TRANSIT
COSTS
PROJECT

The Italian Case:

Turin, Milan, Rome and Naples

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Summary

Abbreviations

ANAC – *Autorità Nazionale Anti Corruzione*. National anti-Corruption Authority. Formerly AVCP – Autorità per la Vigilanza sui Contratti Pubblici. Authority for the Supervision of Public Procurement.

AS – *Alta Sorveglianza*. Project High Supervision function

CdC – *Corte dei Conti*. Court of Auditors.

CIPE – *Comitato Interministeriale per la Programmazione Economica*. Interministerial Commitee for the Coordination of Economic policies.

CSLP – *Consiglio Superiore dei Lavori Pubblici*. Superior Council for Public Works.

DL – *Direzione Lavori*. Work supervision

EU – European Union.

EFRD/FESR – European Fund for Regional Develeopment/*Fondo Europeo di Sviluppo Regionale*.

MIBACT – *Ministero per i Beni e le Attività Culturali*. Ministry of Culture and Heritage

MIMS – *Ministero della Mobilità Sostenibile*. Ministry of Sustainable Mobility.

MIT – *Ministero delle Infrastrutture e dei Trasporti*. Ministry of Transport and Infrastructure.

PD – Progetto Definitivo. Final Design or Developed Design (RIBA)

PE – Progetto Esecutivo. Detailed Engineering Design

PFTE – Progetto di Fattibilità Economica e Finanziaria. Economic and Technical feasibility Project.

RFP – Request for Proposals.

R.U.P. – Respondabile Unico del Proedimento. Chief Project Manager

V.I.A. – Valutazione di Impatto Ambientale. Environmental Impact Review.

V.A.S. – Valutazione Ambientale Strategica. Environmental Strategic Review

1 Introduction

In this in-depth case study of Italian rail rapid transit projects, we investigate how Italian construction costs have changed over time and distill lessons learned to understand how design, procurement, and policy drive costs. We begin with an analysis of a systematic country-level database encompassing 93% of transit projects, as measured by total kilometers built and expected to be completed in Italy between the postwar years through the end of the 2020s. The first section illustrates the overall institutional framework, the various planning and delivery practices of transit projects and their evolution over time, as well as the tools that have been put in place to curb construction costs and improve procurement practices, notably since the 1990s. The second section of the report focuses on four city-level cases: Turin, Milan, Rome, and Naples. Thanks to the analytic study of the history, politics, context, delivery, and design choices, the cases highlight important factors that contribute to the variation of construction costs among the different cases. Finally, the different takeaways derived from this multi-level in-depth analysis of the Italian cases has been summarized in ten main lessons identifying the fundamentals of a cost-sensitive approach to building urban rail infrastructure.

The data collected in the general Transit Costs database situate **Italy as a medium-to-low cost country for metro rail construction**, with an average cost of $159 million per kilometer compared to an overall average of $280 million per kilometer globally.[1] The Italy-specific database encompasses 50 metro rail projects accounting for 307 km or 93% of metro rail mileage built in Italy since the 1940s, currently under construction, or entirely funded and to be completed by the end of the 2020s. The analysis of this expanded country-focused database highlights **a generally lower average value ($120 million/km) and a high variability between projects** and cities, as well as over time: from as little as $22 million/km for Milan's M2 at-grade suburban extension built in the early

[1] This data is derived from our own database that can be retrieved at transitcosts.com

2000s, a cost on par with mainline double track rail, up to the $645 million/km for Naples's line 1 central segment, the most expensive section of metro ever built in Italy. This variability, which will be analysed in greater detail in section 2, is the result of both historic trends, differences in local capacity, and Italy's unique urban morphology.

Section 3 examines the institutional planning framework, funding, procuring and delivering of transit projects that contribute to an average construction cost generally lower than our global averages, especially in North America, albeit with some notable exceptions. The evolution of the Italian project-delivery framework offers a few fascinating lessons, both positive and negative ones, for countries that wants to tackle the upward spiral of transit capital costs. A growing concern for cost control since the 1990s facilitated the implementation of mechanisms, tools and institutions designed to curb waste, and avoid mismanagement and corruption-prone practices in public-works delivery. In the aftermath of these reforms, three main innovations revamped transit project delivery in Italy. First, a new anti-corruption authority (ANAC) was established to clean up public procurement practices. Second, Italy adopted **official reference unit-price lists (*Prezziari delle Opere Pubbliche*)** to determine the benchmark cost of procurement and the bid ceiling. Third, the bidding process was overhauled to incorporate technical scores when assessing a bid rather than focusing exclusively on costs. On the other hand, it is worth noting that, despite **a planning and approval process managed by the civil service and less prone to external lawsuits and NYMBY-induced design**, the Italian institutional framework suffers from important veto points and political meddling than can increase the cost of delivering infrastructure in particular contexts, notably **historic city centers subject to strict heritage protection**.

The **four in-depth cases** presented in the second part of this report examine metro projects built in **Turin, Milan, Rome, and Naples** over the last twenty years. We rely on interviews with public officials, engineers and experts; [2] the analysis of official documents and data provided by transit agencies, as well as reports from national supervising authorities and articles from the specialized transportation press to reconstruct the key factors that drove costs in specific projects. Each city offers insight into the benefits and challenges of different delivery methods, differences in local capacity, urban contexts, and diverse financing structures. What is clear across all of these cases, however, is the importance of building and maintaining in-house technical capacity to procure and manage projects effectively. Furthermore, the cases illustrate how environmental constraints, such as the unique urban and geological conditions of old and dense city centers, and contextual factors, such as political fickleness, bureaucratic veto points, and uncertainties over funding and schedules, can result in overdesign, trigger costly

[2] A total of 24 interviews has been conducted between November 2020 and April 2022.

design choices and scope changes, and promote poorly conceived delivery schemes, that hinder public oversight capacity.

Part I – Building urban rail in Italy

2 Urban rail construction in Italy: a general overview

2.1 A latecomer to urban rail construction

Unlike other European countries that began building urban rail in the 19th and early 20th Centuries, Italy opened its first line after World War II. Despite several attempts in the interwar period to develop metro rail networks in Rome, Milan, Genoa and Naples, the first proper metro line opened only in the mid 1950s. Metro construction finally gained momentum during the postwar years, characterized by fast urbanization and dramatic economic growth, but was hindered by the lack of a national transit policy, which finally emerged in the late 1980s, and by an essentially car-oriented transport policy. Below we identify three critical periods in the history of rail-based urban transit in Italy:

- **1950s - 1970s**. For at least three decades after the war, Rome and Milan were the only cities building heavy urban rail infrastructure. Rome, after the opening of the first section of line B in 1955, initiated the construction of line A in the 1960s. Those were the only urban transit projects financially supported by central government funds, as a 1920s law identified transit infrastructure in the Capital as a matter of national relevance, while considering it a local government responsibility elsewhere. In the 1930s, the city of Milan had already developed a plan for a three-line radial network, but the implementation was delayed by the onset of WWII, and the city only started construction on the first two lines in the mid 1950s. Unlike Rome, the metros were built with local funds, in the form of municipally granted bonds, and were delivered through "Metropolitana Milanese" (MM), a municipally-owned special-purpose concessionaire. In the mid-1970s, Naples was the third Italian city to develop a modern metro system, initially with municipal funds only.

- **1980s – early 1990s.** The period starting in the 1980s saw growing central government involvement in the planning and financing of mass transit infrastructure in large cities. This was a response to growing congestion and the untenable challenges created by rapid urbanization and a dramatic increase in motorization during the previous three decades. Legislative and governmental efforts tried to address growing congestion in major urban areas, while planners popularized the idea of "Iron Therapy" (*cura del ferro*) to highlight the need to develop frequent and reliable rail-based transit in the largest urban areas to "heal" cities from chronic automobile congestion and pollution. This resulted in a boost for transit projects in Rome, Naples and Milan, and in the tentative development of light metros in Genoa and Catania. Overall, these efforts weren't part of a coherent national policy, and the projects initiated during this period are characterized by the use of non-competitive procurement formulas, such as the privately negotiated "concession of sole construction" scheme used in Naples, Genoa and Rome, where metro development was awarded to private consortia without a competitive tender. These opaque delivery schemes were at the epicenter of the vast web of systemic corruption around public procurement that emerged in the far-reaching scandals of the late 1980s known collectively as *Tangentopoli* (Bribe-burg). The sweeping investigation and the following trial, dubbed *Mani Pulite* (Clean Hands), prompted a period of political turmoil during the early 1990s and, ultimately, the collapse of the major parties that dominated the government during most of the postwar period.
- **Late 1990s -2020s.** The 1990s and the early 2000s are characterized by a slowdown in metro openings as a consequence of fewer project starts in the years following *Tangentopoli,* and because of austerity measures prompted by the 1992 public debt crisis and efforts to curb the deficit within the Maastricht's treaty limits.[3] Later, Italy experienced a dramatic surge in the new urban rail starts, especially in the 2010s and 2020s. New dedicated national grants for transit construction in 1992, 2001, 2016 help explain this recent resurgence in transit projects. At the same time, the adoption of cheaper automated light metro technologies and unattended automated operations, that has become the de facto standard for the newer lines opened since the early 2000s, made metro technology viable in smaller metro areas and lower demand corridors. Today, the seven metro systems operating across the country total 222.7 km and support an estimated 2.74 million unlinked daily trips.[4]

[3] The Maastricht treaty (1993), that institutes the single currency, required that the EU countries that wanted to join the monetary union needed to have a public deficit lower than 3% of their GDP and a shrinking public debt tending to 60% of GDP or lower. In 1993, the deficit/GDP ratio was 10% and the debt/GDP one at 115%

[4] Spinosa (2019), processing data from transit agencies for 2019.

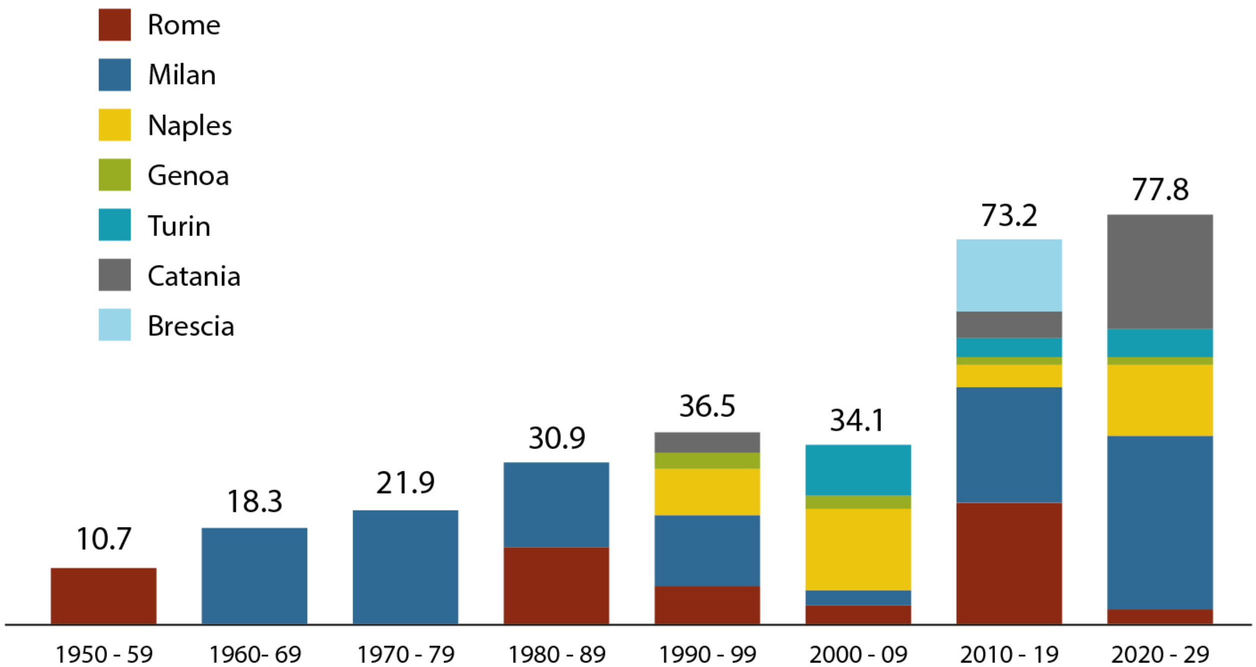

figure 1. New kilometers of metro rail opened in Italy by decade and city. For the decade 2020 – 2029 only the projects currently under construction, or fully funded and having a completion date set before 2029 are included.

2.2 Average costs and patterns in the historic variation of constructions costs

figure 2 shows the actualized cost per km of almost all urban rail projects built in Italy since the 1950s, except for a few metro extensions of lines M1 and M2 built in Milan from the late 1970s to the 1980s and the initial section of Catania's metro, as it was impossible to retrieve trustworthy figures on these projects. Data have been collected from several official sources and, in three cases where official data were not available, from press releases or other sources.[5] Nominal Cost figures derived from official documents and agency's data have been actualized to €2020 (henceforth referred to as "nominal value" or "nominal cost") using the mid-year of construction as the base year and then converted to US dollar PPP values using a 1.3 coefficient. All numbers in the report expressed in "dollar' or simplified as "$" are in 2020 PPP USD dollar real terms. However, it is important to point out that for projects built during the inflationary 1970-80s, characterized by double digit year-over-year inflation, even a minor shift in the identification of the mid-year of construction might lead to a notable difference

[5] For older projects in Milan, data come from the 1959, 1970, and 1975 budgets published by Metropolitana Milanese. For Rome's lines MA and MB, data come from several appropriation laws (1145/1959, 285/1968, 82/1970, 396/1971, 374/1974, 19/1978, and 19/1978) that have financed the early developments. Costs for projects realized after the mid-1990s are mostly derived from the House of Deputies official database of infrastructure projects (SILOS, 2021), and the official report of the Court of Auditors (Corte dei Conti – CdC) tracing the spending linked to the 211/92 transit fund law (CdC, 2017b).

in the actualization coefficient. With those caveats in mind, we identified a revealing pattern in the variation of construction cost over time.

The cost of most metro projects falls within the $ 50-200 million per kilometer range, with a few outliers, mostly located in Naples, Milan and Rome. Out of the 332 route-km collected in the database, 243 km (72 %) are tunneled while the remainder are at grade or elevated. The average nominal cost per kilometer of projects with more than 50% of the alignment tunneled is €115 million ($149 million), while projects with less than 50% tunneled the average cost is €29 million ($38 million, see figure 3). Interestingly, there is not a direct correlation between the length of platforms and the average costs: the 201.3km of route (66% tunneled) that are classified as heavy metros (platforms of 110 or 150m) have an average cost of $122 million per kilometer, while the 72.3km of new generation automated light metros (platforms of 40-55m) have an average cost of $118 million per kilometer. It is worth noting that this might be related to the fact that the light-metro trackage has a much higher percentage of route-km tunneled compared to heavy metro. The less expensive typology on a per kilometer basis, at $88 million, is the first generation of light metros with 80m-long platform, modelled after LRT and Stadtbahn systems and initiated in the 1980s in Naples (line 6), Genoa, and Catania. Catania's very low figures ($ 61 million/km), due to particularly favorable local soil conditions, contributes to driving the overall average down.

Historically, we see a **spike in construction costs from the late 1970s through the mid-1990s and a reduction in costs after, albeit with two notable exceptions**. Almost all the high-cost projects of the 1970s-1990s era, such as Milan's M3 initial segment, Rome's MB extension to Rebibbia and the initial section of Naples's line 1, were connected to the corruption scandals of *Tangentopoli.*[6] The reduction in costs observed from the late 1990s is most likely due to a combination of factors:

- A major reform of the Public Works Code in 1994, the Merloni law (109/94), the first of a series of measures gradually implemented and refined over the following decades to contain costs, improve the transparency of the procurement process **through measures like reference-unit costs, unit-price contracts and the technical scoring of bids**, and greater competition with European-wide procurement (see section 3.4).
- The widespread adoption of new automation technologies allowed for high-capacity rail transit with narrower and shorter trains running more frequently, which resulted in a **new generation of automated light metros with lower upfront capital in fixed infrastructure**, built in Turin, Brescia, and Milan starting in the early 2000s (see figure 4).

[6] See among others: Calise (2021),

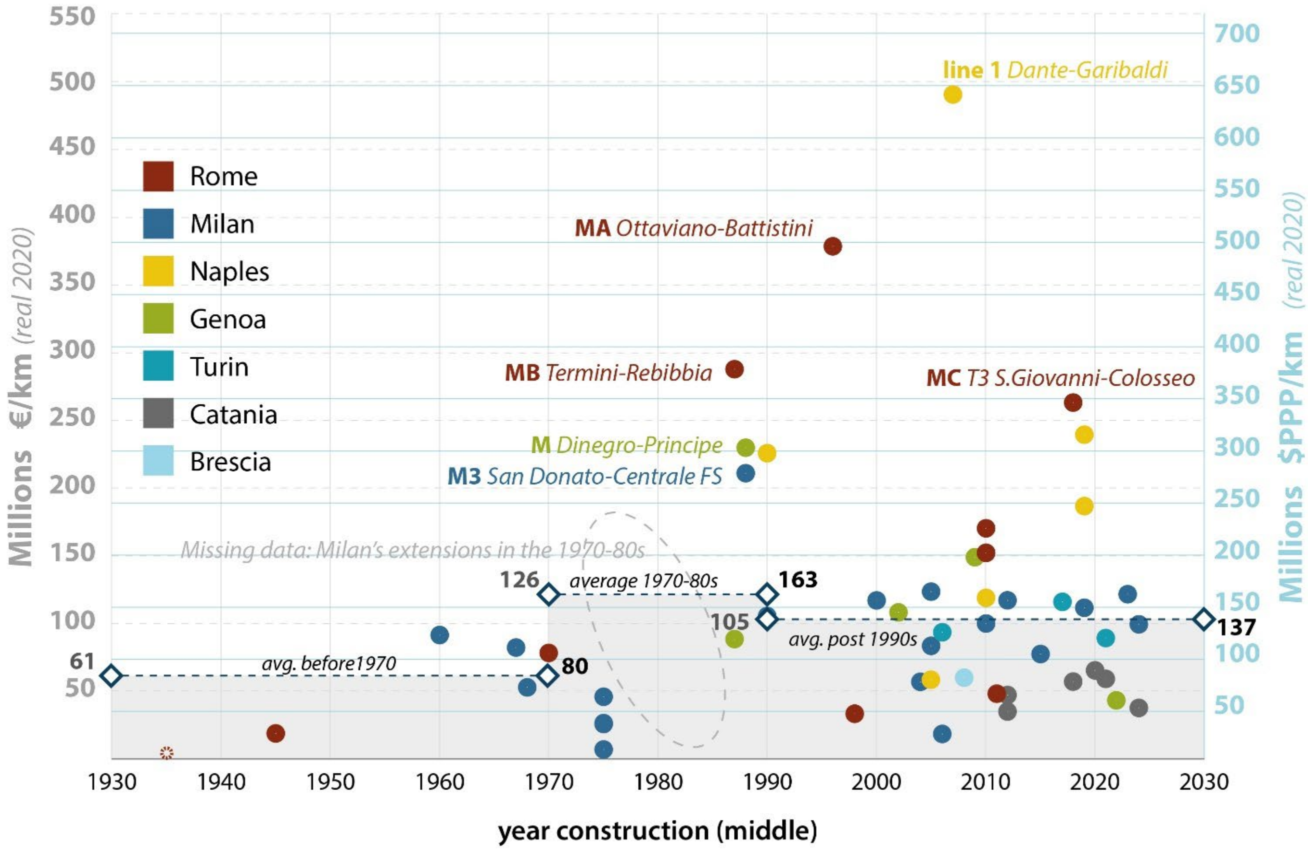

figure 2. Actualized construction costs in Euros and USD PPP by year of construction (middle year of the construction period) and city.

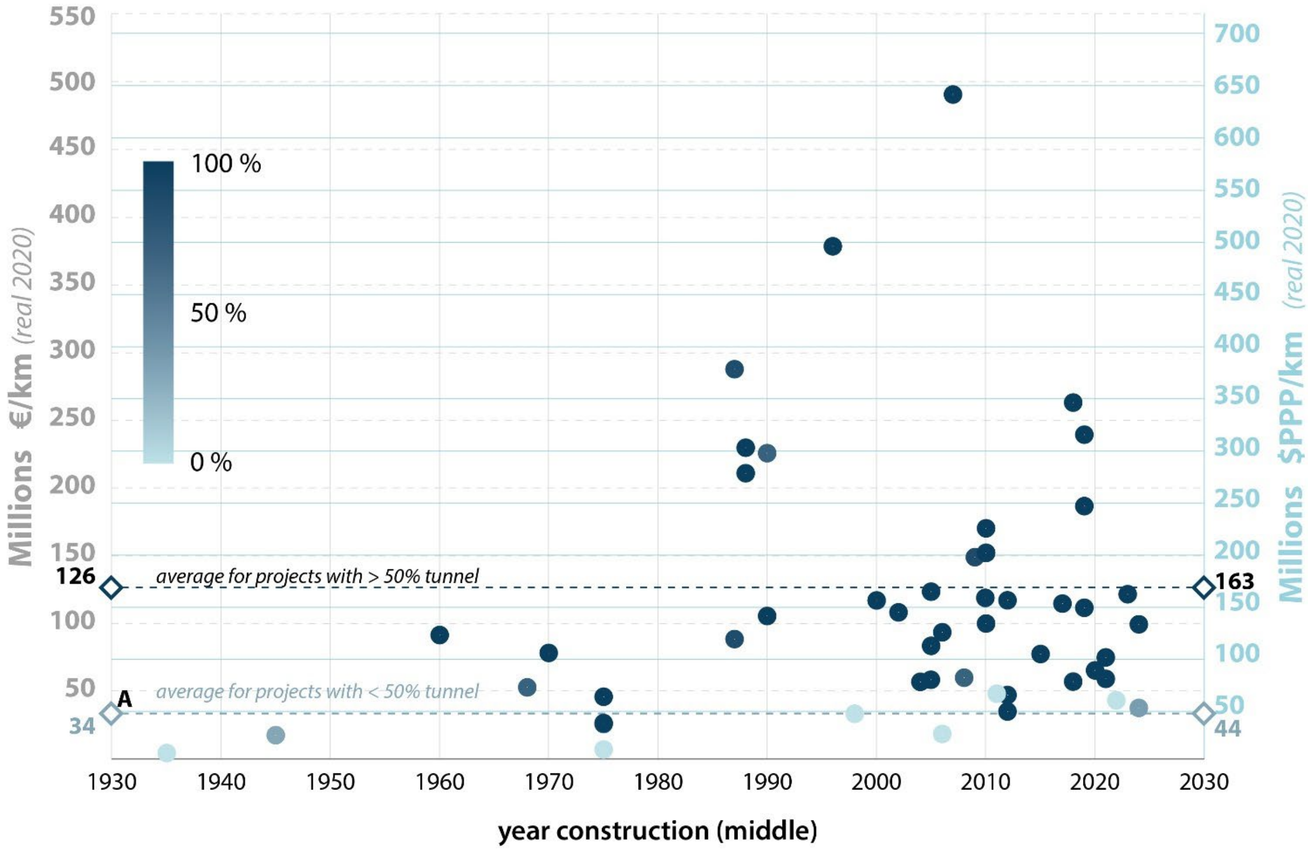

figure 3. *Construction costs by year of construction (middle year of the construction period) and percentage of tunneled alignment.*

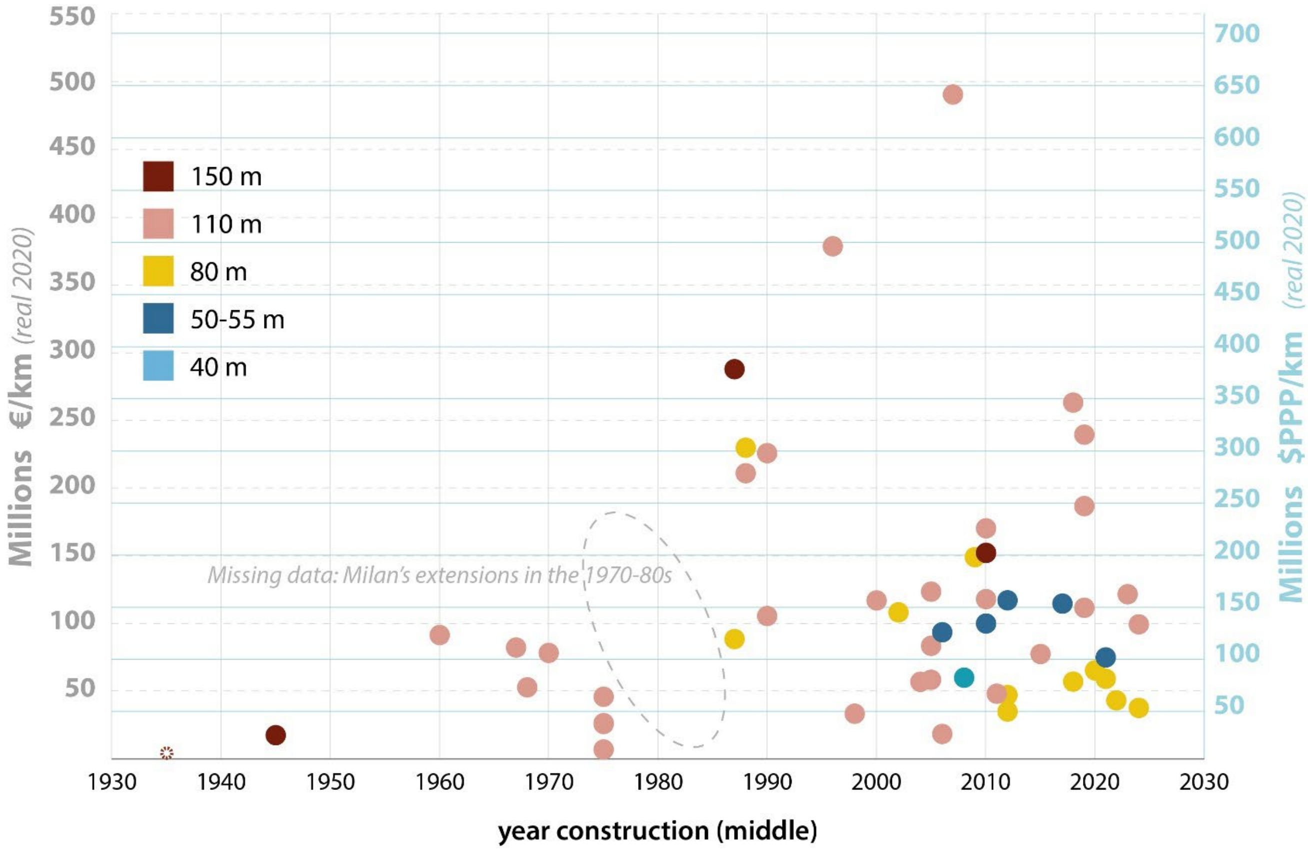

figure 4. Construction costs by year of construction (middle year of the construction period) and size of platforms.

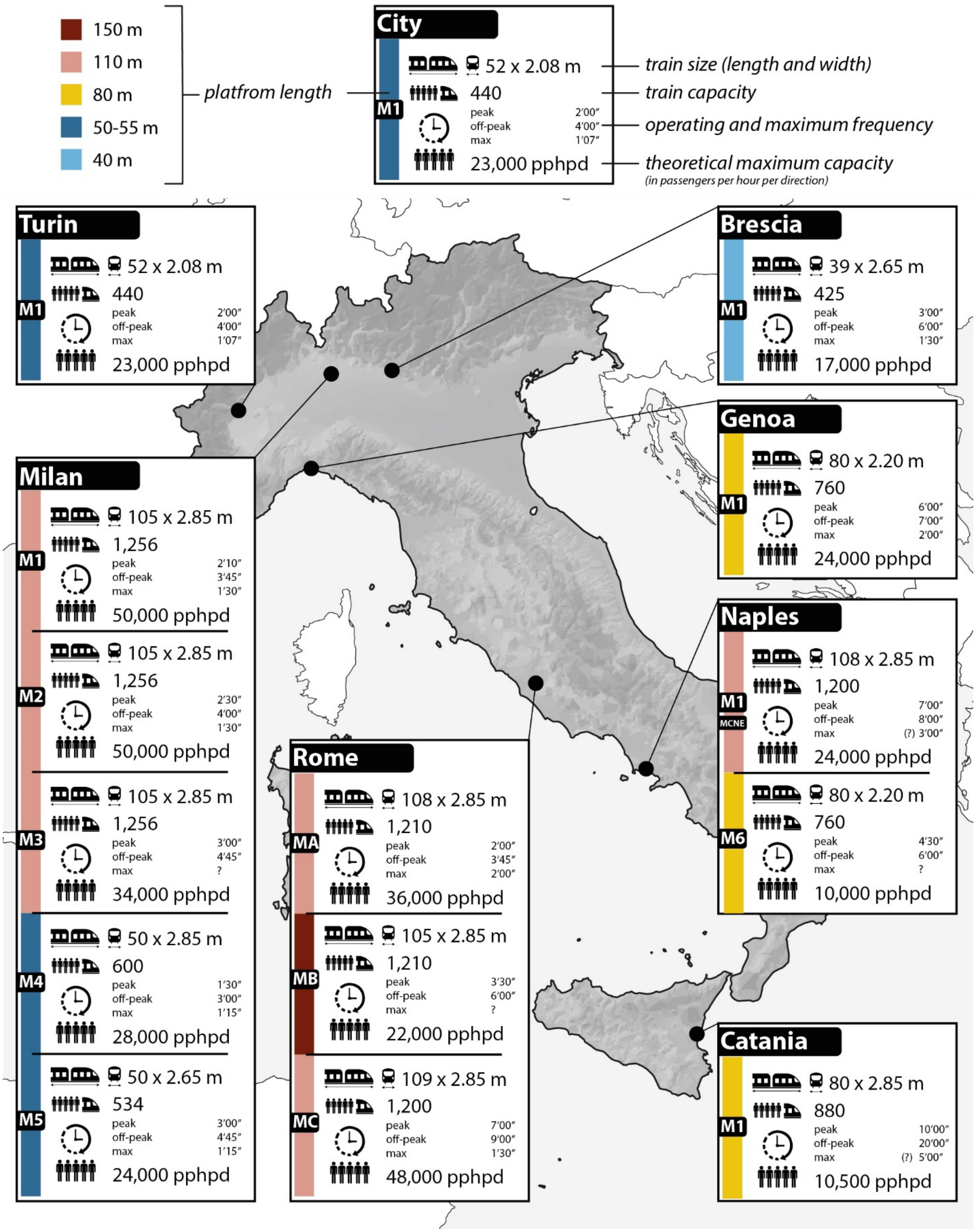

figure 5. Metro systems currently in operation in Italy and their technical characteristics.

2.3 General considerations about the construction sector in Italy and input costs

In order to better understand the analysis of transit projects within the general framework of the construction sector in Italy, this section provides some information about labor-related issues, general capacity of the construction sector and a few references about input costs comparing Italy and the US.

A sample of recent Requests for Proposal (RFP)[7] for construction projects **shows that the proportion of costs allocated to labor comprised of between 19-31%.** This percentage appears to be lower than what is generally considered as conventional in the United States, which is believed to be around 50% (cf. New York case 2022). This might be both the result of lower labor costs in Italy, but also lower productivity in the American construction sector, especially considering that infrastructure contractors are less likely to use light and heavy prefabrication as compared to Italy. However, those observations are derived from anecdotal evidence and need a more thorough investigation to better understand the impact of wages and productivity on the cost divide between Italy and other countries, notably the US.

Labor costs in Italy are regulated by **National Bargains**, that are normally negotiated between the most important national sectoral labor organizations (FILLEA CGIL, FILCA, FeNEAL, etc.) and the national association of construction entrepreneurs (ANCE – *Associazione Nazionale dei Costruttori Edili*). Beginning in the 1990s, the National Government began facilitating these negotiations following a praxis called *Concertazione* (literally, Orchestration) to ease a historically combative relationship between unions and employers. Once terms are agreed to, terms that include salary, working hours, benefits, they are made public and apply to all workers regardless of whether or not they are part of a union.[8]

Finally, it is worth noting that Italy has **a well-developed local industrial expertise in tunneling**, that dates back to the construction of the national railway network starting from the mid-19th century. This expertise has been improved over time, stimulated by the growth of the road and motorway network, the modernization of the rail network, the more recent development of a High-Speed Rail system, and the construction of urban rail systems. The Italian Tunneling Association (ITA – SIG, *Società Italiana Gallerie*) claims that Italy ranks second in the world after China for the combined length of road and rail tunnels, at around 2,100 km[9], ahead of Japan, Norway, and Switzerland. As a result, there are several contractors and consultants who specialize in underground structures and who have pioneered new tunneling techniques, such as ADECO-RS.

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[7] Since 2016, RFPs for public works must explicitly state the incidence of labor on the overall hard costs.
[8] The terms of the national Contract of Construction workers can be consulted here: https://www.filleacgil.net/edilizia/15155-industria.html
[9] SIG, Società Italiana Gallerie: http://www.societaitalianagallerie.it/notizia/1551/presentazione/

The following table highlights a few typical input costs for labor, materials, and energy as of 2021 as derived from official sources and compared to New York City. Labor cost tend to be lower in Italy than in most US jurisdictions, common materials used in large infrastructure, such as Portland cement and steel for rebar have a comparable price, while energy cost are significantly higher in Italy than in the US.

