009	$330 M	
Total Construction	$ 2,2 B PPP				
Total Rolling Stock	$330 M PPP				

Planning, Design and Management Issues

The first phase of M4 encountered several setbacks early on in its timeline due to the lack of a well-developed preliminary design document. This had to do with the ongoing restructuring process of the managing authority of the rail projects in the city, and the nonexistence of a streamlined and established procurement process. The line went from an initial design of a light rail with the majority of its length at-grade, to a 100% underground heavy-rail project. Additional contractors were hired, the timeline almost doubled, and the budget increased by 900%. Moreover, both the stations and the tunnels were over-designed with larger technical spaces than those in later heavy-rail projects, built after the agency started procuring the final design documents from prominent design and engineering firms.

M4's phase one was completed before the Rail System Projects Directorate under IMM was established in 2014. The initial planning and construction works of the line were managed by the owner agency İETT, a department under IMM that was charged with running Istanbul's large bus network and building and maintaining trams and funicular lines.[35] By the time the decision was made to convert M4 to a fully underground heavy rail line, the Rail

[35] İETT is responsible for managing Istanbul's bus and BRT network today.

Systems Directorate under the Transportation Department of IMM had taken over the project, which later in 2012, would be reorganized as a separate department under the IMM. Only in 2014 would the department dedicate a team to the preliminary planning and management of the procurement processes for the rail lines, structured as the Rail Systems *Projects* Directorate.

Without a dedicated team conducting M4's early planning, a detailed final design document was not available to the agency when preparing for either of the construction tenders.[36] Avrasya Consult, which was awarded the second contract after the major scope revision, hired experienced design firms to design the stations, the local Prota, and the tunnels, the Italian Geodata. However, without a binding final design through which the agency would oversee the contractor's design decisions, M4's stations ended up with a generous allocation of spaces and tunnels that were over-reinforced, inevitably increasing material and labor costs. Once established, the Rail System Projects Directorate would start procuring preliminary design documents at 60% design from professional design offices through tenders. Referred to as "final project for application", these documents have informed feasibility studies and afforded the agency better control over projects to this day (Personal Interviews A, C, D 2020 and Y 2021).

Station design was a major cost driver in M4's Kadıköy-Kartal phase. When we compare M4 with more recent lines, we can see how stations have been optimized through the size and configurations of mechanical spaces. In M4, the fan rooms and the additional mechanical spaces organized around them are located in cut and cover structures above the platform levels. Starting with M5 Üsküdar-Çekmeköy's stations, the fan rooms were located in between the platform tubes at the platform level within shorter NATM tunnels. In M5, this configuration applied to 11 stations saved $14,2 million PPP on construction and $72 million PPP in land acquisition costs, as well as an estimated year of going through the more onerous land acquisition processes that would have been required for the larger cut-and-cover structures (Namlı 2017). The fan rooms, generally constituting the largest technical spaces in station structures, were as big as 200 to 240 square meters in M4, whereas they shrunk down to 80 to 140 square meters in the newer projects. Moreover, we see bespoke designs for each station in M4, rather than the almost identical configuration of these spaces in more recent stations. Such an established, repeating design implies a faster design process, which presumably saves additional time and money.

Rapid rail designs have evolved over time to have more generic stations and better customized tunnels in Istanbul. However, İstanbul has not approached the level of optimization achieved in Copenhagen and German cities that

[36] A national law passed in 2003 already required the procurement of a final design document before launching construction tenders for infrastructure projects, however, these documents were prepared by the public enterprise İstanbul Ulaşım A.Ş. (later renamed Metro İstanbul) until 2014 and used to be underdeveloped.

have opted for a performance-based design approach that allows them to reduce the number and capacity of ventilation fans, and scale down the associated mechanical spaces based on performance tests (Personal Interviews R and S 2021).[37] Turkey, similar to the US, follows a prescriptive process, where legislation and contract specifications determine the material, size and configuration requirements of spaces that will ensure safety in case of emergencies such as fire and earthquakes. What is more limiting and expensive, from a capital cost perspective, for Istanbul is that it has not managed to reduce station volumes by building shorter platforms, like Copenhagen, Milan, Turin, or Brescia. In these cities, by contrast, they maintain high passenger volumes in smaller stations by increasing service frequencies, such as trains every 90 seconds during the peak period. Istanbul, on the other hand, builds stations with long platforms to accommodate longer trains to meet growing travel demand. M4, like the rest of the lines Istanbul groups as Metro 1, has 180-meter-long platforms.[38] Hence station designs cannot be optimized to the extent that shorter platforms would allow.

Similarly with most subway stations in Istanbul, M4 stations can be considered bare-bones in terms of architectural features and finishing works. Architects who have worked on rail projects in Dubai and Warsaw point out the contrast between the embellishment and craftsmanship visible in rail stations in those cities with the blandness of Istanbul's (Personal Interviews P and X 2021). This is a conscious choice on the agencies' part, however; IMM and the Ministry of Transit prioritize building more lines, faster and more cheaply ahead of spending money on star architects or expensive art work like in New York and Naples. They utilize a standardized set of plain finishing materials in stations, and designate wall spaces for generic art.

Construction

The primary takeaway from M4's construction is that speed saves money. Due to the challenges in the initial planning and contracting phase which began in 2005, M4's construction progressed slowly until March 2008. Nevertheless, the 21.7-kilometer line was completed within the following four years, hence M4 has one of the fastest construction timelines in the history of urban rapid rail construction in Turkey (Figure 5). While certain forgiving working conditions contributed to speeding up construction, the key element that facilitated the rapid completion of the line was the mutual openness and adaptability to change exhibited by the IMM and the

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[37] A tunnel ventilation expert we interviewed explained that Copenhagen's City Ringen (M3) had minimalist, simplified stations in terms of aerodynamics, with fewer articulations and openings so that ventilation loads could be minimized. Openings of the station such as escalators and entrances would act as shortcuts for the air, weakening the suction required for ventilation, which would reduce the aerodynamic efficiency and require fan capacities to be increased (Personal Interview R 2021).

[38] Marmaray's platforms are 225 meters; M11's, 180 and M5's, 140. Metro 2 lines linking these higher capacity Metro 1 lines operate half the number of trains in traction and so have smaller platforms: M8 and M12 stations are 100m long; and M9, 90m.

contractors. By changing the alignment and modifying tunneling methods, the contractors had to reallocate labor, material, equipment and work schedules.

With construction already delayed due to major design modifications, the agency wanted to proceed as swiftly as possible after the second construction contract was finalized. Three key decisions made in collaboration with the contractor over the months to follow, saved the project a total of 11 months (Sabuncuoğlu 2011). First, in the time that the contractors were waiting for the TBMs to arrive from Germany, they started building the tunnels by drilling and blasting (or the NATM method). Second, they changed the construction schedule to employ the NATM method more extensively, including in segments that were initially planned to be built by TBMs, even after the TBMs arrived (Table 13). Third, they utilized as many as 13 shafts and excavated at up to 17 locations simultaneously within the eastern 14 kilometers of the line in order to surpass TBM speeds and complete the construction quickly.

Table 13. **Planned vs actually employed NATM and TBM/EPB tunneling methods for the section starting from the 13.7th kilometers to the end, studied by Öz (2012).**

	TBM (all values indicate twin boring)	NATM
Initially Planned	Km 3+820 - Km 8+ 520 (4,7 km EPB) Km 8+520 - Km 21+690 (13,17 km TBM)	Remaining tunnels except for a few cut and cover station sections
Actual Construction	Km 3+620 - Km 8+450 EPB/TBM (4,8 km)	Remaining tunnel sections except for the platform tunnels which were built with cut and cover. (16,9 km - C&C sections)

Circumstances favored the strategies used to speed up construction after the second contract went into effect, but the agency and the contractors also deserve credit for making the right calls. Blast drilling can be a rapid tunnel excavation technique when the soil conditions are right, but a major concern is its environmental impact such as the noise, vibration and dust along the alignment. The current law in Turkey requires permits for the blasts, and mandates a work window of 8am-11pm which restricts construction schedules, but this was not the case during M4's construction; moreover, M4's construction took places adjacent to residential neighborhoods. The agency and the contractor informed the public and managed the PR successfully so work continued day and night without facing serious opposition from local residents (Personal Interview M 2021). Interviewees with international experience noted that this kind of flexibility was unique to Turkey (Personal Interview D 2020 and AB 2022).

The flexible and collaborative approach adopted by the agency and the contractor during M4's construction remains a strength of the Turkish rail industry to this day, but the most significant improvement in construction speeds came from the rapid adoption of technology and increased knowledge of tunneling techniques in the years to follow.

Today, TBM tunneling is preferred over NATM due to the easier access and declining costs of TBMs as well as their faster excavation rates.[39] This improvement was possible thanks to a steady pipeline of projects in Istanbul and Turkish firms' rapid adaptation to new technology. In the early years of tunneling, the TBM personnel learned from the Italian, German and Danish supervisors that were hired to train TBM operators. But within the next decade and a half, they gained extensive experience through several rapid rail projects built in the city, with an average length of 15 kilometers and more than 99% of their length tunneled. Commonly, with the exception of stations, platforms and switch tunnels, all subway tunnels in Istanbul are built by TBMs while platforms and switch tunnels are built using NATM. Since Istanbul has hilly terrain, most stations in the city end up 30-50m deep, making stations with tunneled platforms cheaper and more practical than completely cut and cover stations, which require costly excavation support and backfilling.

Similarly with other areas of rail construction in Istanbul, there has been a learning curve in the way contractors procure and operate TBMs. In the construction of the 12-kilometer M1B line which was the first rail line built using TBMs, and which started tunneling in 2006, the contractors were recommended to use a specific type of TBM from the German manufacturer Herrenknecht. These machines required cutter head changes every 6 kilometers, as that first section of the soil was sand/silt clay and the remaining was limestone. The contractors later learned that they could use mixed-design cutterheads suitable for both soil types under such conditions and have adopted these in their recent projects instead. In addition to Herrenknecht, Turkey has purchased TBMs from Terratech, CRCHI, Lovsuns Tunneling and Robbins. Furthermore, they have adopted more efficient TBM-related logistics by embracing multi-service vehicles (MSVs) and belt systems to deliver injection material and remove spoils rather than using train systems.

In the last 10 years, 15 rapid rail construction contracts have been awarded to firms in Istanbul alone, and a majority of these to consortia of two or more contractors, which makes it profitable to invest in expensive technology such as purchasing TBMs. With the exception of the Bosphorus crossing, all lines are designed for standardized external tunnel diameters of 6.3 meters, so that the same TBMs can be used across projects. Most tender specifications require firms to acquire four, six or more TBMs, and longer lines mean going through multiple soil conditions so construction firms prefer to buy TBMs suitable for all types of geology found in Istanbul.

[39] In Turkish projects, NATM tunneling speeds vary between 1-2 meters/day depending on the quality of team management. With TBMs, the speed goes up to 24 meters or 16 segment rings/day.

Turkish contractors bring down TBM costs by purchasing second hand machines and rebuilding them,[40] as well as utilizing the same TBMs in concurrent projects. The cost for each rebuilt TBM in a recently constructed twin bore rapid rail tunnel project was $21 million PPP (Personal Interview T 2021) whereas if these were bought new from Herrenknecht, they would cost $40 million PPP. According to a tunneling engineer we spoke to, the complementary parts, such as the gantry, pipes or cuffs, can be used second hand without the risk of compromising speed, safety or quality of work, while it is preferable for the main gearbox that rotates the cutterhead to be new (Personal Interview T 2021). TBM motors could be reset at the manufacturing company with a 100% warranty, and cost $5.5 million PPP for a $22 million PPP TBM. Costs of equipment can also be shared across projects. One contractor who is simultaneously running two rapid rail projects in Istanbul saved 35% on TBM purchasing costs; 40% on machinery equipment like conveyor belts, gantry cranes, concrete and welding stations and 80% on the costs of electrical equipment (Table 8).

While the TBMs became much more accessible, the market for other construction equipment also grew in Istanbul since the construction of M4. One of the challenges in the construction of M4 was building the Kadıköy Station. The structure was designed with cut and cover mezzanines and tunnel platforms that are 32 meters below ground. It was located under a late Ottoman era historic building used by the Kadıköy Municipality. The geology at the excavation site was difficult to work with, having a variety of soil types: sand, sandy clay, highly weathered rock and rock. Along with three shafts that had to be built to speed up the construction, diaphragm walls were required to keep the water out, as the station was very close to the sea. At the time of the cut and cover section's construction in 2009, equipment used to build diaphragm walls were scarce, so the contractor had only two options for where to obtain them (Personal Interview B 2020). Nowadays, this equipment is easily available and so the costs have come down.

Lessons Learned

M4 suffered from major cost increases and delays due to serious design changes in the early years of its construction. Nevertheless, at $102 million PPP/kilometer, the line ended up among the cheaper lines in the history of Istanbul's heavy rail construction.[41] While the project benefited from both the agency's and the contractor's flexibility to adapt rapidly to changes, saving time and money, we can tell that costs could have been even lower, if the overdesign of the stations and tunnels were avoided. Our understanding is that the setbacks

[40] These TBMs are called "rebuilt", not "refurbished", as some parts are new and some are second hand.

[41] M4's Phase 2 cost $79 million PPP/kilometer. Phases 3 and 4, the construction of which are still ongoing, were contracted for $68 million and 81 million PPP/kilometer respectively. M5's Phase 1 cost $101 million PPP/kilometer and M6, $76 million PPP/kilometer. M9 and M11, the airport connector's Phases 1 and 2 were awarded at $95 million, $90 million and $95 million PPP/kilometer respectively.

during the planning phase, the inexperience of the agency and the relatively recent establishment of the rail construction industry in the city took away from what could have been a much more efficient and cheaper project delivery process. As the agency re-organized, expanded and gained experience over the following years, robust preliminary design processes were established, helping to avoid cost increases due to overdesign and extensive design changes.

In hindsight, experts from the agency and design firms realized that the station-technical spaces were too large and the tunnels were over reinforced. These elements of over design have been attributed to the agency's inexperience with rapid-rail transit procurement and project management. A preliminary design document was not procured, the alignment decisions in the internally prepared design were based on limited information regarding geology and station locations had to be revised after the tender.

The tender documents were also underdeveloped; they lacked sections and specifications that were to be added in the documents of the later projects. The missing sections include an attached geotechnical report based on ground surveys and lab tests, and those concerning public content and safety, rain and ground water drainage systems, testing and protection of existing buildings within the impact area, geomonitoring equipment requirements as well as protection of existing greenery and landscape design. Our understanding is that the costs incurred from additional work required to make up for the errors or shortcomings resulting from the lack of information on these issues were avoided in the later projects through the addition of these specifications.

Preliminary design, planning and tender processes improved and project designs were better optimized in the years that followed M4's construction. Specifically, the Rail Systems Department, tasked with planning, procuring, and managing construction became independent from the İETT. Then it was split into European and Asian side regional departments, and later, a new Projects Directorate office was created to manage preliminary planning. By revamping the Rail Systems Department based on experiences in the field and a growing pipeline of projects, it found the right balance between inhouse and outsourced capacity. More experts were hired under these new administrations, and the total headcount grew to 251 staff members today, with 117 at the Asian side branch office, 107 at the European side branch office, and 27 at the Projects Directorate (Personal Correspondence C 2022). From these offices, IMM now appoints an on-site control team of approximately 10 experts for each project, consisting of architects, engineers (civil, mechanical, electrical, mining, geological, geophysical, signalization), and, where needed, archeologists. The Rail Systems Department has also established specialized teams for design and procurement as well as for BIM.

The agency made up for lost time in the earlier phases of M4 by being flexible and allowing the contractors to pursue their preferred means and methods, such as switching from TBM to NATM tunneling methods to speed up construction. Ultimately, this approach saved both time and money. While the planning challenges in the early stages of the project led to a slow start, once the final decision was made to build a subway rather than an at-grade LRT, tunneling progressed rapidly between 2008-2012, and the 21.7-kilometer line was completed at a record rate. This was also possible due to a lack of restrictions for blast drilling near residential and commercial zones at the time. Mitigation measures have grown more restrictive over the years.