Table 1. Typical input cost for the construction sector in Italy (2020-21)

		€ - Euros	$ PPP (1.3 conversion rate)	NYC (avg.)
Labor [1]				

FOR ITALY. *Labor cost includes: gross salary and other salary-related costs, contractor-side taxes (payroll, IRAP), severance pay, retirement contributions, insurance, etc. as par the National Bargain Contract. It does not include: 12-13 % general contractor's expenses for labor management.*

FOR USA. *Labor costs for construction workers are derived from prevailing wages in New York for the generic "laborer" position. For professional services, data are derived from: "U.S. Bureau of Labor Statistics. Producer Price Index - Engineering and Architectural Services." The amount includes wages and supplemental benefits.*

		€ - Euros	$ PPP (1.3 conversion rate)	NYC (avg.)
Skilled construction worker		**31.4** €/hour	**40.9** $/hour	**92.5** $/hour
Unskilled construction worker		**25.1** €/hour	**32.6** $/hour	**70.5** $/hour
Professional services (senior)		**50.0** €/hour	**65.0** $/hour	**179.9** $/hour average
Professional services (junior)		**34.8** €/hour	**45.3** $/hour	
Professional services (draughtsman)		**26.8** €/hour	**34.8** $/hour	
Materials [1]				
Portland cement (32.5 R - 42.5 R)	*bulk (silos)*	**105-112** €/tonne[2]	**135-145** $/tonne **125- 132** $/ton	**128** $/ton
	packed	**122-129** €/tonne	**158-167** $/tonne **143- 151** $/ton	
Steel rebar (B450C)		**420-445** €/tonne	**545-580** $/tonne **495- 527** $/ton	**720-740** $/ton
Plywood for falseworks (27mm)		**14.5** €/m³	**18.8** $/m³ **1.7** $/sq ft	n.d.
Energy				
Electricity (2019 average)		**0.27** €/kW[3]	**0.35** $/KW	**0.06** $/KW[4]
Fuel (2020 average)		**1.43** €/liter[5]	**1.86** $/liter **7.02** $/gallon	**2.17** $/gallon[6]

Notes

1. *for Italy: data derived from the "Prezziari Regionali delle Opere Pubbliche" of Lombardy and Campania. For the U.S. : https://www.bls.gov/regions/mid-atlantic/data/producerpriceindexengineering_us_table.htm*
2. *metric tonne = 1,000 kg. 1 metric tonne = 1.10 short tons (US)*
3. *data from ARERA, referred to industrial prices for consumers using less than 20 MWh/a: https://www.arera.it/it/dati/eepcfr2.htm#*
4. *data from EIA: https://www.eia.gov/electricity/monthly/epm_table_grapher.php?t=epmt_5_6_a*
5. *data from the Ministry of energy database: https://dgsaie.mise.gov.it/prezzi-annuali-carburanti*
6. *data from EIA: https://www.eia.gov/todayinenergy/detail.php?id=46356*

3 The planning and legal framework of urban transit projects

To better understand the four in-depth cases presented in this report, it is important to appreciate them within the evolving context of the planning and legal framework of urban transit projects and of public works in general. Notably, we will present the implementation of tools introduced through a number of legislative reforms that have played a role in the reduction of construction costs that we observe starting in the second half of the 1990s. Those reforms happened in the context of the strong emotional public response to *Tangentopoli* (Bribe-town) scandals and a growing awareness among policymakers of the necessity to curb costs and improve public spending effectiveness in the context of continuous fiscal consolidation that characterizes Italian public finances since the early 1990s.

As a general remark, it is worth noting that the Italian administrative system is regulated by a juridic rationality that is in part different from the one observed in the US or Canada. It is less adversarial and more similar to the so-called Bureaucratic Legalism, based on the Napoleonic tradition of Administrative Law and on the principle that the State and its operational machine, the Public Administration, are responsible for pursuing the Public Interest. Hence, appeals against decisions of public agencies and authorities, like environmental approval, public contract awarding, expropriation decrees, etc., are dealt with by separate Administrative Tribunals.

3.1 The institutional framework of transit projects

Italy is a Parliamentary Republic and a Unitary State, with forms of devolution of legislative power to Regional Governments[10] and local authorities[11], especially in the urban and transit planning domain. Taxation powers are mostly concentrated in the hands of the National Government, and local authorities mainly rely upon a mix of property taxes, services fees and transfers of funds from the Treasury, with a limited leverage on local fiscal resources and constrained borrowing powers.

Over time, the framework for the planning and delivery of transit projects has shifted from one of local financing and planning to one of shared responsibility between the National Government and the lower levels of government. Today, the National Government bears the largest share of capital funds for new projects, sets very general policy directives, and provides baseline funds for operations through the National Transit Fund. The lower levels of government (Regions, Metropolitan Cities and Municipalities) are in charge of the regional and local level of transit planning and co-funds transit capital projects and operations. In particular:

National Government. Infrastructure spending, including transit, is mainly managed by an Inter-Ministerial Committee for Economic Development (**CIPESS** - *Comitato Interministeriale per la Programmazione Economica e lo Sviluppo Sostenibile*) under the responsibility of the President of the Council of Ministries (i.e. the head of government). CIPES includes, among others, the Ministry of Infrastructure and Sustainable Mobility (MIMS) and the Ministry of Finance and Treasury (MEF). The CIPES is responsible for the final approval of local transit capital projects that applies for national grants, in agreement with the State-Region Conference, a mostly consultative body that gained importance after the 2001 devolution reform, and now works as a de facto negotiation chamber between the Central Government and the Regions. The ministry of Energy and Environment is charged with the evaluation and approval of the **Environmental Impact Reviews** (*VIA - Valutazione di Impatto Ambientale*), a techno-bureaucratic process mostly focused narrowly on ecological impacts (noise, pollution, etc.) rather than community impacts at large. Moreover, most transit projects are not automatically subject to the full national VIA procedure as other large infrastructure projects. Instead, a pre-screening procedure at the regional level determines if a transit project has a potentially relevant environment impact and whether it should undergo a

[10] The Regional level of government comprises 15 Ordinary Regions, 4 Regions with Special Statute (Sicily, Sardinia, Valle d'Aosta and Friuli Venezia Giulia) and 2 Autonomous Provinces (Bolzano/Bozen and Trento). This level corresponds, to a certain extent, to States in the US (albeit with less autonomy) and *Régions* in France.

[11] Until 2015, there were two sub-Regional levels of elective government: Provinces (that correspond roughly to the County level in the US and *Départments* in France) and Municipalities. Since 2015, Provincial governments have been de facto abolished and their responsibilities have been uploaded to Regions or, for the 14 largest urban areas, to newly established Metropolitan Cities, whose executive council is composed by the mayors of the member municipalities and is normally led by the mayor of the largest city.

lighter regional VIA procedure managed by the Regional Environmental Agency (*ARPA – Agenzia Regionale per la Protezione dell'Ambiente*) or no environmental evaluation at all, replaced with just a list of recommendations to be addressed in the final design phase.

Regional Governments. Since the 2001 devolution reform, Regions have gained greater control over transit. They are responsible for transit planning and funding at the regional scale–notably for regional rail–and for setting the overall framework for transit operations (fares, levels of service and subsidies) within the region or between regions through ad hoc agreements. Regions can contribute to transit capital programs with their own funds, especially because they manage **the European Regional Development Fund (ERDF/FESR in Italian) and the European Social Fund (ESF/FSE in Italian).**[12] ERDF and ESF are an important source of funding for transit projects since the late 1980s, especially in the southern, less-developed regions that receive a higher per-capita contribution.[13] Regions are also involved in the approval process of transit projects in the preliminary evaluation of the environmental relevance of infrastructure projects, that determines whether a project must undergo national or regional EIR/VIA or is exempted.

Municipal Governments and Metropolitan Cities. Municipal governments and, more recently, Metropolitan Cities are the main actors of urban transit policies. They are responsible for local transit planning. They devise and approve the local Sustainable Urban Mobility Plans (PUMS), select and propose projects for national grants, and act as the delivery authority of most urban transit projects, either directly or by delegating the project management to transit agencies or, more commonly, to *ad hoc* capital project delivery agencies. Municipalities and Metropolitan Cities normally contribute matching funds to capital projects, mostly through borrowing from banks or from the public lending authority, *Cassa Depositi e Prestiti* (CDP).

3.2 Planning, design, approval, oversight, and management

The way in which large infrastructure projects have been planned, funded, approved, designed, and delivered has changed considerably over time. Successive reforms have refined the definition and scope of planning and design phases, set clearer criteria to identify viable projects, and established increasingly tighter regulations to foster transparency and competition. We will go into greater detail about the evolution of public procurement practices in the following section (3.3). Here, we will illustrate the general framework as it has developed in the last twenty years, even though this matter remains subject to continuous reforms and legislative

[12] Funds are allocated by regions through a 5-year program called POR-FESR.
[13] Calise (2021).

adjustments. In particular, we will present the main planning and design steps, and the main actors charged with oversight and delivery management functions.

Planning and Design steps

Large transit projects go through four main iterations of planning and design, with the first one being a relatively recent innovation (early 2010s): i) Sustainable Urban Mobility Plans (PUMS); ii) Technical and Economical Feasibility Project (PFTE); iii) Final Design (PD); iv) Executive Design (PE).

Sustainable Urban Mobility Plan (SUMP/PUMS – *Piano Urbano della Mobilità Sostenibile*). This is the initial and fundamental planning document for transit projects. PUMSs are 15-year horizon plans, ideally elaborated at the Metropolitan City level, that encompass all aspects of urban mobility, including both people and goods, and set sustainability goals linked to European and national goals of GHG emission, modal shifts, etc. PUMS, as the mandatory cornerstone of local mobility planning, are a relatively recent requirement for cities (since the early 2010s). Many cities, though, already had comprehensive masterplans or strategic plans for transit development linked to the general "Urban Planning and Land Use" Plan (PRG – *Piano Regolatore Generale*) since the 1970s. Moreover "Traffic Management Plans" (PGTU- *Piano Generale del Traffico Urbano*), that were introduced in the early 1990s, normally had a transit component mostly framed as a congestion reduction measure, but they had a weak connection to the capital funding process. During the PUMS's elaboration process, that normally takes two or three years, transit capital projects are evaluated within comprehensive short and mid-term scenarios, in terms of overall efficacy and congruence with the main sustainability goals and are rated through cost/benefit ratios and parametric cost evaluations. General alignment and mode are normally decided at this level of regional network-wide planning. Public participation is mostly done at the SUMP/PUMS phase in a variety of forms[14], even though public outreach can continue in the following phases.

Technical and Economical Feasability Project (PFTE – *Progetto di Fattibilità Tecnica ed Economica*). Formerly called Preliminary Project (PP – Progetto Preliminary), the PFTE represents a level of design that encompasses some elements of preliminary planning (evaluation of local alignment alternatives and selection of the preferred alternative), early design (up to a level of detail corresponding to 30-50% design in the US system[15]) a complete business case and service plan, including a more detailed Cost/Benefit analysis, and preliminary cost

[14] Italy does not have a single national framework defining participatory processes, unlike, for example, the *Débat Public* process in France. Some Regions have their own legislation that defines the forms and limits of public participation. Cities may have their own bodies devoted to participatory practices.
[15] In particular, early design includes preliminary geological and hydrological investigations, archeological pre-scoping (evaluation of the archeological risk), and environmental components assessment (air, soil and water pollutant, noise, vibrations, etc.).

estimates based on a more refined but still parametric evaluation of construction costs. National grants and approval from the CIPE committee are granted based on the PFTE level of design. Delivery schemes corresponding to the Design-Build definition (such as the General Contractor for MC in Rome and the PPP scheme used for M4 and M5 in Milan) normally base their Requests for Proposals (RFP) on a PFTE/PP, even though this is not possible anymore since the 2016 reform of the public works code, that privileges RFP based on Final Design. The environmental pre-screening at the regional level, that determines whether the project will undergo a full EIR/VIA procedure, is also based on the PFTE.

Final Design (PD – *Progetto Definitivo*). This stage corresponds to a level of design where all the technical aspects of the project have been solved in detail. It corresponds approximately to the 90% design or a Construction Document Phase in the US context. All the necessary approvals and recommendations from concerned authorities (for example, monument and landscape protection, fire departments, structural and earthquake compliance, etc.) are secured during the approval process of the PD. Since the late 1990s Public Service reform, those approvals and recommendations are acquired through a joint authorization committee composed by representatives from all the concerned authorities, called *Conferenza dei Servizi*[16]. The PD level of design has sufficient detail to be used for a thorough estimation of costs based on the official regional reference unit price lists (see section 3.6). For example, it involves extensive geological sampling, advanced engineering, and the elaboration of the Design Specifications (*Capitolato Speciale d'Appalto*). PDs include all the elements necessary for devising an RFP in case of a delivery scheme called "Integrated Delivery Contract" (*Appalto Integrato*), that is a procedure used for the joint procurement of Detailed Engineering Design services and construction.

Detailed Engineering Design (PE – *Progetto Esecutivo*). The PE is the most advanced level of design, where all the construction documents and detailed technical drawing are prepared based on the PD. It's the most expensive and labor-intensive phase of design, even though it implies no major design choices compared to the previous phases. RFPs based on a PE are less common in large transit projects procurements, even though there are cases of "traditional" procurement where the agency procure separately the PE and the construction. Unlike the PD, the labor-intensive nature of PE makes it unlikely to be done in-house by public agencies, but there are exceptions, as we will see in the detailed cases.

[16] Actual approval processes might vary depending on Regions, as many matters have been regionalized and are thus subjects to slightly different local legislations and procedures, albeit with a general common national framework.

Management and overview responsibilities.

Italian public project delivery practices involve three important complementary supervising functions that are different from what is normally encountered in the North American context: i) Chief Project Manager (RUP); ii) High Supervision (AS); and iii) Work Supervision (DL).

Chief Project Manager (RUP – *Responsabile Unico del Procedimento*). The 1994 and 1999 reforms of the Public Administration Code requires that project delivery authorities identify a general manager for each project, normally an executive official within the local administration or the delivery agency. That figure is the person solely responsible for the project, both legally and bureaucratically. The introduction of the RUP role, technically an in-house project manager appointed by the contracting authority (i.e. the municipality), might seem trivial, but has proven to be a major positive innovation. The RUP concentrates decision-making powers in the hands of a career civil servant. This arrangement protects the design team from excessive interference from elected officials, such as councilmembers, and from political micro-management of the planning, design and delivery activities of the project.

High Supervision (AS – *Alta Sorveglianza*). The AS function is exclusively encountered in public works. The AS is responsible for supervising the correct execution of the contract. It has a final say about all major changes in the project that involves cost or scope variations and has the ultimate power to accept or refuse the payment to the contractors based on progress, quality of work and contract adherence. The AS function can be assumed directly by the Contracting Authority in-house or by another public agency, but cannot be contracted out to a private firm.

Work Supervision (DL – Direzione Lavori). This function encompasses the control and supervision tasks that are typical of Construction Management, such as frequent worksite inspections, validation of minor change orders and quick fixes requested by the contractor that don't require significant cost or design changes, as major ones must be agreed upon by the AS. This labor-intensive activity is directly related to ensuring the execution of the Detailed Engineering Design, can be outsourced to a private firm. In case of projects delivered through a General Contractor formula, this task is entrusted to an independent firm contracted directly by the GC itself.[17] Moreover, the limit and the respective responsibilities between the role of High Supervision and Work Supervisor is blurred, and it depends on the interpretation that the contracting authority gives of its role, as we will see in the detailed study cases, as those functions have been performed differently, and with different outcomes.

[17] As we will see in the case of Rome's MC, this is a recipe for a hard to manage conflict of interest, as the General Contractor is, at the same time, the controller and the controlled.

3.3 The planning and funding process and its evolution over time

The planning and funding process for mass transit projects has changed multiple times since the first metro line opened in the 1950s. Nevertheless, it is possible to identify four major periods regarding how urban rail transit in Italy was conceived, financed, and delivered, defining a trend characterized by a growing financial involvement by the National Government and an increasingly structured planning and legal framework. In particular, major changes occurred after the approval of the 1994 reform of public works, devised as a response to the late 1980s-early 1990s *Tangentopoli* corruption scandals that involved, among others, the metro projects in Milan, Rome and Naples. As we will see in the four detailed cases, financing metro rail projects has come from a variety of sources and most of the time has been a major influence on delivery methods, project organization, phasing and, ultimately, engineering choices with a non-negligible impact on projects costs.

Early development: municipal and state ad hoc funding

Since 1925 transit has been considered a local matter.[18] Rome, as the capital city, has received funding from the national government to develop a transit network because it is considered to be of national importance, and is tied up with a wider urban renewal program to transform Rome into the "grandiose imperial capital" of Fascist Italy. Financing new transit lines outside of Rome remained the exclusive domain of local jurisdictions until after World War Two.[19] Thus, the first two lines of Milan's metro network were financed via municipal bonds and other local sources,[20] while Rome's lines MA and MB were funded by ad hoc appropriations from the national budget via recurrent dedicated laws.[21] This principle continued into the 1980s, even if lobbying from local governments resulted in occasional funding for selected projects tied to the budget law or other specific legislation, as it happened for example with the post-1980s Irpinia earthquake relief grants being used for Naples's line 1.[22]

Local authorities were also expected to develop network-wide plans within the wider urban planning process. In Milan, where the first three lines were part of a 1942 network plan, the last of several tentative plans proposed during the previous decades,[23] and, for Rome, where the overall network design was developed over

[18] Palma (1972).
[19] This law was only amended in 1970 and the first government contributions to metro construction arrived only during the late 1970s with ad hoc legislation.
[20] Minici (2018).
[21] Notably: laws 1145/1959, 285/1968, 82/1970, 396/1971, 374/1974, and 19/1978.
[22] Calise (2021).
[23] Mai (2009); Metropolitana Milanese spa (1980); Minici (2018).

time, notably with a 1942 masterplan and, later, within the 1964 urban masterplan (P.R.G. 1964). Nevertheless, those plans were rudimentary, mostly no more than a generic network scheme with no delivery horizon nor thorough economic analysis.

The 1992 Mass Transit Funding law

The 211/92 mass transit law was the first attempt to organize funding for mass transit projects on the national level within a coherent long-term framework. The 211/92 law and the connected financing decrees appropriated the equivalent of €8.5 billion over a multi-year period (1992 to 2006 circa) to fund mass transit projects proposed by local authorities.[24] Funded projects were to have "mass transit characteristics", in terms of capacity, frequency, reliability, commercial speed and dedicated rights-of-way. According to the law, up to 60% of the total investment could be covered by grants from the National Government, with matching funds coming from local authorities (Regions and Municipalities), through their own funds or long-term bonds mostly granted by the public lending authority (*Cassa Depositi e Prestiti* - CdP) and guaranteed by the central government. Over 15 years, the 211/92 law funded 76 tramways, metro, and BRT projects including some of the detailed case studies covered in this report. The law has proven to have several shortcomings in the financing methods, from the excessive slowness of implementation to its weak connection with planning tools.

The 2001 "Legge Obiettivo" funding law: a megaproject approach.

In 2001, Silvio Berlusconi's center-right coalition overhauled the financing process for infrastructure projects. The law 443/01, commonly known as "*Legge Obiettivo*" (Target Law) was designed to boost infrastructure building at the national level after the de facto freeze on projects during the 1990s. The law 433/01 mandated the government, notably the CIPESS inter-ministerial committee, to designate a list of large infrastructure projects of national importance (emphatically called Great Works, *Grandi Opere*) to be financed by the Treasury. The National Government's share could cover up to 100% of capital cost for national projects (such as mainline rail, energy and water management) or up to 60% of the capital cost for urban transit, with the remainder being provided by local governments (Regions, Provinces and Municipalities) or, eventually, the private sector, as the law actively sought greater involvement from private operators in both the funding and delivery, notably through Public-Private Partnerships.

[24] A detailed account of appropriations and spending related to the 211/92 law is available in a report published by the Court of Auditors - *Corte dei Conti* (CdC, 2017b).

The list of "strategic megaprojects" (*Grandi Opere Strategiche*) to be financed under the "*Legge Obiettivo*" **was essentially politically motivated**. The list was compiled by cherrypicking projects developed at the local and regional level rather than assessing their merits, value, and benefits. Over time, the list has expanded to include the planning priorities of regional governments, as well as politically motivated pet-projects independent of any planning tool but sponsored by members of the parliament or the cabinet and supported by local interest groups. As a result, the list of strategic projects ballooned while funding remained constant. The list-based mechanism proved ineffective because it failed to provide a methodology for evaluating projects.[25] Furthermore, during a period of austerity, local authorities were unable to provide matching funds needed to get projects built, as their borrowing capacity was capped by the "internal stability pact." This approach was progressively abandoned in the early 2010s, through adjustments made by several governments of different political orientations. In 2016, it was finally replaced with a mechanism to allocate national funds better tied to local and national planning and accompanied by another major reform of the public works procurement process.

The 2016 Mass Rapid Transit fund and the Sustainable Urban Mobility Plans

During the 2010s a consensus among policymakers emerged that the strategic planning of transit infrastructure and the approval and funding for individual transit projects had to be better integrated. Within the context of the European Agenda for Sustainable Mobility, novel, more integrated planning and financing tools have been developed. Since the mid-2010s, Metropolitan Cities and larger municipalities have been required to develop and approve a Sustainable Urban Mobility Plan (SUMP, or *PUMS* in Italian – see section 3.2).

Since 2017, mass transit projects have been mostly financed through a dedicated Mass Rapid Transit Fund (*Fondo per il Trasporto Rapido di Massa, or Fondo TRM*) of approximately €2.5 to 3 billion per year for ten years. Transit capital projects can access national grants only if they comply with an approved local SUMP, have a positive Cost/Benefit (C/B) ratio, help achieve the SUMP's sustainability goals, and follow evaluation standards established by the Ministry of Infrastructure and Sustainable Mobility (MIMS). The C/B ratio, the quality of SUMPs and a set of sustainability and efficacy criteria, such as modal shift or increased coverage, that are rated by a ministerial commission, are taken into account to determine the ranking of financeable projects and the amount of national grants for each project. The National Fund can cover up to 100% of the capital costs, including most hard and soft costs, as well as the rolling stock. So far, three rounds of grants have been awarded using that method, in 2018, 2019 and 2021. Even though the TRM fund is poised to become the dominant source of capital funding from the

[25] For more detail about the problems of law 443/01 see: Beria (2007).

central government, individual projects can also be funded through different ad hoc appropriations in the general budget, through EU regional cohesion funds as well as other local or national sources.

Good Practice focus: grants supporting design.

The 2017 reform also instituted a dedicated grant system, called *Fondo Progettazione Enti Locali* intended to cover up to 80% of the costs sustained by the local governments of large cities and major metro areas to plan and design mass transit projects. The fund was deemed necessary because, as the then minister lamented several times, many local administrations had struggled to submit good quality projects because of a lack of in-house expertise and constrained budgets. The fund has since been replenished twice: €90 million for the 2019-2021 and €116 million for 2021-2023 periods. Money is allocated based on a fixed formula with a light non-competitive application. Unused funds are redistributed to the other recipients. *Cassa Depositi e Prestiti*, the public bank that has among its mandates to support local governments, is charged with administering the fund, and also providing technical support and staffing for municipalities to manage projects and to streamline the process, such as cashflow and financial management. The fund has been generally considered a success by experts and practitioners, as it has sparked a new wave of good-quality transit projects.

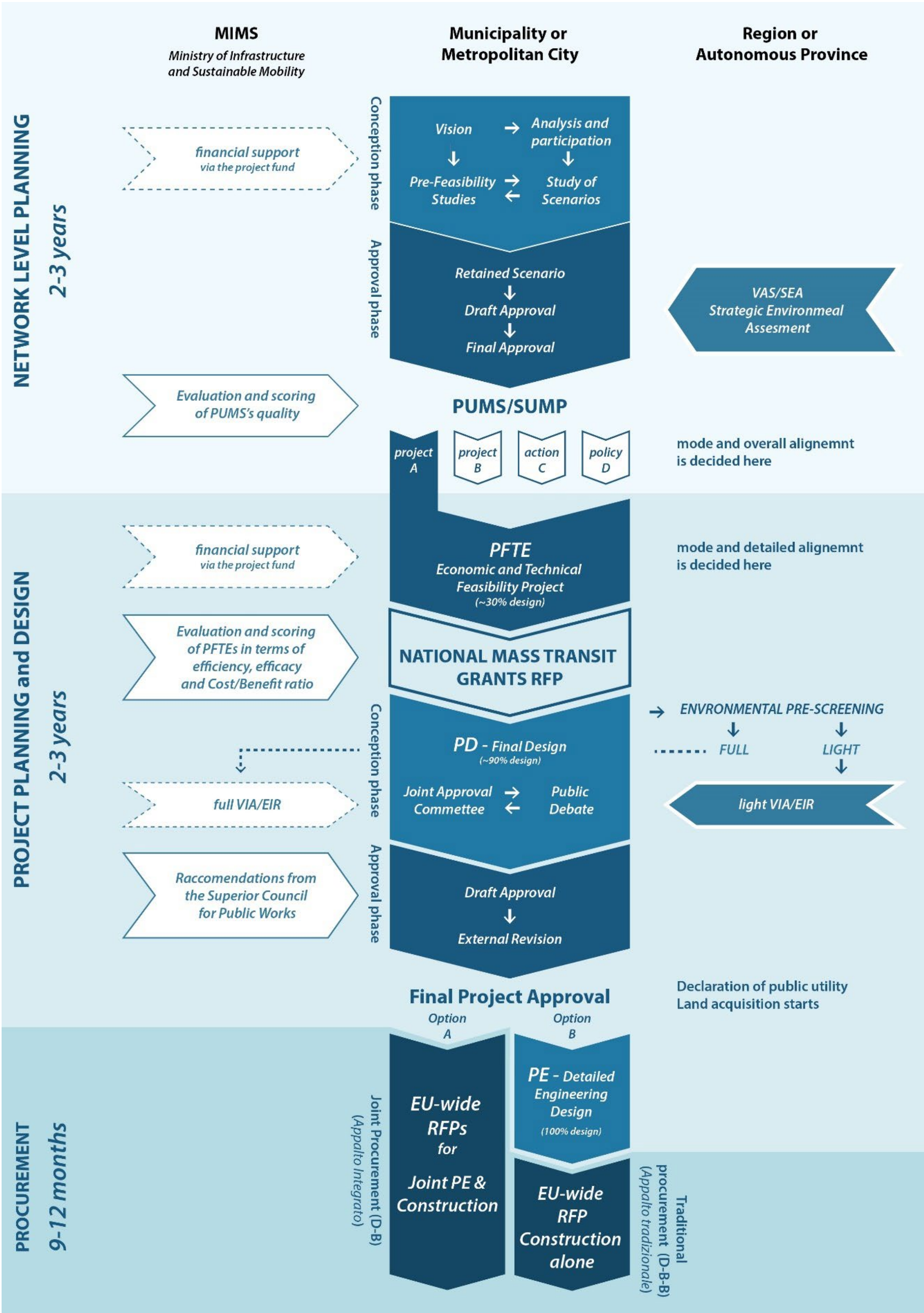

figure 6. A simplified summary of the planning and funding process of transit capital projects after the 2016 reform.

3.4 A great variety of delivery methods: the evolution of bidding and contracting practices.

The Italian case showcases a variety of delivery methods for urban rail construction. The framework for public works has evolved dramatically over time. These changes are partially tied to the overall trajectory of the economic policies at the national and EU levels and to the political history of the country. Until the 1990s, most public works were carried out in a loose regulatory framework first established in the 1890s[26] and only minimally adjusted over time with partial reforms to address specific issues or sectors. Traditionally, low-bid procurement was used with the concession schemes, to delegate to the private sector the construction and maintenance of key national infrastructures, similar to the rapid development of the national motorway network in the 1950s. However, this happened in a context where the public sector was greatly involved in economic life via large publicly-owned corporations operating in several industrial and financial sectors and reassembled under the *Istituto per la Ricostruzione Industriale* (I.R.I.) conglomerate.[27] In this context, the construction of the first metro lines until at least the 1970s was mostly delivered through publicly-owned special-purpose companies, with the involvement of the private sector only in the construction phase, mainly through traditional bidding procedures awarded to the lowest bidder. In 1955, **Metroroma spa** was established in Rome by the I.R.I. to build metro line A. The same year, the city of Milan established a municipally-owned concessionaire, **Metropolitana Milanese spa (MM)**, that issued municipally-backed bonds to build the first two lines and managed all aspects of project delivery, from planning to design, while actual construction was contracted out to private-sector firms.

During the second half of the 1970s and through the early 1980s, the delivery of new metro projects **grew more reliant on various Design-Build (D-B) concession schemes**, in theory modeled after what was considered the successful attempt of MM in Milan to build and consolidate in-house expertise in metro construction. But unlike Milan, those later D-B concessions were directly awarded without public competitive bidding to consortia of public and private firms or even only private ones, based on the claim that local authorities lacked proper in-house expertise in metro construction.[28] Those schemes were called "Concessions of sole construction," that is a non-competitive, loosely defined D-B scheme awarded on the basis of a preliminary transit expansion masterplan. These schemes were used in Naples, with the creation of **Metropolitana di Napoli spa (MN)** and for the E-W LRT (today's line 6), and in Genoa for the construction of its first line in the late 1980s. These opaque concession schemes, often based on a simple general development masterplan for a future metro network supported by a general concept, preliminary cost estimates lacking clearly defined quantities and methods and without a defined

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[26] *Regio Decreto* 350/1895.

[27] The I.R.I. - *Istituto per la Ricostruzione Industriale* (Institute for the Industrial Reconstruction) was established in the 1930s after the nationalization of several large industries, insurances and banks bankrupted by the Great Recession.

[28] Calise (2021); CdC (2017a).

schedule, proved to be a fertile ground for corruption and cost-escalation that characterized public works during the last fifteen years of the First Republic, and eventually led to the collapse of the political system swept away by *Tangentopoli* in the early 1990s.

The 1994 public works reform.

The 1994 public works reform, also known as the Merloni law (109/94) was the first major comprehensive legislative reform about public works since the original Royal Decree 350/1895 approved almost a century before. It came in the wake of the early 1990s scandals, and it was inspired by the principles of transparency, quality of public works, and open and fair competition between contractors. It represented the translation into the Italian legislation of several EU directives targeted at creating a pan-European open market. The implementation of several aspects of the law were postponed for political reasons or even openly reverted for a short period in the early 2000s. Nevertheless, many key innovative procurement practices were refined and implemented in the years following the Merloni law and are now an integral part of the 2016 Public Procurement Code. A few elements stand out as significant improvements to contracting practices brought by the 1994 reform:

- It established **oversight authorities** to ensure the appropriate application of procurement practices by contracting agencies, notably the National Authority for the Oversight of Public Procurement, more recently renamed the Anti-Corruption Authority (ANAC).
- It strictly prohibits Design-Build concession schemes used in the previous decade for metro construction in Naples, Rome and Genoa. Public infrastructure can either be delivered through separate public contracts (*Appalti*) for design and construction (similar to Design-Bid-Build) or with joint-procurement contracts (*appalto Integrato*). Contractors must be selected through fully open RFPs (*gara pubblica*), shortlisting (*gara a inviti*), or public two-step design competitions (*consorso-appalto*).
- It established that, in principle, **planning and design of Public Works is the responsibility of the Public Administration and must be carried out in-house** by the contracting authorities. Part of the design work can be contracted out to private firms in case of insufficient expertise. This principle has been only partially applied because local authorities have been unable to expand their payrolls since the late 1990s because of austerity measures. Furthermore, since 2002, there has been a greater emphasis on including the private sector in the design phase as a strategy to reduce public spending.
- **It defined a low threshold for non-competitive bidding** (it has varied over time between €75,000 and €150,000) and a further threshold (between approximately €2 to €5 million depending on the domain and type of procurement) above which **pan-European open RFPs are mandatory**.

- It required that all bids' estimates be based on **official reference lists of benchmark unit prices** (see section 3.6) updated annually.
- It capped the size of claims a contractor can make for input cost variations based on a threshold linked to the inflation rate and prohibits changes to the unit costs agreed to in the contract. It established a framework to resolve conflicts between contractors and the state through arbitration rather than lengthier judicial proceedings.
- It introduced the **Best-Value-for-Money criteria** (*offerta economicamente più vantaggiosa*) to evaluate bids. Proposals are scored according to technical quality, costs, and schedule. The relative percentages assigned to each category can vary, but technical quality typically represents 50% or more of the overall score. Technical quality includes relevant experience, proposal of improvements of construction techniques, schedule and work site management, and quality of PE design in the case of Integrated Delivery Contract (*Appalto Integrato*). This approach is de facto mandatory for larger procurements, which includes all transit projects. Lowest bidder procurement is still used for smaller, more straightforward procurements based on the Detailed Engineering Design (PE).

Even though many innovative aspects of the 1994 reform were watered down in the following 2002 partial reform (law 166/2002) that pushed for greater involvement of the private sector and introduced project delivery mechanisms, like the General Contractor, that limits the oversight capacity of the contracting authority and outsources important design tasks, the 1994 law and the following amendments established a number of practices and principles that have proven effective in containing costs and improving project delivery.

3.5 Constraints and veto points: the issue of historic buildings and archeology

Italian cities boast historically layered, dense and relatively large urban cores that continue to have a central role in the urban economy, thanks in part to longstanding dedicated policies and a robust urban tradition. Thus, most metro rail projects have cut their way through narrow winding streets to serve the dense historic cores.

Italy has **a particularly strict and complex set of national and regional laws enforcing the protection of archeology, historic buildings and ensembles, and landscape**. The 1948 Republican Constitution specifies the importance of safeguarding heritage in one of its twelve fundamental principles.[29] But heritage protection laws date back to the construction of the post-unitary State. Since 1907, historic buildings and landscape protection

[29] Article 9: "The Republic promotes the development of culture and of scientific and technical research. It safeguards natural landscape and the historical and artistic heritage of the Nation."

falls mostly under the authority of the so-called *Soprintendenze* (Superintendencies). These are territorial authorities that are under the auspices of the Ministry of Culture and Heritage (MIBACT) and are staffed by career civil servants, mostly having backgrounds in archeology, architecture, history of arts or *Beni Culturali* (heritage studies). Moreover, the city of Rome has a locally controlled Superintendency (*Sovrintendenza Capitolina)*, a special body within the Municipal administration, first established in 1872 to protect and manage the Archaeological Park of the Imperial *Fora*, the Aurelian walls, and in general the archeological heritage of ancient Rome. Despite being part of the city's administration, it enjoys greater autonomy than other agencies and departments.

Thanks to laws that have expanded their powers continuously since the 1930s[30], the **Heritage Superintendencies have de facto veto power** over any project that may affect an area or a building that is under their jurisdiction, that is most historic city centers and several landscape protection areas. As we will see in the detailed case studies, the severe constraints imposed by *the Heritage protection bodies* play a significant role in project design and costs, especially in the central areas of Rome, Naples and Milan.

3.6 The use of benchmark unit costs: the *Prezziari Regionali delle Opere Pubbliche*

The use of official unit costs in public works has proven to be a fundamental tool to improve public procurement and stabilize costs. Known as "*Prezziari"*, these official price lists have been implemented over time[31] and are modeled on what was already a common tool in the private construction sector, where the provincial Chambers of Commerce already published yearly updated reference itemized costs largely used in the private sector since the late 1960s.

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[30] Notably, the 1089/1939 (heritage and archeology), the "Galasso law" 431/1985 (landscape) and the following Dlgs. 42/2004, establishing an organic Code for the protection of Heritage and Landscape (*Codice dei Beni Culturali e del Paesaggio*).

[31] The first attempts to introduce itemized costs in public works was done in the early 1970s (law 14/1973) as a way to promote procurement practices based on unit prices instead of lump sum contracts. It had a limited impact because it left to each contracting agency the burden of elaboration its own reference lists and deciding how to apply it. The obligation for contracting agencies to devise their own reference price lists was first introduced with the so-called "Merloni" reform (law 109/1994), but only slowly implemented over time as the law left undefined how to technically elaborate those reference prices. With the devolution of many legislative matters to regions after 2001 and further refinements of the public works law in 2006 and 2010, the competence for the definition of the official reference price lists was finally transferred to Regions and the regional *Prezziari* has become the official reference for bidding prices in public works. Nevertheless, large agencies like RFI and ANAS, which had strong in-house engineering and design capacity, implemented them already starting from the mid-1990s.

In the late 1970s, detailed benchmark unit costs were introduced as the principal tool for determining the base cost of public contracts, but only for specific forms of procurement.[32] Benchmark unit costs became mandatory after the 1994 reform of the general public procurement law,[33] which was refined following the 2006 public procurement code,[34] notably with the introduction of a homogeneous mechanism for the mid-year revision of the benchmark cost of materials. Furthermore, in the following years, the task to maintain and update the official lists of benchmark unit cost was transferred from single agencies to Regional Governments, in an effort to rationalize the process, facilitate the task and avoid inconsistencies between multiple agencies. Since the late 2000s, Regional Governments publish an annual unit cost list called ***Prezziario Regionale delle Opere Pubbliche*** *(Prezziari OOPP)*.

The Prezziari OOPP are detailed lists of itemized benchmark prices for units of finished work, that is, prices that include all the foreseeable input costs to achieve a given quantity of finished work. For example: the cost of one square meter of road paving, one cubic meter of poured concrete with given mechanical characteristics, one linear meter of a sidewalk curb, one linear meter of embedded rail tracks, one converter for an electrical substation at a given voltage, one standard pole of a certain height for an Overhead Line Equipment (OHLE), etc. These prices, called ***Prezzi Unitari*** (see figure 7), are expressed in consistent units (square meters, cubic meters, linear meters, piece, etc.) for a given quantity of finished work, and are calculated by factoring in all the relative input cost of materials, labor, theoretical rent costs of tools and machines, as well as transportation costs for the delivery of materials to the construction site and the disposal of waste from demolitions. A fixed percentage is added to account for the general expenses of the contractor (normally around 12-13%) and for the contractor’s anticipated “fair” profit (10%).

[32] The so-called “concorso-appalto” or a form of RFP procedure involving a shortlisting process.
[33] article 26, law n. 109/1994
[34] article 133, Legislative Decree n. 163, 12 april 2006

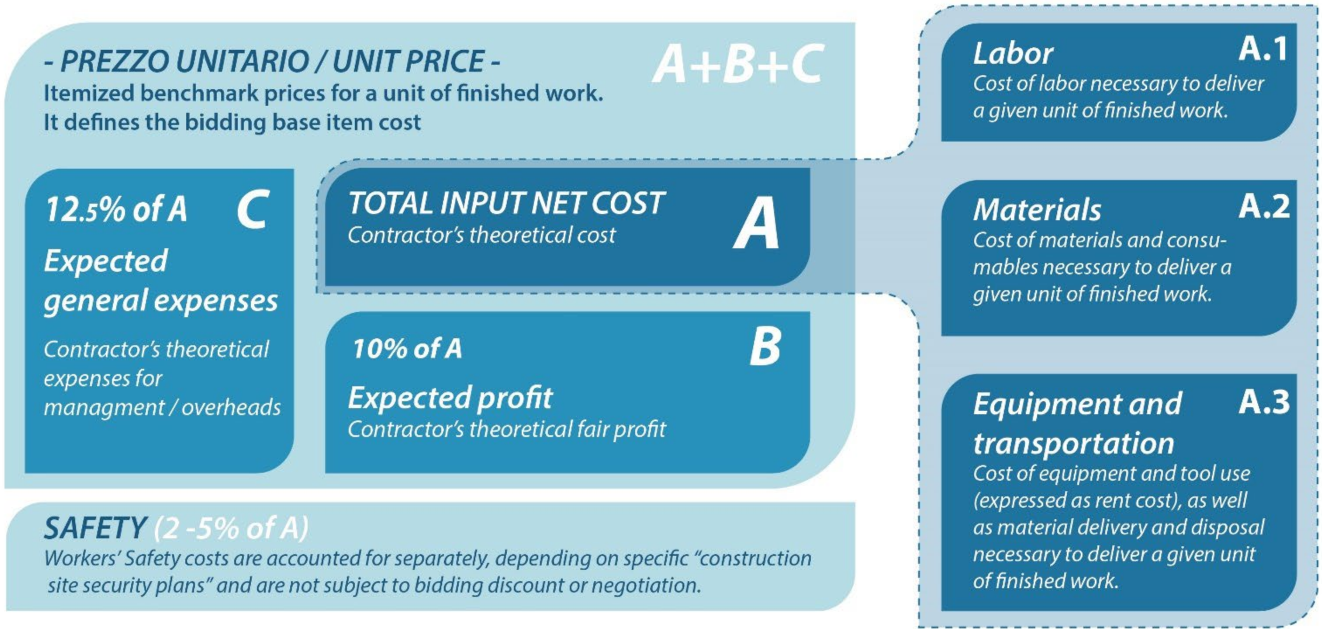

figure 7. A simplified scheme illustrating how benchmark unit prices (Prezzo unitario) are defined.

Reference prices also include disaggregated input costs that can be used by contracting authorities to calculate specific non-standard works and work conditions, such as night work, constrained working space, reduced working hours for noise mitigation, etc. The official list of unit prices is public and freely accessible. They are officially approved and updated yearly by the Regional Governments through a technical commission that includes civil servants and technical experts.[35] Moreover, the Ministry of Infrastructures (MIMS) carries out a mid-year revision of the input cost of raw materials. If during the first six months of the current year the cost of a given raw material has increased or decreased more than 10%[36] over the previous year's average, contractors can claim direct compensation from the contracting agency for up to half of the increase exceeding the 10% threshold. That compensation can be covered by contingencies.

Reference prices are not price controls. Instead, they are used to set reasonable parameters for bids. By injecting greater transparency into the process, reference prices help weed out anomalously low/ high bids and are used to avoid bidders who submit very low lump sum bids and then seek large change orders to compensate

[35] Regional Governments are not the only ones determining official list. Major national agencies involved in large public works, like RFI (national rail network manager), ANAS (national road agency), or even local transit agencies with specific needs (for example, Turin's GTT and Milan's ATM for tramway equipment construction and maintenance) have their own Prezziari that are fully elaborated in-house based on a consolidated experience.
[36] Since 2018, the threshold has been lowered to 8%.

for the low bid after the contract is secured[37]. In fact, bidders must submit their offers by single itemized costs and not by a lump sum in most cases.[38] Eventual change orders will thus be based on the unit price submitted by the contractor for the specific item and cannot be renegotiated except for major changes to the project scope and design or changes that are considered unfair or disruptive for the contractor's workflow.

Reference Prices and the rule of exclusion for "anomalous bids" have worked well because they have been combined with the "***rule of the best value-for-money***" (*regola dell'offerta economicamente più vantaggiosa*) scoring criteria. Best value-for-money contracting scores bids according to a combination of cost (~20-40% of scores), technical quality (~50-80%) and time savings (~0-10%). All contracts greater than €2 million must be assessed via best value-for-money,[39] while low-bid contracting is still used for smaller works. Lump sum contracts are now illegal except for very small contracts or in case of very specific procurements of proprietary technology (that is the case, for example, of the VAL system, as we will see in Turin's case, but also of proprietary CBTC installed in M1 in Milan).

Finally, reference unit prices work as a tool to **set a minimum threshold for labor productivity**, as they implicitly define the "reasonable" level of manpower needed to achieve a certain amount of finished work. Better performing contractors that make more efficient use of their resources can achieve a lower bid or larger profit through economies of scale, better construction techniques (that are also accounted for in the technical score of the bidding), etc. On the other hand, it is important to note that reference prices can indirectly incentivize an abuse of sub-contracting, if the contractor tries to reduce labor costs by sub-contracting to small companies or individual free-lancers who are not subject to the national bargain contracts or even black market labor through long chains of sub-contracting. For that reason, the use of subcontracting has been more tightly scrutinized after each iteration of the 1994 Code of Public Works.

3.7 The "*riserve*" mechanism: the unsolved problem of extra cost claims

Unlike in the US, allocations for contingencies within the project budget tend to be minimal, on the order of a few percentage points (normally less than 5%) and they can be only used to cover change orders validated by the DL or minor input cost variations accounted for by the official "*prezziari*" regular updates and thus granted by

[37] See for example: https://la.curbed.com/2017/1/27/14416120/metro-purple-line-contractor-tutor-perini

[38] The threshold for lump sum contracts varies depending on the type of works, but lump sum contracts are limited to small public works.

[39] Those thresholds are set by EU regulations, and they vary depending on the sector of public procurement and its relevance for the common market, as all bidding process higher than a certain value must be open to all EU contractors.

the contract (see sections 3.4 and 3.7). Over time, legislation and court decisions have discouraged the use of large contingencies intended to cover any extra-cost claims coming from the contractors during construction, as it can create incentives for post-bid cost increase as funds are already allocated in the budget. Hence, additional claims made by contractors during construction are normally accounted for in the project's bookkeeping through a mechanism called ***"riserve."*** This system, rooted in the original RD 350/1895 public works Royal Decree and modified several times since,[40] allows a contractor to accept payments from a contracting authority *con riserva* (literally: conditionally, hence the name) in the project's official accounts, while advancing claims for unforeseen costs that have not been approved by the DL through an official change order or are not part of the contract provision.

Those extra claims are normally linked to an increase in input costs for the contractors caused by circumstances beyond their control, such as archaeological findings or unexpected geological conditions, cascading delays from other contractors' work, postponements caused by delayed bureaucratic decisions, etc. The reasons must be detailed by the claimant and quantified in terms of loss caused by a suboptimal use of the contractor's own resources (for example, the TBM equipment sitting idle or misallocation of labor force). Based on the juridically enshrined principle of "fair compensation" of public suppliers, the contractor can ask for additional compensation of those costs incurred independently, subject to arbitration or, eventually, to a legal decision.

This mechanism has proven to be an unresolved bug in the current procurement process as it can cause lengthy legal proceedings between the contracting agency and the contractors that stall projects for months, and that often continue for several years after the end of construction. The *riserve* has been used as a tool for contractors to increase their margins and recover ex-post part of the discount offered to win the bid. As this mechanism is used to put pressure on the contracting agency, it is also common for contractors to exaggerate claims accounted for as *riserve* during the construction phase, even though normally final negotiations result in additional compensation being as low as 10-20% of the claim or around 1-3% of the initial contract for simpler works (like surface rail transit), up to 5-8 %, or even 10% in a few cases, for riskier projects like tunneled metro construction in complex urban contexts.[41] As we will see in Rome's case, the *riserve* mechanism remains an unsolved problem that can cause uncontrolled cost escalation, especially when procurement is based on poorly defined project scopes and the contracting authority lacks sufficient supervision capacity.

[40] For example, see the DPR 207/2010 and the D.Lgs. 50/2016

[41] Those numbers are mostly derived from interviews with officials and sectorial publications.

Part II – In-Depth Case Studies

4 Four in-depth cases: Turin, Milan, Rome and Naples

4.1 The selected projects

In the second part of the report, we investigate in greater detail five metro projects built during the last two decades, under construction or in advanced stages of planning. The selected projects, located in Turin, Milan, Rome and Naples, total approximately 66 km of new service and 90 stations, accounting for an investment of €9.5 billion in nominal terms or $13.5 billion in 2020 PPP real terms. The selected projects have different technical characteristics, delivery schemes and varying construction costs. Thus, they provide multiple insights into the drivers of construction costs. In particular:

Turin. In In the late 1990s, the capital of Piedmont started to plan its first metro line, the first automated light metro in Italy, based on the **VAL 208 rubber-tired technology** already deployed in numerous projects in France during the 1980s and 1990s. Turin's case helps us understand the benefits and drawbacks of traditional Design-Bid-Build project delivery, how it is possible to develop in-house expertise quickly, the importance of standardized station design, and the design and cost implications of adopting light-automated metros, at the time a new technology for Italy, while still delivering high-capacity transit.

Milan. The capital of Lombardy boasts by far the largest metro network in Italy and is undergoing a major expansion with several new lines and extensions recently opened, under construction and planned. Our analysis focuses mainly on **line M5**, a fully automated light metro line opened between 2013-15 and delivered through a Public-Private Partnership Design-Build Finance-Operate-Maintain (PPP DBFOM) scheme. The construction costs were low, the project experienced limited cost escalation and it was delivered on-time. **Line M4**, another fully automated light metro currently under construction and poised to open in stages between 2022-23, and a **short suburban extension of M1**, a heavy metro currently in the early procurement phase, will be briefly discussed too. Milan's case will mainly highlight the importance of longstanding in-house expertise, emphasizing the role of the municipally owned engineering firm Metropolitana Milanese Spa and how it has retained and leveraged critical in-house technical capacity regardless of the delivery formula.

Rome. The capital of Italy is currently developing its third metro line, **MC**, that will eventually cross the city from West to North via the heart of the old city core. That project has been selected because of a relevant difference in cost between the outer section (T4-T5) and the city center one (T3) and also because of the use of the "General Contractor" delivery formula, a form of Design-Build. The in-depth analysis of those elements highlights the interplay of external constraints, such as archeology and heritage, with political uncertainties and management issues as mutually reinforcing drivers of cost escalation. **Line MB1** has been selected for a direct in-case comparison: built during the same period of MC's T4-T5, it was instead delivered through Design-Bid-Build at a lower cost.

Naples. The central section of Naples's **line 1** (*linea 1 – tratta bassa*) has been selected as a relevant case because it represents the most expensive metro project ever built in Italy. The dense urban context and poor geology, the unique delivery scheme inherited from the 1970s, and the customized design choices, particularly for stations, make it an instructive contrast to the other cases.

4.2 Cost variation among projects: a quick comparison

Construction costs vary widely among the selected projects, from as low as $116.8 million per km for the Northern Section (*Lotto 1*) of M5 in Milan to as much as $635 million per km of the city center section of Naples's line 1, an almost sixfold difference. The in-depth analysis of these projects will illustrate how local circumstances, design choices, delivery formula, and political decisions contributed to these differences despite a common national institutional framework.

Yet, the preliminary analysis of the main cost categories across these projects, which local agencies shared with us, allows us to draw some general conclusions about a few main cost drivers. For the purpose of this analysis, the data have been reorganized into two macro categories and several sub-categories:[42]

[42] There are several minor and a few major inconsistencies between projects that depends on how different elements are accounted for in the documents. The major inconsistencies that result in more pronounced differences will be treated in greater detail in each project's specific chapter.

1. **Hard costs**

    - **Stations.** It includes all civil works; finishings; Mechanical, Electrical Plumbing (MEP) - mechanical (lifts, escalators, and ventilation), non-system electrical, plumbing (fire-extinguishers, sprinklers); eventual costs for the monitoring and reinforcement of the adjacent structures during construction. In three projects (M4, M5 and M1 in Milan) it also includes the cost of civil structures, finishings and MEPs for the Operation & Maintenance (O&M) facilities, that were included in the projects' scope.
    - **Tunnels.** It includes civil works and outfitting (e.g., bottom filling, catwalks, emergency lights) for tunnels and shafts built for emergency exits, ventilation, and TBM launching; eventual costs for monitoring and reinforcement of the adjacent structures during construction.
    - **System.** It includes tracks, traction, OHLE/third rail, signaling and/or automation, Supervisory Control And Data Acquistion (SCADA), telecommunications, faregates, platform screen doors.
    - **Other.** It includes all items not directly linked to the construction of the line, such as archeological excavations, park & ride facilities, on-site utilities relocation executed by the contractor, monument conservation, and, in some cases, surface remediation.
    - **Safety.** It includes expenses for safety equipment. Italian procurement law mandates a separate costed out project-tailored "work safety plan," as they are not subject to bidding.

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2. **Soft cost**

    - **General Soft Cost.** It includes planning, design and management cost, land acquisition, contingencies, utilities relocation executed by third parties, such as private or municipal utilities companies. It also includes transactions for the settlement of contractor's compensable claims for projects that have been concluded.
    - **V.A.T.** It includes the Value-Added Tax (VAT or IVA in Italian) on construction (10%) and professional services (20-22%). A few transit projects done as PPP, such as M5 in Milan, have been exempted from paying V.A.T. for a short period of time.

The proportion of the different categories varies widely between projects, as shown in figure 8, as does the absolute cost per km of the different categories, shown in figure 9.

Relative incidence of hard and soft costs. Hard costs vary between 58.2% and 88.9% of overall project costs. This wide variation depends in part on the delivery formula used in the different projects but also the way soft cost are accounted for within individual projects, as a uniform way of reporting costs didn't emerge until the mid-2000s. As we will see in greater detail in the related chapters, most of Naples's line 1 soft cost's are "hidden" as part of the hard cost, due to the outdated concession formula used to deliver that project, while the very high incidence of soft cost on the Bologna – Conca d'Oro section of line B is the result of particularly high compensable claims due to a change in the environmental classification of TBM excavated ground intervened during construction. If we exclude the aforementioned outliers, the range of soft costs is between 18-32% of total project costs, with most of the projects being in the mid-20s%. The Value-Added Tax accounts for 10-12% of projects' total costs. It is worth noting that, unlike in many North American cases, such as Montréal's blue line, Seattle's Sound Transit 3 and New York's Second Avenue Subway, land acquisition accounts for a very minor fraction, 0.9 % of the total cost on average and never more than 2.9 %. This is both the result of expropriation laws less favorable to private owners and, mostly, to the minimization of land acquisition.

Hard costs. Fully automated light metros have a higher incidence of system-related costs on the overall cost, at between 15.4% for M4 in Milan and 32.4% in Turin's M1 phases 1 & 2. System's cost on a per km basis (figure 9) is also notably higher in automated metros, accounting for between $21.5 million/km and $49.6 million/km, while it can be as low as $9.4 million/km in heavy metros with traditional signaling, like MB1 in Rome. The rubber-tired VAL 208 system used in Turin explains the M1 premium over the already costlier Hitachi Rail steel-on-steel system used in the other automated metros (M4, M5, MC). The very high costs ($ 45.8 million/km) of Naples's line 1 is due to the implementation of a new signaling and communication system on the whole line being applied to in the lower section's (*tratta bassa*) budget.

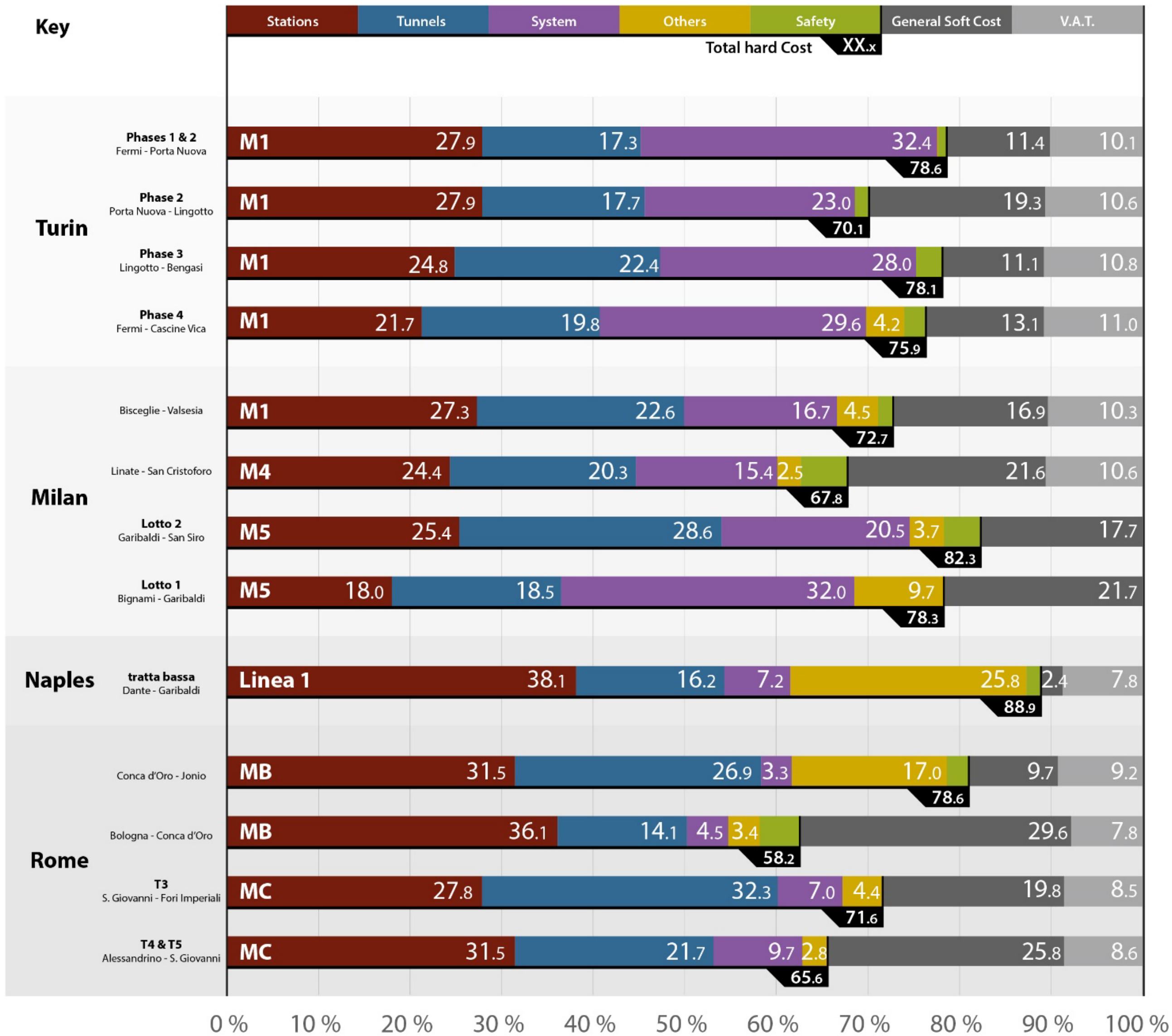

figure 8. Incidence of the different categories on the overall capital cost of the selected projects.

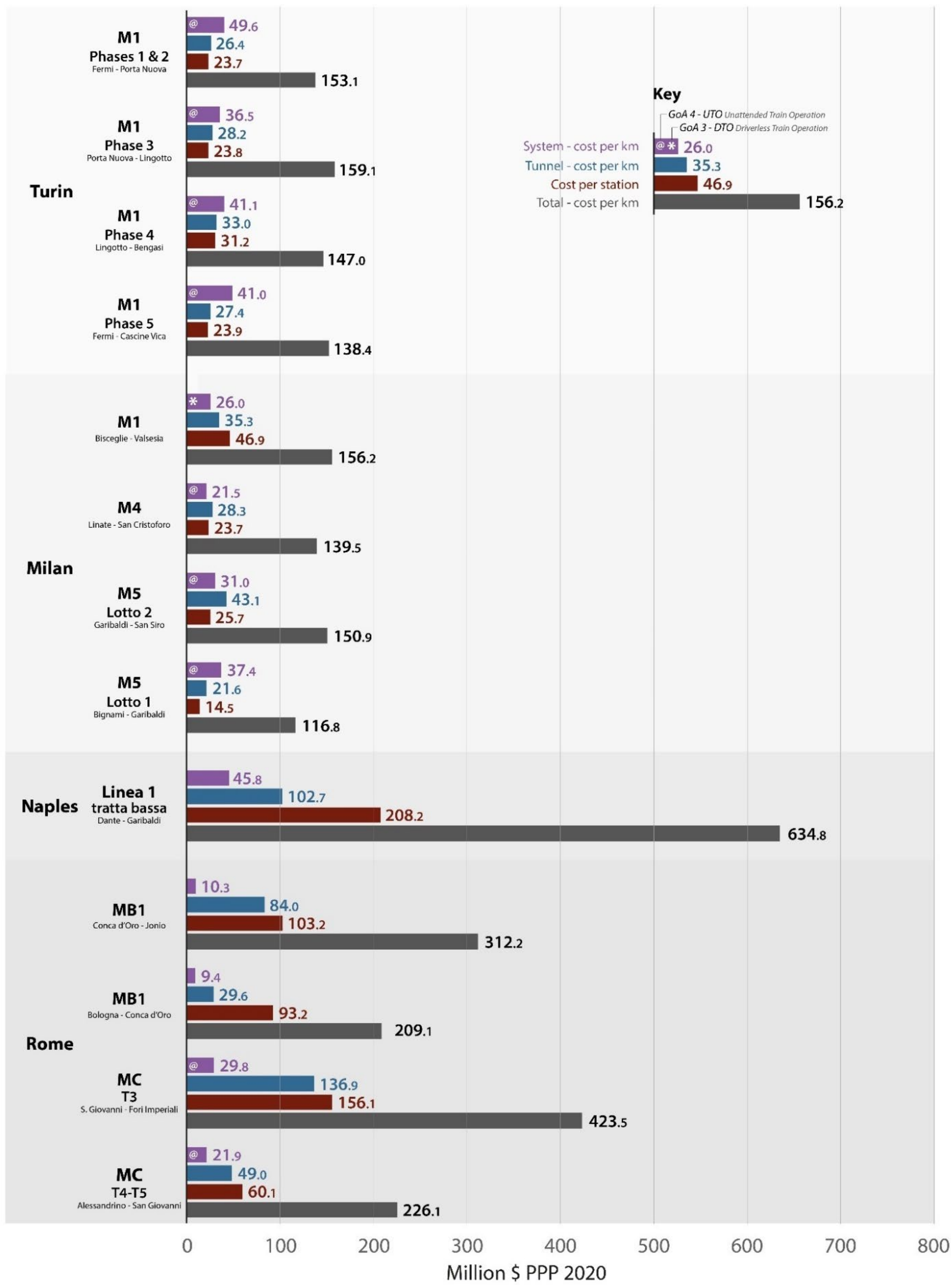

figure 9. *Actualized cost per km in $ PPP 2020 for the selected projects and related cost/km or cost/station of the most relevant categories of hard cost.*

Focus on stations. Among the seven projects we have obtained detailed cost breakdowns for, the civil works, finishing and MEPs of stations and O&M centers represent between 23 to 62% of the hard costs. The wide variation across the cases studied depends on a combination of lower costs for civil structures due to smaller station footprints for light automated metros, partially compensated by the fact that the analyzed light metros tend to have more closely spaced stations (740 m on average) than heavy metros (1,050 meters). Light automated metros show a consistent average cost per station between $14.5 million (M5 – Lotto 1) and $31.2 million (M1 – Phase 4), while heavy metros have a wider range.

The analysis of the individual construction cost of 82 underground stations across six of the selected projects[43] (figure 10, figure 11, figure 12) highlights a remarkable range in cost and a clear divide between metro typologies. The median station cost in $PPP 2020 is $36.9 million, with the lowest being $7.8 million (Isola on Milan's M5) and the highest being $283.5 million (Municipio on Naples's line 1) (figure 10). Considering platform length, light metro systems (50-55 m) have a much lower median cost per station, at $17.2 million, while heavy metros (110-150 m platforms) have a median of $62.9 million (figure 11). Moreover, 11 out of the 15 costliest stations in the database are situated within historic cores[44] and were built as part of heavy metro lines 1 (Naples) and MC (Rome), with a median cost of $147.1 million (figure 12). Finally, station costs are positively correlated with depth when controlling for platform length.[45] Station costs per cubic meter based on the station's "gross volume"[46] is also positively correlated with depth, suggesting that relative costs do not increase linearly as they are built deeper.

[43] Milan's M4 has not been included in this evaluation as only the cumulative cost of all the open-air civil works, which includes stations and the storage, operation and maintenance facility, has been provided by the agency.
[44] Historic cores are defined as the area comprised within the widest walled area a city covered in its history.
[45] The coefficient of correlation is +0.60 for light metros (n=46) and +0.64 for heavy metros (n=35).
[46] The gross volume metric used in this comparison should be taken as an indicative metric of a station's scale, not the effective volume of excavation. Station's volumes have been calculated using station's major dimensions from project's drawings. For stations not completely excavated from above, a "theoretical' volume (footprint on the surface multiplied by the depth) has been used instead. Depth = tracks depth from the surface plus 4 meters, to account for the bottom slab.

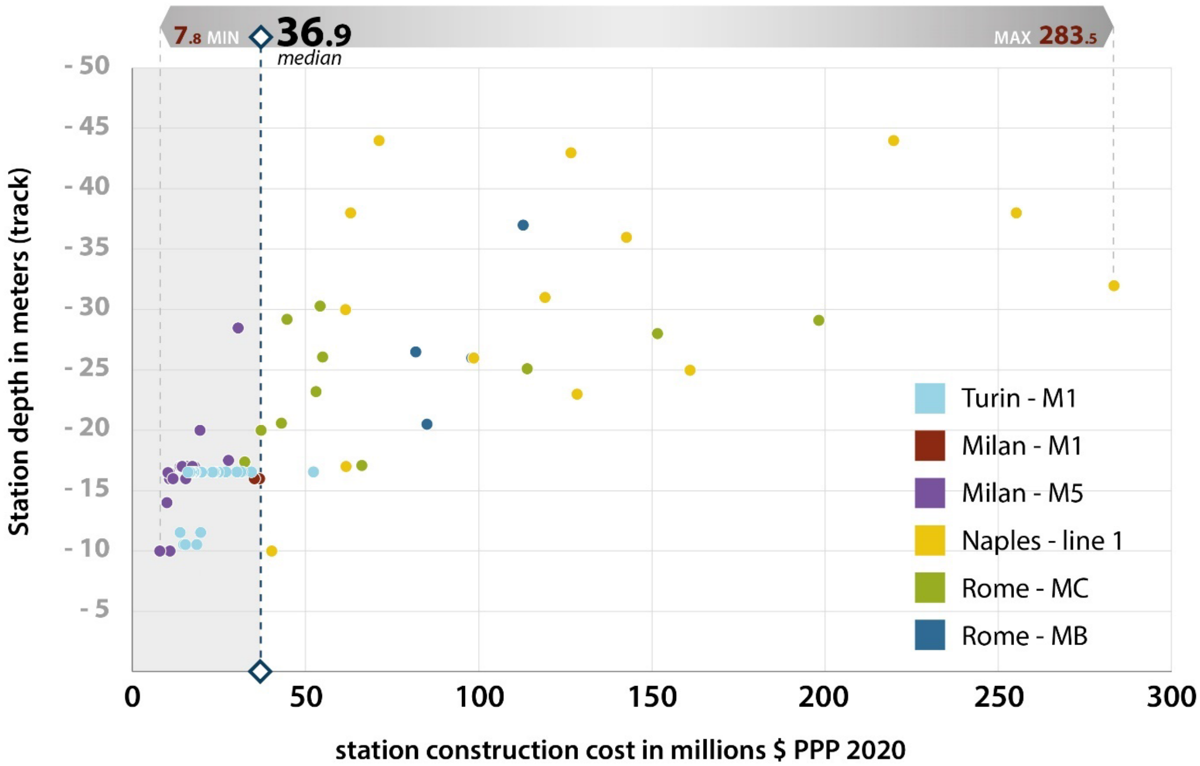

figure 10. ***Metro station costs by project.*** *Total hard construction costs of each station by project in relation to the station's depth, as measured at track level. Costs are actualized to $ PPP 2020 (n=82).*

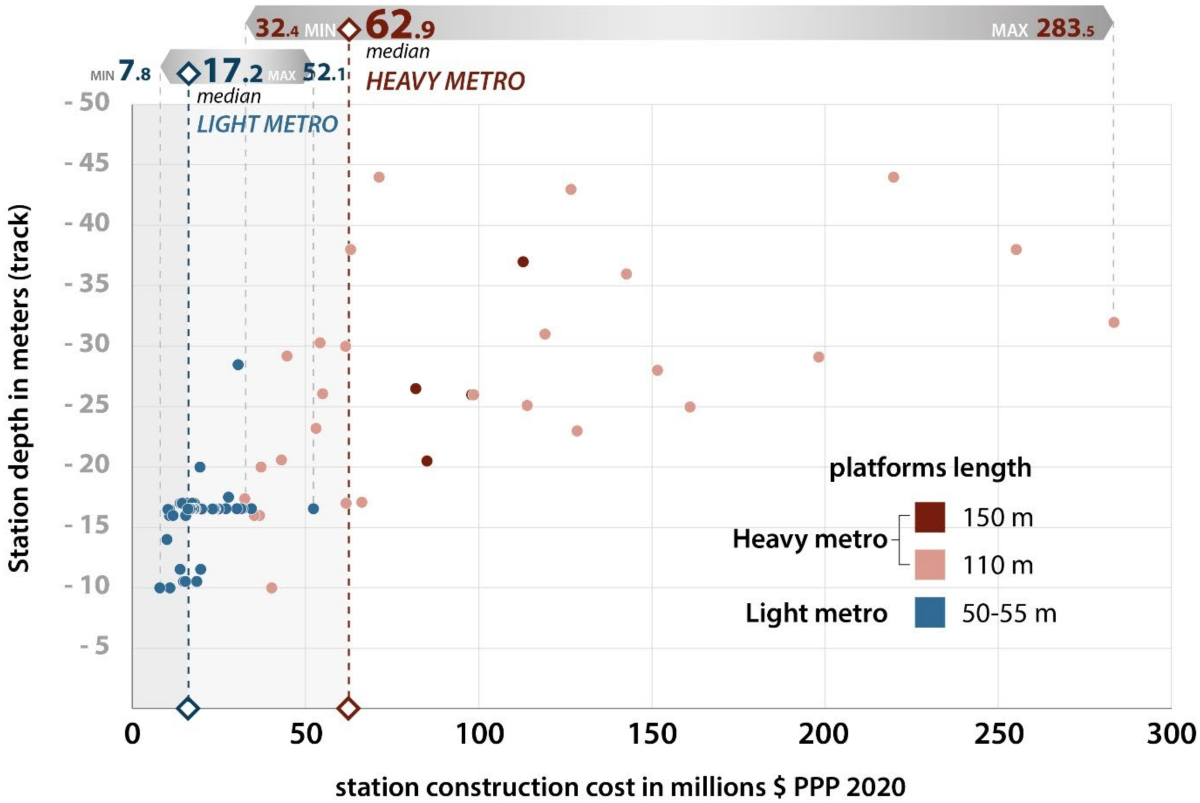

figure 11. ***Metro station costs by platform length.*** *Total hard construction costs of each station by project in relation to the station's depth, as measured at track level. Costs are actualized to $ PPP 2020 (n=82).*

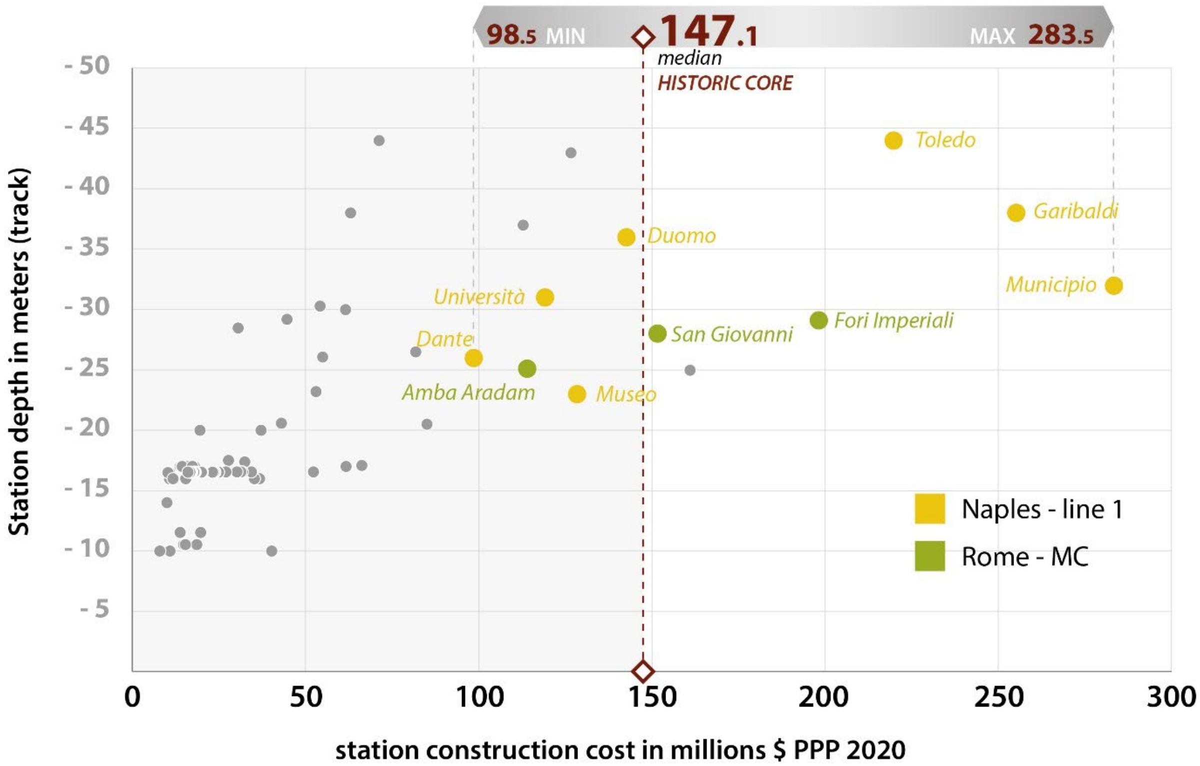

figure 12. ***Metro station cost by location.*** *Distribution of hard costs for station construction based on the station's depth, as measured at track level. Costs are actualized to $ PPP 2020*

5 Turin: M1

5.1 Introduction

Turin (850,000 inhabitants in the city proper, 1.8 million in the metro area) is the capital city of Piedmont, in Northwestern Italy. The city has had plans to build underground urban rail since the beginning of the 20th century. During the 1930s, a short city-center tunnel was built as part of an urban renewal program, but it was never used for regular service. Further plans were made during the 1960s, when the city was booming as the Italian automotive capital, but they never materialized into anything concrete. It was only at the end of the 1980s that the planning process for an automated light metro started and final design was finally approved in 1998.