3.2 Marmaray, the Perfect Storm

Overview

figure 12. Marmaray Commuter Line’s Bosphorus Crossing Phase

To this day, Marmaray is recognized as one of the most ambitious transit projects in the history of Turkish rail construction. While the complete 76-kilometer rail line was designed to accommodate commuter, high speed, main line and freight service, in this case we focus on the 13.6-kilometer Bosphorus Crossing Phase (BC1) (Figure 12). The project presented extraordinary challenges; the scope included a 58-meter-deep immersed tube tunnel to be assembled under the seabed, the right of way was situated in a seismic zone and extensive archeological sites were uncovered at all four of the station sites, some going back as much as eight thousand years. We selected Marmaray's BC1 because at $228 million PPP/kilometer, its cost remains lower than 30% of the projects in our database despite the state-of-the-art technology implemented in its construction, the multiple challenges that were faced and archeologically-driven schedule delays that doubled its timeline.[42]

Politics played a key role in structuring the project-delivery design of this megaproject. The Japanese financiers required the project be delivered using the FIDIC Silver Book (a lump sum, turnkey, Engineering, Procurement and Construction contract template) and the selection of a Turkish-Japanese consortium as the contractor. Unlike the Design-Build contracts utilized in the procurement of most of the rapid rail lines in Istanbul, BC1s's contract specified stringent HSE and quality standards and transferred a greater responsibility and risk to the contractor. The contract set high standards and predefined management solutions that benefitted the project in the long run, but also raised the costs significantly. On the other hand, unlike most metro lines in Istanbul that are owned by the IMM, Marmaray was owned by the General Directorate of Railways, Ports and Airports Construction (DLH) under the Ministry of Transportation of the central government.[43] This meant that the budget increase and time extension approvals could be expedited and the project wasn't subject to conflicts between the local and central governments.

The archeological discoveries made during the excavations of the project changed the known history of Istanbul, but also more than doubled the construction timeline of the complete Marmaray project. The initial schedule of BC1 entailed completing a 1.4-kilometer immersed tube, 10.1 kilometers of twin bore TBM tunnels and four underground stations by 2009. The project was completed in 2014. The works for the remaining 63-kilometer section separately contracted as CR1 was to be completed by 2012, and included converting two existing commuter lines Halkali-Sirkeci and Haydarpasa-Gebze from 2 to 3 tracks, with the new one to serve high-speed intercity trains. CR1's contractor, a joint venture between Alstom, Marubeni, and Doğuş, terminated their contract due to delays in the handing over of the site, likely as a result of complications related to archeology (Personal Interview H), and disagreements with DLH, which led to an arbitration process that finalized with the contractors losing approximately 50% of their bank guarantees (Alstom 2019). This section was re-contracted as CR3 to the joint venture between OHL and Dimetronic, and started service in 2019, with a seven-year delay in the initial timeline.

[42] However, the signaling is outside of the contract because the system had to be integrated with the remaining 63 kilometers of the commuter line and was contracted separately.
[43] DLH was restructured as AYGM (General Directorate of Infrastructure Investments) in 2011.

The mix of traffic along the line makes its signaling more difficult than a regular urban rapid-rail line. The line's three tracks throughout the right of way merge into two along the 13.6-kilometer BC1 section. The commuter trains have 8- and 15-minute headways, and serve 142 trips a day in each direction adding up to 285 trips a day in total. As of August 2021, the high-speed rail service runs seven trains in each direction between Halkalı (European side of Istanbul) and Ankara, and three in each direction between Halkalı and Konya daily. The rest of the high-speed trains stop at Söğütlüçeşme on the Asian side, where a connection is available to Söğütlüçeşme Marmaray service for crossing to the European side. The freight trains have been operating on the line since May 2020.

Lessons learned from this project concern the power of political will, the management of archeological discoveries during underground rail system construction and the importance of selecting contractors and consultants based on their experience with the chosen contracting method:

- First, because the central government championed Marmaray BC1 as a nationally important project that would have a positive impact on congestion, elected officials supported the project even as costs and timelines doubled. This highlights the significance of support from policymakers.
- Second, the lack of a detailed survey of the station sites prior to the construction tender impeded preliminary planning that could prevent delays caused by the archeological remains discovered during the excavations. The station designs and even the right of way could have been redesigned to avoid conflicts with archeology.
- Third, the contractor's outstanding efforts to communicate with the conservation committee regarding the management of archeology helped expedite the processes and make up for some of the delays.
- Finally, as we saw in our Green Line Extension case, due to the lack of experience with the contracting method, in this case the FIDIC Silver Book, both the agency and the contractor were slowed down following specific procedures, consequently increasing costs. Ideally, the contractor, and if not, the consultants should be knowledgeable about the specific type of contract intended to be utilized in construction projects.

Timeline and Financing

Marmaray's history goes back to the later years of the Ottoman Empire. In 1892, Sultan Abdülmecid II hired French engineers to design a tunnel connecting the two banks of Istanbul (TCDD Taşımacılık n.d.). While the project was never completed, the plan proposed building a tunnel supported by columns driven into the seafloor (Figure 13). Nearly 100 years later, in 1987, President Turgut Özal commissioned the first feasibility study which analyzed alternatives and determined the current right of way.

figure 13. One of the earliest depictions of a tunnel crossing the Bosphorus (Marmaray Hakkında n.d.).

The project was put back on the agenda in 1999, when an advance loan agreement was signed between the Turkish Undersecretariat of Treasury and Japan Bank for International Cooperation (JBIC) for $234 million PPP (¥12.5 billion), $63 million PPP (¥3.371 billion) of which was to be spent on the CM contract and $171 million PPP (¥9.093 billion) on building the Bosphorus Crossing (Table 14). This agreement required that the CM and construction contracts of BC1 follow rules established by the Japan International Cooperation Agency (JICA). This meant that only firms from countries on Japan's list of Official Development Assistance Countries were permitted to bid on these two tenders and all critical stages of the tender and the contracts were to be overseen by JBIC.[44] Also, the maintenance and operation of the line following the completion of the project was to be carried out by a Project Implementation Unit created by the Ministry of Transport, Maritime and Communications (Turkish Ministry of Transport, Maritime and Communications [TMTMC] 2013).

A CM contract worth $66 million PPP (¥5.5 billion)[45] was signed with Avrasya Consult consisting of Oriental Consultants from Japan, Yüksel Proje and Japan Railway Tech Service on March 14th, 2002, after which specifications, contract drafts, feasibility studies and tender documents were prepared. After the CM contract was signed, deep water drilling for tests began. On June 6th, 2003, BC1 tender documents were delivered to the pre-

[44] See (Ministry of Foreign Affairs of Japan n.d.) for countries.
[45] We do not have access to the specific conditions of this contract, but assume that the costs approximately doubled by the time of closing (Figure 15).

qualifying contractors and their offers were received on October 3rd. The contract was awarded to the Japanese-Turkish joint venture TGN on May 9th, 2004.

Table 14. Marmaray's timeline

Date	Item
17-Sep-1999	First loan agreement between JICA and Treasury for $234 million PPP. $63 million PPP for the CM contract and $171 million PPP on BC1.
14-Mar-2002	CM Contract signed with Avrasya Consult.
09-May-04	BC1 Bosphorus Crossing Contract signed with Taisei - Gama - Nurol (56-month period).
Oct-04	BC1 construction starts.
18-Feb-05	Second loan agreement with JICA and Treasury for $1.4 billion PPP.
2005	Archeological artifacts unearthed
21-Dec-06	TBMs start tunneling Ayrılıkçeşme and Yedikule tunnels
Apr-09	First contract period is up, project seriously behind schedule. Taisei wanted out as they would be losing money due to inflation.
Jan-10	A cost escalation executive order was passed by the approval of the prime minister, a first in Turkey.
22-Nov-10	Third loan agreement with JICA for $783 million PPP.
04-Aug-13	First test run through Marmaray tunnel
29-Oct-13	Service starts between Ayrılıkçeşme-Kazlıçeşme through the Bosphorus tunnel.
2014	Construction completed.
21-Mar-19	First international trains run through Marmaray. The passenger train set that'll run between Baku and Ankara departed from Halkalı, passed through Marmaray tunnel and continued to Baku.

Initial excavations for the archeological surveys started in June, 2004, at the Üsküdar station site. In February 2005, the negotiations between the Treasury and JBIC on an Official Development Assistance (ODA) loan was finalized and a 40 year-term, 0.75% interest rated loan of $1.4 billion PPP (¥98.7 billion) was granted to Turkey for the Marmaray Project (TMTMC 2013).

Soon after the beginning of excavations, remains of houses and market gardens from the Ottoman and Byzantine periods were revealed. The most stunning discovery however, was the 58,000-square-meter archeological site uncovered in Yenikapı which had been designated for the construction of both the underground stations of Marmaray and M2 metro line's extension between Taksim and Yenikapı. By the time the Marmaray excavations were completed in June 2009, 34 shipwrecks dating back to the 11th century confirmed the theory that the area had been a Port of Theodosius in the Byzantine Empire. An early Byzantine church and part of Constantinople's first city walls had also been discovered (Boninin Baraldi et al. 2019). The tunnel excavations could not begin until December 2009. M2's excavations had also revealed a Neolithic-period village dating back to 6000 B.C and the station construction couldn't start until June 2012.

By April 2009, which marked the end of the initial 56 months, there had been serious increases in material and equipment costs due to inflation as archeological discoveries had delayed work schedules extensively. Within this timespan, only the immersed tunnels had come close to being completed. The Japanese contractor Taisei wanted out unless the contract was amended or renewed. In January 2010, a cost escalation executive order was passed by the approval of the prime minister, a first in Turkey. The contractors added a percentage to all item costs and through this, could retract several of their claims. The Chief Representative of JICA, who had been involved in the project since 2001, emphasized the significance of this decision for the project and issued the following statement, "If the Turkish parliament had not approved the increased construction contract amount to accompany delays from the historical ruins survey, construction might have been interrupted" (JICA 2014).

In November 2010, a third loan agreement of $783 million PPP (¥42.08 billion) was signed with JICA with the same interest rate and payment conditions as the previous agreements; with a 40-year payback timeline, a 10-year grace period and a 0.75% yearly interest rate. Our estimate for the total cost of financing including the interest and fees for the BC1 loans from JICA add up to 20% of the total loans or $430 million PPP, based on the evaluation of the loan conditions by a financial expert specializing in international infrastructure investments (Personal Interview W 2021).

CR3 was financed by the European Investment Bank (EIB) with a €650 million loan granted in two installments: $447 PPP in 2004 and $958 million PPP in 2006. An additional loan of $472 million PPP was granted by the Council of Europe Development Bank (CEB) in 2008. Later, the total value of loans granted by CEB to the project reached $1.7 billion PPP (Council of Europe Development Bank [CEB] n.d.).

Scope and Contracts

DLH, under the Ministry of Transportation, awarded the construction contract to the TGN consortium through a tender. GN built the stations and the Yedikule (Kazlıçeşme) -Yenikapı 2.2-kilometer twin tunnels using a single EPB TBM, Taisei undertook the rest of the tunnel construction including two 8-kilometer twin-bore tunnels built by two slurry TBMs, as well as the immersed tube tunnel of 1.4 kilometers crossing the Bosphorus Strait (Figure 14). Ayrılıkçeşme station was partially constructed within this project's scope, and partially through the M4 Kadıköy-Kartal line's contract. The signaling system was within the scope of the CR3 Commuter Rail Infrastructure and Systems Contract, and together with the Automatic Train Protection systems cost $470 million PPP. Undertaken by Invensys Rail Dimetronic, CR3 also included the systems for the 63-kilometer commuter tracks (See Tables 15 and 16 for BC1s scope and contracts).

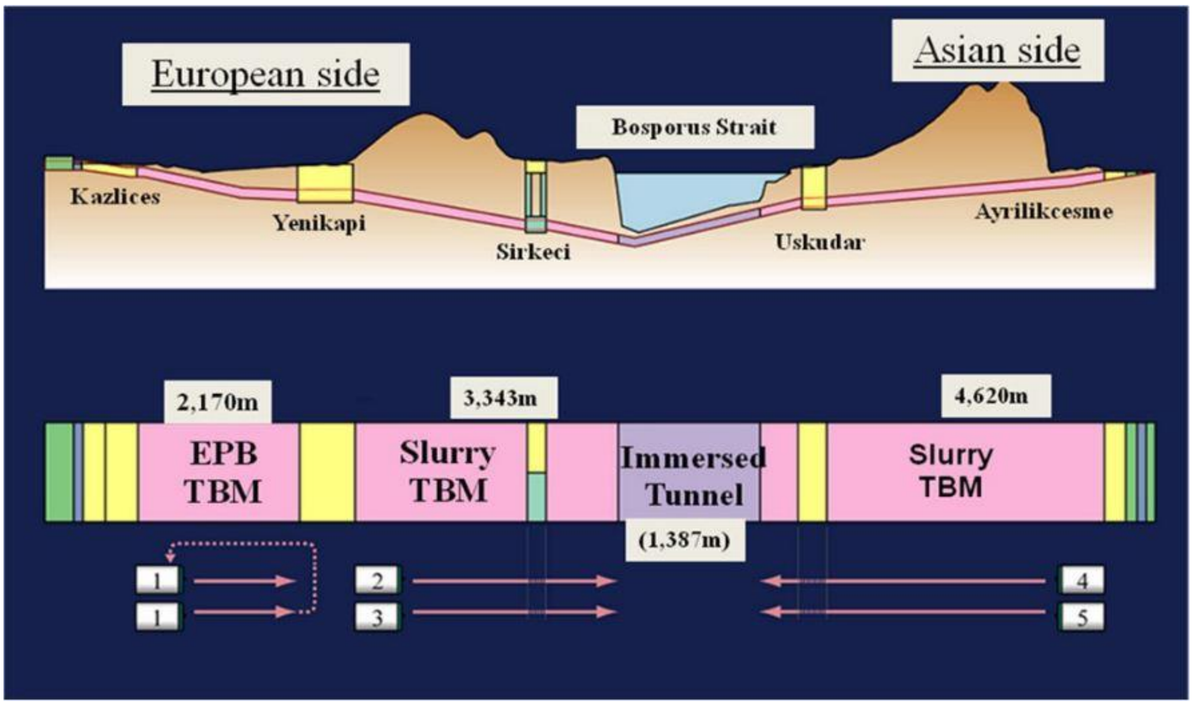

figure 14. BC1 tunnels drawing from Emergency Ventilation Systems Cold Flow & Cold Smoke Tests (Tabarra and Özince 2015).

Even though a lump sum pricing model requires the contractors to bid high to be able to bear the general risks, due to BC1 being a project of national significance, a standardized, Engineering Procurement and Construction contract template outlined in the FIDIC Silver Book was utilized to ensure a smooth project delivery. However, this was a first for the use of a FIDIC Silver Book based template, and it wasn't utilized afterwards, due to the extensive risks placed on the contractor and the increased costs arising from the contract requirements. An example of these risks that the Silver Book assigns to the contractor is unforeseeable ground conditions. In the case of Marmaray BC1, DLH was the responsible party for the costs related to the archeological findings which were the primary reason for severe delays and cost increases. Nevertheless, the contractor lost between $180 and $280 million PPP due to the contract protecting the agency against the majority of the risks including cost increases arising from delays and other complications (Personal Interviews K 2020, and M 2021).