During the early 1990s the city secured an initial grant from the central government, thanks to law 211/92, and a second one was granted as part of the financial support for hosting the 2006 Winter Olympics, allowing for the construction of phases 1 and 2 to take place simultaneously. Ground was finally broken at the end of 2000 for phase 1 and the following year for phase 2, both of which were completed respectively in 2006 and 2007. Funds for phase 3 were secured in anticipation of the celebration of 150 years of National Unification,[47] and phase 3 opened in March 2011. A further extension (phase 4) toward the South went into revenue service in April 2021 and an extension toward the West (phase 5) is under construction, with opening expected in early 2024. Funds for an initial section of line M2 were secured in 2019 with ground-breaking planned in 2023-24. In 2019, the metro carried approximately 150,000 daily riders, running at two-minute intervals during the peak period. In addition to

[47] As the first capital city of Italy, Turin was selected as the main venue for the celebration of the 150th anniversary of the Italian Unification of 1861.

the metro, the city has a 91.7-km tramway network that serves 180,000 daily riders and a suburban rail network (SFM) using the North-South rail link completed in the early 2010s as its central spine.

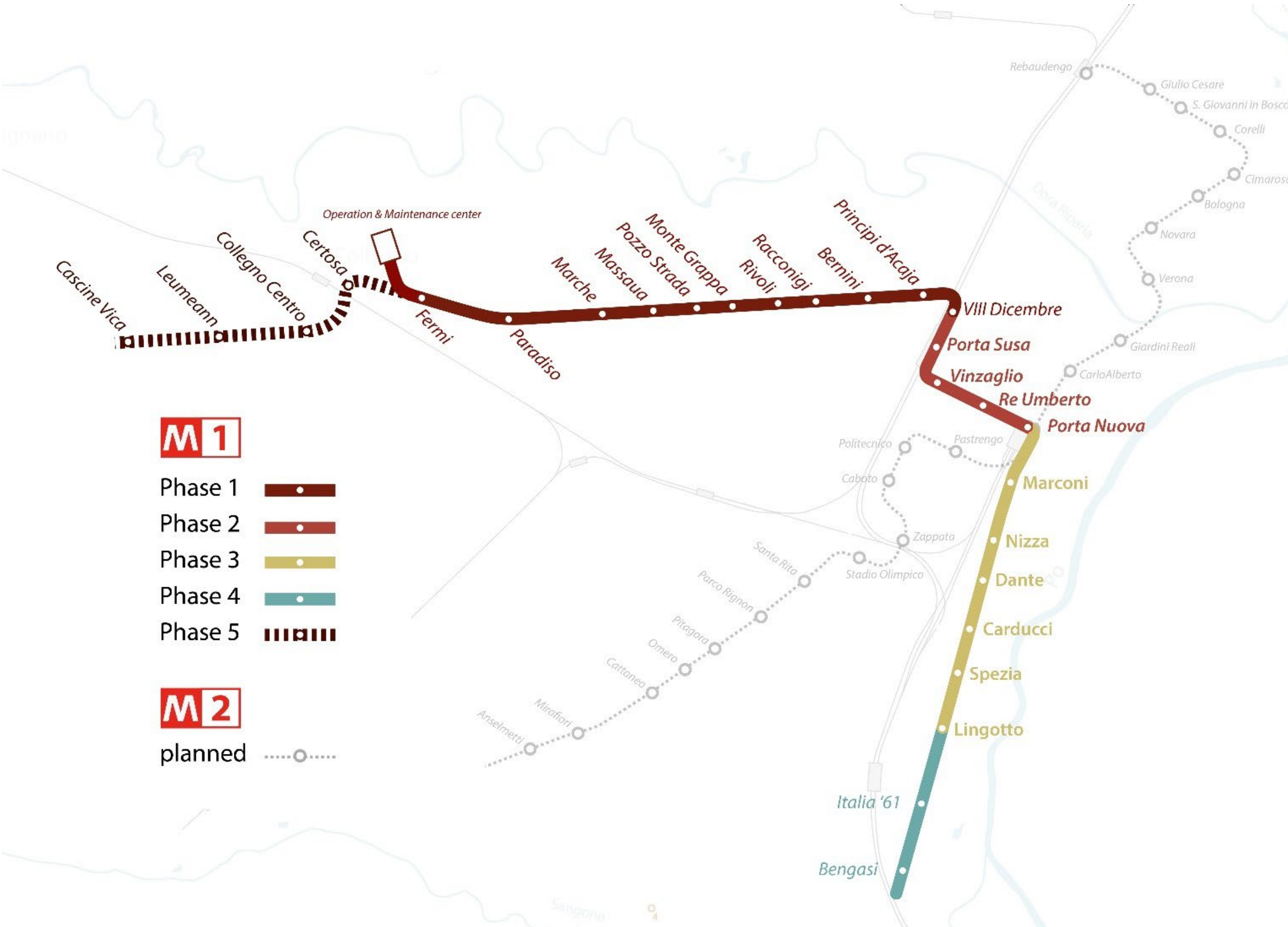

figure 13.   Map of line M1 highlighting the different construction phases.

5.2 Line M1: project overview

As of 2021, Turin's first metro line, which is fully underground, extends for 15.1 kms and has 21 stations, running from West to South via the two main railway stations where it connects with long distance trains and suburban service. M1 uses the same **VAL 208 automated rubber-tired light metro technology** first experimented with in Lille, France in the late 1980s and then deployed in Toulouse and Rennes. Unlike those cities, Turin opted for longer 52-m trainsets comprised of two 26-m trains instead of only one, to accommodate higher than expected demand. Another characteristic of VAL 208 is its narrowness, as trains are only 2.08 meters wide, much less than the 2.85 m standard of postwar heavy metros. The city of Turin chose VAL because it was the only proven light metro automated technology available in the early 1990s.[48] At the same time, Matra, the developer of the VAL system, was also briefly owned by FIAT during the 1990s before being sold to Siemens, and that factor is said to have possibly influenced Turin's choice to select a domestic supplier.

The project was initially managed by the city's transit agency, GTT (formerly SATTI), that was mandated by the municipality to plan, design, and deliver the project. In 2010, the city transferred the ownership of the line and the task of supervising and delivering the new extensions and other mass transit projects from GTT to a newly established municipally-owned company, named InfraTo,[49] in order to separate the infrastructure ownership from operations, as required by the EU rules to open up the transit operations market.

Table 2. M1 - Main Characteristics

	Phase 1-2	Phase 3	Phase 4	Phase 5	TOTAL
Years Construction start-end	2000 - 2006	2001 - 07	2006 - 11	2012- 21	-
Length (km)	9.6	3.6	1.9	3.2	**18.3**
Stations	15	6	2	4	**27**
Station depth	16.5 m	16.5 m	16.5 m	11.5 - 16.5 m	-
Cost Nominal in million € / $ PPP 2020	€ 788 / *$ 1,275*	€ 351 / *$ 513*	€ 189 / *$ 252*	€ 340 / *$ 443*	**€ 1,669** / ***$ 2,483***
Cost/km In million $ PPP/km	**133.1**	**143.7**	**133.8**	**138.4**	**136.2**
Alignment	underground TBM single bore tunnel Ø 6.7m	underground TBM single bore tunnel Ø 6.7m	underground TBM single bore tunnel Ø 6.7m	underground NATM single bore tunnel Ø 6.7m	-

Projected maximum capacity:	23,000 pphpd at 67 seconds minimum interval.
Vehicles	VAL 208, rubber-tired automated GoA 4 (2.08m wide x 52m long), 440 places
Platform length	55 m
Delivery method	Design-Bid-Build
Financing	**100% public**

[48] Ansaldobreda's steel-on-steel light metro was under development at the time and going to be deployed in Copenhagen.
[49] See: https://www.infrato.it/the-company/

5.3 Cost and design choices

Phases 1 through 5 of Turin's metro have a cumulative capital cost in nominal terms of **€1.669 million**. Considering that the project was been implemented over a two-decade period, the actualized cost of all the phases in $PPP 2020 terms is around **$2.48 billion** for 18.3 km and 27 stations, resulting in an overall cost of **$136 million per km**. Hard costs account for €1.27 billion or 76.2 % of the overall cost. As in most projects, a significant portion of the soft costs are represented by the V.A.T., while the remaining 12% comprise professional services, planning and management costs, land acquisition, commissioning and testing, etc. (See figure 15).

The nominal cost in euros has grown over time for the subsequent phases: €82 million/km for phase 1-2, €98 million/km for phase 3, €101 million/km for phase 4, €106 million/km for phase 5. Nevertheless, when inflation is accounted for, the per km cost is consistent among the different phases and it doesn't show an upward trend: $133 million/km for phase 1-2, $143 million/km for phase 3, $134 million/km for phase 5. Moreover, it is worth noting that the first three phases have a shorter interstation spacing, every 620 meters on average, than phases 4 and 5, which, respectively, have a station every 940 meters and 800 meters.

Phases 1 through 3 were all completed on time and on budget, taking on average 4.5 – 5 years to build. Phase 4, on the contrary, was mired in delays and incurred a minor cost overrun. Coming on the heels of the 2008 recession and the 2010-2012 European debt crisis, the initial Phase 4 contractor found itself in deep financial difficulties. InfraTo suspended works in 2014 and retendered the contract while solving disputes with unpaid subcontractors. All of these additional hurdles added costs and delays. Work finally resumed in 2018 and the extension opened in 2021. Phase 5, which is approximately 30% completed, is planned to be commissioned by early 2024 and appears to be on track and on budget.

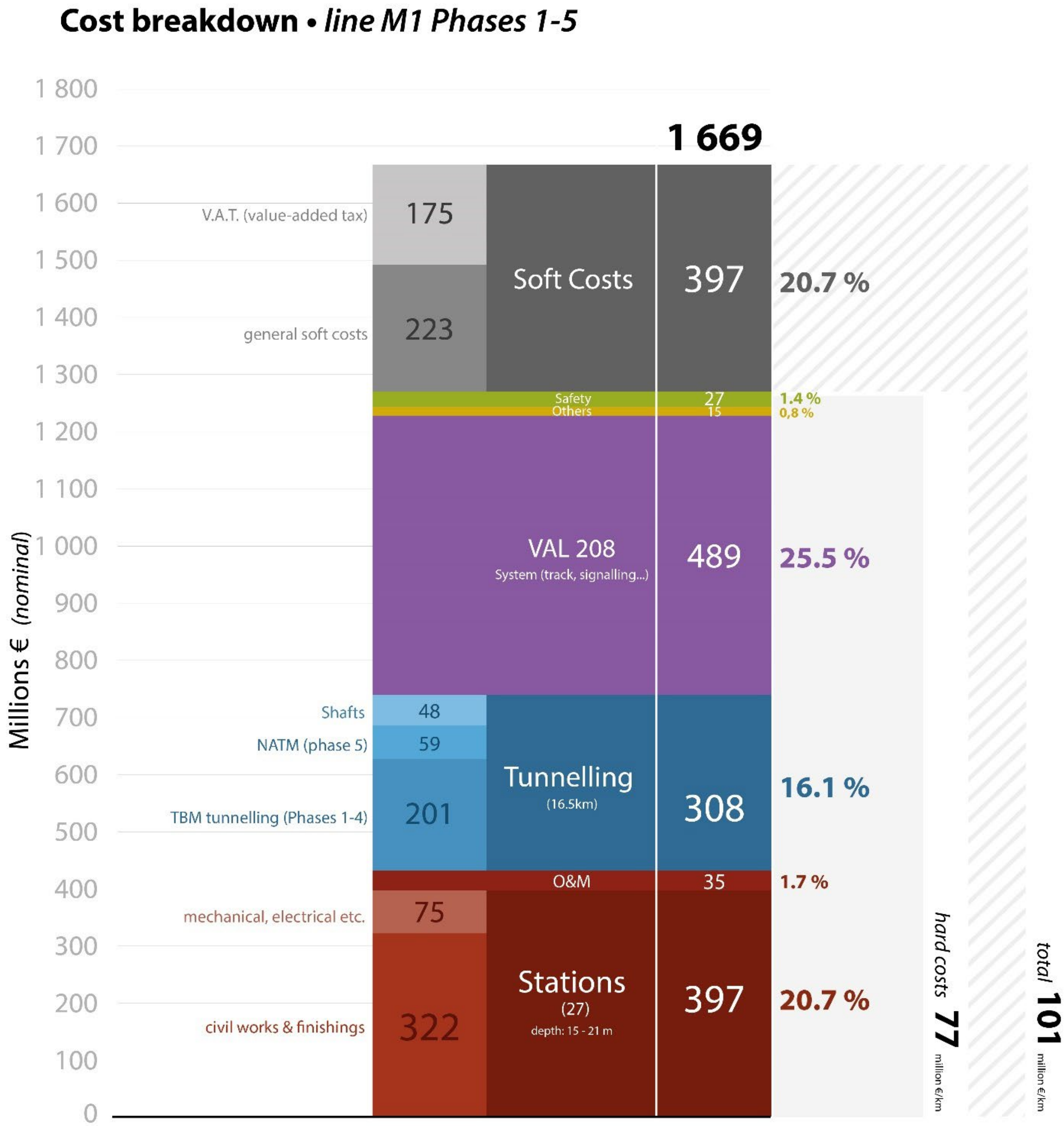

figure 14. Detailed cost breakdown for the five phases of M1 metro line in Turin

VAL: a costly technology. A remarkable feature of Turin's metro is the very high cost of the system's components – such as tracks and the guideway for the rubber tires, automation, platform screen doors, SCADA, ticketing and faregates, etc. – as a proportion of the overall cost. The €489 million in systems costs, or 25.5% of the overall cost or 38.5% of the hard costs, is the highest percentage among the studied cases. As mentioned in the previous chapter, that means an outstanding €27.1 million per km in real terms or $40.2 million per km in $PPP 2020 terms for the 5 phases. The bulk of this cost is represented by the automation technology and by the aforementioned guideway.

Tunneling: exploiting the potential of VAL to its maximum. Despite being a relatively costly technology, VAL allows for a very flexible deployment and can reduce costs associated with civil works. VAL allows for a flexible horizontal and vertical geometry of tunnels, being able to navigate a horizontal radius as tight as 90m in normal operations and down to 40m in particular circumstances and climb continuous gradients as steep as 7%. Moreover, thanks to its narrow dimensions VAL 208 can fit into smaller diameter tunnels. Thus, a 6.7m-wide bore can accommodate both tracks in a single tunnel whose diameter is only slightly larger than what is normally used for one track in standard metros. As a result, the per kilometer cost of tunnel excavation is very consistent across all phases, at between $22.9 and $23.9 million per kilometer. Interestingly, this cost is similar for both TBM excavations (phases 1-4) and for the NATM-like "traditional" one used in the under construction phase 5. It is worth pointing out that Turin lays upon an old alluvial soil with geotechnical characteristics more favorable to excavation compared to the other three cities studied in this report, notably because of a much deeper water table in many parts of the city where line M1 was built.

Stations: a very standardized design. Station costs vary between €8.7 and €32.2 million in nominal terms, but most of them cluster around between €13 and €18 million each in real 2020 terms (figure 15), with the shallow stations currently under construction for phase 5 being the least expensive in actualized terms. In terms of parametric cost relative to volume, most stations cost between €425 and €630 per cubic meter in real terms. The main exceptions are Italia '61 and Bengasi, the stations built as part of the unfortunate phase 4 plagued by the contractor's financial difficulties and considerably delayed.

The reason behind consistent costs across stations is **an extremely standardized design**. In the first four phases, all the stations but four have the same exact design. The bulk of the typical 30,000 cubic meter volume of each standard station is made of a 65m x 22m box, 21m deep with track located at approximately 16.5m below the surface. A mezzanine for faregates and technical rooms is located on a slightly shifted shallow additional volume on one end of the station. All the stations have side platforms and a generally open volume without full intermediate slabs. A central flight of fixed stairs and two escalators connect the mezzanine to an open landing over the tracks where a stair and an escalator reach the platform level. A separate longer up-only escalator per platform provides a more direct exit route to facilitate outflow and platform level clearance. Stations are fully accessible: each station also has one or two lifts from the street level to the mezzanine and one lift connecting each platform. In addition to reducing upfront capital cost, GTT claims that by standardizing station design and the selecting durable finishing materials (nonporous stone and glass) reduces maintenance cost (see figure 16).

Another unique characteristic of Turin's metro is the complete separation of the tunnel and the platforms. The track area is isolated from the passenger areas of the station via full-length platform screen doors and a glass vault. As a consequence, the requirements for smoke removal in the case of a fire are reduced, the overall air quality within the station is improved because the particulate pollution produced by braking and rubber tires is filtered out, and it's easier to keep stations cool because the heat given off by the train doesn't affect platform temperatures (see figure 16).

All stations are located directly under the street surface or in Turin's larger squares, as the line mostly follows the 19th century wide multi-way boulevards typical of the city's urban morphology. The station's volumes were all excavated using the cut-and-cover bottom-up technique. In order to maximize labor productivity during construction, which lasted between three and four years, traffic was diverted to the lateral access lanes of the boulevards or re-routed along parallel streets, and, occasionally, there were full street closures. The access from street level to the mezzanine are also located within the street, either on the boulevard medians, sidewalks or in public squares. In the longer section under Corso Francia, shafts for ventilation and for natural lighting of the mezzanine are integrated with the landscaped median along the boulevard, that was reconfigured into a more pedestrian friendly "complete street" after construction[50] (see figure 16).

The most notable exceptions, both in terms of cost and design, are a few non-standard stations and those located in areas with a high underground water table. XVIII Dicembre, Porta Susa and Porta Nuova serve the two main train stations and provide connections to the tramway network and are larger stations with additional escalators and lifts to cater to larger crowds. Porta Susa stands out as the most expensive station along the line. It cost €32.2 million in nominal terms and more than €40 ($52 million) in real 2020 terms. As the main transit hub of the city and future interchange between lines M1 and M2, the station has a much larger volume, has more entrances, a wider mezzanine, and includes direct access form the rail station's main hall. Moreover, the phase 3 stations, despite having the same standard design, are all located below the water table; thus, requiring jet grouting to waterproof the bottom of the station's box prior to full excavation, a necessity that increased costs relative to standard stations built in the previous two phases. [51]

[50] The reconstruction of Corso Francia wasn't part of the M1 capital budget but was paid for directly by the city.
[51] According to numbers derived from cost estimations for line M2, the jet grouting injection for water proofing of a station's bottom can add up to € 2-3 million to the overall cost.

Station costs - line M1 - Turin

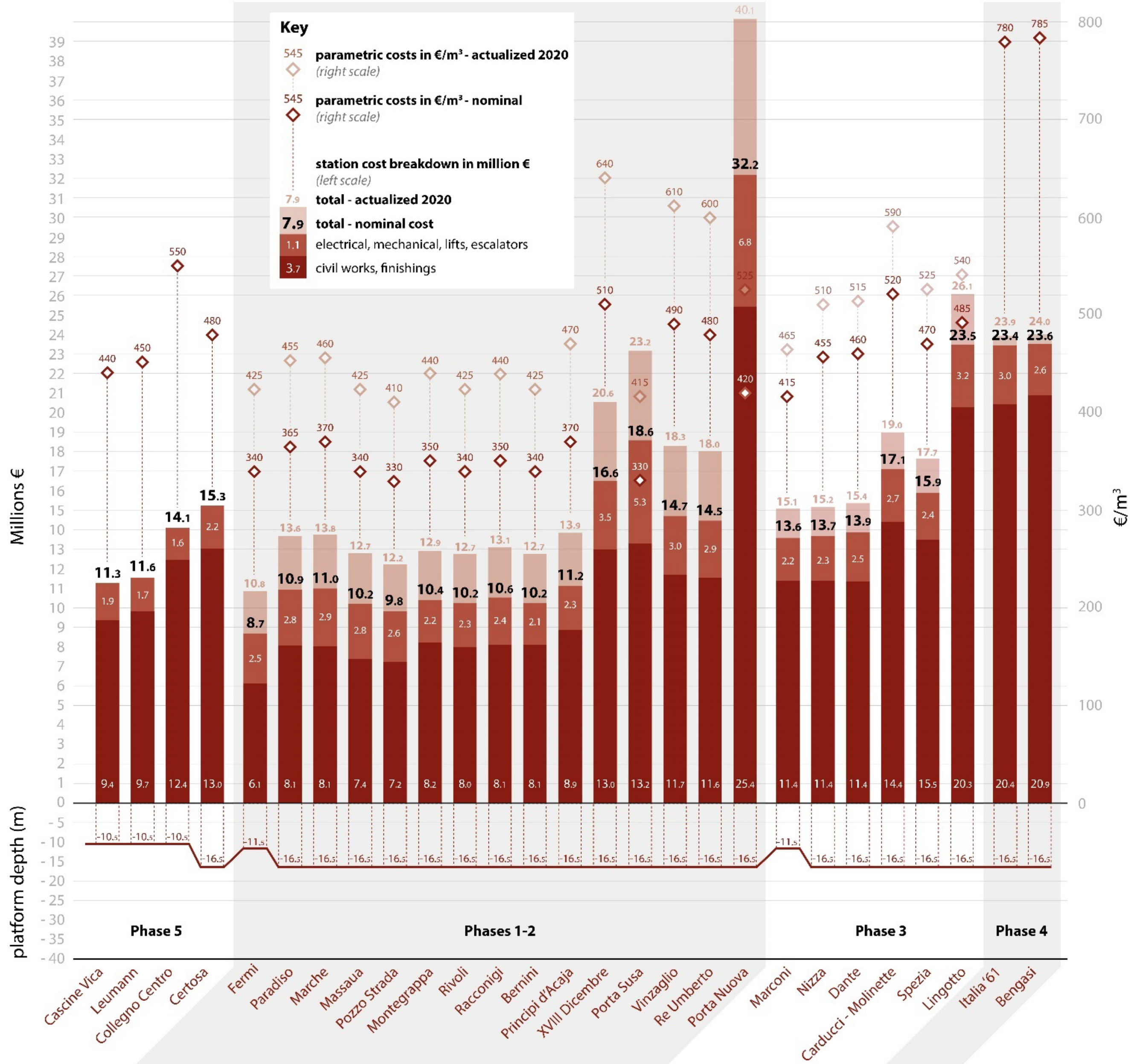

figure 15. *Detailed cost breakdown of Turin's M1 stations.*

figure 16. Pictures of typical M1 stations. (a-b) Stairs from the mezzanine to the intermediate level. (c) Platform level with the tunnel vault. (d) axonometric diagram of the typical station. (e,g,h,i) Typical main and secondary entrances. (f) Landscaped boulevard median integrating natural light and ventilation shafts.

5.4 Building in-house expertise from scratch for an effective Design-Bid-Build

When the project started in the late 1990s, GTT and the city of Turin had extensive experience with tramway operations and construction but little with underground urban rail. The city appointed one of its own chief engineers as the head of the M1 design unit established within GTT and hired a small group of professionals, around fifteen to twenty people, to staff the R.U.P.[52] project delivery office. They were mainly recruited from either the private sector, notably companies with a "general contractor" profile, or other public agencies, with engineering (civil, rail, electronics) being the prevailing domain of expertise on the team.

The first three phases of the project were entirely delivered through a traditional Design-Bid-Build formula, with planning and design carried out partly in-house by GTT (later InfraTo), and partly by external consultants. The early planning, the preliminary and the final design were all done in-house with the support of a "strategic knowledge transfer" consultancy contract with the French team of experts that worked on Rennes's VAL metro within the French city's transit agency. Later, GTT itself helped Brescia's transit agency develop its own light automated metro, leveraging the knowledge acquired from the French and its own field experience gained while building M1.

A second external support consultancy contract was awarded to a French architecture firm[53] who had previous experience in metro station design, to help devise the project's "chart of architecture," defining the main elements of the standard design for stations described above. The architect's concept was then refined in-house, notably by further simplifying the design (from two ovals to a simpler parallelepiped). Other smaller external contracts were awarded for ad hoc sectoral studies, such as geological and archeological preliminary investigations. The Detailed Engineering Design (PE) and the work supervision (*Direzione Lavori* – DL), a labor-intensive activity that couldn't be carried out by the limited in-house project team, were awarded to an external engineering firm, with the R.U.P. office holding the function of High Supervision (*Alta Sorveglianza* – AS).[54]

For the first three phases, around twenty construction and design packages were awarded, organized around three main items: i) civil works, with different contracts for tunneling and stations; ii) finishings and MEPs; iii) the development and installation of the whole VAL system (tracks, automation, trains), was awarded without an open tendering process to Matra/Transima who owned the patent. For phases 1-3, Requests for Proposal (RFP)

[52] For the importance of the role of the R.U.P. (Responsabile Unico del Progetto) as the chief manager and the figure that insulate the technical team from political interference see chapter 3.2.

[53] Bernard Kohn et associés: https://www.bernardkohn.org/fr/architecte/projets/ligne-1-metro-turin.html

[54] As one responded pointed out, the RUP carried out its role of High Supervision in a very proactive manner, participating in all the important decisions taken during construction throughout the different phases of the project.

were based on the PE, the most advanced level of design, while for phases 4 and 5 the RFP was an "integrated procurement" that allows the contractors to finalize the Detailed Engineering Design (PE) based on the final one (PD - 90% design) provided by contracting agency.

5.5 Maximizing technological benefits, standardized station design and strong in-house supervision.

Turin's M1 case, with its remarkably stable construction costs over time, the mostly on-time delivery performances, and the overall design choices provides three main positive lessons and two cautionary warnings.

First, Turin's M1 maximized the advantages of the light automated metro technology by tailoring the project's design around the specific characteristics of the VAL 208 technology: a very flexible geometry for the alignment, but most of all the narrow and relatively short trainsets compensated by the very high frequency that the VAL automated rubber-tired technology permits, delivering a current hourly capacity of 15,000 passengers per direction (pphpd) that can be increased to 23,000 pphpd with a larger fleet. That means a capacity higher than many North American LRTs, that have longer and wider trainsets but much less frequent service due to limits imposed by level-running and manual operation. Privileging electronics over concrete, Turin built a line that caters to 150,000 daily riders. This translates to a remarkable 10,000 riders per km, and a per rider capital cost of around $16,000.[55]

Secondly, the agency took advantage of specific out-of-agency knowledge by hiring architects with previous experience in metro station design, but without indulging the temptation to commission spectacular architecture and overly customized designs we see in many contemporary metro projects, and we will see in Naples's case. Instead of landmark architecture, the project's team at GTT/InfraTo mandated the architecture firm to devise a straightforward design, favoring legibility, durability of materials and ease of flow inside of the station as the main design principles. Nevertheless, the overall user experience is extremely pleasant as stations are plain but functional, bright, clean, and easy to navigate.

Thirdly, Turin was able to do so with limited initial in-house expertise by "learning from others." Leveraging the experience of Rennes, a city that had deployed the same VAL 208 system only a few years before, Turin's GTT quickly built up the necessary in-house skills to deliver a complex project on time and budget. As the first city to import light metro technology to Italy, Turin has supported the diffusion of the necessary knowledge to other

[55] As a comparison: Los Angeles purple and red lines (heavy metro) have a ridership per km of 4,600, while the LRT lines have 1,100; Atlanta's MARTA (heavy metro) has 2,700; Seattle's light rail has 2,450 (Spieler 2021).

domestic agencies. Even with a relatively small team, the R.U.P. project management office did a good job supervising this novel project, thanks to a staff encompassing all the necessary technical skills in addition to managerial capacity. Even if the retention of this capacity has proven challenging because of the slowdown of metro construction after the conclusion of phase 3, InfraTo has been able to deliver the subsequent extensions and is currently staffing-up again as it prepares to build a second line and more extensions.

It is worth pointing that some contextual positive and negative elements that had an effect on the project are beyond the control of the project management and policymakers: on the positive side, the relatively good soil under the city and an urban morphology dominated by wide multi-way boulevards facilitated the project's construction within a developed urban context. On the other hand, the deep liquidity crisis that hit the Italian construction sector in the 2012-14 cannot be blamed on the local construction industry.

Finally, Turin's case offers some cautionary tales for policy-makers. The VAL 208 system is both more expensive than other comparable light automated metro solutions in terms of upfront costs and bears a much higher risk of early obsolescence and technological lock-in with subsequent expansions and modernizations. The choice of a patented, proprietary technology that was discontinued by Siemens[56] makes it difficult for InfraTo to expand the fleet. The recent RFP for the procurement of new rolling stock, that will have to be specially designed by the contractor, comes with one of the highest per meter costs of any metro trainset built in Europe in recent years. The same ongoing procurement for the automation system from analog to digital has proven equally challenging and costly.

[56] Siemens, that purchased the VAL patent from Matra in the late 1990s, has discontinued the commercialization of the VAL 208 in the 2000s, replacing it with an incompatible system called Neo-VAL.

6 Milan: lines M5 and M4

6.1 Introduction

The city of Milan is the economic capital of Italy and the center of the largest metropolitan area in the country (1.4 million inhabitants in the city proper and 4.9 million in the metropolitan area). As of 2021, the Milan Metro, the largest in Italy, is 96.8 route kilometers (60.1 mi) with 113 stations and four lines that carry 1.35 million unlinked trips per day. A fifth line, M4, is currently in an advanced stage of construction and poised to open between 2022-2023, bringing the network to 110 route kilometers. Several other expansions of existing lines are also under construction or in advanced design and will open throughout the 2020s, notably a 12.6 km northern extension of M5 to Monza. Beside its metro, Milan's extensive legacy tramway network spans 180 km and carries 290,000 daily passengers. Milan is also the center of a 12-line suburban rail network (*linee S*), which includes a 6-km cross-city tunnel (*passante ferroviario*). Services stretch 450 km into the suburbs and caters to 350,000 users on an average weekday. Finally, several Regional and Regional Express rail lines connect the city's core with the wider region.[57]

The history of Milan's urban rail network has a number of interesting features. After several projects, early planning and failed attempts through the first half of the 20th century, in **1955, the city of Milan established a municipally-owned company, called Metropolitana Milanese spa (MM)**, tasked with the design and management of metro construction. It is still the engineering arm of the municipality, and plays the important role of providing **effective in-house expertise**. Metro Milan's first line, line M1 - Red Line, opened in 1964 as the initial section of a planned three-line network. The system continued expanding through the seventies and eighties, but construction

[57] Ridership data are from Spinosa (2019).

halted during the 1990s and early 2000s, mostly linked to the already-mentioned generalized slowdown in public works during that period.

Even though data for historic construction costs before the 1990s are less reliable,[58] and cost numbers for the M1 and M2 extensions built in the late 1970s and 1980s couldn't be retrieved, construction costs since the 1950s cluster below the $200 million/km threshold, after adjusting for inflation, with the two above ground extensions in the database costing between $8.7-$18.7 million/km. M3's initial 11.8-km section between San Donato and Zara, opened in the early 1990s, is the notable exception to these generally low cost projects. It is reported[59] to have cost 2.3 trillion Lira or $275 million/km in today's real term. M3 was central in the *Tangentopoli* scandal that emerged in the late 1980s and resulted in the already-mentioned 1990s *Mani Pulite* sweeping investigation and trial.

[58] Most pre-1990s data are from Metropolitana Milanese spa's fact sheets and reports published as part of the company's budgets and reports to the shareholders. The high volatility of the Italian Lira from the late 1960s through most of the 1970s, with double digit inflation rate topping at 20% annually, makes accurate actualization difficult for projects that last over several years.

[59] That number is derived from various non-official sources, all of them referring to an original 1992 investigation carried out in the frame of the *Tangentopoli* scandal. Unfortunately, it has been impossible to retrieve the original source.

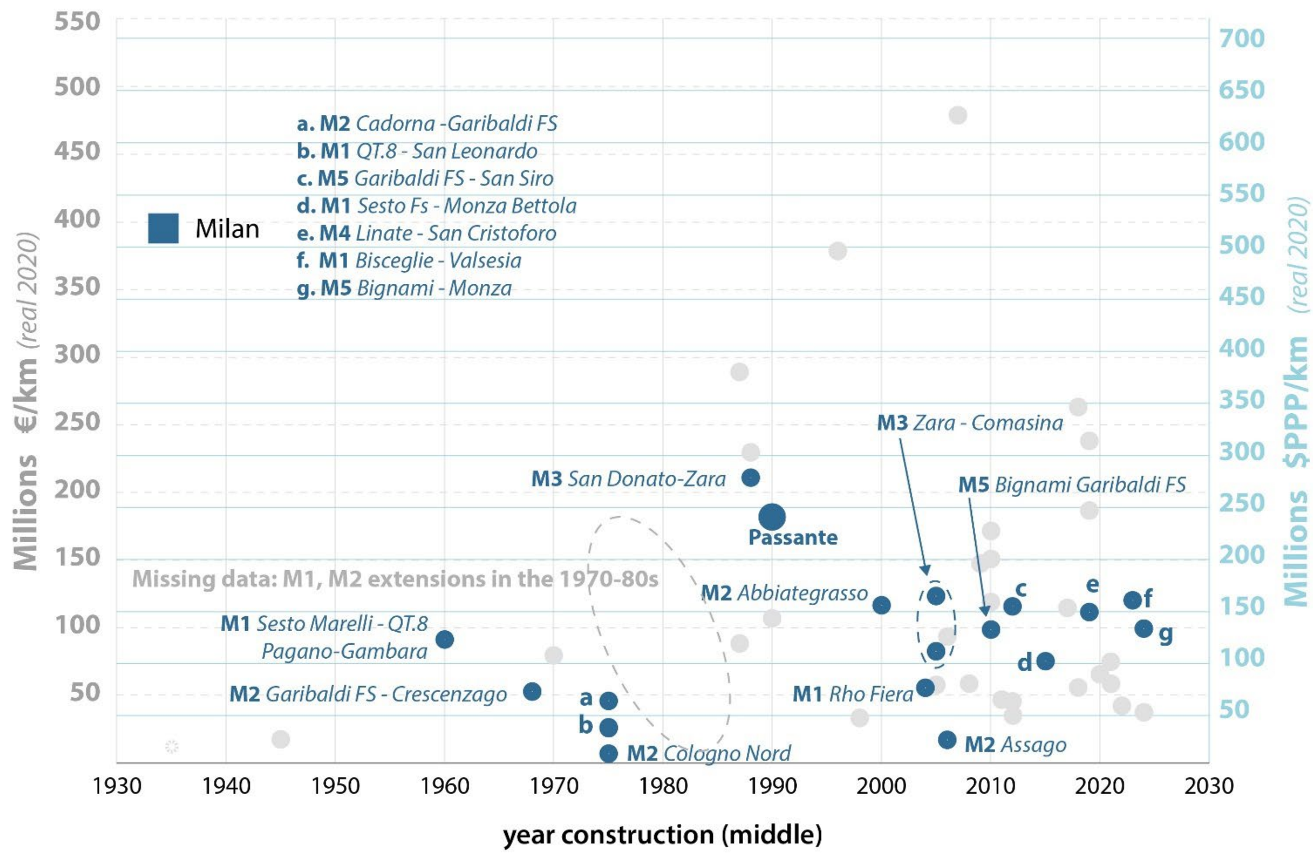

figure 17. Historic costs of metro projects in Milan since the 1960s

In our in-depth case, we will focus on M5, one of the latest additions to the network and the soon-to-open M4. M5 is part of the new generation of "light" automated metros which offers high peak capacity (above 20,000 pphpd) using short trainsets (50-55m) running at very high frequencies (< 90 seconds) as a way to reduce construction and operating costs while increasing operations flexibility. Both lines use Hitachi Rail (formerly AnsaldoBreda) automated rolling stock and signalling, similar to the systems operating in Copenhagen, Brescia and Taipei. Both lines have been delivered through Public-Private Partnerships (PPP), albeit with different DBFOM concession arrangements. Our detailed analysis will mostly focus on M5, as M4 costs are not entirely settled. Yet, we will refer briefly to M4 and an upcoming heavy metro extension of line M1 to Baggio,[60] to show that relative low costs are a common feature of Milan's metro projects regardless of the delivery scheme and technology.

[60] Cost estimates for the 3.6km, 3 station extension of M1 to Baggio, that is currently in final design, are derived from the detailed estimations made for the final (90%) design and publicly accessible bidding documents.

6.2 The role of Metropolitana Milanese (MM)

Metropolitana Milanese S.p.a. (MM) is a municipally-owned engineering company originally established in 1955 by the city of Milan to design, build and operate the city's urban rail network under a concession regime. In 1964, after the city decided to consolidate the subway and surface transit operations in the hands of Azienda Trasporti Milanesi (ATM), the municipal transit agency, MM became the in-house engineering arm of the city. Since its founding, MM has been responsible for planning and designing the metro network, the tramway network's modern expansion, and the cross-city suburban rail tunnel *Passante*. As the pioneer of metro construction, MM developed new excavation techniques, namely the "Milan method," which uses slurry walls and top-down techniques to build shallow cut-and-cover. This technique set the standard for tunnel construction in all subsequent metro projects in Italy for decades. Since MM is technically an engineering firm, it has also worked as an external consultant to the design and development of several metro rail projects in Italy since the 1970s (notably Naples and Rome) and, more recently, abroad, for example for Riyadh's and Thessaloniki's metros as part of broader consortia of Italian Design-Build contractors. More recently, MM has expanded into a municipal engineering and utility agency taking on a broader mandate managing the city's water network, social housing stock and the general maintenance of the city's urban infrastructure.[61] As of 2020, MM has almost 1,300 employees across four divisions, and while only 16% of its revenues come directly from engineering services,[62] by consolidating all municipal infrastructure and engineering services within a single entity has allowed MM maintain and develop its engineering expertise and provide a more stable stream of work and revenues.

The MM case is notable because it represents the oldest and most durable example of how in-house engineering for public works has been retained over time at the municipal level. The relationship with the municipality of Milan, that owns 100% of the shares of the company, is regulated with a long-term framework consultancy contract that allows the municipality to directly award engineering contracts to MM without public tendering at a fixed discount of -28% compared to the reference professional rates established by the Ministry of Justice. This arrangement allows MM to seek more profitable external consultancy contracts while retaining its role as the city's in-house engineering division.

[61] See : https://www.mmspa.eu/wps/portal/mmspa/en/home/the-company/who-we-are

[62] See : MM Spa, Bilancio d'Esercizio 2020

6.3 Line M5: project overview

M5 is Milan's fourth metro line. It crosses the city form North to East and runs underground for 12.9 km and serves 19 stations. Unlike the other lines, it doesn't connect to the city's historic core. Rather, it runs through the modern CBD situated in the Porta Garibaldi station area, a major regional transit hub. M5 connects with M3, M1, and M2 and the *Passante* cross-city rail link, and carried 171,000 daily passengers on an average weekday in 2019.[63] It is fully automated and runs peak headways of 180 seconds, while minimum design headways can be as low as 75 seconds.

The line was opened in sections between 2013 and 2015, with works starting in 2007 for the Northern section (*Lotto 1*) and in 2010 for the Western section (*Lotto 2*). M5 was delivered through a **Design-Build-Finance-Operate-Maintain PPP formula** and was funded with a mix of private and public sources from the local and national governments. The concessionaire will operate the line until December 2040 and will recover its investment through a yearly fee paid by the city that covers operation costs and buy-back of the infrastructure.

M5 is the culmination of combining two planned lines into one during the planning stage and early construction phase. The northern section of the line was initially envisioned in the 1990s as the conversion to pre-metro of a tramway line. It was eventually be extended further out to serve the vast crown of sprawling towns between Milan and Monza, once served by an extensive interurban tramway network. The 2001 mobility plan opted instead for a light metro technology, modelled after what was being planned and built at the time in Turin, Brescia and other cities in Europe. In 2006, also the plans for the Western section of the line, initially envisioned as a pre-metro, were converted to light metro (called M6). Both lines were intended to terminate in Porta Garibaldi on two sides of the M2 metro station. It was only after the DBFOM contract for the northern section of the line (Lotto 1) was awarded to the consortium Metro 5 spa in 2006 that the city decided to merge the two lines into a single project, necessitating a complete redesign of the Garibaldi FS node to allow for through running between the two sections. Rather than issuing a new tender, the city of Milan awarded the construction of the Western Section directly to Metro 5 spa in order to complete it in time for the 2015 Expo.

[63] Spinosa (2019).

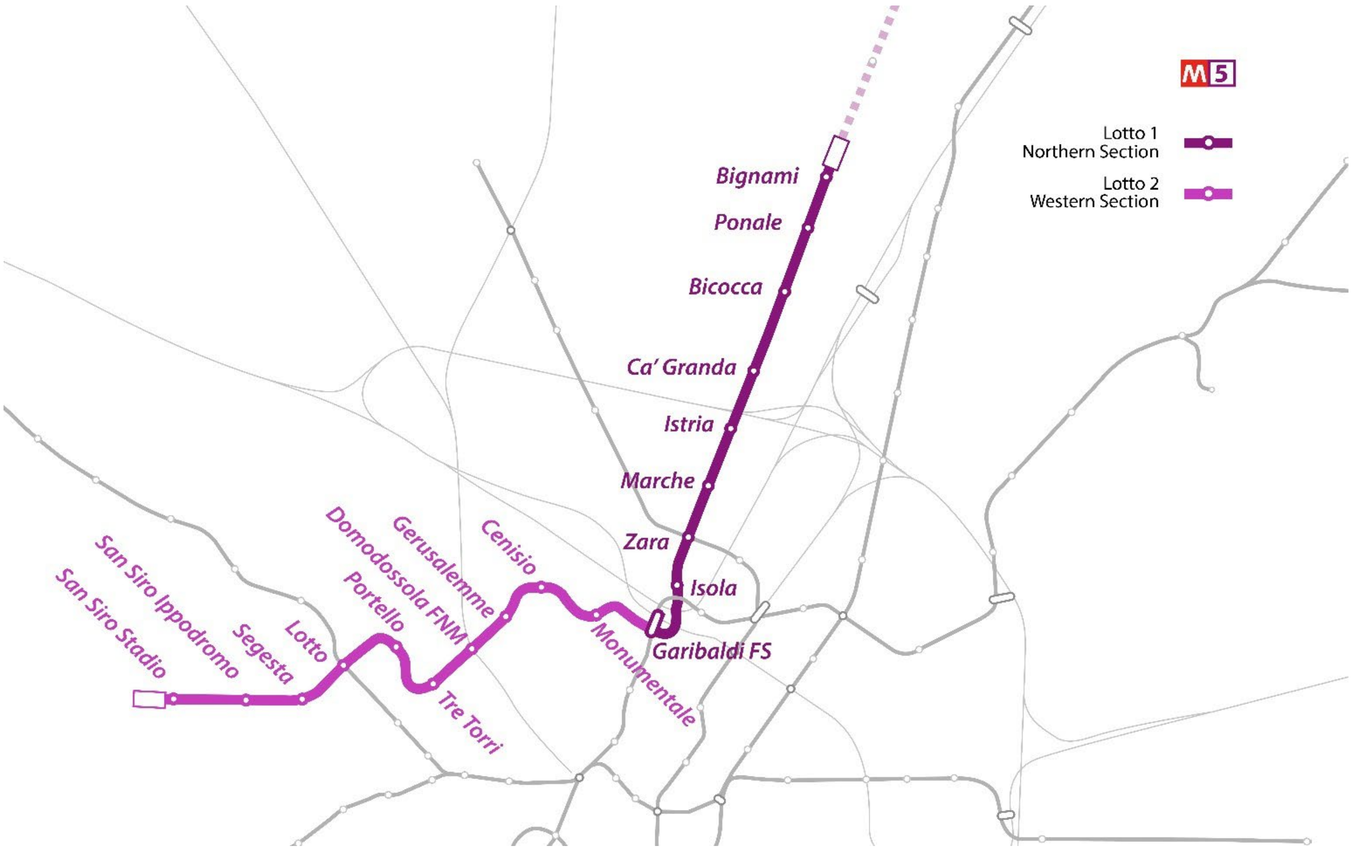

figure 18. The two construction phases of line M5.

Table 3. M5 - Main Characteristics		
	Northern section Lotto 1	**Western section Lotto 2**
Years Construction start-end	**6** 2007-13	**5** 2010-15
Length (km)	5.6	6.7
Stations	9	10
Station depth	10 - 20 m	17 - 28 m
Cost In million € (nominal) and $ PPP 2020	€508 *$724*	€751 *$1,010*
Cost/km In million $ PPP 2020 per km	**$129.3**	**$150.9**
Alignment	underground single bore and twin bore tunnel, C&C Ø 9.4 m	underground twin bore tunnel Ø 6.2 m
Projected maximum capacity:	25,000 pphpd at 75’’ headway	
Vehicles	AnsaldoBreda driverless GoA4 (50.9 m long, 2.65m wide). 1,200 places.	
Platform lengths	50 m	
Delivery method	PPP – DBFOM (Design- Build-Finance- Operate-Maintain)	
Financing	**56% public** (Central Government, Milan’s municipality) **44% private**	

6.4 Costs and design choices

The construction of M5 required an overall capital investment of €1.259 million (€1.373 million, if rolling stock is included), divided between €508 million for the Northern section (Lotto 1, Bignami – Garibaldi) and €751 million for the Eastern section (Lotto 2, Garibaldi – San Siro). In 2020 PPP USD terms that corresponds to **$129 million per km for *Lotto 1*** and **$ 151 million per km for *Lotto 2***. That makes the Northern section (lotto 1) the cheapest metro on a per km basis among our in-depth cases. Hard costs account for approximately € 1,016 million or 90.7% of the overall cost. Systems represent the largest component of hard costs at €317 million, with integral automation, SCADA and telecommunications representing more than half of that. This finding is consistent with other project data and interviews with experts indicating that light-automated metros’ “electronics” have a higher relative cost than “concrete.” As we saw in Turin, light-metro technology allows for smaller tunnels and stations, which reduces the cost of civil works; however, that savings in civil works is partially used to pay for greater systems outlays. Tunnels and shafts represent the second largest expense, at €309 million, while the 19 stations and the two underground storage and light maintenance facilities located at both ends of the line account for €282 million.

Another unique element of Line 5 is that it doesn't have a full Operations and Maintenance facility yet. As we saw in our Green Line Extension case, these facilities can be large cost drivers depending on their capacity and footprint. For the time being, there are two smaller underground facilities for storage and light maintenance at both ends of the line. For major repairs, trains are transferred to the M2 maintenance center via a connection between the two lines. A proper M5 O&M facility will be built when the 12.3 km northern extension to the suburban Monza, where land is cheaper, is completed.

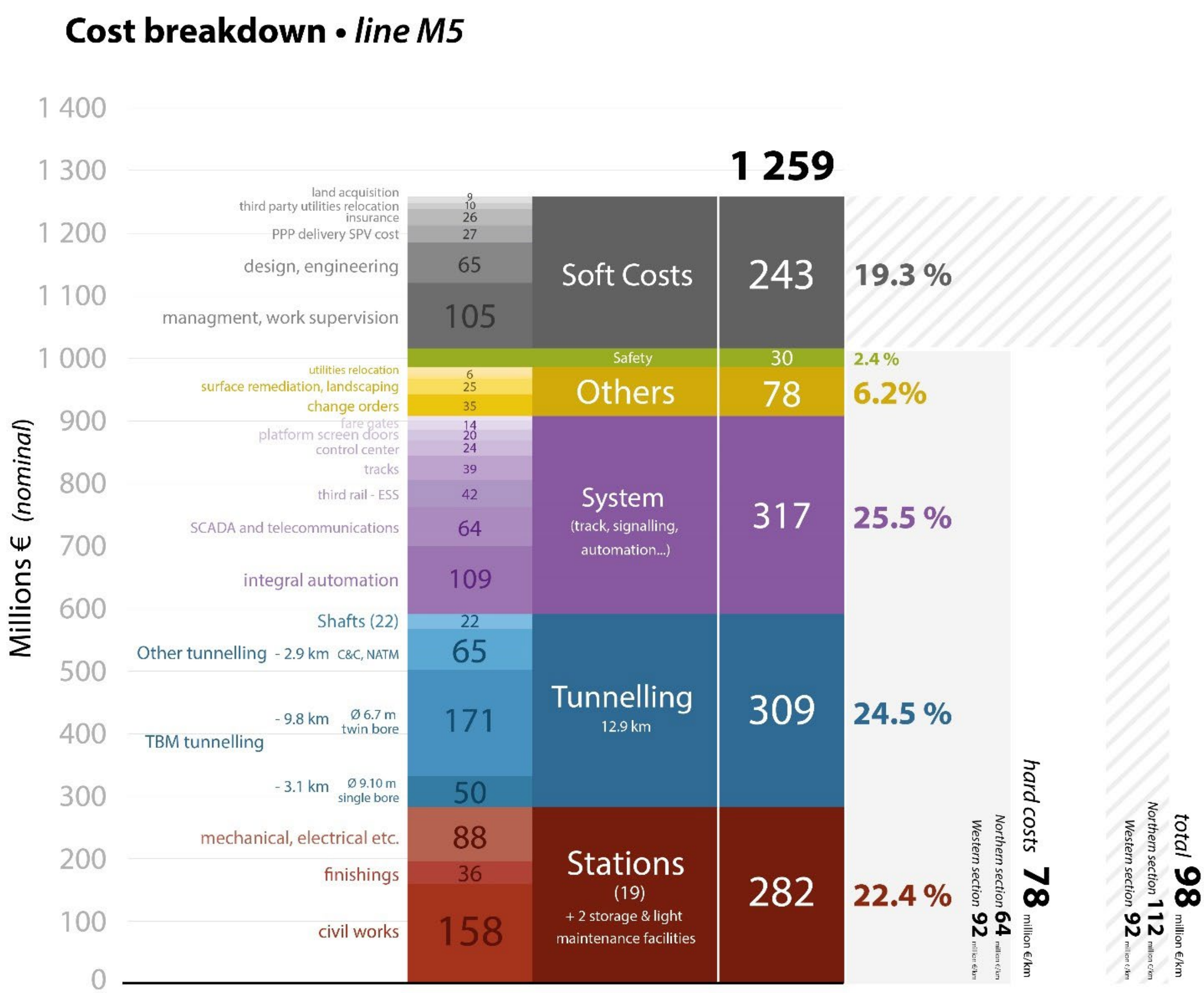

figure 19. Detailed cost breakdown for line M5

Simple and standardized station design. Stations' construction costs vary **between €5.4 and €20.5 million**, including civil structures, finishings, mechanical (lifts, escalators), and electrical/ventilation (see figure 20). All of the stations except for Zara[64] were built using the C&C bottom-up technique and are located under streets, public spaces or on land made available by the developer as part of a redevelopment scheme.[65] Tracks are normally 16-17 m below the surface level with a few stations being shallower or deeper, usually because of conflicts with pre-existing or planned underground structures.

Overall, station design is quite simple: a rectangular station box of roughly 60 by 23/26m contains three levels: a subsurface mezzanine hosting faregates, an intermediate level for technical rooms that is inaccessible to the public (absent in shallower stations) and the platform level with either side or island platforms. There are normally two or three entrances from the street level to the mezzanine that are mainly a flight of stairs with a shelter located on the sidewalks or in boulevard medians to provide better connections with tramways. Stations tend to have six escalators: two from the surface to the mezzanine and four from the mezzanine to the platform level (two up and two down) as well as fixed stairs. Each station has four lifts: two from the street level to the mezzanine and two after the faregates to the platforms.

There are two notable exceptions to this base design. First, there are stations that need additional space to accommodate connections to other metro or rail lines, electrical sub-stations, greater passenger volumes at stations that serve large venues like San Siro Stadium. Second, for lines dug by a TBM, the TBM launch box is repurposed into a station after the tunneling is completed; thus, the dimensions reflect the needs of getting the TBM into the ground rather than ridership projections. Lotto, the most expensive station in the line, is unique because it needed more space for connections, and it had to be constructed much deeper than other M5 stations because the tracks pass under M1 at 28m below the surface. It incurred an extra €3.9 million in civil works and equipment for two additional entrances for the combined M1-M5 station complex.

The average cost of the typical stations differs between the two segments: between €7 and €7.6 million for the Northern section, and €10.2 - €13.3 million for the Western section. This is mainly due to different platform designs along the two sections. On the Northern sections, stations have side platforms and measure 23-meters wide. Western section's stations have island platforms and are 26-meters wide. Moreover, as an MM planner pointed out in an interview, the Northern section was built to a "low-cost" standard (such as cheaper finishes, and

[64] Zara station was built using ADECO-NATM for platforms in a space adjacent to the existing mezzanine of M3 metro station that ensure seamless transfer within faregate area.
[65] Tre Torri station was built as part of the *City Life* redevelopment scheme and it's directly accessible from a sunken pedestrian plaza at the center of the area.

minimal surface remediation) while the ones on the Western section were built to a more expensive standard as more funding became available in advance of Expo 2015 (Personal interview, February 2021). The same official pointed out that the “right approach” was in-between the two extremes, as the Northern section’s stations are too spartan and the Western’s are slightly overbuilt. Finally, it is worth noting that the average parametric cost is around €300 per cubic meter, with 16 out of 19 stations costing between €235-€325 per cubic meter, a cost that places them below the €460 average of our Italian sample.

Station costs - line M5 - Milan

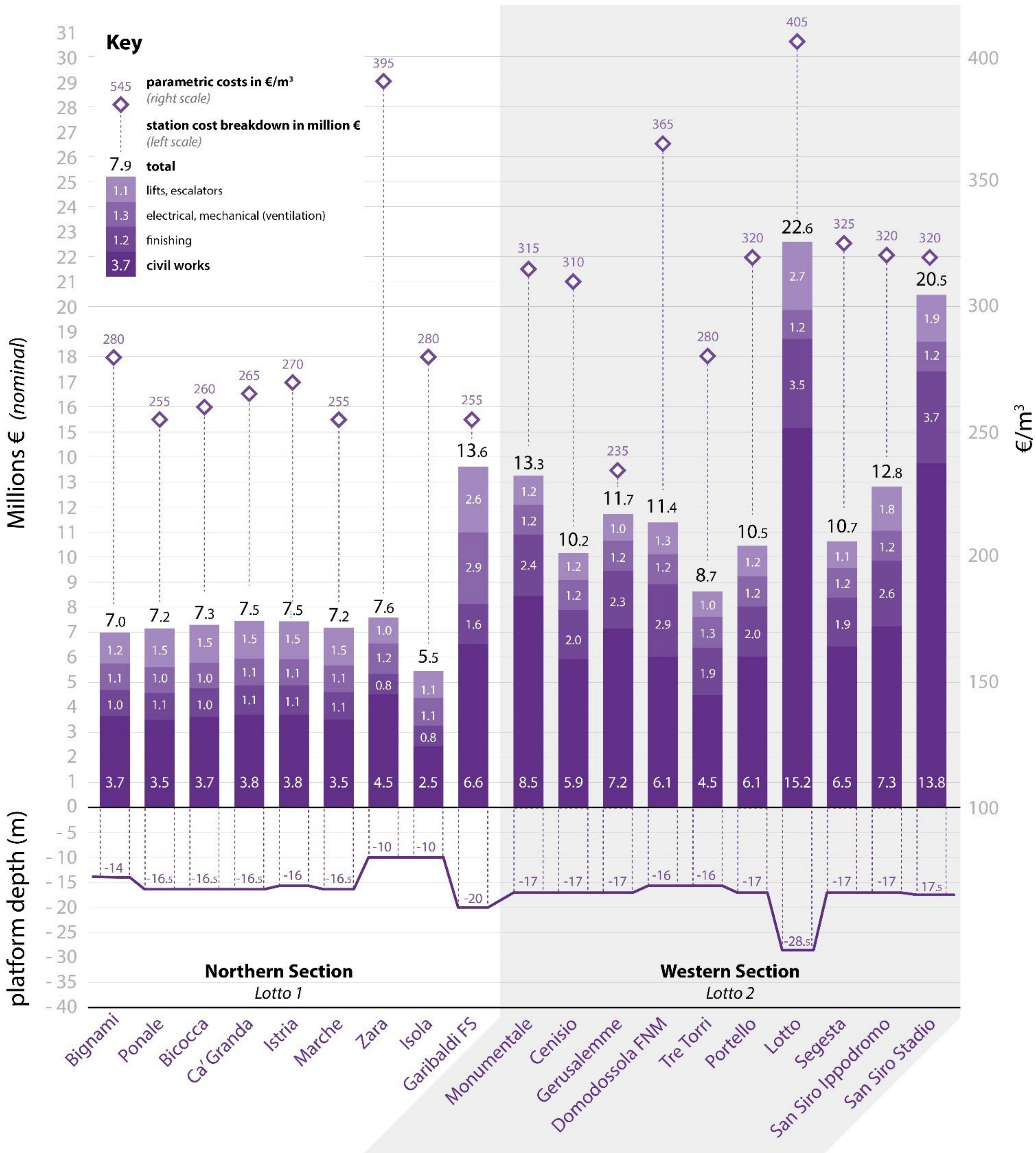

figure 20. *Detailed breakdown of station costs for Milan's M5*

Tunneling typologies and costs. M5's tunnel structures, including shafts, cost €23.9 million per km in nominal terms. The costs by segment, however, vary significantly, as M5 used a wide variety of tunneling solutions tailored to the specific conditions (see figure 21). Most of the northern section (Lotto 1), which runs for approximately 3.1 km under Viale Fulvio Testi, a rectilinear 55 m-wide multiway boulevard, was built using a double-track 9.1-m wide tunnel bore with a single Earth Pressure Balance (EPB) TBM. The alignment is on average 16.5-m deep and doesn't cross any major underground or aboveground structures. This relatively straightforward section of the alignment cost approximately **€14.1 million per km**.

Most of the western section (lotto 2), between Monumentale and San Siro Stadio, was tunneled using 6.7-m wide EPB TBMs to build twin-bore tunnels. MM decided it would be easier to use twin bores rather than a single bore based on the alignment's curves, which brought the tunnels underneath several buildings and other underground structures, including a four-track subsurface rail tunnel, M1 metro line and a road tunnel. Moreover, four TBMs were used to dig the two sections simultaneously, east and west of the Tre Torri station, so that it would be ready for the 2015 Expo. All these elements, including a shallower water table on the western side of the city required extensive jet grouting, which increased the segment's costs to around **€40 million per km**.

Metro line M5 also used NATM/ADECO,[66] a non-fully-mechanized tunneling technique, and cut & cover structures of various depths built with the so-called "Milan method." On average, the 2,090 meters of single and twin-bore route length built using that technique have an average cost of around **€20 million per km**. Notably, the complex node between Isola and Garibaldi stations, where the line weaves above and below seven underground structures in less than 500 m, combining various technical solutions, notably ADECO with extensive consolidation and a very short C&C section under an ongoing development (see the box on figure 21)[67], cost roughly **€25 million per km**.

Finally, the 1.5-km tunnel built using cut & cover cost an average of **€49 million per km**. When we looked deeper at these numbers, we saw a correlation between the alignment's depth and costs: The shallow cut & cover section near Isola station, where tracks are between 8- and 12-m belowground, cost approximately **€13.1 million per km**. As the alignment went deeper, such as in the section of C&C (17-m deep) that also necessitated more complex structures because of the conflicts with the ongoing *City Life* redevelopment project around Tre Torri station, the tunnel was built at the relatively higher cost of **€29 million per km**. Finally, the two C&C structures

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[66] ADECO is a tunneling method for incoherent soils developed mostly in Italy since the 1990s that involves a continuous monitoring of the excavation front combined with a targeted consolidation of it using various types of jet-grouting or freezing techniques in water rich soils. See for example: https://www.rocksoil.com/documents/ADECO_english.pdf
[67] For more details, see also

located at both ends of the line provide tail tracks/turnback sidings as well as the storage and light maintenance facilities cost **€69 million per km**, as they are wider (three and four tracks) and quite deep (between 15 and 18 meters), with excavation volumes comparable to those of stations rather than tunnels.

M5 highlights the relative impact of local conditions, external constraints, and geometry on the cost of tunneling, showing that the choice between the various excavation techniques is to be understood as a balance of trade-offs between cost and risk tied to local context. Nevertheless, it is possible to say that shallow cut & cover and linear single bore under a wide boulevard (similar to Turin's M1) are the least expensive excavation techniques in our study.

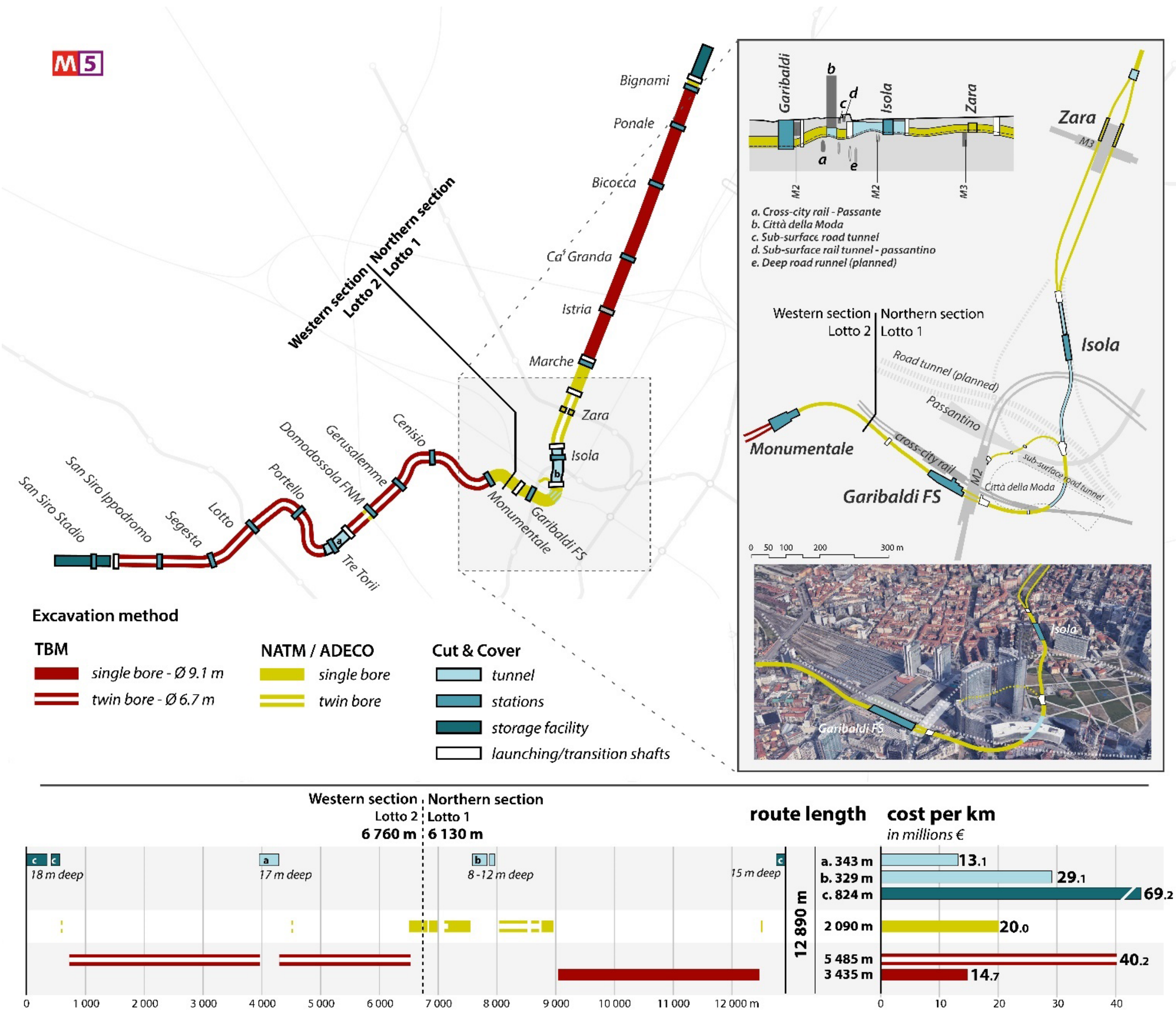


figure 21. Tunnel typology and relative length and cost for both M5 segments.

6.5 Public-Private Partnership, but with strong public oversight

Line M5 was delivered via a Public-Private Partnership (PPP). The 2001 infrastructure law that provided most of the funds for M5 had the distinct goal of generating greater involvement of the private sector in the delivery of transport infrastructure. M5 was mostly financed through a mix of public and private funds with 56% of the capital cost covered by the central government (44%) and the city of Milan (12%), while the remaining 44% was financed by the winning private consortium Metro5 Spa.[68] The PPP formula used for M5 most resembles a Design-Build-Finance-Operate-Maintain (DBFOM) contract implemented through the legal mechanism of a concession. The Metro 5 Spa consortium, selected through an open tender, finalized the design, built the civil works and the system's components, and will operate M5 until December 2040, under a 35-year build-and-operate contract. The city will pay an annual operation and availability fee that covers both the operations and buys down Metro5 Spa's stake in the line. At the end of the concession period, the city will own all the assets and decide whether to re-tender the operations or transfer them directly to ATM, the municipal transit agency.

Critically, **the city retained direct control over the main phases of planning and design and also the direct oversight of construction** through Metropolitana Milanese. MM was tasked with preparing the early planning, feasibility study, and preliminary project documents for the whole line, and also with the final design of the second section (*Lotto 2*). The critical high supervision function (AS - *Alta Sorveglianza*), which has oversight powers over the direction of works (DL), was also entrusted to MM. The choice of a DBOFM PPP was driven more by the necessity to raise private money to finance construction than because of the will of the city to outsource design and management. As many sources pointed out, the DBFOM PPP formula has been de facto used as a way to bypass the strict borrowing cap imposed on municipalities since austerity measures were adopted in the early 2010s. Despite the atypical DBFOM PPP project delivery, MM retained its traditional management and oversight responsibilities. M5 was delivered without any major cost or schedule incidents in large part because MM's decades of experience remained central to the project.

[68] M5 factsheet: http://allegati.comune.milano.it/trasportiambiente/SportelloUnicoMobilita/LINEAM5.pdf

6.6 Line M4 and M1 extension

We examined Line M4 and the M1 southern extension to Baggio to contextualize the M5 case. M4, the fifth metro line of Milan, is currently in an advanced state of construction and will open in phases between 2022 – 23. It runs on an East-West alignment for 15 km with 21 stations, connecting the city airport Linate to San Cristoforo via the city center. It will connect with M1, M2 and M3 and with suburban rail services at three stations. It is expected to carry 200,000 daily riders when it opens. M4 uses the same light metro technology used in M5, but with slightly wider trainsets to accommodate higher expected ridership. Since construction is ongoing, we don't have precise final costs, but the latest update of the economic framework made in 2019 quotes the overall project cost at €1.696 million (€1.944 million including the 47 trainsets), or €116 million per km, which, in PPP 2020 terms, is $145 million per km. That makes M4 costs comparable to those of the "twin metro" M5. A more detailed cost breakdown from the 2013 DBFOM contract (€1.572 billion) estimates similar tunneling and station costs for the Western Section (Lotto 2) of M5, which has similar characteristics, such as a twin bore tunnel and C&C stations. It is worth mentioning that M4 has larger diameter tunnels (9.7m) in the city center section to accommodate platforms. The six stations of this section were built with C&C access shafts for vertical circulation and platforms were built within the tunnels to minimize surface level disruptions.