The use of FIDIC standards was mandated by the credit-granting institution, JICA, and FIDIC standards called for the implementation of a number of measures that we do not see in any other rapid rail project in Istanbul. Firstly, the HSE mitigation measures as well as Quality Assurance and Quality Control (QA/QC) processes were implemented at a very high standard. Secondly, an independent design verification engineer was hired by the contractor reporting directly to the agency. This was a separate entity from the CM and was a consortium of Turkish and foreign firms. Thirdly, a dispute adjudication board (DAB) was established, the $9 million PPP cost of which was covered 50%-50% by the contractor and the agency. Due to the technical requirements brought on by an immersed tunnel and a mix of commuter, high speed and freight traffic planned on the line, the unit costs in this project were higher than the national standard unit costs utilized in subway projects.

Both the timeline and the costs of the project almost doubled. The construction contract was initially 56 months, at the end of which the contractor was granted an extension for 42 months, and then another for 37 months. Following this final extension, the contractors completed construction within 12 months, not using the remaining 25 months they had, making the total duration of construction 110 months (56+42+12). The first contract cost $1.4 billion PPP and the extension of 42 months for the completion was granted through a supplementary agreement approved by the central government that was worth $780 million PPP. With the addition of price adjustments, change orders and claims, the final price tag of the construction contract reached $2.7 billion PPP, excluding the commuter rail phase, rolling stock, systems contracts and financing costs (Figure 15).

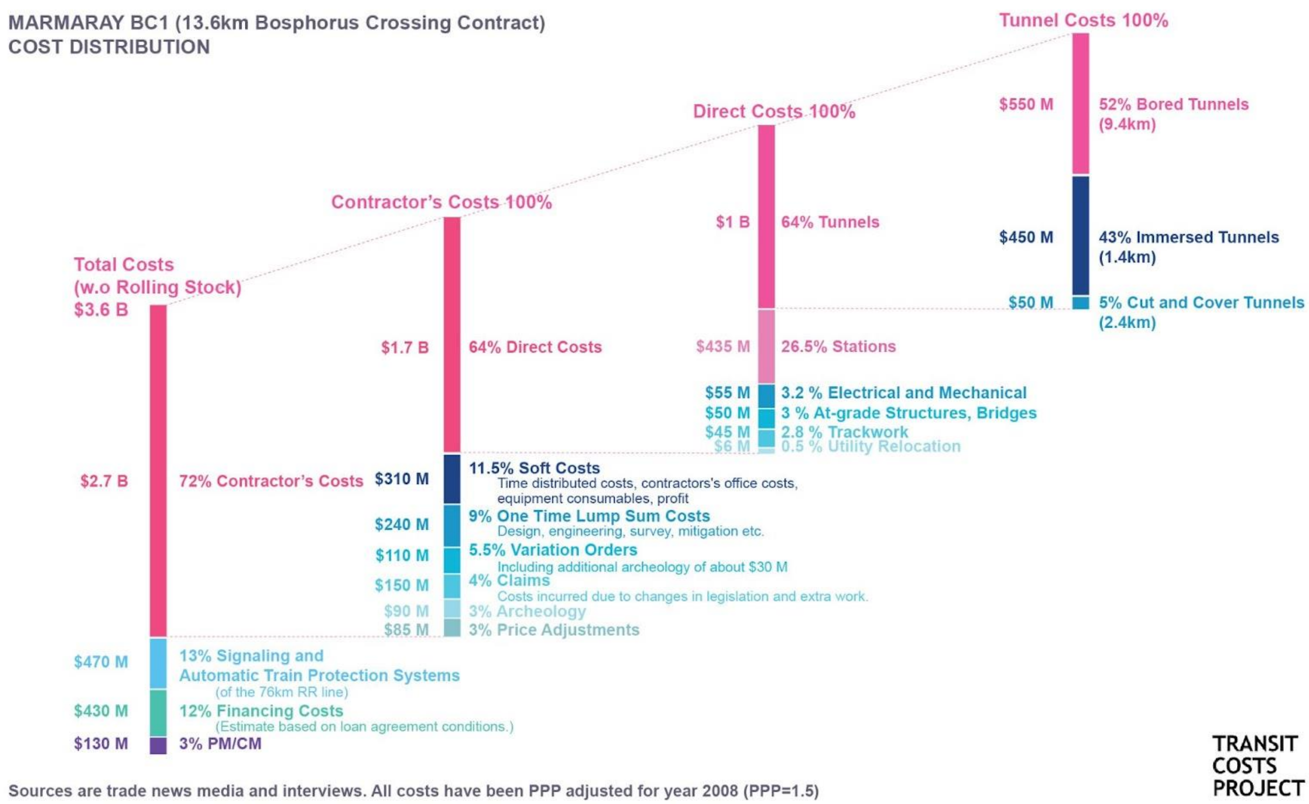

figure 15. Capital Costs Breakdown of Marmaray

Table 15. Marmaray's Scope

ELEMENT	SCOPE	FEATURES
Guideway	• Immersed tunnel going under the Bosphorus and TBM tunnels to connect the existing commuter lines of Gebze-Haydarpasa and Sirkeci-Halkali	•100% Underground elements • Partially shared corridor with high-speed rail
Track	2 new LVT tracks to be shared between high speed, commuter and freight trains.	

New Stations	3 new underground stations (100,000 m2 total)
	• Yenikapı
	• Sirkeci
	• Üsküdar
	Partial work on the at-grade Kazlıçeşme and Ayrılıkçeşme stations. Ayrılıkçeşme (Ibrahimaga) station was within the scope of the M4 line.
	(CR3 includes 35 existing surface stations to be renovated)
		• Yenikapı Tube Station: 245m long, 24 m deep
		• Sirkeci Station: 225m long, 60m deep and 22m wide
		• Üsküdar station: 300m long, 30m deep, 30m wide
		• Ventilation shafts of 25,000 m2 in total:
		  • Yedikule ventilation shaft: 90 m long and 14 m deep
		  • Yenikapı ventilation shaft: 135 m long and 20 m deep
		Ayrılıkçeşme ventilation shaft: 80 m long and 20 m deep

Tunnels	• Total of 9.7-kilometer twin-bore tunnels • 1.4-kilometer immersed tunnel (Dept: 58 m) • 444m of NATM tunnels • 1080m of out of the track route	Track Route Tunnels: • TBM 1 (EPB): 2.2-kilometer tunnel bw Kazlıçeşme and Yenikapı • TBMs 2 & 3 (SLURRY): 3.3-kilometer tunnel bw Yenikapı and Sirkeci • TBMs 4 & 5 (SLURRY): 4.6-kilometer bw Üsküdar and Söğütlüçeşme • Cut and cover tunnels: Yenikapı and Üsküdar station tunnels • NATM tunnels: Sirkeci station and Üsküdar crossover tunnels Tunnels Out of the Track Routes: • TBM: 120 • NATM: 960
Bridge Structures	2000m of at grade and C&C bridge structures	• 28 m span Yedikule steel railway bridge structure • 19 m span Ayrılıkçeşme steel railway bridge structure • 22m span Yedikule highway bridge: pre-stressed precast • Kosuyolu highway bridge • Dr. Eyup Aksoy intersection arrangement (2 overpasses and one grade road repair)
Systems	• Traction power supply system • Overhead catenary system • SIRIUS CBTC, ERTMS signaling systems • Telecommunication system • SCADA system • Operation control and administrative centers • Electrical distribution system	
Support Facilities	• Depots • Stabling yards for the intercity and commuter rails • Workshops	

Table 16. Marmaray Contract Cost

Contractor	Scope	Cost	Year	USD with PPP
Oriental Consultants (Japan), Yüksel Proje, Japan Railway Tech Service	• Control/supervision, engineering and consulting	¥ 5,500,000,000.00	2002	$66,000,000.00 (we estimate a 100% increase, thus a $130 million final price tag, due to the doubled timeline)
Taisei (Japan) - Gama (Turkey) - Nurol(Turkey) Joint Venture	BC1 - Bosphorus Crossing Engineering/design, procurement and construction of 13.6-kilometer railway and related structures: • 9.4-kilometer twin bore tunnels • 1.4 immersed tunnel • Underground and surface stations with cut-and-cover and NATM tunnels • Bridges	¥ 102,372,748,108.00	2003	$2,400,000,000.00 ($2,7 million after the claims, variation orders and price escalations)
Invensys Rail Dimetronic	Signaling and Automatic Train Protection systems. (Within the scope of the CR3 contract)	€195,000,000.00	2011	$407,000,000
Hyundai/Rotem (S.Korea)	CR2 - Rolling Stock Contract Engineering/design, manufacture and delivery of 440 rail cars: • Testing and commissioning of the new rolling stock, • Training of the Employer's staff in train operation, • Provision of spare parts and maintenance of railcars for defined periods.	€543,000,000.00	2008	$1,302,000,000

Unprecedented Challenges

Many aspects of Marmaray demanded unique planning and management solutions, on top of which, archeological discoveries brought on immense unanticipated challenges for the contractors and DLH. The environmental impact assessment (EIA) process was longer, mitigation measures mandated by the contract were much more stringent and the management scheme had more layers of oversight and approval than that of a regular metro project. In addition to the JV, CM, and DLH, there was also a Dispute Adjudication Board, an Independent Design Verification Engineer, and a separate Technical Assistance Team. Furthermore, the Museums Directorate became almost as significant a stakeholder as DLH in the project. These led to cost increases and delays, but most importantly revealed the shortcomings in legislation and organization of the agencies involved in the management of infrastructure projects. Some of the negative consequences such as the coordination problems with the Museums Directorate in regards to the management of archaeological discoveries were overcome within the timeline of the project; solutions such as the requirement of a more specific geomonitoring plan prior to the start of construction was adopted in later rail construction contracts; while some including the lack of a framework for dealing with archeology during infrastructure construction still persist to this day.

The EIA process was unlike that of a standard metro line, as the scale, scope, contract and implementation of the project varied greatly from a metro project. The initial feasibility and EIA studies were conducted in 1998 (Personal Interviews Z and AA 2021) and the construction contract was awarded in 2004, which is a long timeline for the planning of a rapid rail line in Istanbul. While we do not have the exact dates of the EIA process or whether an environmental impact statement was issued, the mitigation measures implemented during construction reveal that these processes were not expedited, as is done for metro lines in Istanbul, but involved meticulous study.

The geotechnical planning of Marmaray also differed from metro projects at the time. IMM started requiring geological analysis reports regarding the impact of planned construction to surface structures from metro contractors only after 2014. Before that, this was not mandatory and rather than detailed preliminary surveys and the reinforcement of buildings before construction, repair costs were paid if a building was damaged during construction. For Marmaray, on the other hand, despite being a project that pre-dates this regulation by a decade, the contract required a Risk Assessment Mitigation Plan covering HSE mitigation measures from the contractor. It was determined through this analysis that the TBM tunnels were in close proximity to 158 old buildings in structurally problematic conditions. The combined risks posed by Istanbul being in the earthquake zone and the impact of ground vibration to be generated by the TBMs on these buildings required preliminary tests that would determine whether to demolish or reinforce them.

The dispute adjudication board (DAB) which had been set up as a requirement of the FIDIC Silver Book was helpful in resolving disagreements between the agency and the contractor, but often ended up bringing on unanticipated costs and delays to both parties. The disputes arose from the agency initially presuming that all costs be accounted for in the lump sum bid and wanting to charge all risk to the contractor. Later, as they came to a mutual agreement on getting the project done, such conflicts were overcome. Nevertheless, the disputes cost the contractors about $45-75 million PPP and more importantly, lost them time (Personal Interview M 2021).[46]

One costly and time-consuming disagreement was in regards to the 158 buildings that the Risk Assessment Analysis found to be within the impact area of the BC1 corridor. The contractor claimed that the costs related to the protection or demolition and rebuilding of these should be borne by the agency. The DAB referred to the Silver Book and concluded that if after the contractor carried out a structural analysis and determined that a building was near-collapse and that it should be demolished, the agency would pay for the demolition. If, on the other hand, a building could be supported, the contractor would be responsible for its reinforcement. Gama-Nurol spent $5.2 million PPP to reinforce or repair buildings between Yedikule and Yenikapı and relocate residents during construction. Additionally, they had to run on-site simulations and install extra layers of window panels to the hotel rooms around the Sirkeci and Yenikapı station sites for noise mitigation.

Today, geomonitoring of the buildings that fall within the impact boundaries by a rail line construction is a requirement for all projects. The contractor's designer provides a geomonitoring plan and, before starting construction, the contractor visits all buildings under risk with a notary and records existing damage to avoid conflicts later. Allowable settlement limits are determined by the monitoring design, so it varies across projects, sites and buildings. Once the construction starts, the damage risk is on the contractor.[47]

More demanding mitigation measures and inexperience with the Silver Book contract undoubtedly burdened both the DLH and the TGN, but the main reason behind the doubling of costs and construction timeline was the discovery of archaeologically sensitive sites at the station locations. With the heavy construction equipment on site, ready to start excavations, the overhead costs kept adding up while waiting for the completion of the archeological work. These time-distributed costs increased by more than 200%, from around $100 million PPP to $310 million PPP. $120 million of this increase was due to the price adjustment applied to make up for the cost increases resulting from inflation through the long delays in the construction schedule.

[46] For example, they lost four months just for bureaucratic procedures waiting for a permit on a section of the tunnels around Sirkeci. They lost another five months due to miscommunication regarding discovered archeological structures; the Museums Directorate didn't want to remove them, but they eventually had to be removed for the guideway. The findings were documented in 3d, the contractor also did a structural analysis, which the board didn't initially require but requested later, nevertheless, the structural analysis had to be re-done.

[47] In 2018, a sinkhole that opened up during the excavations of the M8 line caused the death of two security personnel working at a nearby residence. The following lawsuit charged 9 staff members of the contractor and the subcontractor including project directors, deputy directors, and chiefs of the geotechnical, tunneling and depot construction crews, with 6 years and 8 months of imprisonment (Çekmeköy Haber 2018).

Major design revisions were required due to archeological findings at all station sites. Station layouts including the entrance locations had to change to protect archaeological remains that were to be conserved on site rather than removed. The longest archeological digs which were at Sirkeci and Yenikapı Station sites lasted 76 months. They took six months at Ayrılıkçeşme, 37 months at Üsküdar and four months at Yedikule-Kazlıçeşme (Personal Interview K 2020). During the excavations, construction at the site stopped, and as the digs were completed section by section, the teams could go back in and continue construction. Hence the station excavations slowed down drastically.

The archeological excavations were outsourced to TGN by the Ministry of Transit.[48] So even though TGN was compensated for the overheads, profits, and roughly a 22% commission for the indirect costs of aiding the archeological work, the unanticipated schedule delay that resulted from this work ended up eroding TGN's profits. An example was the job of purchasing for the archeological team, including materials from office supplies to trowels, brushes and spoons (Personal Interview M 2021) which was cumbersome; no matter the scale of the purchase, three quotes were required for every item with the lowest bid selected as required by the contract. Total costs for archaeology were $120 million PPP, but ultimately the work ended up costing the contractors much more when accounting for increased overheads due to delays. One senior manager who directed the QA/QC for the project explained: "If you spend $10 on archeology, you will most likely get $3-4 back with claims. It is very difficult to plan for archeology. Losing time means losing money: you pay $100,000/month for a tower crane, once you've leased it, you keep paying for it even if construction has to stop" (Personal Interview M 2021).

Throughout the archaeological excavations on the project site, the contractors were required to present reports to the project committee at the Museums Directorate and wait for their approval before proceeding with work. This process would take three to four months during which construction had to wait. The contractor eventually adopted a different approach to expedite the processes that involved coordination with the committee. They hired academic experts to help them prepare for the meetings and visited the committee offices regularly to avoid missing necessary procedures and better understand their concerns. These meetings guided their work and reports, ultimately preventing delays. The contractor also made the archeological team's life easier by purchasing its material and tools without waiting for approvals from the agency, even if this meant that sometimes the items wouldn't be fully reimbursed by DLH. Our interviewee concluded that the contractor spending an extra $5,000 to

[48] Similarly, the archeological excavations at the adjacent site of M2 were outsourced to the project's contractor by the IMM. This was necessary because the responsible entity Istanbul Archaeology Museum only had 30 archeologists on staff, no budget and no authority to hire temporary staff. The contractors hired subcontractors, who hired freelance archeologists, conservators, unskilled workmen and specialists (between 260 to 380 people) as well as setting up labs and hiring equipment for the sites (Bonini Baraldi et al. 2019).