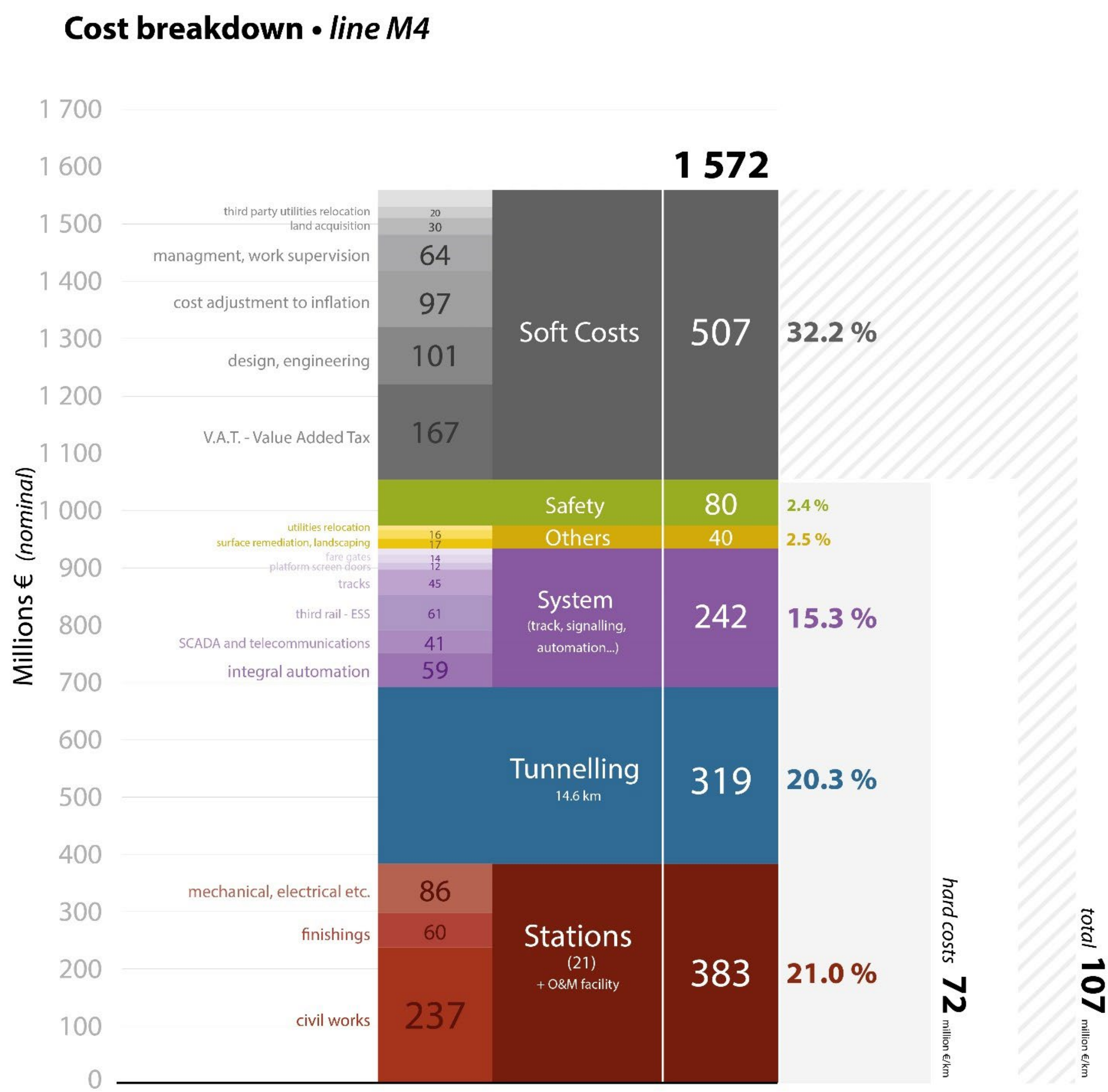


figure 22. Cost breakdown of line M4

The M1 extension to Baggio is currently being procured, and construction is slated to start in 2023. It has a similar cost profile to M4. It is a 3.3 km, 3-station, fully underground extension West of Bisceglie, mostly in a suburban setting with an aboveground Operation and Maintenance facility just outside of the ring motorway. The whole project is estimated to cost €396 million or $156 million per km, slightly higher than M4 and M5. The higher cost is mostly due to the addition of an O&M center (€12 million for civil works, €6 million for tracks, €2 million for the equipment) and for a higher per station cost, at around €27-€28 million each. On a per station basis, that is more than the average cost of M5 stations, but, considering that M1 is a heavy metro with stations that are 120 m long, 25 m wide, and 16 m deep at track level, the average station volume is more than double that of M5. Hence, the parametric cost per cubic meter is between €450-€470, an estimated cost similar to M5 stations in the "wetter" part of the city requiring bottom jet grouting. Tunneling costs also resemble those from other single-bore projects: €88 million or €27.1 million per km, including ventilation shafts, TBM launching and extraction shafts and a short C&C section for the O&M access ramp. When we break these tunneling costs down into smaller line items, we see that the TBM tunneling is projected to cost €52 million for 2.9 km, or €17.9 million per km, which compares well with other projects, like M5's single bore and similar projects in Milan and Turin.

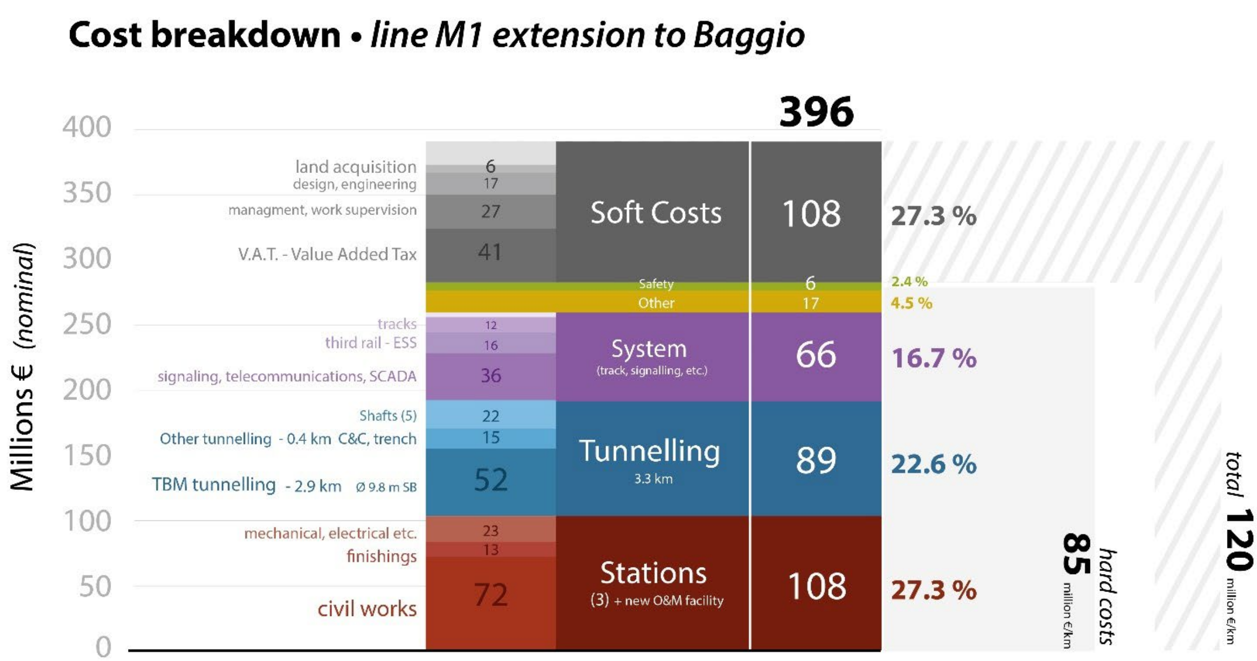


figure 23. Cost breakdown of line M1 extension to Baggio

What is more interesting is M4's **DBFOM contract**, for which we have more detail compared to M5's. Even if the economic and financial plan (PEF – *Piano Economico e Finanziario*) detailing the long-term cashflow and lifecycle costs for the municipality is not publicly available, the concession contract[69] highlights some of the long-term costs and how risk transfer has been balanced. The concession has a duration of 370 months, 88 months for construction and 282 months for operations and maintenance. As the contract cannot be extended, a delay in the

[69] The full concession contract is accessible here: https://www.metro4milano.it/wordpress/wp-content/uploads/2016/09/Testo-Convenzione-di-Concessione.pdf

construction would result in a shorter O&M duration, which will eat into potential revenues for the concessionaire. The construction risk (or availability risk) is essentially the only form of risk that has been transferred to the private partners through the DBFOM, as the contract guarantees a minimum yearly fee of around €94 million from the second year of operation (indexed to inflation), corresponding to a per trip fee of €1.094 applied to a minimum yearly "guaranteed" ridership of 86 million trips per year, enough to guarantee a return on investment to the private partners. If annual ridership exceeds 86 million, the concessionaire will receive €0.45 per additional trip. The additional fee is capped at a maximum that corresponds to 2% of the annual growth of the contractual Internal Return Rate of 5.93 %.[70] Even if all of the financial details aren't public, the Internal Rate of Return (IRR) is higher than the typical borrowing rate for municipal and national bonds, suggesting that long-term costs for the city are higher than a fully publicly funded option. In fact, it is generally recognized that the two DBFOM schemes used for M5 and M4 have been a way for the city to circumvent the cap imposed on municipal borrowing by the National Government. Thanks to the central government's renewed commitment to public-transit projects, Milan has shied away from PPPs and reverted to the more traditional Design-Bid-Build approach through Joint Procurement (*appalto integrato*) for newer projects, such as M1 and M5 extensions.

Unlike M5, the Municipality maintained greater control over the concessionaire by creating **a Special Purpose Vehicle (SPV) company**. The private consortium selected via a DBFOM tender joined the SPV "Metro 4 Spa" whose main shareholder is the city (2/3 of the shares), with the private partners owning the remaining balance of shares (see figure 24). As for M5, the city also retains a direct control over the design process, with MM having done the preliminary design and being responsible for the work supervision (DL). Also, ATM, the city's transit operator, will be responsible for operations, as it was part of the winning consortium. ANAC criticized this arrangement as highly unusual, but the city argued that by including these known entities, the city would have greater control over the delivery process.

[70] For the value of the IRR see: https://www.metro4milano.it/la-giunta-approva-delibera-per-m4-si-tratta-di-un-provvedimento-necessario-per-la-realizzazione-dell-opera/

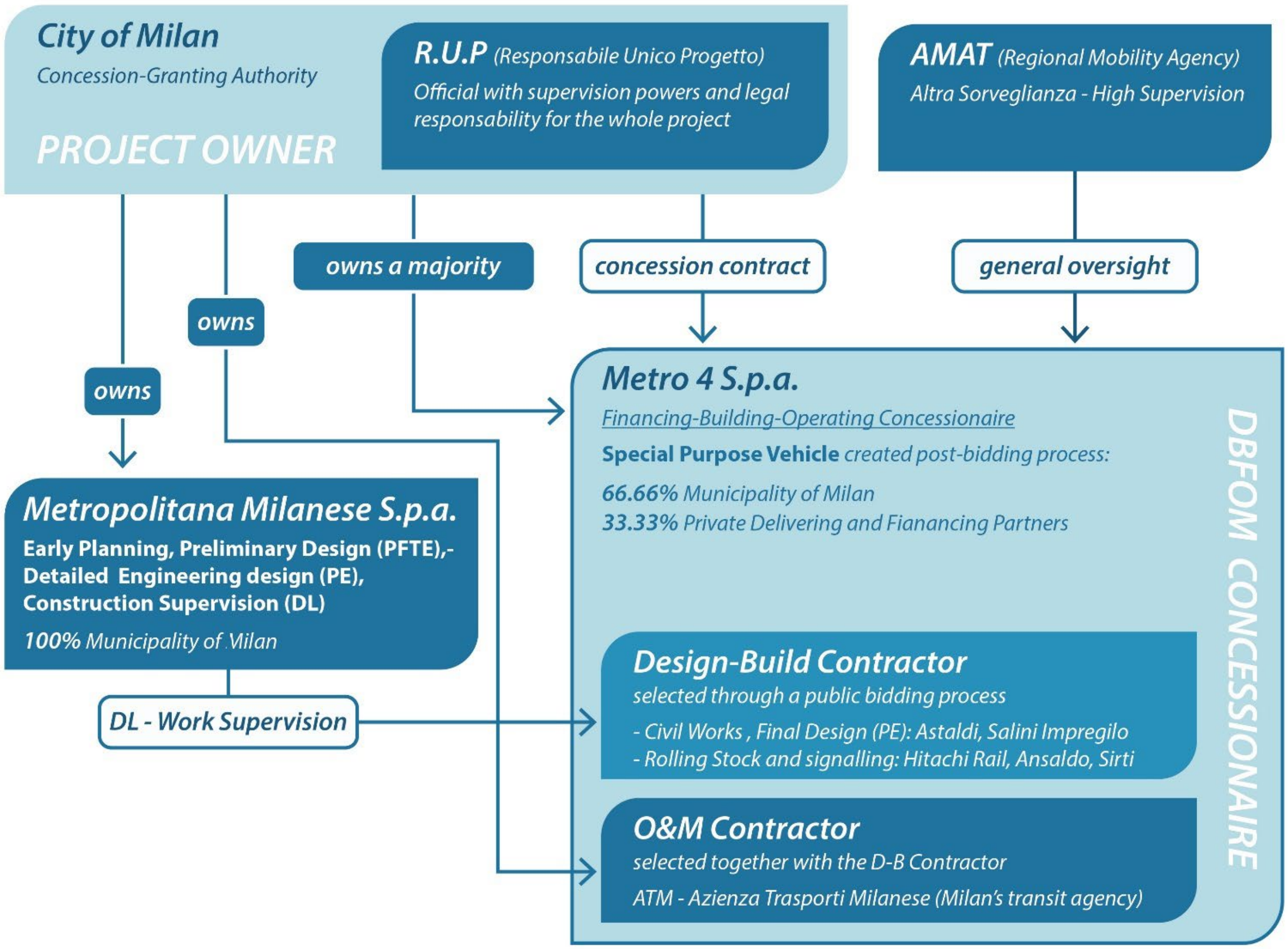


figure 24. Line M4's DBFOM structure.

6.7 Longstanding in-house expertise, pragmatic approach, standardized design

Milan's longstanding history of building cost-effective metro projects is the result of its longstanding in-house rail-transit construction expertise. As we saw in Turin's case, the analysis of station costs and design suggests that a greater standardization of station layouts and construction processes is central to disciplining costs. As we have seen in Boston, New York, and, later, Naples, projects tend to lose budget discipline when station designs are bespoke and more concerned with community placemaking versus functional design.

Moreover, the decision to build a complete line in two larger phases, such as for M5, or even in a single phase as was done for M4, seems to be a factor contributing to savings compared to other projects, by allowing for a better location of land intensive facilities, such as O&M centers, at the margins of the built-up area and other savings through economies of scale in tunneling and a more rational distribution along the line of facilities such as crossover boxes and staging sites for the TBM.

The supervision and longstanding design capacity provided by the in-house engineering firm Metropolitana Milanese emerges as a key element to control costs, produce high quality projects and avoid scope creep through the planning, design and procurement processes even in the case of projects delivered through DBFOM schemes, where part of the design and management was outsourced to the private sector. In Milan’s case, the premium normally observed in DBFOM delivery schemes doesn’t seem to have a direct impact on capital construction costs, but more on the long-term cost the city will sustain to pay back the private capital investment, even though this claim would require a deeper study of the economic arrangements. The DBFOM model seems to have been retained solely as a way to bypass austerity limits on borrowing more than a way to transfer risk as it is often framed in the literature or as a way to outsource part of the contracting authority’s responsibilities in terms of design decisions, oversight of the procurement and construction, that the city of Milan has kept through the involvement of MM in key roles throughout the process. The lesson of Metropolitana Milanese, with its hybrid private-public statute, provides an interesting blueprint for a third-way of building and retaining in-house engineering capacity for cities that are engaged in long-term expansion programs of their rail transit network.

7 Rome: Lines C and B1

7.1 Introduction:

The city of Rome (2.78 million inhabitants in the city proper, 4.05 in the metro area) is served by a three-line metro network spanning 59.4 km with 73 stations and serving 985,000 unliked trips on an average weekday[71]. The urban rail network of the city is rather undeveloped and relatively recent compared to European peers. The development of the system has been slow and plagued by delays, scandals and downscaled ambitions. In 1962, Rome developed a transportation masterplan outlining a four-line metro network that is complemented by trams and suburban rail, but the construction of the third metro line, MC, only started in 2007, with the goal of adding 25 km of new heavy rail to the city within a decade. In this case, we will analyze MC and MB1. MC is Rome's most recent metro line project, and it is partially under construction. MB1 is a branch of metro line B built at the same time of MC and will mostly serve as a reference to measure the cost implications of technical characteristics, construction techniques, alignment, project management and delivery method.

Line MC is an illustrative case about the drivers of construction costs because it features multiple alignments as it crosses diverse urban contexts - spanning from the external eastern suburbs to the core of the old city - and presents a **relevant difference in construction costs between the different sections.** Line MC is being built using a delivery method labelled as "general contractor" (*Contraente Generale*), introduced by the 2002 reform of public procurement, that can be qualified as a form of Design-(Manage)-Build with limited public supervision. Yet, there have been relevant differences in the way the project has been contracted out for each section, as a result of intricate early planning, design and approval process. Moreover, the **MC case highlights very clearly the impact**

[71] Spinosa (2019).

of archeology and monument protection on design requirements, and, more importantly, **how unanticipated archeological findings increase costs, especially when combined with political fickleness within the municipal government**. Both MC and MB1 cases illustrate that the choice to break down a larger metro project into smaller, more financially palatable sections, resulted in higher overall costs at the end.

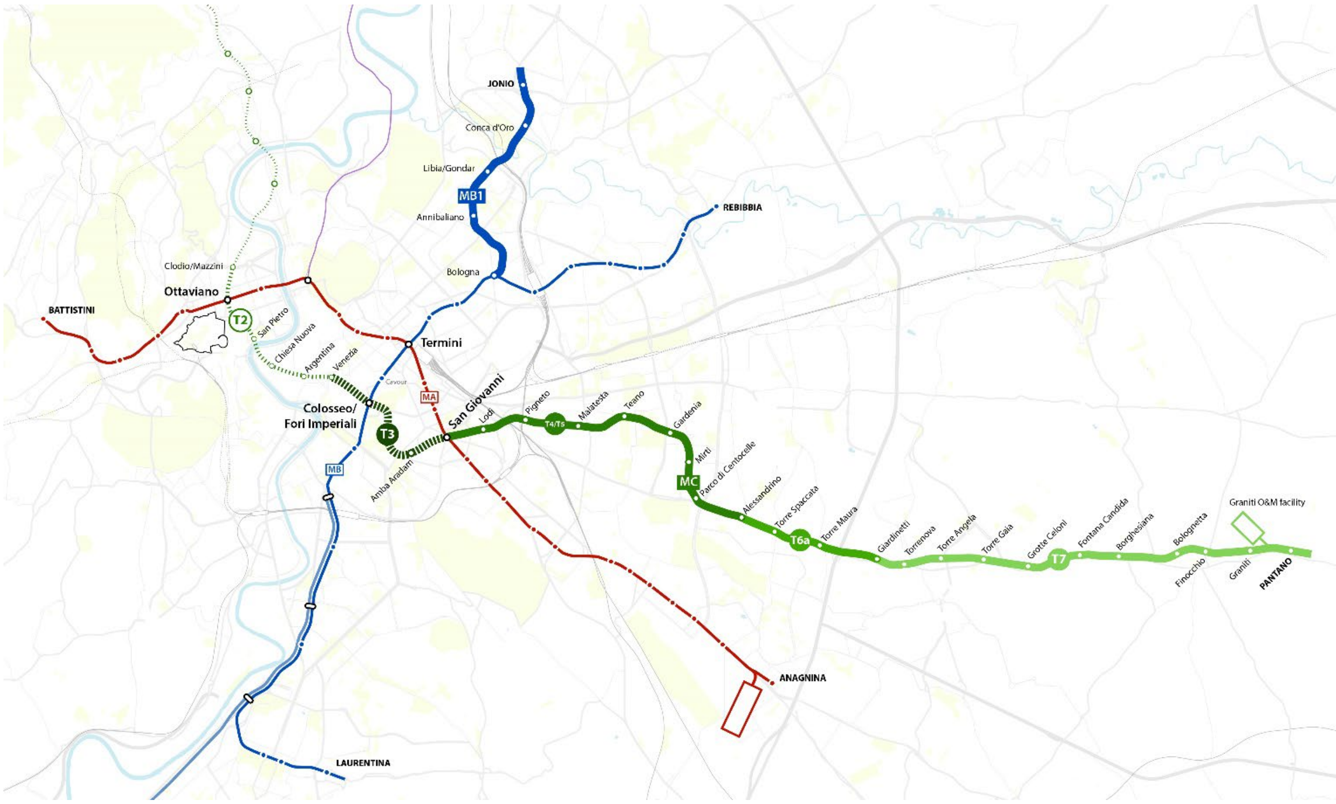


figure 25. Rome's metro network as of 2021. Lines MC (green) and MB1 (blue) are highlighted.

7.2 Context: historic costs of metro construction in Rome

Rome began construction of its first metro line relatively late compared to other European capital cities. Work on an electric suburban rail featuring urban metro characteristics started in the mid 1930s on a line connecting Termini station to the E.U.R. '42 exposition site. As works were suspended during the war, the line, now part of metro MB, was finally inaugurated in 1955, thus becoming the first proper subway section opened in Italy. Rome's network developed slowly in the following years. Even though Metroroma spa, a public special purpose delivery company was established in 1955 to develop a multi-line network, construction on the second, fully urban line, MA, started only in 1964, following the alignment outlined in the 1962 masterplan that envisioned a three-line radial network (lines A, B1/B2, and C) and a fourth circumferential elevated line (D) in the median of an urban expressway.

MA was planned as a mostly cut & cover *Milan method* project, but as construction started on the outer sections, surface-level disruptions were deemed too onerous and construction was halted while the project underwent a redesign that called for a deeper bored alignment with fewer street-level challenges in the early 1970s.[72] After many delays and cost increases, Rome's first fully urban metro line opened in 1980.

Since Rome's metro projects were financed by special laws and appropriations approved by parliament, it is possible to reconstruct all of its historic construction costs since the original Termini-EUR section (see figure 26). MA Eastern extension and MB Northern extension are among the costliest metro lines ever built in Italy, despite being built in dense postwar expansion areas and not in the archeologically and historic sensitive urban core. Also, Rome's costs vary more than Milan's, with several projects being significantly higher than the €200 million per km ($265 million per km) observed in Milan as the upper limit of all but one project.

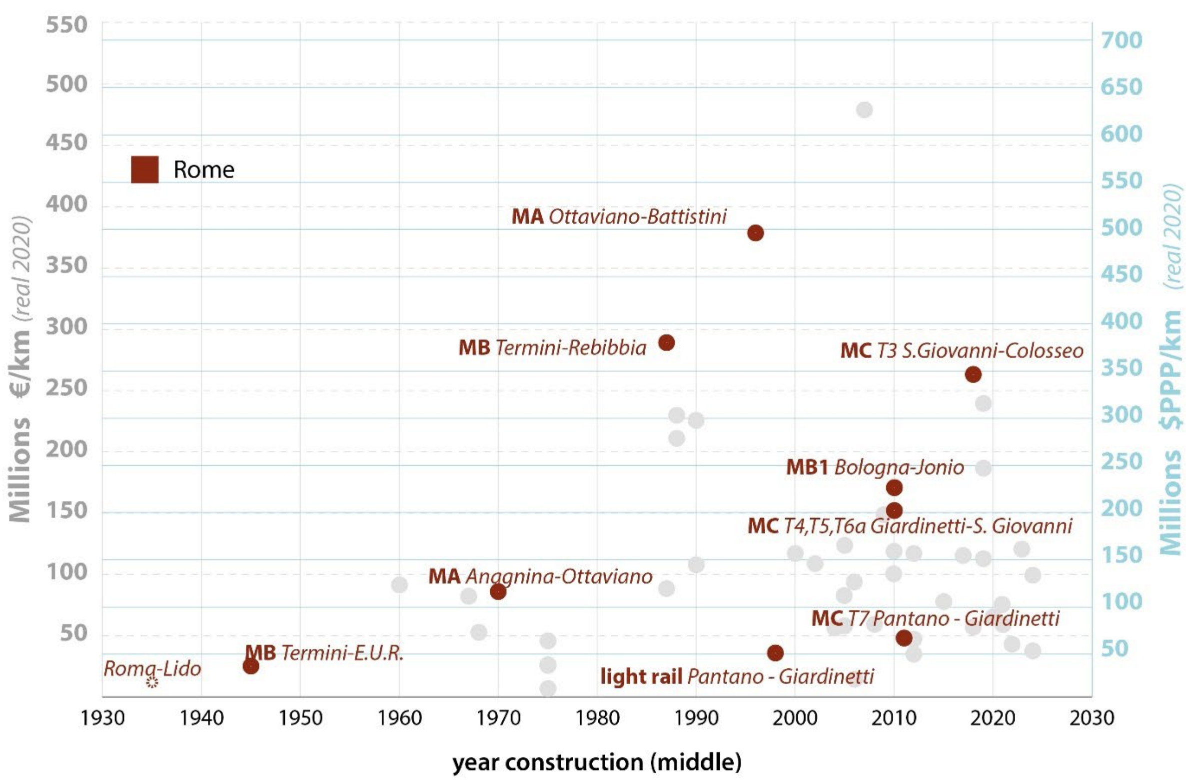


figure 26. *Actualized construction costs of all metro sections built in Rome since the 1930s, in euros (left scale) and dollar PPP (right scale).*

72 For a complete reconstruction of Rome's line A history see: Palma (1972).

7.3 Line C: project overview

Line C is the newcomer among Rome's metro lines. Construction started in 2007 after several years of planning. The core section of the line crosses the city from East to West, from the far eastern suburbs situated outside of the GRA ring motorway along via Casilina to the central neighborhood of Prati, connecting twice with MA at San Giovanni and Ottaviano and with MB at Colosseo/Fori Imperiali. Once completed, the core section of MC will span 25.5 km with 30 stations and provide direct metro service to the job-rich city core and several touristic sites: the Capitolium, the *Ansa Barocca* (the oldest part of the medieval and Baroque core of Rome adjacent to the Tiber meander, home to the Pantheon and Piazza Navona), Sant'Angelo Castle and Saint Peter, serving 300-350,000 daily users and relieving the overcrowded MA.

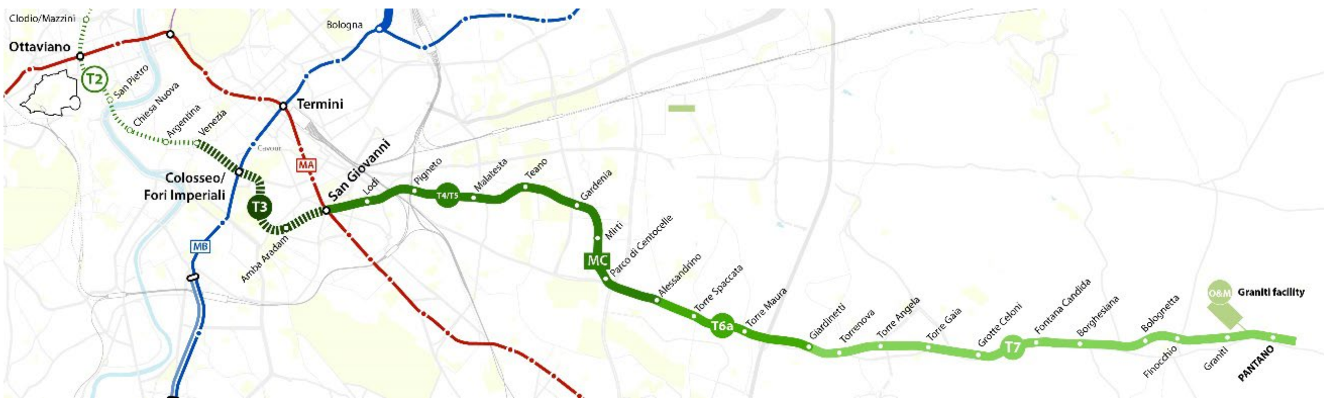


figure 27. The alignment of MC with its different construction sections. Solid line (O&M and T7, T6a, T5/T4) is operational; dashed (T3) is under construction; dashed thin (T2) is under project review.

Table 4. MC - Main Characteristics

Sections	T7	T6a	T4-T5	T3	T2
Years Construction start-end	2008-14	2008-14	2007-15 *2018* (S. Giovanni)*	2011-2023	-
Length (km)	8.2	2.8	7.3	2.8	4
Stations	10	4	9	2	-
Station depth	-	20 m	17-30 m	30-32m	-
Cost Nominal In million € And in $ PPP	€ 637[1] *$ 892*	€ 399 *$ 519*	€ 1,090 *$ 1,417*	€ 735 *$ 955*	-
Cost/km In million $ PPP/km	**108.7**	**185.3**	**194.1**	**341.2**	*400-500* (preliminary estimates)
Alignment	at grade elevated open trench	underground twin bore tunnel Ø 6.7m	underground twin bore tunnel Ø 6.7m	underground twin bore tunnel Ø 6.7m	underground twin bore tunnel Ø 6.7m

Projected maximum capacity:	40,000 pphpd
Vehicles	AnsaldoBreda driverless GoA4 (109.4m long, 2.85m wide).
Platform lengths	110m
Delivery method	General Contractor (*Contraente* Generale), i.e. Design-(Manage)-Build.
Financing	**100% public** T2-T3-T6a: 70% Central Government, 18% Municipality, 12% Region T4-T5 : 70% Central Government, 30% Municipality

Notes

1. This section was reconverted from the outer section of the Roma-Giardinetti-Pantano light rail line, a 1916 meter-gauge interurban that was upgraded to almost metro standard (full grade separation, longer stations) during the late 1990s-early 2000s. This first upgrade cost 350 bn liras, that is €274 million in 2020 prices. The further adaptation and integration into MC (regauging, full station refurbishment, rigid overhead catenary, platform screen doors, noise barriers, etc.) cost €363m (not including the expansion of the depot and maintenance centre).

Plans for MC have been on the books, albeit with different alignments for some sections, since the 1964 masterplan. Provisions for a connection with MA were built during the construction of San Giovanni station in the early 1970s. Despite the promise of MC, its realization was scuttled by corruption scandals in the 1980s (see section 2.2). MC was postponed several times before an initial segment, corresponding to sections T4-T5, was approved and partially funded in the mid-1990s. In the following years, the scope of the project was expanded, notably with a new, more central alignment through the city's core and the incorporation of the outer part of the Termini-Giardinetti-Pantano interurban tramway, which was in the process of being upgraded to full-grade separation with metro standards during the second half of the 1990s. The project received a final approval by the

CIPESS inter-ministerial committee in 2003 with enough funding to begin sections T7, T6a, T4/T5. The project was to be delivered through a form of D-B scheme known as General Contractor, with the goal of increasing the participation of the private sector in the delivery of public infrastructure and seeking forms of risk transfer.

Since section T4-T5 was initially intended to be delivered with a more traditional Design-Bid-Build formula, the public bidding process for the designation of the D-B General Contractor was based on a more refined level of design for those sections (corresponding to a PD or Final Design), but only on a very Preliminary Design for the remaining sections (T7, T6a, T3, T2), including the very delicate and riskier sections through the historical, archeologically rich core of the city. Notably, the preliminary design envisioned an untested construction technique for sections T3-T2 poised to minimize disruption to the archeological layers that in some areas could be as deep as 20 m.[73] This design, hence dubbed the "Rome method" and later used for the central section of M4 in Milan, consists of enlarged twin TBM bored tunnels (up to 10 m diameter) that includes both the track and the platform, while inclined tunnels containing stairs and escalators mined from small shallow shafts provide access to the surface (see figure 28), with an additional vertical shaft for elevators, ventilation and emergency exists. The exact locations of the shafts were to be determined after a preliminary, non-invasive archeological investigation via test borings that were taken in potential locations to identify the areas having minimal risk of encountering major archeological remains.

This technique of identifying archeologically sensitive sites had several shortcomings. The very first test borings in the mid 2000s highlighted the presence of an archeological stratum richer and deeper than expected. Hence, the construction of the mined inclined access shafts was a great risk to the archeological layer because of the destructive excavation techniques involving jet grouting. The various Superintendencies expressed several reservations about the plan, issued a negative assessment of the plan described in the preliminary project documents, and asked for the archeological plan to be amended in the final design.

[73] RM (2021b).

figure 28. The initial plan for the T2 section of MC. In white, the twin bored large diameter tunnels. In red, the station access built with inclined mined tunnels and shafts. Courtesy of Metro X Roma.

The overarching challenge which MC encountered stems from the decision to speed up the procurement phase in 2004-06, in part, to satisfy political pressure over funding allocations and upcoming National and Municipal elections in 2006 while ignoring the Superintendencies' concerns about the risky construction method for the central sections of the project. By flouting these concerns, the project incurred severe cost overruns and the project was almost brought to a complete halt between 2008-10, when the central government intervened and nominated a "Czar" (*Commissario Straordinario*) to resolve the archeological conundrum that stymied the project.

Because of these challenges and delays, costs have increased and the T3 segment has advanced slowly and been partially descoped, namely the construction of Piazza Venezia station was put on hold and de-funded while it was redesigned. The segment T2 through the Ansa Barocca, probably the most challenging but most important part of the whole project, frozen in 2008, despite several attempts by the General Contractor Metro C spa to advance that section, either by containing costs and avoiding technical challenges through extensive descoping (in a 2011 project revision, Metro C Spa proposed scrapping most stations in the central section) or by proposing a PPP scheme. Both options were ultimately rejected by the municipality. The continuation of the project beyond Piazza Venezia or even the completion of the section to Fori Imperiali has been jeopardized by growing public skepticism and the initial political opposition of the city government's Five Star Movement majority, which was elected in 2016. More recently, the project appears to be back on track thanks to local support from grassroots advocates who have advocated for MC through the participatory process mandated by the PUMS mobility plan. Furthermore, the central government's renewed commitment to the project has put it on a more secure financial footing. Section T2 has been completely redesigned to incorporate lessons learned from T3 construction and the superintendencies' recommendations about archeologically sensitive construction. Its cost is now estimated at around €1.5 - €2 bn.

Table 5.	MC - Project's Timeline summary
Early 1990s	First project rejected after a negative E.I.S. (V.I.A.) evaluation. Partial financing of €532 million *ex lege* 211/92 for sections T4 and T5.
2000-2003	Preliminary project approval by CIPE (Inter-ministerial Committee for Infrastructure). T7 trough T4 sections are financed under the "*legge obiettivo*" framework.
2004-2006	**Public Bidding Process for the designation of the General Contractor** won by Metro C Spa, a consortium of Astaldi Spa (head), Vianini Lavori Spa, Consorzio Cooperative Costruzioni, Ansaldo Trasporti Sistemi Ferroviari Spa.
2006	**Preliminary works** (first level archaeology diggings, utility relocation)
2007	**Construction starts** on sections T4-T5
2008	**Construction starts** on sections T6a-T7
2009	**First major cost increase** for the sections T6A-T7- O&M Graniti – €189.6 million
2010	**Section T3 approved and financed** with some major modifications to the San Giovanni station.
2011	**Proposal from the Metro C Spa contactor to build the T2 section as a PPP concession instead of CG.** Proposal is refused and considered inadequate (reduced number of stations in the central section, not economically sound).
2011	**Construction starts** on section T3
2012-2013	**Ongoing litigation** between the contractor and Roma Metropolitane about cost increases and delayed payments. Works are halted several times for short periods.
2014	**Opening of the Pantano- Parco di Centocelle section (T6A-T7)**
2015	**Opening of the Parco di Centocelle – Lodi section (T4-T5)**
2018	**Opening of San Giovanni station (T3)**
2018	**Beginning of a major project revision of the central section (T2).**

Notes

For more details about the project's timeline, see: http://silos.infrastrutturestrategiche.it/admin/scheda.aspx?id=1312; and also: http://www.romametropolitane.it/articolo.asp?CodMenu=18&CodArt=22#m2

7.4 Detailed overview of MC and MB construction costs in detail

The overview of MC's detailed construction costs[74] and the comparison with MB1, especially for stations and tunnelling, highlights a remarkable difference in costs between two sections in particular: T4-T5 and T3. Despite both sections being fully underground and using similar construction techniques (twin-bore tunnels and cut-and-cover stations), **the construction costs per kilometer of T3 is more than 75 % greater than T4-T5**. Design and engineering factors, a more complex urban environment, heritage and archeology, schedule uncertainties, bad luck and poorly evaluated risks have all contributed to much higher costs for T3.

T4-T5. Alessandrino - San Giovanni

This twin-bore-fully-underground segment stretches 7.3 km and includes 9 stations from Alessandrino to San Giovanni, where the line connects with the existing metro line MA. This section opened in 2015, after 8 years of construction, but San Giovanni station opening was delayed until 2018, due to the archeological findings during the early excavations and the subsequent redesign of the whole node, a major change that had a significant impact on the cost, as it will be further illustrated in greater detail. This section of the line crosses through a mix of dense inner-city neighborhoods developed in a period spanning the interwar years—including pockets of unplanned 'spontaneous' developments like the Pigneto—and high-density expansion areas of 8-10 story apartment blocks developed during the postwar decades during the economic boom, such as Torpignattara and Centocelle. As is common in Italy, the stations are located under public squares, streets or in open areas involving minimal land acquisition. The station boxes were built using cut and cover, with platform depths varying between 17 and 30 meters, with a few having part of the platforms built through enlarged tunnels whenever the space for a full cut and cover box was unavailable.

The final cost of T4-T5 is €1.206 billion ($1.417 billion PPP) or **€159 million ($206 million PPP) per km**. Hard costs account for €104 million/km ($135 million/km), 65.6% of the total, while soft costs account for the remaining third, a rate far higher than the average 20-25% found in other projects in Italy. That is partially an accounting artefact, as the €124 million in extra costs claimed by the General Contractor (GC) and agreed upon in 2011-12 have been add to the soft cost assumed by the contracting agency.[75] Interestingly, GC's soft costs, which should cover project management and design and risk assumption, accounts for 9.5% of the final capital cost. The nine stations account for the largest share of the construction cost, at €380 million (31% of total costs and 48% of

[74] Detailed construction costs have been provided by Roma Metropolitane.

[75] This is somehow a misuse of the established accounting principles that has been sanctioned by both the Court od Auditors and the ANAC, since the extra claims made by the contractors using the *riserve* system should not be settled before the end of the contract the way it has been done with an extracontractual transaction in 2012.

hard costs), but San Giovanni alone accounts for almost a third of the total, at €110 million (see figure 29). Excluding San Giovanni, whose costs increased dramatically, the per kilometer construction cost (hard costs only) of T4-T5 is about €90 million ($117 million/km)

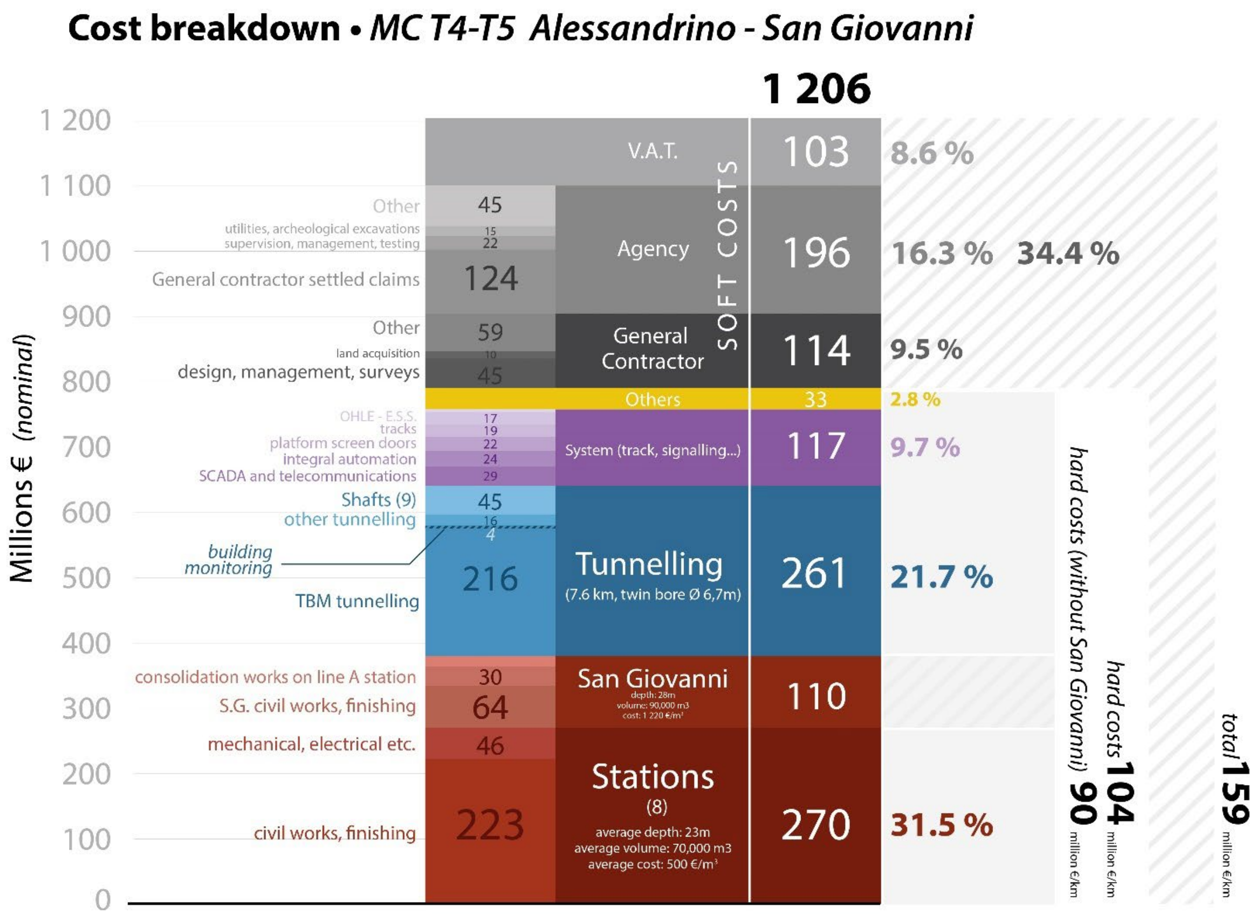


figure 29. Detailed cost breakdown of MC's T4-T5 section of metro line MC.

T3. (San Giovanni) – Fori Imperiali – (Venezia)

The T3 section is the first segment of MC built within the perimeter of the city center defined by the Aurelian Walls. It encompasses 2.65 km of twin-bore tunnels from San Giovanni station (excluded) to Piazza Venezia station (excluded), and two intermediate stations: Amba Aradam, near the Aurelian walls, and Fori Imperiali, where there is a connection to MB station near the Colosseum. The line passes under or near several important heritage sites, including the Aurelian Walls (3rd century CE), the church of Santo Stefano Rotondo al

Celio (5th century CE), the Colosseum (1st century CE), and the monumental complex of the Imperial Fora, notably the Basilica of Maxentius (4th century CE). Works started in 2011 but have been delayed because of archeological findings that emerged during the excavation of Amba Aradam metro station. These findings triggered a legal battle between the general contractor and Roma Metropolitane, which has created uncertainty about whether the line should continue past Fori Imperiali. T3 is now expected to open in 2024.

Section T3 experienced a 70% cost increase, growing from €510 million in the initial bidding to **a total of €862 million as of 2020. That corresponds to €325 million per km ($422 m/km), more than double the previous sections (T4-T5)**. Two factors have contributed to this far higher cost: the cost per station, which is far higher than the average station costs for T4-T5, and tunnel-related costs. In particular, even though the TBM tunnelling cost per km is only slightly higher than in other comparable projects, it represents only less than half of the total tunneling-related cost (€124 m of €278 m). The remaining €154 is for the two main shafts at via Sannio and Piazza Celimontana, that double as crossovers and account for €64 million, and the short 150-m long sections of micro-tunnelling under the existing MA San Giovanni station quoted at an astounding €62 million (that is €200 m/km). The cost variation for stations and tunnelling between the different sections and their reasons will be discussed in greater detail in the following section.

Finally, it is worth noting that detailed costs provided by Roma Metropolitane estimate that **€77 million or 12.2% of the hard cost were expended on archeological and heritage preservation**.[76] Monitoring activities on building stability alone account for €42 million, while €35 million was spent on preventive restoration, temporary support and structural consolidation of several fragile heritage structures potentially affected by tunnel or station excavation. Finally, there are even more additional costs that are the indirect result of constraints imposed on construction as part of archeological and heritage preservation measures, such as deeper tunnels and stations that were selected to reduce the risk of even a minimal damage to listed structures.

[76] That amount does not include the preventive archeological excavations and the preparatory studies that are accounted for in the soft costs borne by the General Contractor, that is estimated at around €7 million.

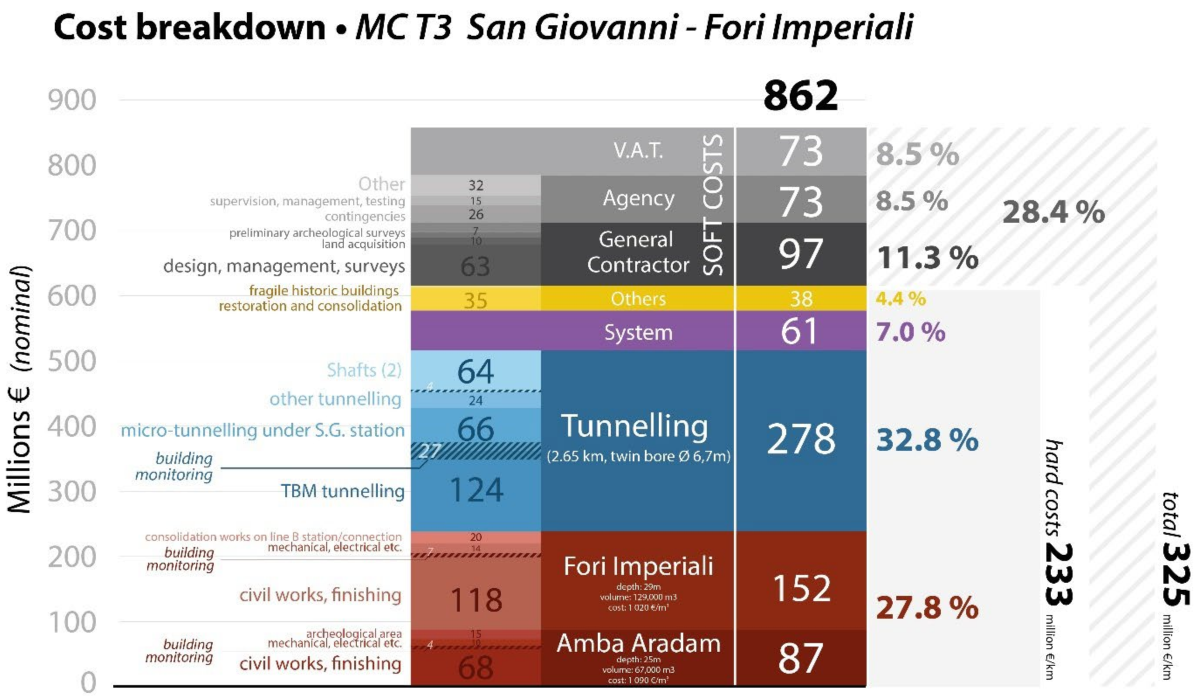


figure 30. Cost breakdown of T3 section of metro line MC. Own elaboration using data from Roma Metropolitane.

figure 31. The temporary structural support for the Basilica of Massentium, an example of the structural reinforcement and temporary provisions that had to be put in place to secure monuments during construction. Source: Metro C spa.

MB1

Line MB1 **cost €761 million ($1.101 billion in PPP 2020 terms), or $231 million per km**. The line was built in two separate packages, which differ significantly on a cost per km basis. The section from Bologna to Conca d'Oro, which includes 3.7 km of twin-bore tunnels and three stations, cost €534 million, or **$209 million per km** in actualized terms, while the final short section to Ionio, which includes 1.05 km of single-bore tunnel and Ionio station, was €226 million, or **$312 million per km**. As we will see in detail later, the difference is mostly the result of greater tunneling costs due to higher fixed costs, such as the launch box.

MB1's stations, both in terms of costs and dimensions, differ from the previously mentioned MC sections. This can in partly explained by the technical characteristics of MB1, which has longer platforms (150 m compared to MC's 110 m platforms) and requires bigger stations, which means that MB1's station are more expensive on a relative basis than MC's. Another unique element of MB1 is that three out of four stations include multi-story underground public parking structures that cost €23 million. Finally, the stations' depth and the high-water table, as the line crosses through the valley of the river Aniene, all add additional costs.

MB1's soft costs represent 31.9 % of the project's total; however, this is due to the fact that €98 million in compensable claims and an on-time delivery bonus were included in the soft costs. Moreover, most of these additional costs are the result of stricter spoil disposal regulations that were adopted during construction. The remainder of soft costs, excluding the V.A.T., includes professional costs related to project management and design (€32 million), ancillary projects excluded from the main contract, payouts for utility relocations directly executed by utility companies and land acquisition totalling €82 million or 10.7 % of the total.

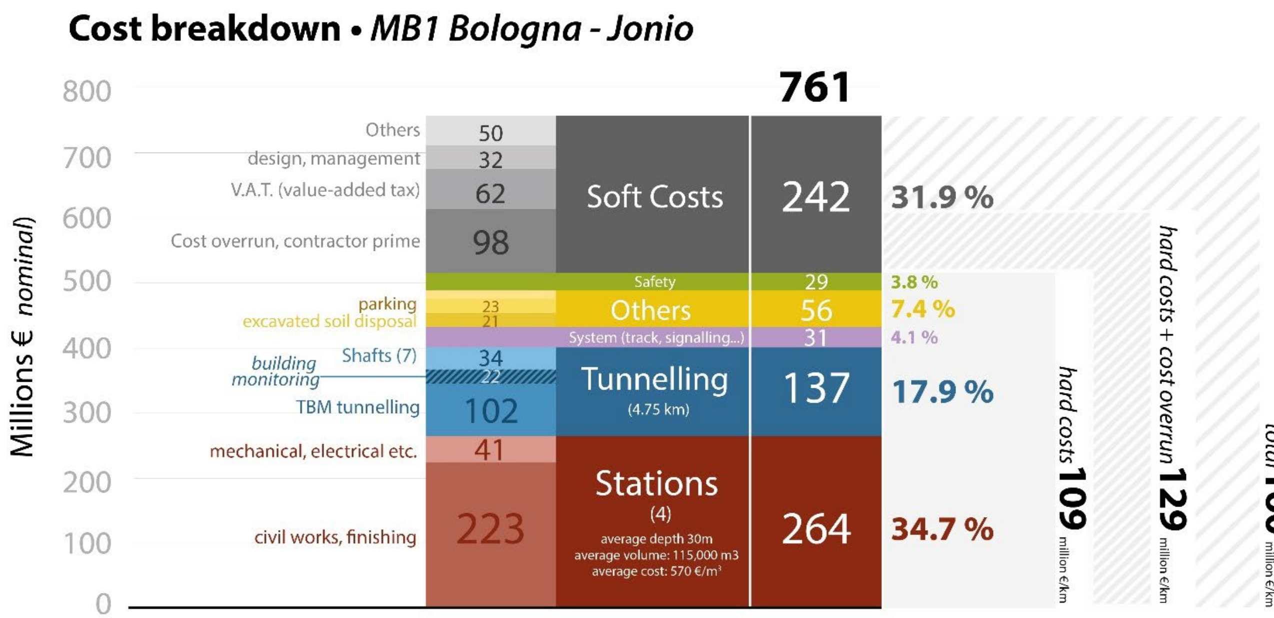


figure 32. Cost breakdown of MB1 extension.

7.5 Significant variations in station and tunnelling costs

By studying MC and MB1 side by side, we quickly see what drives construction costs. In urban rail, civil engineering structures such as tunnels, shafts and stations are by far the leading source of cost, accounting for as much as 80-90 % of hard costs.

Stations

Station costs are mainly comprised of two main categories: civil works and electrical/mechanical. The former includes the works needed to realize the structural components of a station box (excavation, perimeter walls, slabs, beams and columns, waterproofing, etc.), and finishings. The latter is made up of the cost to install electrical and mechanical equipment, such as lighting, fire prevention, ventilation, lifts and escalators, but not system-related costs, like platform-screen doors, passenger information system, SCADA, etc. that are normally accounted for as part of the systems. More complex stations can involve related works on existing or ancillary structures, and extensive reconstruction of the public realm above and around the stations.

figure 33 provides a comparative analysis of station costs on sections T4-T5 and T3 of MC and MB1, highlighting some interesting patterns. **Most stations on the outer section of MC (T4-T5) cost between €22 and €46 million**, with an average station cost of €34 million. The cost soars to more than €100 million on average for the three stations in the central section (San Giovanni, Amba Aradam and Fori Imperiali). At €58-78 million, the four stations on the MB1 metro extension are more expensive than MC's similarly located stations in dense interwar and postwar neighborhoods. The key difference, however, is that MB1 stations are deeper and have longer 150-m platforms versus MC's 110-m platforms. To account for these differences, we developed a parametric cost in €/m^3. Even though this parametric cost is simplified,[77] it is worth noting that **most MB1 extension stations and MC T4-T5, excluding San Giovanni, have a €/m3 between €410 and €670, while the city center stations, characterized by a robust archeological and urban historical environment, have parametric costs well above 1,000 €/m^3**. A more detailed analysis of San Giovanni and Fori Imperiali, the costliest stations so far, reveals that a combination of factors drives cost upward, mainly as a result of costlier design choices selected to preserve Rome's rich archeology.

[77] Station volume has been calculated using design drawings provided by Roma Metropolitane and simplifying more complex station layouts as simpler equivalent parallelepiped.

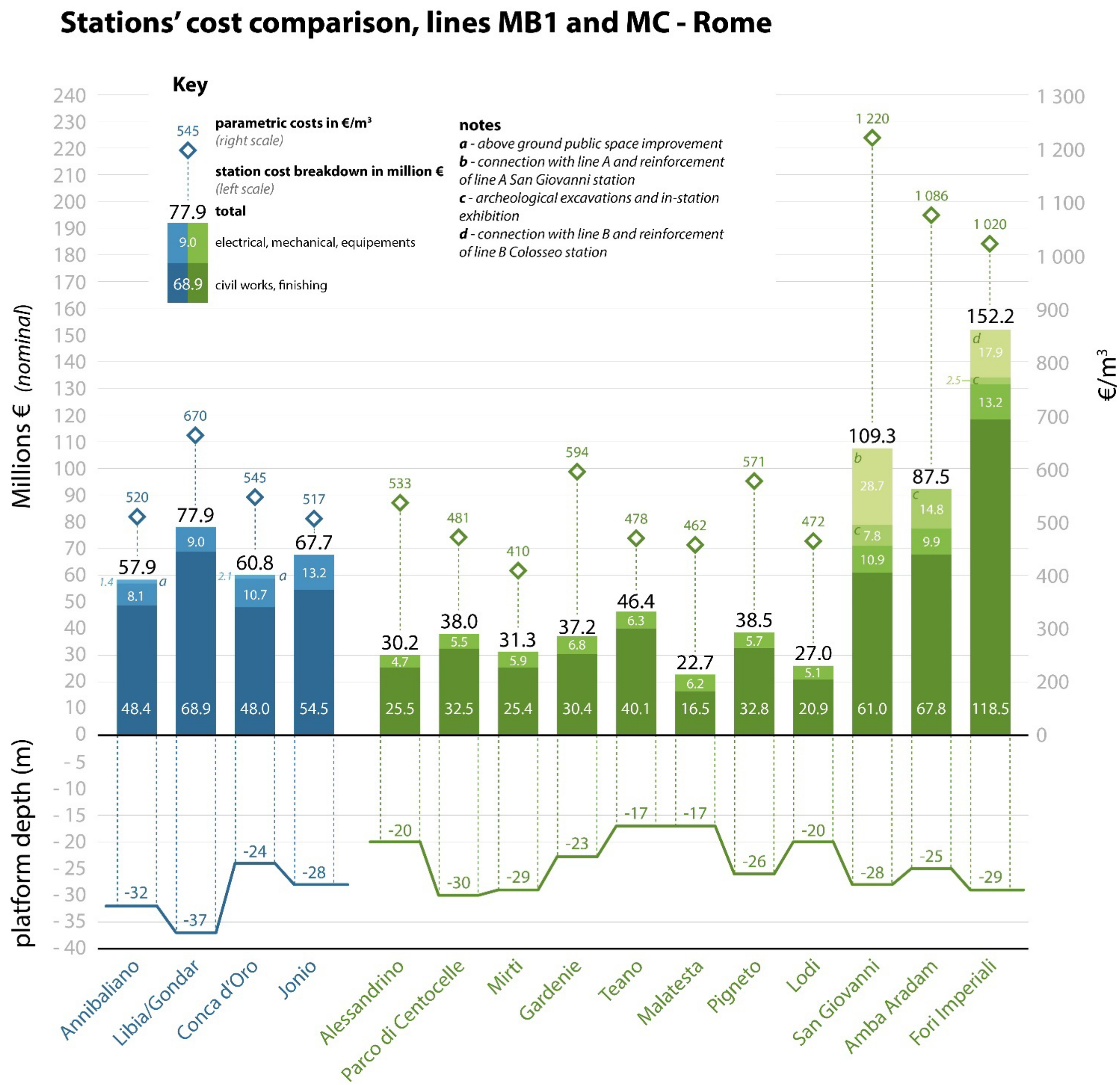


figure 33. *Comparison of MC station costs (segments T4-T5 and T3) and MB1.*

San Giovanni

The San Giovanni node, where MC connects with MA, shows how archeological risk can quickly drive cost escalation. In the original design, the station was planned to be built at a shallow alignment, with the platform level situated immediately under the mezzanine at around 12 m below street level. The station was to be constructed within a 250-m cut-and-cover box that would contain both the station and a crossover. Additionally, the station box was going to double as a TBM launch box, a common practice that we see in our New York and

Istanbul cases. MC's tracks were initially designed to cross the existing metro station at a higher level than MA's, in a space left empty in the 1970s for that purpose, as the station was already planned as an interchange between MA and MC in the 1964 masterplan. **The discovery of important remains from an Imperial age suburban agricultural estate**, not detected during the preliminary test-boring investigations and the potentially "fertile" archeological layer as deep as 19 m, **forced a complete redesign of the station layout to reduce surface excavation, with major cost implications**. First, the station was sunk an additional 14 m to allow MC to pass under the MA station box, which resulted in a much deeper alignment for the tunnel both before and after the station. The crossover was placed after the MA station in a new, deeper shaft that was to be used as the launch box following section T3. Costs usually scale with depth, though often non-linearly. For example, by increasing the perimeter walls' thickness from 80 to 120 cm and digging the station an additional 14 m deep costs more than doubled.[78] The need to go under the existing MA station box without interrupting service added €28 million in consolidation works for the existing station structures. Moreover, the limited clearance between the new MC tunnels and the foundation slab of the existing station required extremely costly and time-consuming excavation techniques involving ground freezing and micro-tunneling for the 150 m long tunnels connecting the San Giovanni MC station with the new crossover shaft on the other side (more about this particular element in the following section about tunneling). Archeological excavations and the decision to realize a permanent exhibition of the most interesting findings within the station itself added another €7.8 million to the bill.

Fori Imperiali

Fori Imperiali is the most expensive MC station, totalling €152 million. The station is situated under Via dei Fori Imperiali, a large, monumental boulevard built in the 1930s to connect Piazza Venezia to the Colosseum. The station is 29 meters deep and connects MC with the existing Colosseo station along MB, a vaulted structure built in a shallow alignment during the late 1930s and opened in the 1950s. **The station's high cost stems from numerous site-specific constraints**. Because of the decision to avoid the complete closure of Via dei Fori Imperiali to vehicular traffic,[79] the station was built in two phases as two contiguous independent boxes; thus, doubling the number of deep diaphragm walls necessary for construction and requiring costly demolition in the subsequent phases. Furthermore, the particular two-step excavation technique developed with the archeological protection agency for the city-center stations, involves the construction of a first level of perimeter diaphragm walls to contain the archeological excavation, and then a second level of deeper diaphragm walls reaching to the impermeable layer of the Pliocenic clays that act as a waterproof bottom for the excavation. Moreover, costlier

[78] For a complete description of the technical details of the station redesign, see RM (2021a)
[79] Eventually, the street has been closed to private traffic in 2015, while the station was already under construction.

piling techniques had to be used in some areas to preserve the archeological layer from concrete spillovers. As a result, the various piles and diaphragm walls alone cost €29 million. On the other hand, massive prefabrication of construction elements (beams, slabs, perimeter walls) were used to reduce construction time and costs.

Due to the lack of aboveground space, the station box is L-shaped and incorporates only one of the tracks, while the other platform had to be partially built (80 m out of 110 m) through the enlargement of the TBM tunnel, accounting for €29 million, €17 million of which was used for ground consolidations prior to the enlargement excavation. Other factors that have contributed to the high costs are monitoring (€6 million), aboveground reconstruction of the public domain (€8.5 million), archeological excavations and an in-station ticketing hall for the Colosseum (€7.5 million) and all the costs related to the pedestrian connection with line MB (€17.9 million), that consists of a two-level tunnel whose upper deck was cut through the brick vault of the existing station during night and weekend closures.

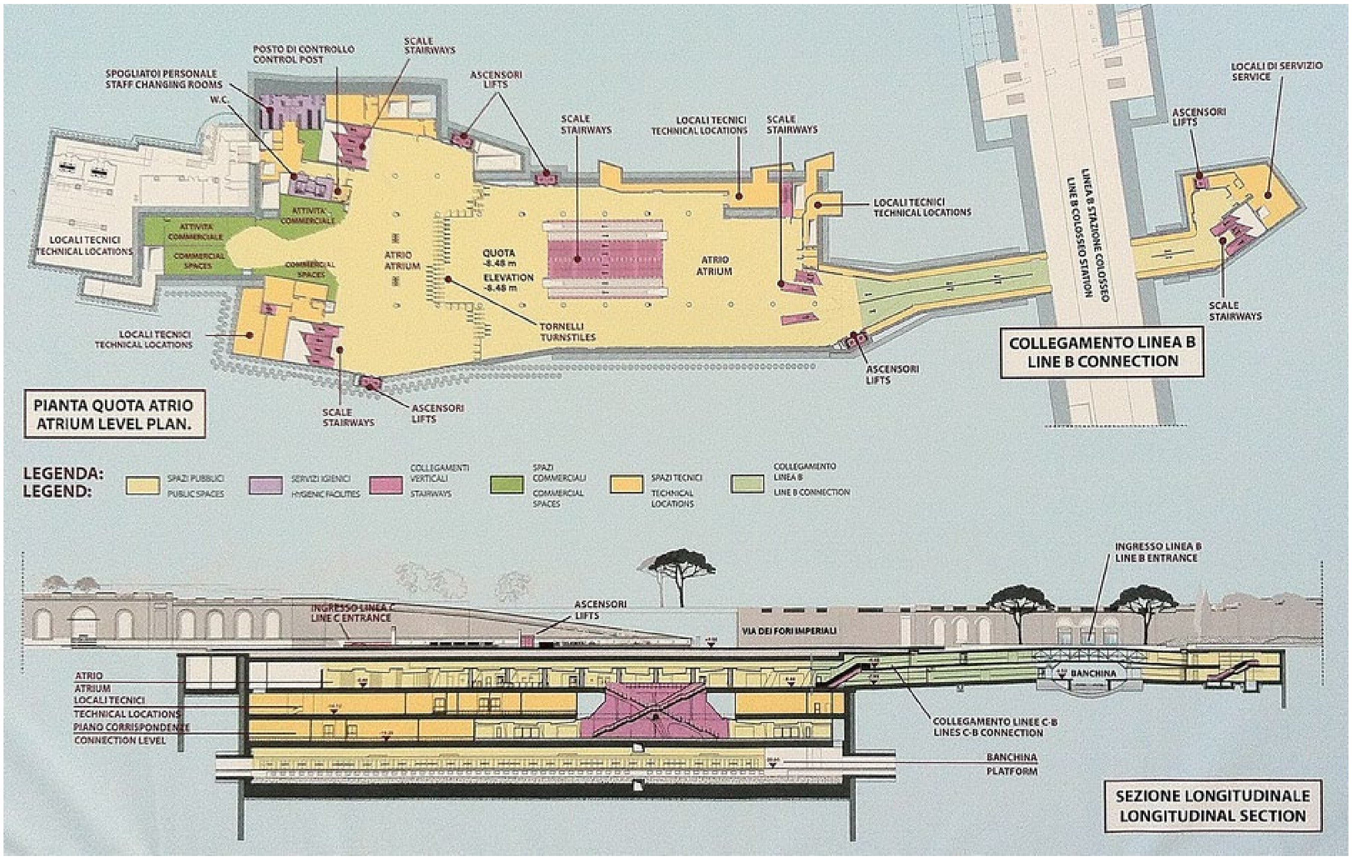


figure 34. Plan and section of Fori Imperiali metro station and of the connection with metro line MB station. Source: Metro C spa.

MB1 stations

As we have seen in the previous paragraphs and graphic (see figure 33), the four MB1 stations have a higher total per station cost than MC stations along the T4-T5 section. MB1 stations cost between €57.9 and €77.9 million. Despite the overall cost difference in the different stations, they compare more favorably when we compare costs per cubic meter, to control for variation in station volumes. This finding suggests that the primary driver of costs is station size. Libia/Gondar, the station with largest costs per cubic meter, is also the deepest of the four MB1 stations (42 m to the bottom of the excavation, 53 m for the retaining walls). Using data provided by Roma Metropolitane, it is possible to break down the costs of the station construction's main components (see figure 35).

Civil works represent between 75.6% and 81.3% of station costs, with the structural components of the station's box being the largest factor. All stations were built using the top-down cut-and-cover method, albeit with different configurations to adapt to local conditions: Annibaliano and Libia have stacked side platforms, while Conca d'Oro and Ionio have side platforms at the same level (see figure 35 for each station's general layout and volume). Due to the shallow water table and resulting hydrostatic pressure, all stations **required a waterproof bottom layer built using jet grouting from the surface** prior to excavation. Waterproofing the station floor is the most expensive item for each station, accounting for between 19.2% to 25.1% of the total station cost. Retaining walls, which were generally built using hydromills, are the second most expensive elements, while excavation and disposal of spoils is the third most expensive. The internal structural elements, that is the lateral walls, the intermediate slabs and all the other concrete structures such as platforms, fixed stairs and lifts boxes, are the fourth most expensive element for stations. The remaining costs associated with structural elements are for the bottom and top slabs (between €1.9 and €2 million per station) and temporary structures for the maintenance and transport of the TBM through the stations and the installation of temporary noise and dust protections used during construction. The rest of the civil works' costs are mostly for finishings (plaster, paving, cladding of walls and ceiling, etc.), additional entrances, site remediation, station furniture, wayfinding, and entrance canopies.

Mechanical and Electrical accounts for between 8.2% and 13.1% of station costs. Escalators are the largest cost at €4-5 million per station, while elevators, normally three per station, account for only a few hundred-thousand euros in total. Site preparation, including temporary diversions, building monitoring, utility relocations executed by the contractor (essentially sewage relocation) and public domain improvements in the affected areas beyond the simple site remediation, such as public squares and gardens on top of the station box make up the rest of the costs.

Even though each project has its own unique quirks, these examples highlight that even though no two stations are identical, civil works represent the lion's share of station costs. These costs vary based on the overall dimensions of the box and, notably, its depth. Moreover, geology plays an important role in determining costs. In our Italian cases, specifically, a shallow water table increases the costs of underground stations, as we have seen in Turin and Milan, and will see in Naples's case.

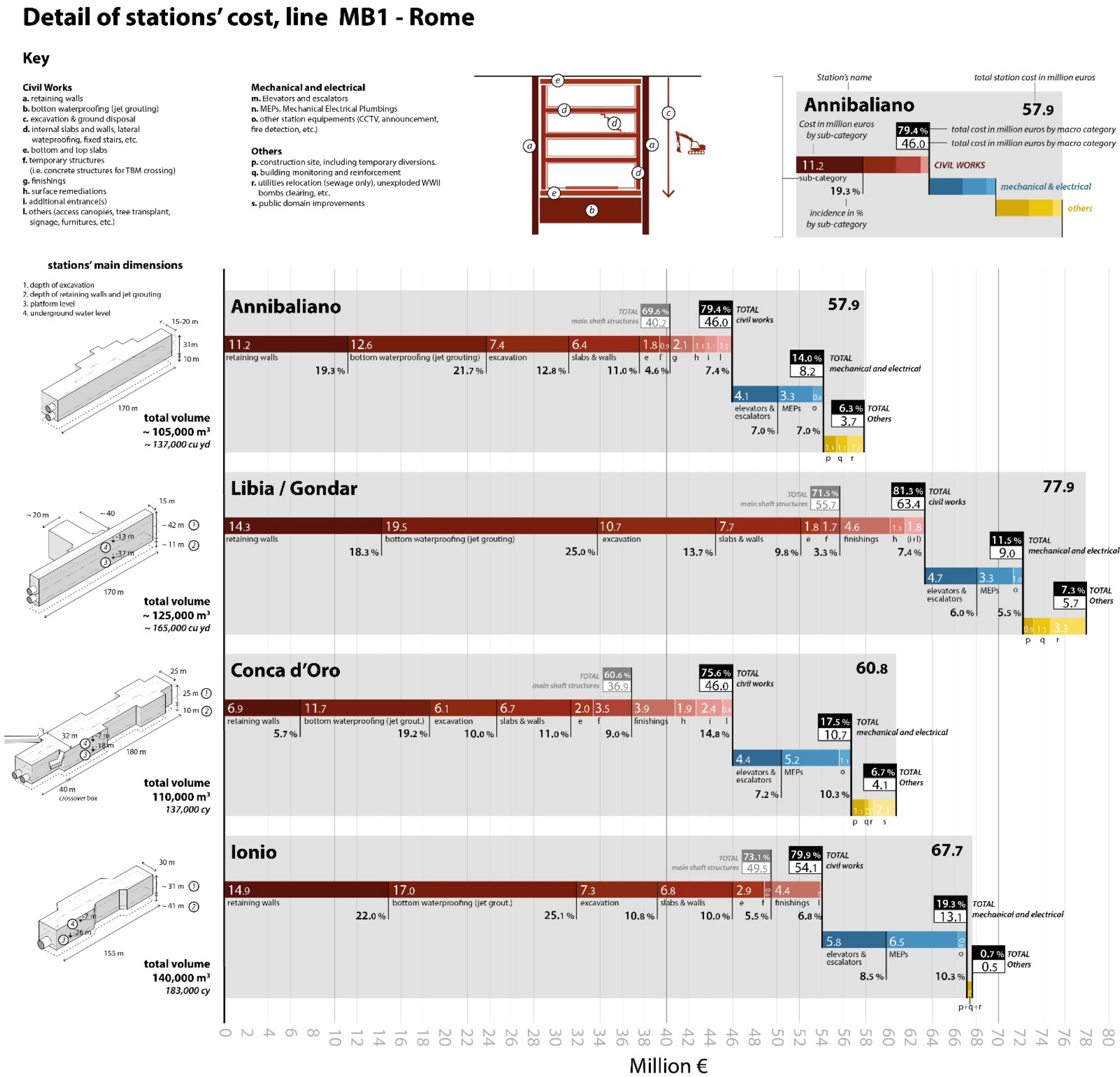


figure 35. Detailed breakdown of cost by item of MB1 stations

Tunnels

The other main civil engineering component of underground metro lines is tunnels and tunnel-related infrastructure, such as shafts needed for ventilation, emergency evacuation, crossovers, and TBM launching and extraction. In Rome's case, the analysed projects (T3, T4-T5 for MC and MB1) have all been built using Earth Pressure Balance (EPB) TBM machines, given the presence of high-pressure underground water and incoherent alluvial soil. For T3 and T4-T5, the route consists of twin bore, 6.7m wide (external diameter), single-track tunnels with lateral evacuation walkways and overhead fixed catenary for trains having similar dimensions. Only the final section of line MB between Conca d'Oro and Ionio has been built using a single bore, 10 m-wide double-track tunnel.