$10,000 to make these arrangements possible, ultimately saved them months of delays, and consequently, a lot more money than those extra costs (Personal Interview M 2021).

The delays caused by the archaeology extended to the CR3 work as well. Haydarpaşa Terminal's depot area to be used for Marmaray's rolling stock is still being renovated as of 2022. The archeological remains found at only 50 cm below the surface are from four different time periods; late Roman, Byzantine, Ottoman and early Turkish Republic. These excavations have been going on for over four years. It is not unusual to uncover archeological heritage during infrastructure construction in a city like Istanbul; Kabataş and Beşiktaş metro excavations also revealed remains. Despite the numerous examples of unearthing archaeologically significant sites during excavation, which drive delays and costs, there is no standard framework for managing construction at these sensitive sites.

The city of Rome's approach to dealing with the archeology that is discovered during excavations of rail construction is a good example that Istanbul, and other cities which need to manage historical heritage alongside infrastructure work, can benefit from. The Roman protection agency, *Sovrintendenza ai Beni Archeologici*, came up with a set of guidelines *Prontuario Archeologico* around 2010-2011 to manage the archeological excavations for remains discovered during metro construction projects. These guidelines, agreed upon by all the stakeholders at the time they were being compiled, provide directions to devise practical handbooks for how to deal with stations, shafts and ways to proceed in case of major findings. In a city like Istanbul where it is common to discover archeological remains during metro excavations, such a guidebook would be invaluable.

Another management challenge that Marmaray's contractors and the DLH faced was political pressure from the central government, which also led to cost increases. The ministry demanded that the BC1 be completed in time for the celebrations of the 90th anniversary of the Turkish Republic, on October 29, 2013, and indeed, the line opened to revenue service on the date. The east shaft of Sirkeci station was not complete at the time of opening; the fans in this section were installed and the ventilation system tests were completed in 2014. While this, together with the phased opening of the line as BC1 and CR3 was considered a safety issue by some trade unions, a tunnel ventilation expert we interviewed stated that the incomplete tests and certification only concerned the freight operations, which wouldn't go into service until 2019 (Personal Interview AA 2021).[49] The majority of the additional costs incurred paid for the construction of a temporary command center at the Üsküdar station, which

[49] The Union of Chambers of Turkish Engineers and Architects declared that early opening compromised safety of operations due to the phased opening of the line and incomplete certification process (Sendika.org 2013).

enabled the BC1 section to operate before the 65-kilometer commuter section was complete, and was later transferred to the commuter line's Maltepe station.[50]

The DLH concluded at the completion of BC1 that had it worked with a contractor who had experience with navigating archeology, DLH could have avoided such a large cost increase (Personal Interview M 2021). On the other hand, a study of the management scheme of the archeological excavations reveals that ad-hoc approach to managing these events; the lack of legislation on protection of archeology discovered during infrastructure excavations, combined with the extreme centralization within the Ministry of Culture and Tourism prohibited the hiring of temporary staff by the Museums Directorate and this led to a "multi-layered outsourcing approach" to deliver human and financial resources in the Marmaray (and M2) archeological excavations (Bonini Baraldi et al. 2019). This inevitably "increased the overall complexity, cost, and level of conflict within the system" (p.439)"

Everything Cost More

At the time of its construction BC1 was the deepest immersed tunnel project in the world among 150 similar projects, including BART, Hampton Road, Baytown, Baltimore Channel, Parana and Tama Tunnels (Personal Interview K 2020). Additionally, the water current speeds at the upper layers of the Bosphorus Strait were 2.5m/sec and 1m/sec at lower layers, in opposite directions. From the costs of tunneling and ventilation to the tracks installed, multiple components of the Marmaray project were more expensive than that of a regular subway (see Figure 15). The line had larger diameter tunnels, longer platforms and had to be resistant to higher temperatures in case of freight fires as it would serve mixed traffic. Moreover, the tunnels came close to the surface around residential neighborhoods and track vibration had to be minimized to prevent noise pollution. To make up for the extensive delays in the schedule due to archaeology, work had to be expedited which also increased costs.

Marmaray's tunnels were more expensive due to their diameter and passive fire resistance requirements. Since they were designed to accommodate freight as well as high-speed and metro trains, the tunnels have 8-meter external diameters, which is larger than the 6.3-meter wide (5.7-meter internal diameter) metro tunnels in Istanbul. Freight trains demanded the design of the system for higher intensity fire risk and also necessitated larger evacuation corridors. As a result, the TBM tunnels cost approximately $60 million PPP/kilometer, almost double the cost of standard metro tunnels in Istanbul.

[50] Media sources speculated that the command center cost $22 million PPP.

The concrete used was required to have the same specifications as the Öresund bridge in Denmark: it had to have a useful life of 100+ years and no early age cracking. This level of specification was uncommon and expensive. Gama-Nurol set up a $5.2 million PPP concrete testing lab at Istanbul Technical University. Marmaray was the first project in Turkey where concrete temperature monitoring and cooling was implemented. Although Taisei initially planned to manufacture its own concrete, it ended up using the concrete manufactured by GN for the immersed tube tunnels as this concrete performed better in tests. Having acquired the experience, Turkish contractors now undertake immersed tube tunnel projects around the world.

Another reason for costlier construction was the urgency with which the contractors had to operate in, to avoid further delays after the discovery of the archeological remains. To facilitate faster drilling of the tunnels, the contractors used a 12-bar slurry TBM, and instead of sand-grout, an AB component system based on sodium silicate in spite of higher costs (Personal Interview N 2021). This system is not utilized in other metro tunnels in Istanbul. The fire proofing material which consisted of panels for the immersed tunnels and was sprayed on for the others which are usually $155 PPP/square meter, cost over $220 PPP/square meter to facilitate speedier construction.

BC1's unique ventilation and fire protection design was a result of a number of specifications mandated by the contract on top of those mandated by Turkish rail construction standards. The differences in this aspect between projects in countries that use similar standards such as the NFPA 130 occur, because of the additional and unique technical specifications each administration requires that a project satisfies (Personal Interviews R and S 2021). The differences between projects in the US and Turkey, for instance, are an example of this. Even though both utilize NFPA 130 standards, the emergency ventilation and egress systems are designed for more stringent measures in the US. Similarly, Marmaray was different from regular metro projects in Istanbul due to its contract's particular specifications. The fire-resistant tunnel coating and the high capacity of the ventilation required by the contract led to unique and cost intensive fire protection and ventilation design solutions.

First, additional tunnel coating for passive fire protection was required due to the addition of overnight freight trips. Moreover, the ventilation fans needed to be designed to maintain operations in temperatures as high as 250℃, or 482℉. The tunnel's coating was designed to provide a minimum of four hours of resistance for 100 Mw fire. Istanbul's other metro tunnels are designed to withstand 23 Mw or lower fires. Thus, for BC1, the specifications called for concrete that would stay intact at oil-burning temperatures that are four times hotter than the fires subway concrete is designed to resist. This extra fire-resistant coating was one of the major cost drivers for Marmaray and is not utilized in subway projects since concrete itself is known to be resistant to regular subway fires. However, the technique implemented in Marmaray's construction was later applied in the Eurasia road tunnel as well as other projects across Turkey.

Second, BC1's 225-meter-long platforms added costs by increasing station-box volumes and the capacity of station MEP finishes. The longest metro platforms in Istanbul are 180 meters. BC1's 25%-longer platforms meant longer construction times and more earth needed to be excavated and disposed off, all of which added costs. The inclusion of high-speed rail and less frequent service plan, with minimum headways going from 90 to 128 seconds, the platforms had to be widened to accommodate the increased volume of passengers waiting on the platforms (Personal Interview M 2021). Additionally, the larger diameter of the tunnels compared to regular subways increased their volume by 60%. This meant that each BC1 station needed four to eight tunnel ventilation fans, whereas most Istanbul metro stations have four, and large shafts to house station technical spaces that connect to freestanding surface ancillary structures (Figures 16-17).[51]

Third, the contract required the ventilation system to be designed to operate at the minimum air temperature of -20℃ for which the ventilation capacity had to increase even further, due to air getting heavier at lower temperatures. According to a tunnel ventilation engineer who worked on the project, this additional capacity was uncalled for, as air temperatures in Istanbul almost never reach such extreme lows (Personal Interview AA 2021). Nevertheless, the agency could not be convinced to change what the consultants had specified in the contract early on.

[51] Marmaray's ventilation scheme is very different from what is commonly implemented in Istanbul. In regular lines, even the Metro 1 type, 180 meter-platform stations, there are 4 tunnel ventilation fans (TVF) in addition to 4 station exhaust and inlet fans. 2 shafts connect the fan rooms to the surface, one at each end of the station, and each circular shaft is divided into two with the larger portion dedicated to the TVFs and the smaller, to the platform ventilation. The tunnel and station ventilation fans are horizontally configured and the grates of the shafts open to public land or road sides, flush with the ground. No at-grade structures are necessary, these shafts are built as part of the station structures and are 100% underground, which satisfies the NFPA regulations. Some "shaft" type stations designed by the Italian designer Geodata have their fan rooms in the large, central shafts.

figure 16. Marmaray’s Sirkeci Station east ventilation shaft (Google Maps a).

figure 17. Marmaray’s Sirkeci Station west ventilation shaft (Google Maps b).

Some unique components of the line being implemented for the first time in Turkey or even in the world, were also major cost drivers. The 1.4-kilometer-long immersed tunnels 58 meters under water cost $450 million PPP. Track construction was also expensive because low vibration tracks (LVT) were preferred throughout the line due to some sections’ proximity to the surface. They also had to be compatible with freight, high-speed rail, and metro trains. They cost $45 million PPP.

Land Acquisition

In Istanbul, agencies dislike allocating time and resources to land acquisition processes which are carried out prior to the construction tender, and this played a role in further complicating the construction process of Marmaray's Sirkeci station. Generally, in Turkey, the agency buys the land from the owner at market value. If the parties cannot agree, they go to court, which can take at least two years to resolve. This is also the kind of conflict that will likely receive media attention, which both the agency and the contractors want to avoid. Because Istanbul is densely built and several lines are being constructed at the same time, avoiding land acquisition is a priority in designing the right of way and selecting station locations. This does speed up the initial phases but is not ideal; stations are often built-in parks, gardens or other empty land where they become harder to access from major residential or job centers, thus reducing the efficiency of transit systems.[52]

During the construction of the entrance and ventilation shaft structures of the Sirkeci deep tunnel station, an archeological site could have been avoided by acquiring a few nearby buildings, but the building owners objected strongly, which meant the process would be costly and time consuming. Rather than embarking on a contentious condemnation process, the agency and contractors preferred to deal with the costs and delays posed by archeology (Personal Interview M). All of this could have been avoided, had a more extensive initial survey of the site been conducted prior to the construction tender and the alignment been revised, or a framework addressing the management of archeological sites during infrastructure projects was available that also addressed land acquisition conflicts.

Another lesson that the Marmaray Project taught the agencies building rail in Istanbul was that the private contractors do not have the leverage the state has when it comes to land acquisition. In the Commuter Rail Phase (CR3) of the project, which involves 63 kilometers of at-grade commuter rail rehabilitation and addition of a third track to the system, acquiring land was initially a part of the construction contract. According to a senior engineer we interviewed, the arduousness of this task was one of the reasons why the contract had to be canceled and re-awarded to different contractor teams twice (Personal Interview I 2020). Eventually, the agency took the expropriation job on themselves.

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[52] An agency planner expressed his concern on the issue: *"We should prioritize better route design and acquire land where necessary. Construction of a line planned to take 4 years takes 6-8 years in any case, so why not utilize this time better?"* (Personal interview C 2020).

Staffing and Internal Capacity

Unlike the standard metro projects in Turkey that are known to employ smaller management teams compared to the teams of rail projects abroad, Marmaray's construction was managed by a number of larger teams.[53] This was both a requirement of the FIDIC Silver Book, and the complexity and prominence of the project necessitating a bigger management team.

For the BC1 Phase, the Ministry of Transit allocated between 30-50 staff members to DLH including everyone from cleaning staff to regional directors. Avrasya Consult hired as the CM employed 50-100 people, which would be considered high for a metro project of the same length but was necessary because they were managing and coordinating three contracts at the same time.[54] Between 2004 and 2009, a separate Technical Assistance Team (TAT) of 5-10 people were hired to manage the DLH's relations with the CM and the contractor. At the end of the first 56 months, the TAT was dissolved, since the agency felt that they had enough experience to handle the operations internally.

The contractor was responsible for their own QA/QC team, and additionally they appointed a Verification Engineer for every major work group like construction or electromechanics who made sure production was carried out in accordance with the design. The contractor also required a minimum of one HSE staff and one QC supervisor from large subcontractors, so in total, 30 HSE staff worked on the project.

Quality Standards, Contingency and Profit

There has been a paradigm shift in Turkey over time: cultural heritage and environment are valued highly and mitigation measures are taken more seriously. As a megaproject, Marmaray was a milestone in terms of raising standards and dealing with these issues during infrastructure construction. According to the contractor's QA/QC manager, the contractor developed an internal quality-control method to catch and address any construction irregularities (Personal Interview M 2021). For example, both a tunneling and a TBM expert were on site weekly to provide oversight and open nonconformance reports (NCRs), that are normally filed by CMs to document deviation of work from design specifications. They were opened by the contractor's own quality control staff to prevent the CM from opening them. This was preferred as it would take longer to close the NCRs opened by the

[53] According to senior managers at contractor firms that build rail in Turkey and abroad, at every stage of the life of a rail project, Turkish teams are smaller compared to those in other countries including US, Canada, Poland and Qatar.
[54] In addition to Gama-Nurol and Taisei's contracts, a contract was made with BEM, Taisei's Electrical and Mechanical department operating as a separate entity.

CM, which meant the progress payments and consequently, the construction would be delayed. None of these are common practices in Istanbul's metro construction processes.

Turkey still spends less time and money on environmental impact analysis and mitigation, occupational health and safety measures and community engagement than the United States and Europe. Putting aside Marmaray as an exception, local experts in the field agree that the agencies should do a better job enforcing protective regulations, CMs should put more pressure on contractors and contractors should make more of an effort on these fronts. On the other hand, avoiding unnecessary delays through easing bureaucracy seems to be a strength of Turkish agencies, which contractors we spoke to appreciate especially when comparing their experiences in Istanbul to those abroad.

According to our interviews, when bidding on contracts, contractors will often propose contingencies less than 10% so they can submit more competitive bids. In the case of an immersed tube project, contingency and risk should account for at least 10% of the contract value. As these items cannot be explicitly shown in the itemized costs, risk is added as 10% and profit as 3% onto each item. In the case of BC1 an additional 5-10% was added on top of claims, change orders and archeological spending for contingency and profit, as this work constituted a serious burden to the contractor. Experts estimate that a total of 15% profit was gained from Marmaray and this is considered a high percentage when compared with the profit margins of rail projects in Turkey today. In total, 13% profit is considered good, but this number can go down to 4-5% depending on contingencies.

Lessons Learned

The design, planning, management of the HSE conditions as well as the QA/QC processes were carried out to an exceptionally high standard in the construction of Marmaray; which enabled this immensely challenging project to be completed without major technical flaws. On the other hand, lack of experience and established mechanisms to manage archeological discoveries during rail construction projects proved to be costly and led to extensive delays. Ultimately, despite all the significant cost drivers, Marmaray BC1's construction costs remain only 14% above the average PPP $210 million/kilometer among the projects in our urban rapid rail costs database.

Legislation regarding HSE impact mitigation changed in 2012, during Marmaray BC1's construction, but since the project had adopted a higher standard from the outset, no changes needed to be made. The contractor required and made sure that subcontractors abided by their occupational health and safety standards. We understand from our interviews with the senior management staff of the contractor that these measures were costly but paid off as the BC1 phase was completed with no fatal occupational accidents and set an example for other projects in the city in terms of HSE and QA/QC management (Personal Interviews K and M 2020).

BC1's construction involved managing several teams with large numbers of staff, which was carried out meticulously. Engineers who were hired to do constructability reviews of the design were graduates of top engineering programs in Turkey. Designer team's representatives were required to go to the site once a week. QC and site engineers were not permitted to become close acquaintances. The contractor paid bonuses at milestones to lower turnover and increase efficiency, as there was a lot of construction work available at that time, not only in Turkey, but all over the world. The contractor also required the subcontractors to keep their staff turnovers below 5-10% to save training time. 30 occupational safety and health engineers worked on Marmaray unlike regular subway projects in Turkey, which employ 10 or fewer HSE staff.

The management of construction alongside extensive archeological excavations was one of the toughest challenges dealt with in Marmaray's BC1 Phase. Clever coordination with the Museums Directorate proved to be key in saving time and money; however, legislative and administrations' organizational shortcomings in managing archeological excavations alongside the construction of a mega-infrastructure project in Turkey led to an increase in the complexity of operations; thus, delays and cost overruns were inevitable.

The cost of professional services like surveying, design and engineering together with mitigation in Marmaray (See Figure 15) were very high compared to other infrastructure projects in Turkey; they made up 9% of the contractor's costs. But according to a design director who worked with both contractors of Marmaray's BC1 phase and who also has experience working in metro construction projects abroad, the level of risk taken versus the time and money spent on HSE mitigation measures as well as quality control in the Marmaray project was optimal (Personal Interview G 2020). Moreover, the engineers and experts having worked on this and other rapid rail projects in Istanbul whom we have interviewed agree that Marmaray is an example of best practices in terms of developing a good final design, planning for HSE mitigation, applying quality standards and adopting competent technical and managerial expertise.

3.3 M9 Ataköy-İkitelli as a Recent Project

Overview

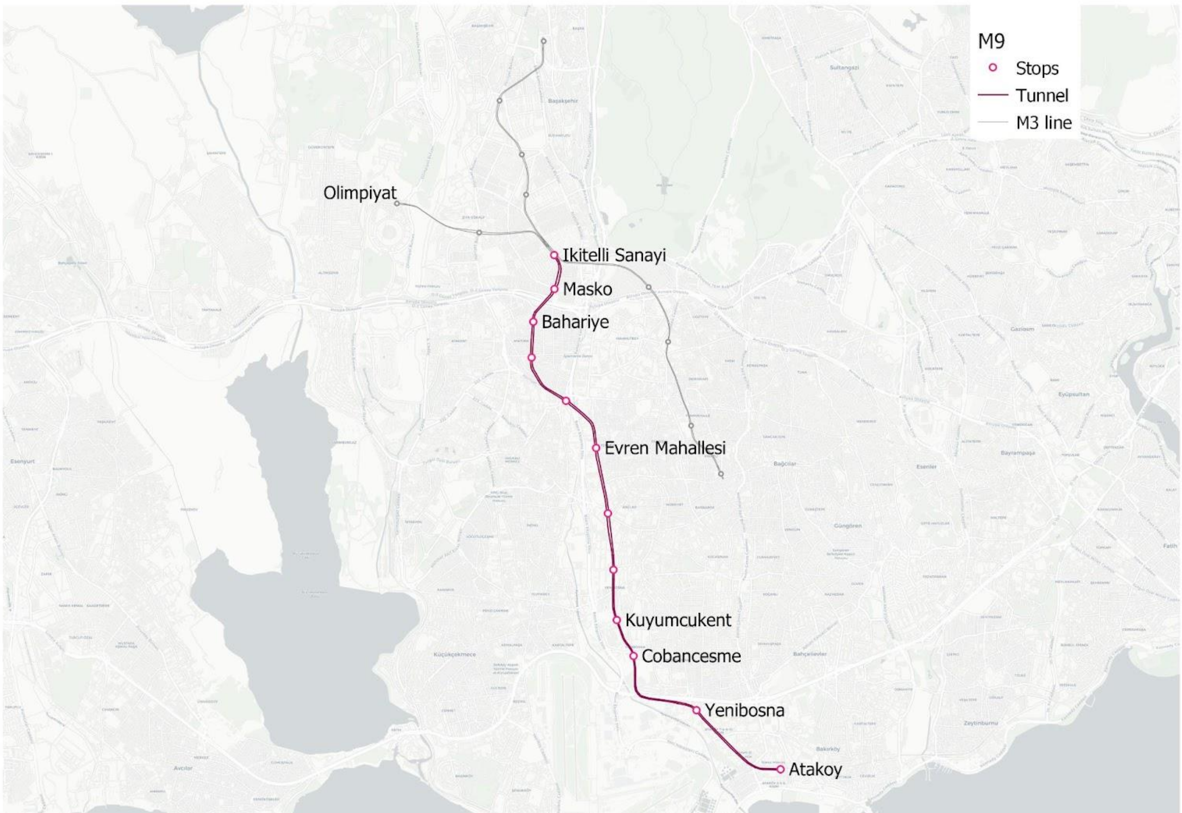

figure 18. M9 Ataköy - İkitelli Metro Line.

M9 Ataköy-İkitelli is an under construction 13.4-kilometer-long, 12-station line on the European side of Istanbul, connecting the city's rapid rail network (Figure 18). Transfers are planned with Marmaray, M1A, M1B, M2, M3 and M7 metro lines. The right of way passes M3's İkitelli station near the İkitelli Industrial Park, follows the Basın Ekspres Highway that connects the TEM and D100 highways, and ends at Ataköy Station. The route goes through both commercially and residentially dense neighborhoods, and aims to relieve congestion on the Basın Ekspres corridor, TEM and the D100 highways. The owner agency is IMM.

As our final case, M9 demonstrates how after years of agencies, contractors and consultants muddling through rail-construction projects, they now know what they need to do and have established mechanisms to efficiently build rail lines at a fraction of the cost of their international counterparts.

We selected M9 for a number of reasons, first, it is on track to cost $95 million PPP/kilometer.[55] Second, it is a contemporary project. Construction began in 2016 and as of May 2021, it was 70% complete. Additionally, all preliminary planning, procurement and supervision of the final project, management of the consultants and coordination with third parties have been carried out by the Rail System Projects Directorate; an experienced department with improved internal capacity.[56] Furthermore, it was one of the first rail projects in Turkey to integrate BIM into all stages of planning and construction.

This project exemplifies the benefits of cultivating a rail construction eco-system for a city and the effective use of technology in dealing with technical challenges during the planning and design stages of a rail project. Despite the contractor's lack of experience building rail projects, a national economic crisis that started in 2018 and a change of municipal government resulting in a slowdown of construction for 11 months; the work on M9 rapidly resumed and the line partially opened to revenue service in mid 2021 without foreseeable cost overruns.[57] We believe that the expertise and know-how acquired by the municipality as well as the designers, consultants and subcontractors working in the field through the last 20+ years of urban rail construction made it possible for the Ataköy-İkitelli project to stay on track. Also, the full integration of BIM in all processes of the design and construction helped resolve technical problems, especially those related to integration with other lines avoiding cost overruns and further delays.

Timeline and Financing

The initial idea for M9 Ataköy-İkitelli, which was included in the 2011 Urban Transportation Master Plan, called for a 12.2-kilometer line between İkitelli to Yenibosna (İBB). In this plan, M9 was envisioned as a "Metro 2," a 4-car operation serving stations with 90-meter platforms similar to most north-south lines in Istanbul's urban rail network. The maximum planned capacity was 36,000 passengers per hour per direction.

In September 2014, 36 lots along the right of way were identified for acquisition (European Investment Bank [EIB] 2016) (Table 17). Two thirds of these were privately owned but none were developed; thus, no demolition or resettlements were required. However, the land acquisition process was not completed until November 2016,

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[55] We use PPP based on 2020 as the mid-year of construction.

[56] As also mentioned earlier on in this document, this directorate was established under the Rail Systems Department and the General Secretariat of the Metropolitan Municipality of Istanbul in 2014, and started procuring final design documents at 60% design to facilitate accurate cost estimates and tendering the construction of rail lines with itemized costs.

[57] Note that this line's contract value was agreed upon in € currency which became an advantage for the contractor as the Turkish Lira lost up to 70% of its value against the € since the contract date (as of September 2021). Contracting with foreign currencies was prohibited by legislation later in 2016.

when an urgent expropriation decision was issued (DPA 2016). Construction was already underway at this time. This delay is most likely due to the revisions that had to be made by the contractor's designer.

Table 17. M9 Timeline (Cumhuriyet 2020b, EBRD 2021, EIB 2016)

Date	Item
Sep-14	Expropriation decision published for 36 lands
26-Jan-15	Feasibility study issued
19-Mar-15	"EIA not required" decision issued
02-Feb-16	Construction contract awarded to AGA for $911 million PPP
08-Apr-16	CM contract awarded to Emay Engineering for $29 million PPP
May-16	Ground breaking at Cobancesme Station site
Dec-16	Environmental and Social Due Diligence prepared to apply to European Bank for Reconstruction and Development (EBRD)
22-Dec-16	EIB approves $600 million PPP loan to the Istanbul Metropolitan Municipality for the project.
11-Jan-17	EBRD approves $262 million PPP loan to the Istanbul Metropolitan Municipality for the project.
9-Aug-18	Aga laid off 700 workers, the works slowed down or entirely stopped on some sites.
Mar-19 to Jul-19	Construction stopped due to ground conditions at certain locations. The new municipality states that 36% had been completed by 2019.
20-May-20	Rail installation starts
8-Jul-20	TBM tunneling completed (61% of the overall construction)
May-21	Masko and Bahariye Stations open, connecting to and extending M3's Otogar-İkitelli branch to Bahariye. 70% of the construction is complete.
2023	Planned completion date

IMM procured the final project ("final project for application") and feasibility studies for M9 from Istanbul Ulaşım, the public-benefit corporation owned by IMM which operated the rail lines of Istanbul as well as providing maintenance, engineering and consulting services locally and abroad. In January 2015, Istanbul Ulaşım issued an 86-page feasibility report, including travel projections, demand analyses and operation plans, economic and financial feasibility studies as well as financing schedule alternatives (Demircan 2015). This document put the first detailed cost estimate at $1.9 billion PPP including the rolling stock, based on the following breakdown (Table 18).[58]

Table 18. M9 initial cost estimates

	Item	Unit	Quantity	Unit Cost (in Million $ PPP)	Cost (in Million $ PPP)
Construction	Line (Including track work)	km	13.4	28	376
	Stations	#	12	58	700
Electrical and Mechanical Systems	Elevators and Escalators	#	144	0.4	57
	Power Supply and Traction	km	13.4	10	136
	Signaling	km	13.4	7.8	104
	Communication Systems	-	1	83	83
	Environmental Control Systems	-	1	104	104
	Station Support Systems[59]	-	1	49	49
Rolling Stock		#	72	3.7	270
TOTAL					**1,880**

The environmental impact screening process started soon after, and the Ministry of Environment and Urbanism issued an "EIS not required" certificate in March 2015.[60] The construction contract was awarded to Aga Enerji for $911 million PPP in February 2016 and the CM contract to Emay Engineering for $29 million PPP the following April. Construction was planned to take 38 months. Aga had submitted the lowest bid among 13 construction companies. Emay, on the other hand, won the tender as the fourth most expensive bidder among the 10 CM firms who submitted bids, as technical qualifications factor into the CM selection process.

As commonly seen in the decision processes involving transit infrastructure investments in Turkey, conflict arises as soon as the government and the opposition get involved. In the case of M9, the municipal parliament run by

[58] The earliest cost estimate for this line from the 2011 Transportation Master Plan is $ 1.5 billion PPP for a 12.2 km right of way.
[59] Includes drainage, fire control and protection, AG power distribution, lighting, clean and wastewater systems.
[60] See Appendix D for information on the EIS process in Turkey.

AKP at the time approved the decision to apply for international loans to fully finance the $911 million PPP construction in March 2016. The members from CHP voted against this plan, suggesting that at least a small percentage of the project should be self-funded by the municipality to minimize the debts that would be incurred from interest payments. AKP argued that there were five rail lines under construction, hence the municipality could not finance new projects relying on their own resources, and that investing in M9 would pay off in the long run. The decision passed, with the majority of votes coming from AKP members (Ocak 2016).

In May 2016, Aga Enerji broke ground at the site of the Çobançeşme Station, and within a few weeks, at the sites of Bahariye and Masko Stations. Çobançeşme was selected as the launch box location for all four TBMs, which proceeded in pairs digging north and south (Figures 19 and 20). In November, the cabinet of ministers issued a decision for the urgent expropriation of lands in the Bakırköy, Bahçelievler, Bağcılar, Küçükçekmece and Başakşehir districts (DPA 2016). By then, work was underway at Evren Mahallesi, Kuyumcukent and Yenibosna Stations as well. Mimar Sinan and Malazgirt, which are two main roads providing connection to the Basin Ekspres Highway were closed to traffic in December 2016, for two years. In January 2017, two of the four TBMs were delivered to the Çobançeşme site. By February, there was active construction at 8 separate locations (Wowturkey 2017). TBMs began tunneling in May. The TBMs maintained a 150-meter buffer between them to ensure they were operated safely and that vibrations from one TBM didn't impact the progress of the other.[61]

No ground water was encountered at the Çobançeşme site, which enabled construction to start smoothly. However, at the time when the first TBM started mining towards İkitelli Station in the north, its conveyor-belt system was still being installed; therefore, it could only proceed six meters a day. Nevertheless, the contractors preferred starting the work, rather than waiting until the installation was complete. The second TBM began digging in the same direction in early June. In August 2017, Mayor Topbaş attended the welding ceremony as part of the installation of the 3rd and 4th TBMs. He reaffirmed that the line would be completed on schedule, by 2019.

The first two TBMs reached Kuyumcukent station in October, 2017. By mid-December, 2017, the TBMs mining towards İkitelli had completed 1312 and 999 meters, and the two digging towards Ataköy were at 1107 and 654 meters (Wowturkey 2017) with an average advance rate greater than 20 meters per day. While the TBMs worked in both directions from the Çobançeşme station, the NATM method was used to excavate the tunnels starting from İkitelli, the northernmost station, to Halkalı. By July 2018, 50% of excavations had been completed.

[61] TBMs digging in parallel in the same direction require at least 150m distance between them due to the ground vibration they create, so before the second one starts tunneling, the first needs to have advanced at least 150m.

In September 2017, which was a few months after M9’s TBMs started tunneling, mayor Topbaş resigned and Mevlüt Uysal was appointed mayor. Both mayors were backed by the central government, yet media sources speculated that AKP forced Topbaş to resign to stop his spending on transportation projects, a large portion of which was allocated to metro constructions (Büyükşahin 2017; BBC Türkçe 2021). When Mevlüt Uysal became mayor, he suspended several metro lines, but M9 was spared. Nevertheless, the municipality failed to make progress payments to the line’s contractor Aga, which led to mass layoffs and the effective suspension of construction at most of the M9 sites.

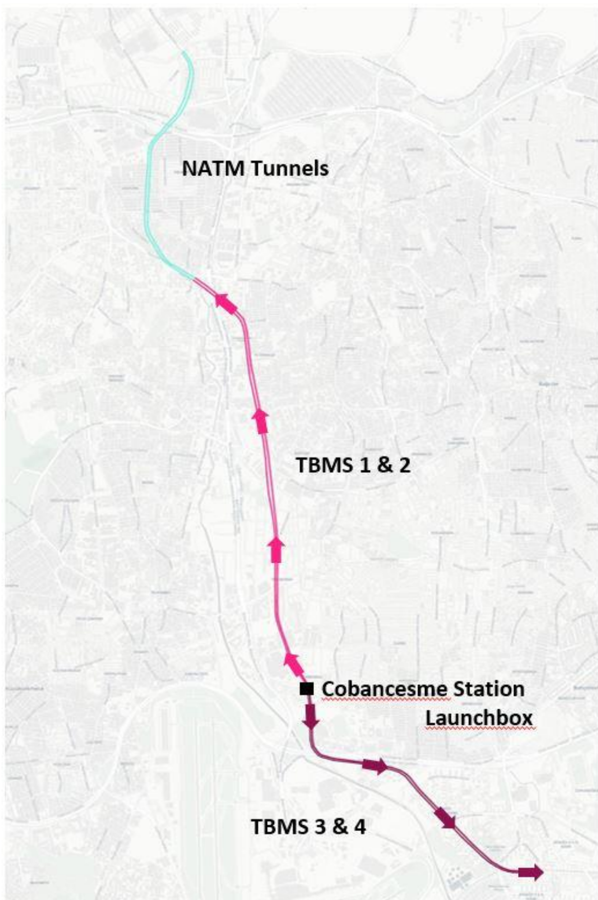

figure 19. M9’s tunnel excavation methods.

Rail tenders accepting bids in Dollars or Euros was common practice when M9’s construction tender was done. With the Turkish currency steadily losing value against the Euro, this meant that the initial ₺1.2 billion contract value had gone up to ₺2.2 billion in by August 2018 (Toker 2018). Even though a new law had been passed in

November 2016 prohibiting the tenders and contracts for public works to be executed in any currency other than the Turkish Lira, it excluded contracts that were already in effect.

The works on M9 construction sites slowed down significantly on August 9, 2018, when Aga Enerji (Bayburt Group which owns Aga) laid off 700 workers without notice. No explanation was given to the workers, their insurance plans were terminated and they were asked to sign an agreement forgoing any additional compensation. The Construction and Building Workers Union (İYİ-SEN) provided them with legal advice. Aga claimed, and professionals we have interviewed in the field later confirmed that the reason behind the mass layoff was delayed payments from IMM. This was likely due to nationwide financial challenges and the contract having been denominated in Euros. Additionally, the IMM's debt had grown at a rate that even the central government did not approve, even though the municipal government was still run by the AKP.

M9's case presents an extreme example in terms of the scale and severity of the layoff conditions, yet the Turkish construction industry is known for its mixed labor standards. A very small percentage of construction workers are unionized in Turkey. This is partly due to the work being seasonal for most workers who move from construction site to construction site in different cities, and return to other jobs in their hometown once work is completed. The other reason is that unionization has never been supported by legislation and collective bargaining is not a well-established practice in the country. Only 10% of workers are unionized, and among construction workers, less than 3% are employed under collective contracts (Confederation of Progressive Trade Unions of Turkey [CPTUT] 2019).

As was the case in M9, the use of third-party trade labor is very common in rail construction, and in the Turkish construction sector generally. Stations or diaphragm walls can be built with turnkey subcontracts given that the construction documents are supplied to the subcontractors. If construction was not subcontracted out, one line would require 1100 on-site workers, and if excavated earth shipping is included, this number would go up to 1300. In the beginning, contractors of Istanbul metros tried building with minimal subcontracting, but they found that the most risk-averse way of managing projects this large, is to subcontract jobs and distribute some of the risk. However, oftentimes, construction work ends up being subcontracted several times. This lowers the wages significantly and offloads responsibility to smaller and smaller contractors that are harder to keep accountable (Personal Interview O 2021). Hence, it was easier for Aga, the main contractor of M9, to terminate contracts with a few subcontractors than dealing with hundreds of workers, when the payments stopped coming.

TBMs stopped working in September 2018 and remaining works slowed down to the extent that most of the sites were abandoned completely. IMM declared that 30% of construction was complete and updated the planned date of revenue service to 2020. In January 2019, the agency pushed the opening back to 2021, but denied the termination of any construction work (Wowturkey 2019). At the time of the election of the new mayor in June 2019, only 36% of works were complete, but later, construction sped up again.

While the M9 project was never officially suspended, the construction of M1BX, M3-P3, M5-P2 + M13, M7-P3, M10+M4-P4 and M12, stopped in early phases when the 2018 financial crisis hit. The municipal government had failed to secure funds for these rapid rail projects prior to their tender in March 2017 and within a few months after signing their construction contracts, the works came to a stop due to the inability of the municipal government to make timely payments. In August 2018, the Ministry of Finance passed an executive order that allowed contractors to extend their delivery schedules or transfer their contracts. IMM signed protocols with all of the contractors to extend their work schedules. This allowed the contractors to make price adjustments based on Turkey's producer price index (ÜFE).[62] This only partially covered the losses of the contractors, as ÜFE had increased by 60% while the US dollar had almost doubled since 2017 (₺3.65 at the time of tender in March 2017 and ₺6.8 as of August 2018). The construction of these projects could only resume once the new mayor secured loan agreements with European funders.

In the case of M9, loan agreements had been signed with EIB and European Bank for Reconstruction and Development (EBRD) in 2016 and 2017, early on in the project timeline, but the municipal government under mayor Topbaş failed to provide securities required to receive the payments from the loan-granting institutions, which delayed construction (Personal Interview Z 2021).[63]

In March 2019, İmamoğlu was elected mayor and promptly made financial plans and secured funds to restart all the suspended rail projects. He issued municipal bonds, a first in the history of Istanbul, to finance some of the projects that were suspended (Railly News 2021). In July, 2020, at M9's TBM Excavation Completion Ceremony, the mayor announced that the first 2.1-kilometer, two-station section of the line from İkitelli to Bahariye would be commissioned in early 2021, and full length of the line, in 2022.[64] He also mentioned that construction had briefly stopped in March 2019 due to unanticipated ground conditions and in a later press conference, that much of the progress had been made in 2020. 61% of works had been completed by July 2020. On May 29, 2021, the İkitelli-Bahariye section started revenue service.

[62] ÜFE is an index based on products in farming, fishing, mining, energy and production sectors.
[63] Securities that the municipalities present to receive loans can be in the form of deposits on hold, receivable assets or mortgages.
[64] Upon request for information in September 2021, the Rail Systems Department declared the planned date of completion as 2023.

figure 20. Image by IMM, Mayor Topbaş attending the TBM welding ceremony at the Cobancesme launch box.

Scope and Contracts

M9 provides a cross-over connection with M3 at the İkitelli Station, so the trains will continue up north from İkitelli to Olimpiyat which was part of M3 but will now be operated as M9 (Figure 21). M9's scope included integrating the existing M3 signaling systems with the newly built stations, Masko and Bahariye, that were commissioned on May 29, 2021, with the remaining stations to be completed in 2022[65] (See Tables 19 and 20 for scope and contract details). This integration also allowed for the existing M3 storage yard to be shared obviating the need to build a new facility.

[65] Currently slated to open in 2023.

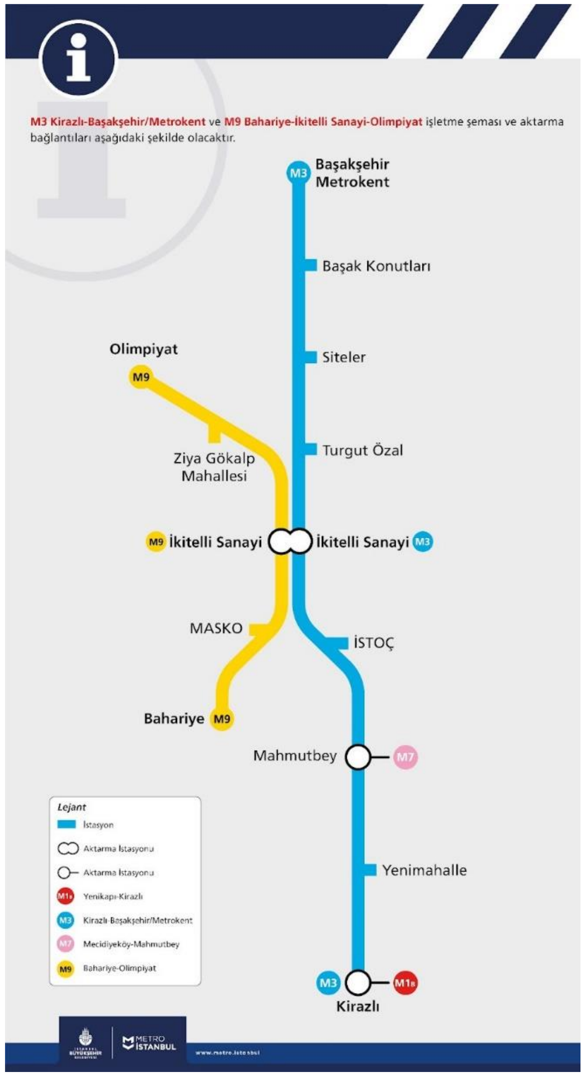

figure 21. M3-M9 map by IMM. Olimpiyat, Ziya Gökalp and İkitelli Stations used to be operated under M3, but now belong to M9.

Table 19. M9's Scope

ELEMENT	SCOPE	FEATURES
Guideway	• 13,39 kilometers guideway	• Single line • Completely underground system
Track	• Twin tracks	
New Stations	10 new stations + finishing and electromechanical works of Masko station. İkitelli station had previously been completed as part of M3 construction starting service in 2012. • (İkitelli Guney Sanayi) • Masko • Bahariye • Atatürk Mahallesi • Halkalı Cad (212) • Evren Mah • Mimar Sinan • Doğu Sanayi • Kuyumcukent • Çobançeşme • Yenibosna • Ataköy	• Masko: deep tunnel and C&C construction, 26 meters deep (Civil works had been completed previously) • Bahariye: deep tunnel and C&C construction, 18 meters deep • Atatürk Mahallesi: deep tunnel and C&C construction, 22 meters deep, transfers to M7. • Halkalı Cad: deep tunnel and C&C construction, 25 meters deep • Evren Mah (15 Temmuz): deep tunnel and C&C construction, 30 meters deep • Mimar Sinan: deep tunnel and C&C construction, transfers to M1 at concourse level • Doğu Sanayii: deep tunnel and C&C construction, 25 meters deep • Kuyumcukent: deep tunnel and C&C construction, 36 meters deep • Çobançeşme: C&C construction, 21 meters deep, planned transfer to Sefakoy Incirli • Yenibosna: deep tunnel and C&C construction, 22 meters deep, transfers to M1 at concourse level • Ataköy: C&C construction, 21 meters deep, transfer to Marmaray
Tunnels	• 13.39 kilometers twin bore tunnels	• 4 TBMs utilized for 11 kilometers of tunnels. All were launched from Çobançeşme station, each pair mining in opposite directions (North - South). • Tunnels between İkitelli and Halkalı were built with NATM.
Systems	• Traction power supply system • Overhead catenary system • Signaling systems • Telecommunication system • SCADA system • Operation control and administrative centers • Electrical distribution system • Elevators and escalators	• Signaling Grade of Automation: 2 • ThyssenKrupp: 25 elevators and 116 escalators.
Support Facilities	• The line will share M3's yard at Olimpiyat Station for maintenance and storage.	• Control center and offices will be located in a structure to be constructed on top of the existing M3 maintenance yard.

Table 20. M9 Contractors

Contractor	Scope	Cost	Year	USD with PPP
Emay	• Control/supervision, engineering and consulting	₺36,936,185	2016	$29,740,593
Aga Enerji	• Construction and electromechanics	€338,272,200	2016	$911,194,382

Competition

Istanbul rail construction tenders are often subject to intense competition, with six, eight or even ten contractor teams vying for the lowest bid. Bidders are required to secure bid bonds with a value of 3% of their bids, to be submitted with their offers, and performance bonds with the value of 6% of their bids at time of signing the contract, if they are awarded the tender. Additionally, they use "construction all risk insurance" which covers liabilities re: emergency events like fire, flooding etc.[66] These extra costs, and the qualification requirements at the RFQ stage act as barriers against smaller contractors, however, smaller contractors can bid in tenders by forming joint ventures with larger firms. This increases the overall competition for these contracts and has resulted in fierce competition in the rail construction industry.

There are over 450,000 contractors in Turkey (Balbay 2020), and while the number of firms that have the capacity and know-how to undertake rapid rail projects is small, it is large enough to increase competition and lower the bids. Many sources mentioned that the level of competition is very high in Turkey, and in some instances becomes unfair. In one instance, 17 bidders qualified for a tramway construction tender.[67] When there are too many bidders, prices go too low and so the 20% cost increase cannot be avoided.

Since construction contracts are awarded based on the lowest-bid criterion, a comparison of the project cost estimates obtained by the agency and the contract values can provide a sense of how low construction firms are willing to bid, in order to win contracts. The estimated values are not revealed prior to the tender, but since an itemized list of quantities is provided to bidders as part of the tender documents, and a majority of the material,

[66] This is very different from the US where insurance is required to cover 100% of the costs.
[67] 17 firms were shortlisted, 6 of them submitted bids (Rayhaber 2020).

equipment and labor are priced based on standardized cost lists, the contractors have the information they need to attain similar estimates.

Looking at the differences between the estimates and contract costs of 16 lines, we see that save for five projects that were tendered in March 2017, the contract values go as low as 35% below the estimated costs (Table 21).[68] In fact, in the case of M9, the contract was awarded to Aga Enerji at a value that is 31% lower than the project's estimated cost, which can be attributed to the increased number of firms that qualified to bid, due to the lowering of the qualification requirements in the tender call.

A comparison of the call for tenders of M5 (06-28-11) and M7-P1-2 (12-18-13) reveal the change in qualifications requirements in the tender calls. In the earlier M5's call, work under either of the following three groups of work areas qualified: G-I) Railway, Rail Systems, A-III) Foundation-Tunnel, Closed Drainage, Gallery (and Shaft) Works D-IV) Electromechanical Works, Rail Systems Electrification Works; while in M7-P1-P2's call, work under either of the following two groups qualified: A-VI) Railway Works (Infra+Superstructure) or D-VI) Electric Transit Vehicle Technology Works. The latter included Electromechanical works, Rail Systems Electrification, Rubber Tired Transit Electrification, Cable Transit Electrification and Electric Vehicle Charging Station Works. This meant that a contractor who had built an Electric Vehicle charging station could bid for a rail tender that involved several kilometers of tunneling.

This change in the qualification requirements applied to all rapid-rail tenders opened after M7, and allowed smaller firms with little to no experience in rail construction to enter and win tenders. For Aga Enerji, known to be "good friends" with the AKP government, it meant winning the bids for both M3-P3 and M9, without having to form joint ventures with larger, more established construction firms.

Senior managers who have worked for contractor firms in Turkey and abroad mentioned that the level of competition lowers costs to the extent that contingencies are not planned for and quality of construction is risked especially after the qualification conditions were lowered to allow for inexperienced contractors to bid on rail projects (Personal Interviews I and J). However, supporting evidence is hard to track down; many of these lines are new, if not still under construction. Maintenance and downtime costs over several years should be considered and possibly compared with other systems around the world for a conclusive verdict. On the other hand, based on our interview with industry experts, the agencies IMM and AYGM, the designers, the CMs and the

[68] These five lines's tendering processes were heavily criticized for interfering with competition and for political corruption. The contracts were awarded to five different consortia on the same day, and each of them had bid for all 5 projects, strategically winning only one.

subcontractors have gained a level of experience and know-how that can make up for the shortcomings of the contractor, guaranteeing an acceptable level of construction quality.

Table 21. Estimated vs. contract values of projects (Data from Anil Acar)

LINE	CONTRACT DATE	CONTRACT VALUE	COST ESTIMATE (pre-tender)	PERCENT DIFFERENCE
M5 Phase 1	3-7-12	€563,899,995	€725,114,251	78%
M7 Phase 1-2 (partial)	12-18-13	₺849,440,000	₺1,301,139,309	65%
M3 Phase 2	3-3-15	€241,931,244	€273,364,236	89%
M4 Phase 3	3-4-15	€169,500,810	€226,329,378	75%
M7 Phase 1-2 (partial)	5-13-15	€369,000,000	€507,120,700	73%
M9	2-2-16	€338,272,200	€490,904,390	69%
M8	2-12-16	€558,800,000	€758,774,349	74%
M11 Phase1	12-7-16	€999,769,692	€1,085,758,113	92%
M12	4-14-17	₺2,469,924,400	₺2,182,165,754	**113%**
M1B Phase 2	4-14-17	₺2,414,401,632	₺2,112,656,587	**114%**
M13 + M5 Phase 2	4-14-17	₺2,342,385,741	₺2,058,446,722	**114%**
M10 + M4 Phase 2	4-14-17	₺1,613,815,000	₺1,417,538,734	**114%**
M3 Phase 3	4-14-17	₺969,114,610	₺846,210,928	**115%**
M7 Phase3	8-17-17	₺3,049,994,728	₺3,099,751,852	98%
M11 Phase2	3-7-18	₺4,294,713,000	₺5,080,000,440	85%
Gebze -Darica	6-12-18	₺2,488,489,457	₺2,797,169,356	89%

Challenges and Technological Approaches

Coordination, not only between multiple engineering and design teams but also with the ministries and the military during M9's construction was critical in avoiding potential conflicts. The line was designed to integrate with six other metro lines and the right of way intersected with the Ayamama stream, a NATO oil pipeline, and an international telecommunications line. Several parts of the route went through weak soil and in some sections of the line through silt-clay (AASHTO classification A5)[69] that required extra support using umbrella arches and frequent braces which was costly (Personal Interview H 2020). Moreover, the line went through dense settlements with low quality building stock, necessitating extensive geotechnical planning and monitoring during construction. Like most north-south metro lines in Istanbul, the stations have 90-meter platforms and are smaller than their east-west counterparts, requiring meticulous coordination to integrate mechanical and electrical systems inside smaller spaces.

The designers hired by the contractor addressed some of these issues using Building Information Modeling (BIM) technology during different phases of the construction. BIM is a technological innovation on the software side of rapid-rail design, management, and construction that allows three-dimensional architectural and structural models of built assets to be linked with multidisciplinary information including labor, material, equipment, cost and scheduling data. In Istanbul, BIM has been used in rail projects' design since 2013 and has been added to contracts as a requirement from the contractors since 2014, starting with M7's construction tender. Having detailed BIM specifications in the construction contracts allows for seamless coordination across teams at every stage of a project, from planning to construction. This emphasis on BIM in Istanbul has been acknowledged globally; local firms have won multiple BIM design awards for the successful implementation of BIM solutions in rail projects.[70]

M9's designers working with the contractor used BIM models to determine the shaft and station locations of the line, while avoiding existing buildings and infrastructure (Figures 22-24). While building the BIM model, they laser-scanned the sites and used point cloud technology. Construction progress was updated in real time on these models and shared with all teams, coordinated by the design team and approved by a BIM manager appointed by the CM or the agency. Tunnel excavation and final lining process work program verification was done through 4d models integrating time as a component in the 3d models which prevented the TBM schedules from conflicting

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[69] Meaning 35% or more of the material would pass through a 0.075mm sieve (Jamal 2019).

[70] Designer firm Yüksel Proje won Autodesk's AEC excellence awards in 2019, in both the large and medium scale project categories, for the BIM project of M12 line and their "Istanbul Rail Systems Design Services" for other Istanbul metro projects they have utilized BIM. Prota Engineering was shortlisted for the same awards in 2020 with their BIM projects for the Istanbul M9 and Mersin Metro lines.

with the construction schedules of station components, which is critical to keeping phased construction on schedule and from preventing mishaps. Integration of the line with the existing transfer stations also benefitted from laser scanned point cloud models. QR codes were utilized in technical rooms providing instant access to Room Data Sheets which helped staff monitor construction (Personal Interview Y 2021).

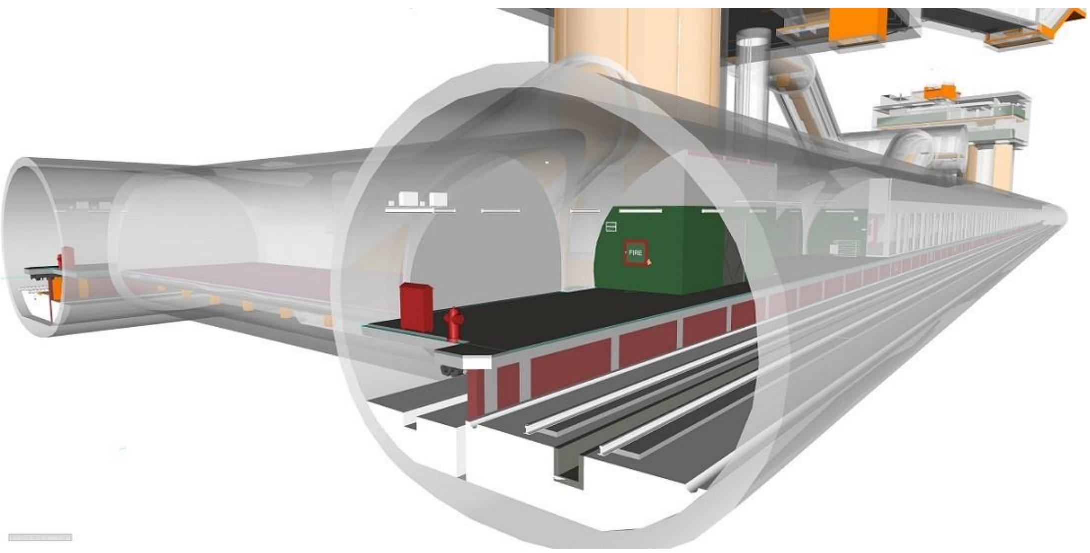

figure 22. BIM Model of M9 Platform tunnel. Courtesy of Prota Engineering.

figure 23. Yenibosna Station BIM model and existing site conditions (laser scan) integration. Image courtesy of Prota Engineering and Aga Energy.

figure 24. Doğu Sanayi Station: Existing site conditions (laser scan) integration. Image courtesy of Prota Engineering and Aga Energy.

M9 is seen as a pioneer among Turkey's rail infrastructure projects in terms of the level of integration of BIM technology in its construction processes along with M8 Dudullu-Bostancı. M9 was an infrastructure category finalist in both of Autodesk's 2018 and 2020 AEC Excellence Awards that honor the innovative applications of "technology for collaboration, prefabrication, and design automation" in the building industry (Autodesk n.d.). Both the Rail Systems Department under IMM and the Ministry of Transit under the central government value investing in the integration of BIM technology in their infrastructure construction processes. Following her appointment as the head of Rail Systems Department of IMM by the new mayor İmamoğlu, Dr. Alpkökin initiated the establishment of a new BIM team within the directorate. Also, the Ministry of Transit issued new BIM specifications for infrastructure contracts in 2021.

Lessons Learned

We believe that M9's relatively steady progress, following the 2018 economic crisis, can be attributed to a number of factors, most of which are consequences of the competitive construction market, as well as years of accumulated experience within IMM's Rail Systems Department and the city's rail infrastructure construction sector. Despite Aga Enerji's own lack of experience, it had access to engineers, consultants and subcontractors in the market who had gained expertise through decades of building rail in the city. Moreover, by the time work started on M9, the IMM had overseen 100 kilometers of rapid-rail construction with another 135 kilometers in progress. During this period of intense rapid-rail construction, the agency reorganized itself, established working relationships with competent consultants and contractors, refined its procurement process, and improved standards to enhance working conditions and manage nuisances. Aside from the delays due to financing issues, M9's construction proceeded without major setbacks and the line is expected to be completed by 2023 with minimal to no cost overruns.

By the time of M9's construction, the Rail Systems Department had established mechanisms to manage the contractor more effectively. One example of this was the geotechnical planning specifications in the project's contract. Rigorous geotechnical monitoring and relevant mitigation measures had been adopted by the agency after the establishment of the Rail System Projects Directorate under the department. Specifications for a ground settlement monitoring plan and monitoring-system equipment were provided in the contract. The geomonitoring implemented for the construction of M9 involved hourly readings from sensors at multiple locations, through which any surface deformation was reported to the NATM and TBM teams, the CM, and the agency. The scope of the monitoring was specified in the contract in detail, and involved the definition of an impact zone which would cover all locations where a ground settlement over 1 cm (0.4 inches) was expected.

Aga Enerji, which had only built highways and was known as an excavation subcontractor when it won M9’s construction tender, benefitted from its collaboration with Prota Engineering, whom it hired as its designer. Prota had designed several rapid-rail lines in Istanbul and other cities in Turkey, including Istanbul’s M4, the CR3 phase of Marmaray and a light rail line in Izmir as well as having experience in Europe, designing Warsaw’s line II. It had worked with both the IMM and the AYGM under the Ministry of Transit in Istanbul. Prota was also the driving force behind the adoption of BIM in the infrastructure sector, which the municipality adopted and mandated in 2015. So even though Aga Enerji lacked experience, it worked with experts in the field and invested in developing the expertise to build rail in the future.

Mismanagement of M9’s project financing was the major culprit behind the delays over the life of the project (Personal Interview V 2021). Even though agreements with European grantors had been signed early on, resources to be declared as securities to receive the payments had not been allocated, hence the agency missed payments to the contractor. Works on M9’s construction sites slowed down and wouldn’t pick up for a year. Istanbul’s newly elected governor İmamoğlu was well aware of the urgency of the city’s transit infrastructure needs, so soon after taking office in 2019, he secured new resources to fund M9 and all the metro projects that had stopped construction because of the 2018 financial crisis.

4 Conclusion

4.1 What is There to Learn from Istanbul?

Based on our study of Turkish rail construction, we found that there were four primary factors that kept construction costs low and the processes efficient. First, there was an ongoing political commitment spanning different administrations to build an extensive rail network. Second, through years of construction experience, initially learning from foreign experts brought in to consult and train the Turkish teams, and later collaborating with Turkish contractors and consultants who were now building rail all over the world, the agencies gained the capacity to streamline processes and manage projects efficiently. Third, market competition encouraged contractors and consultants to lower their costs, while developing their technical and technological capacities. Fourth, all parties involved quickly learned that speed saved money, and refined their processes to avoid unnecessary delays. Ultimately, these conditions cultivated a competitive, agile and competent rail sector.

Throughout the last 20 years, the IMM has developed know-how and optimized its procurement processes to better manage rail construction projects. On the other hand, the AYGM under the central government has recently hired former IMM personnel as AYGM has begun to manage more projects in Istanbul. Since 2014, the IMM has utilized "final design for application" projects that are at 60% design, which has helped it go to construction tenders with more detailed information and better control over projects. In the earlier projects where the agency was still figuring out how to build subways, they would go to tenders with an underdeveloped preliminary design, leading to higher costs due to overdesign overseen by the contractors, as was the case for M4 and earlier projects. By the time the agency started working on M5, it knew enough to specify better optimized station and tunnel designs. The contractors we interviewed agreed that this was one of the major changes that improved rail-construction processes; over the last 15 years, the agency has learned to spend more time on the design, working with experienced design consultants, prior to the construction tender.

Developing a good working relationship between public agencies and contractors has been critical to Istanbul's success building more than 300 kilometers of heavy rail between 1989 and 2030. The agencies and contractors have struck this balance by tendering based on itemized costs and procuring the construction through as few contract packages as possible, which help the agency keep the process and costs under control. Additionally, agencies have expedited approvals and paperwork that allows for construction to start and advance quickly once the contract is signed. With the agency and contractor working together, the preliminary designs can be altered and innovative solutions can be developed quickly. While the costs are locked in through the contract, since the contracts are based on itemized costs, increases are allowed based on changes. However, the total increase is limited to 20% of the contract value. Increases beyond 20% need cabinet approval, which is almost always avoided to prevent delays. Nevertheless, through regular progress reports and payments, spending is kept under control by the agency. Additionally, multiple people whom we interviewed including one senior agency executive concluded that distributing risk among multiple contracts and contractors is unnecessary, and Istanbul saves money and time by avoiding breaking the work into multiple contracts (Personal Interviews G, J, L 2020 and P, V 2021).

It is not uncommon for a metro construction tender with a scope involving over 10 kilometers of tunnels to receive six or more bids, even when there are several lines under construction at the same time. The intense competition for metro construction encouraged contractors to innovate and bring their prices down. Contractors are motivated to win bids because there is a clear pipeline of new metro projects and many have invested in technology and expanded their equipment pools. Since 2014, Building Information Modeling (BIM) has been used in design, planning and management of construction, and it has been mandated through the agency's contract specifications. Design consultants, construction managers and contractors rapidly adapted to the new requirements and all attribute their improved coordination and more efficient management of projects to BIM solutions. In addition to greater competition amongst general contractors, it is also now easier for contractors to buy or rent construction equipment, which reduces costs. Many contractors own TBMs, and keep costs low by utilizing the same machine on multiple projects. They also understand the specifications of the equipment better, and therefore can buy TBMs suitable for different soil conditions rather than changing cutter heads during construction, which slows down the pace of tunneling and adds costs.

The agencies, contractors and consultants understand that speed saves money. The Environmental Impact Statement (EIS) certification and preliminary approval processes are rapid, and the contractor starts excavating as soon as the project's rough boundaries, such as station exits and entrances, are determined. The contractors obtain pre-approval to start excavating before the designs are 100% complete and break ground, even though this sometimes means needing to do revisions. A senior manager we spoke to attributed Istanbul's speed and lower costs to the Turkish teams' ability to think outside the box (Personal Interview I 2020). The contractor and the agency develop quick solutions for problems that come up and find ways to work within the plans, standards and regulations. So, the project ends up changing a great deal throughout the construction process, but is completed within the planned budget, or with the 20% allowable cost increase, and fast, relative to other countries in our database.

A steady stream of projects, competition between the IMM and the Central Government's Ministry of Transportation, as well as a robust pool of contractors vying for work has cultivated a productive rail-construction ecosystem in Istanbul. This benefits the city, even in cases where a contractor lacks experience, the agency, consultants, subcontractors with years of experience in the field along with the now established procurement mechanisms can make up for these shortcomings by helping the contractor learn on the job and deliver projects with minimal delays and cost overruns.

4.2 Is There Room for Improvement?

While Istanbul has managed to expand its rail network rapidly and at a fraction of the cost compared to cities in Europe and North America, a number of issues remain unresolved in the rail-construction industry. The agencies and the contractors building rail in Istanbul know that speed saves money, yet rushing through certain stages, especially the preliminary planning processes can bring on challenges later, during construction. Health, safety and environment (HSE) mitigation budgets are small and without a prevailing culture of community engagement related to infrastructure projects, environmental disruptions can be overlooked. Low labor and white-collar wages bring down labor and professional service costs, but at the cost of unionization and precarious labor conditions, which are susceptible to the will of the contractors. Local and national politics help boost rail projects, but political conflicts also delay schedules and lead to cost overruns. Archeology remains a challenge for tunnel excavation in Istanbul, and the city lacks a guiding framework defining the principles of managing an infrastructure project in the presence of archeological discoveries.

Even though many practices and conditions have improved over the years, especially after the establishment of the Rail System Projects Directorate under the IMM; experts who have long been involved in rapid rail construction in Turkey agree that there is still room for improvement on the following issues:

- Speed can sometimes come at the cost of quality. Supervision is not always strict and intervention is minimal to keep construction going, so the end product may not last as long. The British say their new lines will last 120 years. In Istanbul, many new lines will likely need to be replaced/repaired in less than 100, according to a few sources who expect this to reflect on the maintenance costs in the future (Personal Interviews G, I 2020 and T 2021). However, maintenance costs are a problem for rail infrastructure in many countries we have studied, and it is also difficult to make comparative projections for which system will require costly maintenance earlier in their useful life.

- Mitigation and preliminary planning budgets are low, so, even though there has been greater emphasis on HSE mitigation measures, they are not as well planned and prepared for as in European and North American countries. One senior quality engineer explained that the agencies could save 5-10% by spending 2-3% more on the preliminary design as well as HSE mitigation measures; by which he implied that Turkish teams were generally not good at this, and lost money in the later phases of construction having to do repairs related to environmental damage and design revisions that could be avoided with more rigorous planning early on in the project (Personal Interview M 2021).

- Labor is cheap and teams work around the clock. TBMs operate 24 hours a day, and teams take one Friday off every two weeks. The agency and the general contractor lack sufficient control over the work conditions of subcontractors. In terms of the quality of production, this has less influence on the tasks that require expertise, such as TBM tunneling, because local teams need to compete with international teams and so are required to provide high quality services (Personal Interview AB 2022).

- Professional staff are paid too little. Engineers, designers and CMs receive a fraction of the contractor's fees or what their counterparts would be paid in Europe and North America. This impacts the time and effort spent on design, planning, quality assurance/quality control (QA/QC) and mitigation. Turnover rates at consultant firms are also high, meaning, experienced teams do not remain together for long.

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- The RFQ standards have been lowered, which is one reason for increased competition. The other reason is that Turkey has over 450,000 contractors. This also means less experienced contractors can be awarded large subway projects.

- Politics are very much a part of how rail systems are planned and constructed in Turkey. The central government and the local municipalities run projects separately and the central administration does not pay for municipally run projects. Political pressure can speed up construction but may also hinder

QA/QC processes by rushing the commissioning dates. Conflicts between the local and central governments can delay permits and increase third-party costs. Also, changes in political administration can result in mass firings and hirings, which means the agency may be unable to retain experienced personnel, as was the case when the İmamoğlu administration beat AKP in municipal elections. However, several of these experienced staff members were hired by the central government which currently oversees more than 80 kilometers of rapid-rail construction projects in the city.

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- Archaeology has and will continue to be an issue in rapid-rail construction. Therefore, it is important to develop guidelines on how to manage rail-construction projects in archaeologically-rich environments, similar to those we saw in Rome.

Istanbul, having started building its rapid-rail infrastructure in the late 1980s, has come a long way within three decades, owing to sustained political will, a steady pipeline of new projects, evolution of the owner agencies, streamlined procurement processes, and the cultivation of expertise in its rail industry leading to competition between contractors and the lowering of costs. On the other hand, rail construction in the city suffers from the impact of political squabbles between the central and local governments, inadequacies in the implementation of HSE mitigation measures, substandard labor conditions and corruption. Produced as part of a series of case studies from around the world within the scope of the Transit Costs Project, this report argues that based on Istanbul's positive *and* negative experiences other agencies can bring down construction costs through efficient management while maintaining standards for labor, mitigation and the quality of construction.

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Personal Interview S, April 2021.

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6 Appendices

Appendix A: Operation and Ridership

Istanbul metros run between 6am and 12pm during weekdays, with headways ranging between 5-10 minutes at peak hours. Since 2019, lines M1A, M1B, M2, M4, M5 and M6 are operated 24 hours a day on weekends and state holidays, with 20-minute frequencies and double fares.

Below are monthly ridership numbers of active lines in Istanbul, in millions, for the months of February between 2016 and 2020. February was selected as the last month before Covid-19 lockdowns impacted ridership. The month of October shows the highest ridership with 20% more riders per line on average than February; and August the lowest, going as low as 20% below February numbers on average for these five years.

Table A-1 Monthly ridership in millions of passengers

	Feb-16	Feb-17	Feb-18	Feb-19	Feb-20
M1	12.2	11.8	12.4	11.9	12.1
M2	12.2	11.3	12.2	12.3	14
M3	1.7	1.7	1.9	1.8	2.1
M4	7.4	8.1	8.3	7.5	7.3
M5*	-	-	2.1	4.7	6.1
M6	0.5	0.5	0.5	0.5	0.6

*M5 started service in December 2017. M7 line started service in October, 2020 and the latest ridership data shows 1.7M as the highest number of passengers in the month of November, 2020.

The highest daily ridership of the Marmaray commuter line to date has been recorded as 500,000 on November 20, 2019 (TCDD Taşımacılık 2020).

Table A-2 **Yearly ridership data of Istanbul lines. M5 started service in December 2017.**

	2016	2017	2018	2019	2020
M1	151.5	152	155.9	149.5	83.1
M2	137.4	141.8	150.7	161	76.7
M3	21.3	22	23.2	23.7	16.6
M4	87.5	99.7	101.8	88.7	41.2
M5*	-	1.3	32.3	66.5	38.7
M6	5.5	5.9	5.7	6.1	2.4

Appendix B: TBM Staff Wages

Istanbul wages on this and the following tables are for January 2021, a 37% raise was applied to all wages due to rapid inflation later in the year. Old wages are used as they are compatible with the latest PPP of 2020, which is not available for 2021 as of June 2021.

Table B-1 **Istanbul *monthly* wages of workers in a 2 TBM rail construction.**

TBM CREW Net Monthly Wages for each person working one 12-hour-shift a day starting at 7.30 am or pm	**1 worker's wage** (exr.:7.4, not PPP adjusted)	**1 TBM** # personnel	**2 TBMs** # personnel	**2 TBMs cost** (PPP= 3.3)
TBM Tunnel Chief	$2,000	1	1	$6,600
Shift Engineer*	$810-$1010	2	4	$10,070-$13,330
TBM Operator	$1,075	2	4	$14,190

Erector Operator	$663	2	4	$8,745
Segment Crane Operator	$613	2	4	$8,085
Injection (Grout) Master	$613	2	4	$8,085
Injection (Grout) Worker	$563	2	4	$7,425
Bentonite Master	$563	2	4	$7,425
Conveyor Belt Master	$563	4	8	$14,850
Segment Lining Installation Master	$563	4	8	$14,850
Rail-Walkway Installer	$563	4	8	$14,850
Pipe + Plumbing Pump Master	$563	4	8	$14,850
Master Electrician	$675	2	4	$8,910
Electrician	$525	2	4	$6,930
TBM Repair and Hydraulics Master	$888	2	4	$11,715
Disk Installer, Maintenance and Greaser	$613	2	4	$8,085
Welder	$625	2	4	$8,250

* Min and max. wages based on level of experience

	1 TBM	2 TBMs	2 TBMs cost (PPP= 3.3)
Tbm Crew Size	41	81	
Tbm Crew Total Net Monthly Wage			**$175,890**
Tbm Crew Total Monthly Costs (wages *1.4: includes insurance, accommodation, food)			**$246,246**

Table B-2 Istanbul *monthly* wages of workers in a 2 TBM rail construction.

TBM SURFACE SITE CREW	1 worker's wage (exr.:7.4)	2 TBMs Day Shift, # personnel	2 TBMs Night Shift, # personnel	2 TBMs cost (exr:7.4, PPP= 3.3)
Electric Crew				
Electrical Engineer	$1,200	1	X	$3,960
PLC Operator	$950	1	X	$3,135
Electrical Foreman	$1,050	1	X	$3,465
Electrician Master	$675	1	1	$4,455
Outer Site Electrician	$590	3	2	$9,735
Survey Crew				
Topographical Engineer*	$540-$675	1	X	$1,780-$2,230
Topographical Technician*	$470-$810	1	1	$3,120-5,350

Equipment Operator	$550	1	1	$3,630
Chainman	$338	2	2	$4,455
Workshop Crew				
Machine Supply Chief	$1,200	1	X	$3,960
Mechanical Engineer	$800	1	1	$5,280
General Foreman*	$675-$1070	1	X	$2,230-$3,530
Installation Foreman	$1,100	1	X	$3,630
Mechanical and Hydraulic Journeyman	$900	1	1	$5,940
Workshop Mechanical Assistant	$600	2	2	$7,920
Auto Electrician	$600	1	X	$1,980
Welder	$638	4	X	$8,415
MSV Operator	$622	5	4	$18,480
Belt Supervisor (Site+TBM)*	$510-$810	1	X	$1,700-$2,675
Belt Staff (Site)	$542	3	3	$10,725
Outside Site Plumbing + Chiller*	$405-$565	2	2	$5,350-7,455
Surface Site				
Outside Site Boss	$800	1	1	$5,280
Shaft Head Segment Transfer and TBM Logistics	$450	5	5	$14,850

Shaft Tail Segment Transfer and TBM Logistics	$447	8	8	$23,595
Portal Crane Operator	$500	2	2	$6,600
Grout Station Operator	$575	1	1	$3,795
Grout Station Assistant	$475	1	1	$3,135
Reporting Staff	$600	1	x	$1,980
* Min and max. wages based on level of experience				
		2 TBMs Day Shift	**2 TBMs Night Shift**	**2 TBMs** (PPP)
Surface Site Crew Size		54	38	
Tbm Surface Site Crew Net Monthly Wage For 2 Tbms				$176,220
Tbm Surface Site Crew Total Monthly Costs (wages *1.4: includes insurance, accommodation, food)				**$246,708**

Table B-3 New York ***weekly*** **wages of workers in a 2 TBM rail construction.**

TBM Staff	1 Worker's Total Wages and Benefits	1 TBM 1 Shift Personnel	Union	1 TBM Shifts/ Day	1 TBM Total Personnel /Day	1 TBM Staff Total Weekly Fees
General Foreman	x	1	SH (local 147)	3	3	x
Walking Boss	x	1	SH (local 147)	3	3	x
Journeymen	x	6	SH (local 147)	3	18	x
Miner- Mole Nipper	x	1		3	3	x
Miner- Brakeman	x	2		3	6	x

Electricians	x	2	SH (local 147)	3	6	x
OE- TBM	x	1		3	3	x
OE- Locomotives	x	2		3	6	x
OE- TBM Maint Engineer	x	1		3	3	x
OE- Main Man	x	1		3	3	x
Laborers	x	2	SH (local 147)	3	6	x
TBM Crew Total		**20**		**3**	**60**	**$221,159.52**
Support Gang						
Labor Foreman	x	1	Local 731	3	3	x
Laborers	x	2	Local 731	3	6	x
Miner-Superintendent	x	1	SH (local 147)	3	3	x
Miner Foreman	x	1	SH (local 147)	3	3	x
Miner Change House	x	1	SH (local 147)	3	3	x
Miner Safety	x	1	SH (local 147)	3	3	x
Miner Top Bellman	x	1	SH (local 147)	3	3	x
Miner Top Laborer	x	1	SH (local 147)	3	3	x
Miner Top Nipper	x	1	SH (local 147)	3	3	x
Miner Bottom Bellman	x	1	SH (local 147)	3	3	x
Miner Bottom Laborer	x	1	SH (local 147)	3	3	x
Miner Bottom Dumpman	x	2	SH (local 147)	3	6	x
Miner Bullgang Foreman	x	1	SH (local 147)	3	3	x
Miner Bullgang Laborers	x	2	SH (local 147)	3	6	x
OE- Crawler Crane	x	1	OE- Local 14	3	3	x

Oiler- Crawler Crane	x	1	OE- Local 15	3	3	x
OE- Loader	x	1	OE- Local 14	3	3	x
OE- Compressor	x	1	OE- Local 15	3	3	x
OE- Muck Conveyor	x	1	OE- Local 15	3	3	x
OE- Master Mechanic	x	1	OE- Local 14	3	3	x
OE- Maintenance Foreman	x	1	OE- Local 15	3	3	x
Surveyor	x	1	SH (local 147)	3	3	x
Teamsters	x	1	local 282	3	3	x
Support Gang Total		**26**			**78**	**$269,892.51**
Management Staff	**80% of management costs are for the TBM work**					
Safety personnel	x	1		3	3	x
Field Engineer	x	1		6	6	x
Superintendent	x	1		7	7	x
Office Engineer	x	1		6	6	x
Project Manager	x	1		3	3	x
Cost Engineer	x	1		1	1	x
Time Keeper / secratery / Front desk	x	1		3	3	x
Construction Manager Personnel	x	15		1	15	x
Management Total		22			44	**$172,307.69**
All Staff Total					**182**	**$593,359.72**

Appendix C: Utility Replacement

Similarly with the case in New York, underground utility systems in Istanbul are not well documented, and oftentimes require a new utility relocation plan once the excavations reveal the underlying systems. One engineer recalled the plans versus the actual locations of utilities varying as much as 15 meters in the city (Personal Interview M 2021). However, the municipality is known to assist contractors with the acquisition of permits from the utility companies during rapid-rail construction. An interviewee working for the former municipal government claimed that the municipality was quick to resolve utility relocation problems, probably faster than the Ministry of Transit who also builds lines in the city, since they have a lot more experience (Personal Interview F 2020). He referred to a high voltage line of TEIAS (Turkish Electricity Transmission Corporation) that was discovered in the right of way of M7 during excavations, for which the agency and the contractor got in touch with TEIAS and designed a solution within days. This is a good example of the Turkish contractors and the agency cooperating well.

Some utility companies in Istanbul are private and some are run by public enterprises. According to one senior level engineer with years of experience in rail construction, dealing with one is not easier than the other. He also mentioned that the previous municipality was better at easing the process of utility relocations; whereas the new one doesn't cut corners, but is especially keen on going through with the legal approval processes, in turn slowing down the construction. A likely reason for this could be that the current government being from the opposition party, is more likely to get audited by the central government, hence is generally more meticulous in bureaucratic procedures.

Utility plans are commonly inaccurate, nevertheless, there has been a lot of improvement on this front in the recent years. The government owned gas company IGDAS, currently in the process of being privatized, works with Geographic Information Systems (GIS) and provides largely accurate plans for areas that have been built within the last ten years. Water administration has also improved, but owns older infrastructure that is not well documented. Electricity and telecommunication are the hardest to work with, and cause a lot of delays as generally, their documentation is not managed well (Personal Interview F 2020).

Appendix D: EIS Process in Turkey

If a project falls within the category of projects that are subject to EIA or, is evaluated and granted an "EIA required" status, the owner submits an EIA application to the Ministry of Environment. The Ministry examines the file and creates a committee to evaluate the application, and forwards the file to the local governorship (the city), which announces the project along with public participation notices on the official online EIA portal, "e-ÇED." The public can submit opinions, questions and suggestions about the project to the city within 10 days. The owner submits a project promotion file to the committee and the committee meets, attended by a ministry official. The clerical duties are handled by the ministry. The ministry may bring in experts from academic and research institutions, trade organizations and unions, NGOs or other organizations to the committee.

Before the first meeting of the committee, a public participation meeting is organized in which the public is informed, and their opinions, questions and suggestions are reported to the committee. The committee meets, and the owner presents the project along with the public engagement meeting report. The committee decides on a scope and format for the EIA Report. The project owner has one year to prepare and submit the EIA Report to the ministry, but can request a one-time extension of 6 months.

Upon submission of the EIA Report to the ministry, a formal auditing is carried out and if the submission is approved, the committee evaluation starts. The report is also made available to the public, with announcements. The committee meets for evaluation and issues a decision within 10 days following the meeting, also taking into account any public input. The committee may request material, or visit project sites to make a decision and for a maximum of two times, they can request revisions. The report is finalized and is submitted to the ministry by the project owner. The report is made available to the public and the ministry makes a final decision on the report taking into consideration any new public input. Finally, the ministry issues an EIA Negative or EIA Positive decision. The decision is valid for 7 years, within which the project needs to commence, otherwise the process should be repeated.

The deadlines specified for each step of the process have been revised through amendments to the EIA by-law since it was put into force in 1993. Through 7 revisions in 1997, 2002, 2003, 2008, 2013 and 2014, the due dates were expedited, so that each process takes between a maximum of 3 to 10 business days (Bilgin 2015). The EIA preparation deadline for the owner is limited to one year and can be extended by six months.