Despite similar technical characteristics, **the relative per kilometer cost of the different tunneled sections varies greatly**, as shown in figure 36. Sections of MB1 were tunneled for as little as €24.3 million per km, while MC's T3 segment cost €105.2 million per km. The primary reasons for this 400% difference in costs are TBM productivity, tunnel dimensions and shafts, building-stability monitoring, and specialized excavation techniques:

- **TBM tunnelling.** The T3 segment of MC has by far the highest TBM tunneling costs, at €37 million per km, except for the short section of MB1 built with a larger single bore TBM, at €42 million per km. Yet, the reason for higher cost on MB1 Conca d'Oro - Ionio section is mostly related to the relationship between the short distance of the tunnel, in this case 1.1 km, and the high fixed costs of TBM tunnelling techniques, namely the purchase/rent, transportation, assembly and launching of the TBM. In the case of T3, many factors contributed to a TBM excavation cost far higher than in the T4-T5 section, despite identical soil characteristics, tunnel diameter and TBM machine: i) a **consistently lower average digging speed (5m/day for T3 versus 18m/day for T4-T5)**[80], mainly caused by longer delays imposed by the time required to move the TBM backstage from the initial launching shaft (see point iii), but also by non-technical factors, such as the political indecision over whether to continue the line past Fori Imperiali up to Venezia, that held the TBMs at Fori Imperiali station for several months; ii) the **decision to bury the TBM shield under Piazza Venezia**, since construction on that station has been delayed for technical and financial difficulties, and political squabbles, that caused €4.5 million in extra costs; iii) Further, €3.9 million was spent **moving the TBM staging site during construction from the initial launch box to the Amba Aradam station**, to allow for an anticipated opening of the crossover at shaft 3.3 – via Sannio, necessary to increase frequencies on the already opened section until San Giovanni.
- **Fixed cost.** The relevant difference in tunneling cost within the MB1 project can be explained mostly by the very high fixed costs on the much shorter 1km section between Conca d'Oro and Ionio. The decision to switch to a single bore tunnel for this final section, in order to build the crossover within the tunnel without requiring an additional shaft, required the contractors to acquire, transport, install and then

[80] The two TBMs used on segment T3 took approximately 520 days each to dig 2.65 km of tunnel each, with an average of 5 m per day including stops. The same two TBMs were used for section T4-T5 and T6a, digging approximately 9.5 km each in 540 days, an average of approximately 18 m/day.

dismantle a new TBM for a very short section. The impact of those fixed costs namely construction staging and logistical issues on the per km cost was dramatic. Moreover, in order to vacate the Conca d'Oro station for an early commissioning of the Bologna-Conca d'Oro section, an additional shaft needed to be built a few dozens of meters north of Conca d'Oro station's box. This supplementary shaft was necessary in order to create a vertical muck-removal system for the earth excavated by the TBM shortly after it began its drive. Initially, the conveyor belts transporting the excavated earth were horizontal, thus stretching back into the tunnel. Once the decision was made to press MB1 into testing and revenue service, a second muck removal solution had to be devised to allow for both muck removal and active train operations. This scenario is similar to the one described in the previous section for T3 and is **an example of how uncertainties over the workflow and external necessities (such as early openings)[81] can trigger cost increases**.

- **Shafts.** Ventilation or emergency access shafts located between stations tend to be quite small and cost a few million euros each for T4-T5 and MB1. TBM launch box costs run into the tens of millions of euros because they have the dimensions of a station and require significant excavation. While these launch boxes are often repurposed as station boxes, there is still a need for dedicated shafts when there are space constraints or a desire to speed up the construction schedule. Again, **section T3's shafts budget was very high**. It cost €28 and €36 million to dig two shafts (3.2 and 3.3), which is similar to the station costs for the T4-T5 section. These shafts are so expensive because they double as crossovers, are quite deep (notably 3.2 – Celimontana, which is 59 m deep), and required partial tunnel enlargement to accommodate the crossover track geometry. By breaking the project up into multiple phases, a hallmark of American projects, namely Los Angeles' Purple Line and New York's Second Avenue Subway, rather than building it all at once, there needed to be additional crossovers spaced at a very short distance to allow for higher frequencies as each segment opened for revenue service.
- **Monitoring.** Building-stability monitoring costs is a much greater for MC's T3 city-center section (12.7% of the tunneling cost) versus only 2% for the outer T4-T5. For MB1, monitoring costs ranged between 13.7% and 24.5% of the tunneling cost due to its winding alignment with stacked tunnels that don't follow a single aboveground thoroughfare, but pass under high-density interwar and postwar housing built on inconsistent soils, and its crossing the river Aniene.

[81] M4 offers a similar example: the political will to anticipate the opening of a section, mostly for electoral reasons, is a factors that influence negatively the optimal workflow and add costs because of special provisions such as doubling testing and commissioning operations.

- **Unique excavation techniques.** T3's detailed costs show how a single node can increase costs dramatically if it entails non-standardized excavation conditions and techniques. The already mentioned decision to sink the MC alignment below the MA station while building a new TBM launching shaft for the T3 section (3.3 - via Sannio) located on the opposite side, resulted in the necessity to excavate the remaining 150 m with a costly approach. As part of the tunnel crosses under the base slab of the existing MA station, it **necessitated an ad hoc approach that included the use of a pilot tunnel bored by a micro-TBM to prepare the ground for additional non-mechanized excavation** (see inbox in figure 36)[82]. **This very short, non-standardized 150 m twin tunnels increased the cost of T3 tunneling by €63.2 million**.

Overall, tunnelling costs are sensitive to a combination of factors: longer TBM sections tend to be cheaper on a per kilometer basis because high fixed costs diminish over greater distances; interaction with and constraints imposed by above ground structures (limits on ground settlement, interference with above and belowground structures) can be extremely onerous, forcing consolidation and constant monitoring; political uncertainty and design changes during construction can increase the final costs of tunnelling by reducing TBM productivity and the overall efficiency of construction phasing and workforce allocation.

[82] For a more detailed explanation of this particular excavation technique, see RM (2019).

Tunneling cost comparison, lines MB1 and MC - Rome

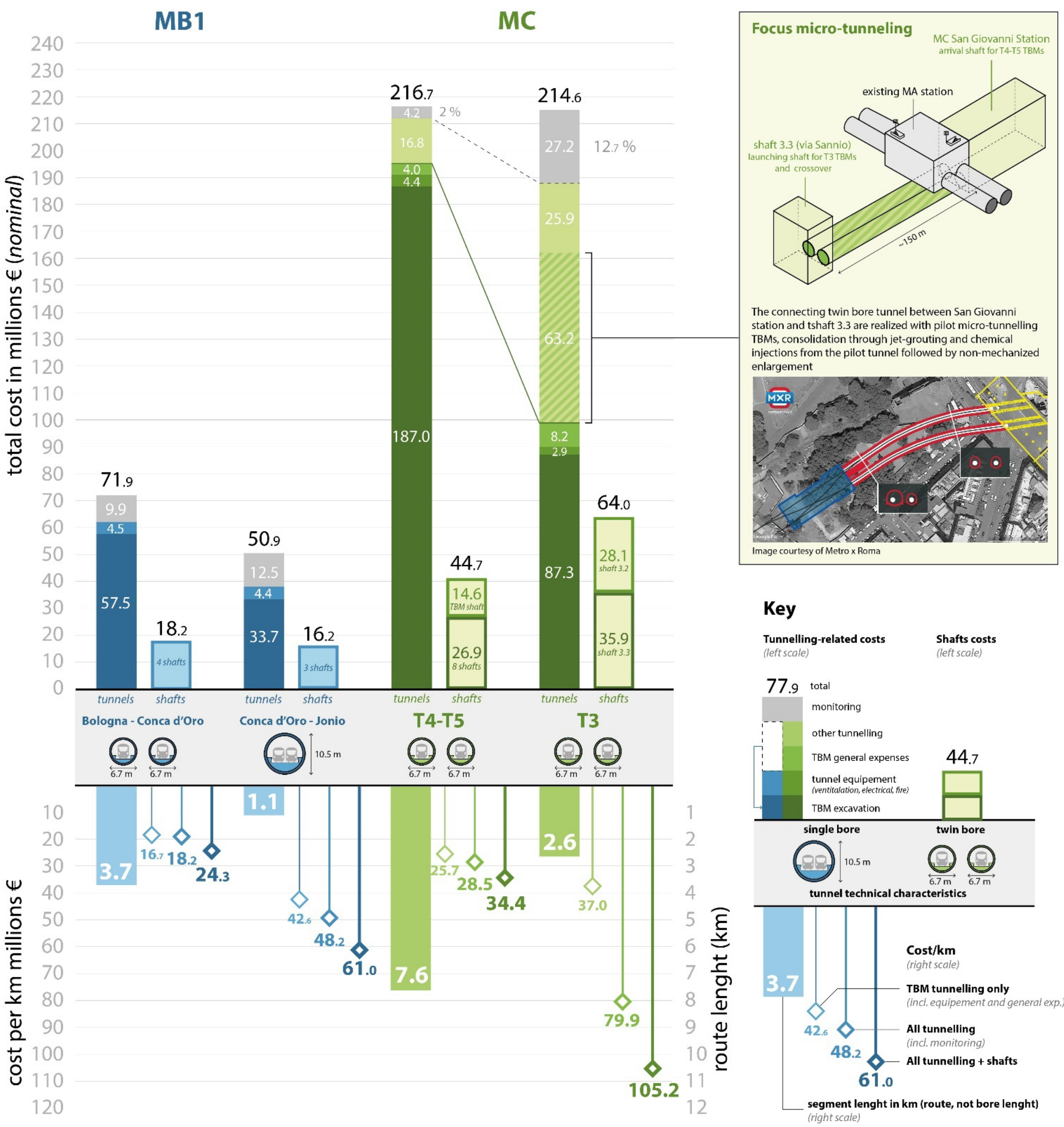


figure 36. Tunnelling cost comparison, lines MB1 and MC (segments T3 and T4-T5).

7.6 Cost overrun: the archeological problem and who bears the risk?

MC ran into major cost overruns from the initial bidding and contract signature in 2004, when the budget grew from €3.047 billion for the entirety of T2-T7 to €3.739 billion in 2012, a 22.7% increase. The major changes in overall cost, depicted in detail in figure 37, are mainly due to two major project revisions. In particular:

- **2004 (A). The total project cost was €3.047** billion for the so-called "fundamental section" which encompasses sections T2 to T7, from Clodio/Mazzini to Pantano. The construction contract, which includes hard and soft costs related to the project design and management function of the General Contractor was €2.051 billion.
- **2007 (B). Total project costs remain unchanged, but construction costs are slightly reduced to account for the winning joint venture, Metro C spa, which came in 6% lower than expectations.** Total project costs are unchanged as savings are added to the project's contingency and partially transferred to the future T2 section.
- **2009 (C). The project encountered its first major contract revision.** The overall cost remained unchanged, but the hard costs increased from €2.365 to 2.558 billion. These additional expenses, covered by contingencies, were mainly related to a large change order for technological improvements (essentially a move toward better automatic train operations and the full automation of station operations).
- **2010 (D). A second major contract revision was finalized**. Archeological findings at the San Giovanni Station required a redesign from a shallow station to a deep station (see description in section 5.5). In addition to these design changes, there was also a two-year reappraisal of the construction process prompted by the *Sovrintendenza* for archeological protection and carried out under the supervision of a "Czar" nominated by the Central Government. The overall project cost reached € 3.338 billion, a 9.5% increase.
- **2012 (E)**. The final major cost increase is linked to litigation between the contracting authority (Roma Metropolitane) and the General Contractor about extra costs claimed under the "riserve" mechanism (see section 3.5) that was settled in 2012 after €124 million in additional compensation was agreed to for sections T7 to T4. The projected cost rose to € 3.739 billion, a 23% increase compared to the initial estimations.

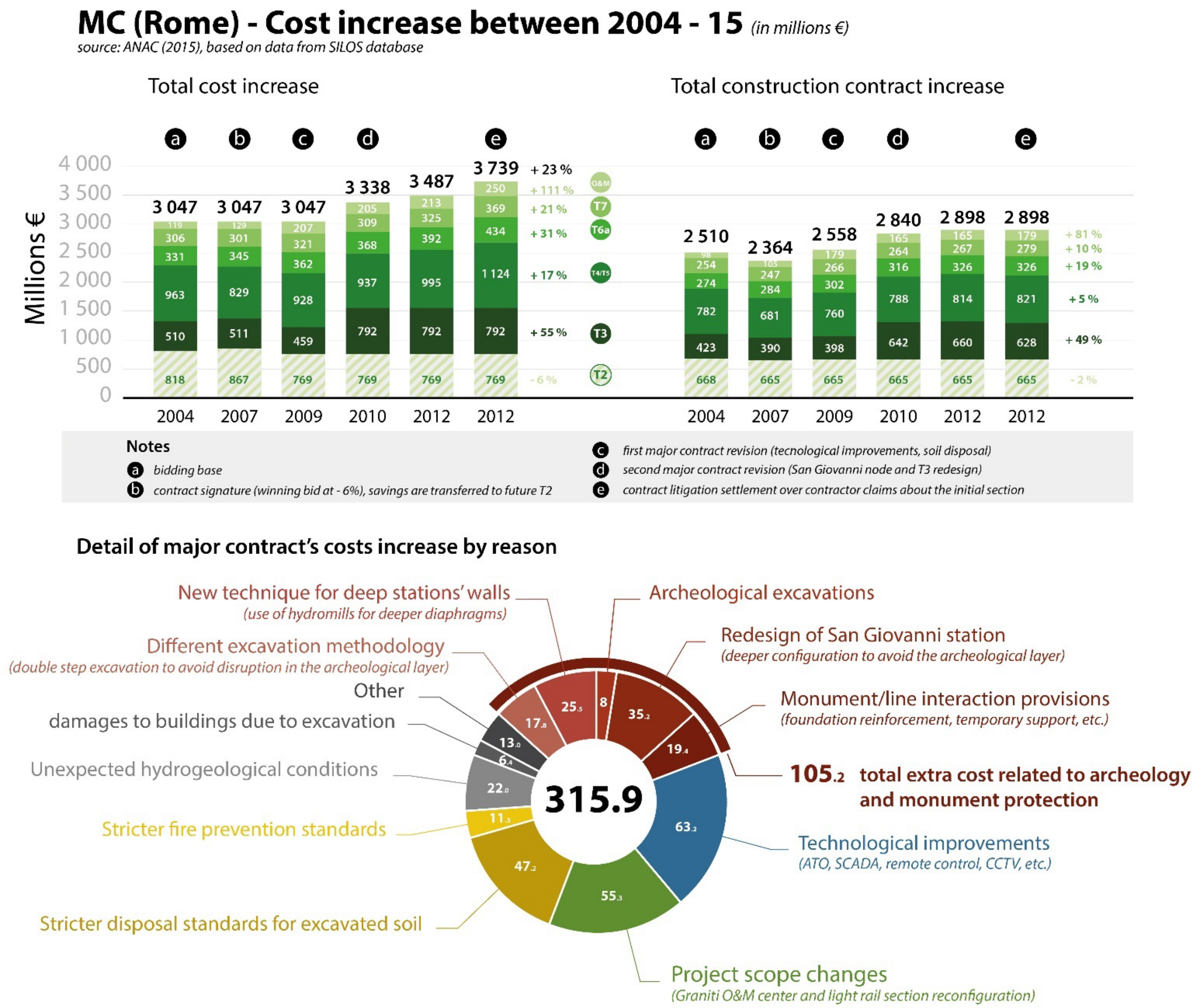


figure 37. Summary of MC cost increase, 2004-12.

The cost increase between 2004 and 2012 was not equally distributed across the project's budget. The most relevant cost variations are concentrated in two sub-sections of the contract: the Graniti Operation & Maintenance (O&M) facility, whose cost more than doubled between 2004 and 2012 and the T3 section in the city center, which experienced a 55% increase. While the increases to the O&M facility are significant, they are also largely an accounting trick. The facility was supposed to be enlarged in the 1990s under a separate project was absorbed by the MC more than a decade later. The T3 section's cost increases are mostly attributed to unanticipated archeology-related changes, notably the complete redesign of the San Giovanni node and its cascading effects.

Sub-sections T4 and T5, despite being completely underground and also encountering unanticipated archeological findings had relatively modest 5% cost increases, mostly due to changes to the automation system decided after the contract was signed and geotechnical problems that damaged adjacent above ground buildings. If we include the contractor's claims,[83] overall costs rose by 17% between the contract signature and the commissioning in 2014. Even considering that this section is less challenging than the city center stretches (T3 and T2), it is generally acknowledged by engineers working in the project and by official project overviews[84] that **the fact that T4 and T5 did not run into major cost overruns is in part due to the contract being awarded based on a more refined level of design compared to the historic core's section (T3)**, where the project's design and estimates were based on an insufficient assessment of the archeological risk and its consequences for station and tunnel design. The choice of rushing the procurement phase in the early 2000s was due to many factors, including the political pressure to start building as soon as possible, even if financing for the whole line was not yet secured and the project was still partially undefined, notably the archeological risk and the related excavation method to be used in the city center sections.

The unsolved problem of the compensable claims

Part of the story about cost increases remains to be written. The General Contractor, Metro C Spa has claimed a significant amount of "*riserve*" (compensable claims) over the T3 section, whose precise amount has not been disclosed yet. Thus, it is possible that the final cost of the T3 section could increase by another 5-10 % before the end of the project. The long-term D-B framework contract signed with the general contractor, which includes the construction of all sections from T2 to T7 as funds become available, but doesn't establish a clear process for resolving compensable claims before the end of construction.[85] The future of MC is unclear because of the issue of compensable claims, Roma Metropolitane's legal liabilities[86] and Rome's precarious financial condition.

[83] The extra costs claimed by the contractor through the "*riserve*" system (see chapter 3.7) were awarded.

[84] (ANAC, 2015; CdC, 2011)

[85] According to the law, however, as spelled out by the ANAC and the Court of Auditors, compensable claims should be settled only after construction has concluded. This poses severe cashflow problems for a DB contract with no clear timeline.

[86] Unlike Metropolitana Milanese, which is only the technical in-house consultant of the city of Milan, which remains the contracting authority for metro projects, Roma Metropolitane, and not the city of Rome, is legally the contracting authority of MC and thus RM is directly financially and legally exposed for compensable claims pursuits. This flaw in the juridical arrangement has put RM is a precarious situation with a clear solution to the risk of bankruptcy not yet reached.

7.7 Archeology, political squabbles, and a lacking project as the main drivers of cost increase

Rome's MC is an extremely informative case that shows how costs rise and fall based on a large number of inter-related variables that are affected by constraints and scope changes that appear to be minimal to observers but have a dramatic effect on costs. To summarize, it is important to highlight four key lessons that emerge from Rome's MC case.

First, there are a litany of constraints that arise from Rome's urban form and geology and requirements imposed upon construction to protect Rome's historic heritage. In every city we have looked at there are different "rules of combat" or "rules of engagement" that structure design decisions, construction techniques, and the projects' overall schedules. In Rome, poor ground conditions and the Heritage Superintendencies' strict 3 mm ground settlement limit meant that stations and tunnels were dug deeper than in previous generations and monitoring construction impacts was a greater concern.

Second, **changes made in the middle of construction, especially when those changes need to conform to the rules of combat outlined above, generate a snowball effect on costs**. The redesign of San Giovanni Station triggered the need for additional shafts for crossovers because of schedule delays on other sections, the relocation of the TBM launch boxes, the shifting of construction staging sites, etc. Large metro projects are massive coordination projects. Changes accumulate and ramify through the project rather than simply adding or subtracting easily. What looks like a minor change order can be the equivalent of pulling a string that ripples through the entire project.

Third, the choice to deliver the project through a Design-Build **"General Contractor" procurement played a role in inflating costs, or at least in weakening the supervising capacity of the public authority**. Soft costs linked to the General Contractor function of design and delivery management, which accounts for 10.6% of the overall cost of sections T7 to T3, are slightly higher than comparable projects when the contracting authority-side soft costs are also included (6%). **In return, the risk transfer from the public to private sector implied by the D-B formula didn't work**, even if this is one of the major arguments in favor of shifting project design and management to a private entity through alternative-project delivery schemes that tend have higher upfront costs. The cost increases and the still unsettled compensable claims documented in this chapter underscore how risks that were shifted onto the General Contractor, ended up being pushed back onto the public. As the Court of Auditor and ANAC repeatedly stated,[87] the General Contractor delivery formula failed to determine who was the real bearer of risk. They determined that it is impossible to account for archeological risk when the archeological issues are

[87] (ANAC, 2015); CdC (2011).

insufficiently studied and enumerated. Since the bidding process was expedited and based on preliminary project documents that lacked adequate detail to quantify risks. **At the same time, the transfer of the DL (work supervision) function to a firm directly hired by the GC hindered the capacity of the contracting authority to be an effective AS - *Alta Sorveglianza***. One official we spoke to who was involved in the project explained that in principle the General Contractor procurement strategy should align the contracted-out construction manager and Roma Metropolitane to manage the contractors effectively. In practice the contractors and construction management were organized against Roma Metropolitane (Personal Interview A 2021). With limited internal resources to manage the project effectively, similar to what we saw in our Green Line Extension case, and prolonged uncertainty about the viability of the project, public oversight capacity proved inadequate.

Finally, **political indecisiveness and conflicting directives** proved to be another cost driver of MC. T3's high tunneling costs and the slow pace of excavations stem from the municipal government's inability to decide whether or not to continue the project beyond Fori Imperiali station. Similar political fickleness over funding the whole T2 section may result in incredibly high costs for the Piazza Venezia station, whose construction in a separate contract from the T2 section is currently under discussion, even though it will lead to higher costs because of complex logistical issues and the need for a deep cavern for an additional crossover.

8 Naples: line 1

8.1 Introduction

The city of Naples is the center of the third largest urban area in the country (940,000 inhabitants in the city proper, 3.6 million in the metro area) and has a long tradition of building complex urban rail infrastructure. The city boasts Italy's first cross-city rail line for long distance and suburban service, which opened in 1927, and a well patronized network of legacy suburban lines radiating out from the city center terminals: the Cumana and Circumflegrea lines to the West, and the Circumvesuviana network to the East. Yet, Naples started to build its first proper metro line only during the 1970s and projects to expand and improve the existing rail transit network have been plagued by delays, cost overruns, weak political commitment and challenging geological conditions. Today, the metro network extends for 28.5 km carrying 150,000 daily passengers, mostly on the urban loop line (line 1) and in the linked interurban metro to Piscinola-Aversa (MCNE-line 11). Two more sections of the line 1 loop, accounting for 7 kms and 8 stations, are now under construction and are planned to open by the mid-2020s. Line 6, a 6.7 km, 8-station light metro, that originates from an abandoned 1980s LRT project, is currently under construction and will open in 2022-23.

The history of the development of Naples and Campania's urban rail system is a fascinating and instructive one, with many positive lessons such as the development of one of the earliest and more thoughtful experiments regarding fare integration in the late 1990s (UnicoNapoli and UnicoCampania) and a regional planning framework for transit. On the other hand, line 1's long-winding, more-than-four-decades-long saga and its relatively high capital costs are a lesson in the multiple drivers of construction costs. The central section of line 1, that we will analyze in greater detail here, is **by far the most expensive metro line built in Italy, at €406 million per kilometer with a real value of $635 million in actualized PPP terms**. Line 1's costs far outstrip other Italian projects, and, in a way, share similarities with challenges encountered in Rome: a very difficult urban and geological context, archeology, and funding uncertainty. In addition, Naples's line 1 had the added goal of providing additional public benefits, such as rebuilding the old city's public realm. This mixed mandate led to **oversized, expensive stations. Finally, the persistence of an opaque, non-competitive Design-Build delivery scheme further contributed to inflating construction cost**.

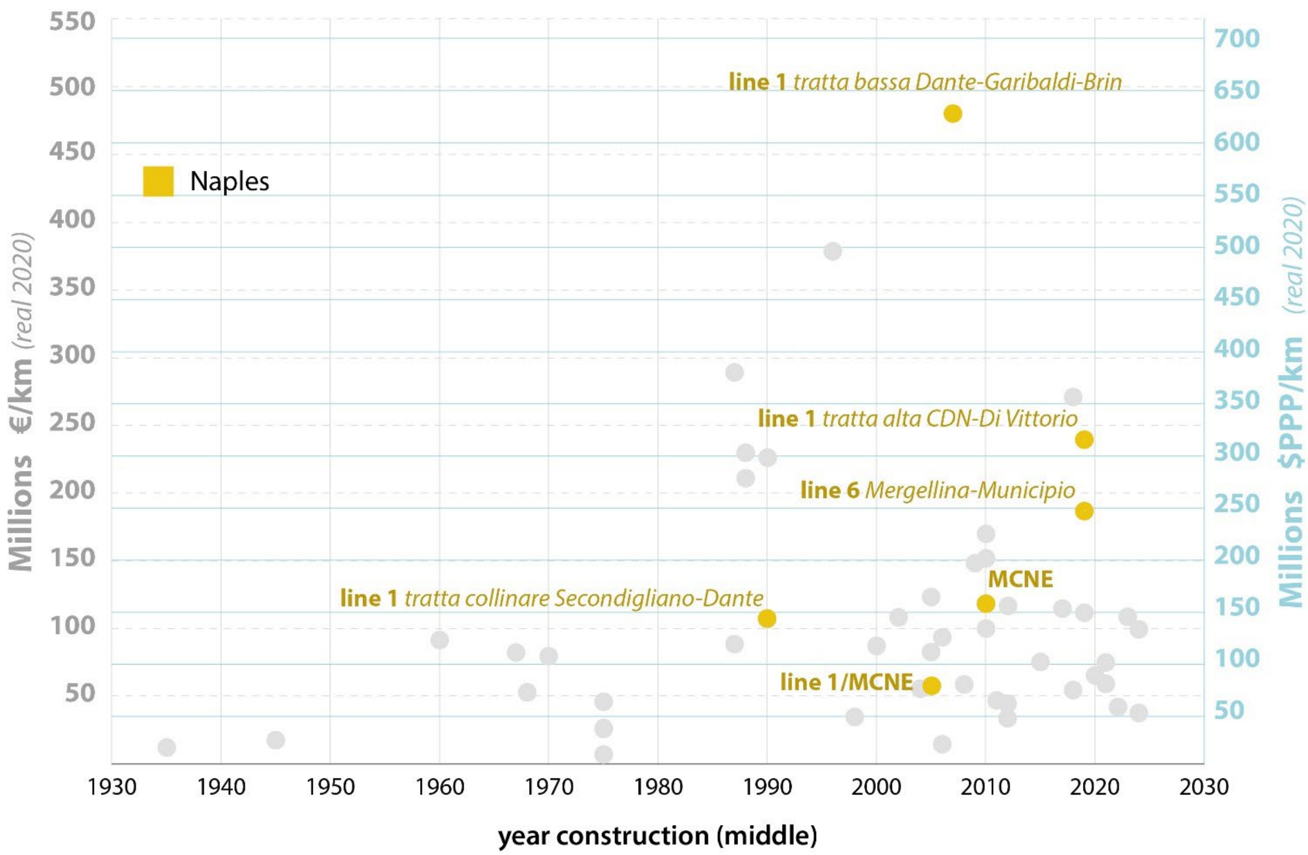


figure 38. Historic construction costs of Naples metro lines in real terms, Euros and Dollar PPP (2020).

8.2 Line 1: project overview

Naples's line 1 is a heavy-rail line serving the core of the city and its major transportation hubs. As of 2021, it extends for 18 km with 19 stations, stretching from the peripheral neighborhoods of Scampia through the hilly Vomero and then down to the city center up to Garibaldi main railway station. The particular shape of the line, it includes a loop and a very steep section (5.5% grade), responds to the city's topography. As most of the pre-1980s metros, Line 1 has the same technical characteristics of Milan's original three lines and Rome's MA, that is 110m platforms and 2.85-m wide trains, as this was the technical standard established in the postwar period for heavy metros.

Line 1 dates back to the 1970s, when the city of Naples began planning a rail-based connection between the rapidly growing hilltop neighborhood of Vomero and the city center. The line was initially dubbed the "metropolitana collinare" (hilly metro, TC in the map pictured in figure 39) and a rack railway technology to secure the rolling stock as it climbed and descended the changes in elevation. In 1976, the city awarded a "concession of sole construction" (a form of Design-Build) without a public tender process to a consortium of companies called Metropolitana di Napoli Spa (MN), initially led by Metropolitana Milanese, who eventually exited the venture a few years later (see section 6.2). This single decision locked in a long-term binding agreement without a clear timeframe, clearly defined scope of work, or alignment for Line 1. The first section of line 1 was a short two-station pilot funded by the city during the second half of the 1970s. After the Irpinia earthquake in 1980, construction stopped and designs were redrafted to comply with the tougher seismic regulations. Works resumed in the mid-1980s thanks to an injection of funds from the central government and the EU, while a mostly elevated extension to Piscinola (TV in the map) was also approved and funded by the national government. Thanks to law 211/92, L1 was extended down the hill from Vanvitelli to Dante (TB.1 in the map), while an additional extension through the core of the old city from Dante up to Garibaldi Station (TB.2, pictured in the map and the focus of our analysis) was also planned, but with an alignment different from the one eventually built. Finally, in 1993, after fifteen years, the first section of the line was opened for revenue service.

In the years following the first section's opening, **the alignment and the scope of the project** evolved multiple times within the very fluid political environment of the early 1990s and amid the corruption scandals of *Tangentopoli*, that also affected line 1 construction. In particular, during the second half of the 1990s, a new progressive municipal government, devised a comprehensive plan for the expansion of the urban rail network in the metro area, while starting to implement a fully fare-integrated system (UnicoNapoli). Following the 1997 Municipal Transportation Plan (*Piano Comunale dei Trasporti*), also known as the "hundred stations plan," line 1 took its current form: a loop line connecting the city's core–where Municipio station is a major node that serves line 6 and the ferries to the Islands–central Station, airport, and the modern CBD. **The project's scope broadened from a simple transportation project to a far-reaching tool to reconfigure the city center.** "*Stazioni dell'Arte*" (Art Stations), to take one example, gained momentum and became a consistent design approach making the new metro stations into unique showpieces designed by renowned architects. These changes in scope and the project's orientation are one of the key drivers behind the central section's dramatic cost increases, which saw its final cost triple between the early 1990s estimates and the completion of the project in the 2010s.

Preliminary works on the city center section of the "tratta bassa" (TB.2) eventually started in 1998. Yet, construction was dramatically delayed by **extensive archeological findings during the major stations' excavations**, in particular at Municipio and Duomo stations. The extent and relevance of the archeological findings almost brought construction to a halt in 2008, when a joint "Czar" (*Commissario Straordinario*) for both Naples and Rome's MC was nominated to solve both cities' archeological challenges. Like in Rome, unanticipated archeological discoveries have been a major factor in increased costs and delays. As a result, the opening of the city center section was delayed several times and was eventually completed in phases between 2011 and 2015, with the Duomo station only partially opened for revenue service in 2021, some twenty years after works had begun.

Cobbling together the funding for line 1 has been a persistent problem. Line 1 was initially funded by the city via municipal debt or from the public lending authority, CDP. In the aftermath of the Irpinia earthquake, the EU played a key role in securing funds for Line 1. **European funds funneled through the Regional Development Fund (ERDF)** covered up to half of the €1.75 billion for the "tratta bassa" city center section, with the remainder coming from the city and national government.[88] Even with this assistance from the EU, the stop and go nature of funding and construction has contributed to cost increases.

Two more sections of line 1 are currently under construction: the 3.5 km, 4-station extension from Centro Direzionale to Capodichino airport (€652 million or $242 million per km) and the 3.3 km, 4-station extension from Secondigliano to di Vittorio (€356 million or $154 million per km). Both sections have encountered funding and schedule delays, just like the rest of the line. The extension to the airport was descoped in 2012 by cutting one station and scaling back the architectural grandness of the remaining 4 stations to reduce the overall costs by around €300 million. The second section that is managed directly by the Campania regional government, in part, because it will serve line 1 and suburban metro MCNE once completed, was started and halted several times because of political squabbles between the city and the region following a shift of the regional government from

[88] For an exhaustive reconstruction of the complex history of line 1's funding, see Roberto Calise's "la metropolitana Europea" (Calise, 2021).

the center-left to the center-right between 2010-15. The remaining gap in the loop (a short tunnel section and di Vittorio station) has been funded recently and will possibly be completed by the mid-2020s. Even though we will not cover these more recent project iterations in detail, these recurrent problems of discontinuous political commitment and inter-governmental fights were highlighted in an extensive Court of Auditors report (CdC, 2017a) detailing the general governance problem that has plagued the project throughout its history.

linea 1 - Key

Sections	lenght (km)	stations	year opening
TC **TC -Tratta Collinare** (Hilly section) *Vanvitelli - Colli Aminei*	3.8	6	1993
TV **TC -Tratta Collinare** (Elevated section) *Colli Aminei - Piscinola*	5.0	3	1995
TB.1 **TB.1 -Tratta Bassa 1** (Lower section n. 1) *Vanvitelli - Dante*	4.9	5	2001 - 2003
TB.2 **TB.2 -Tratta Bassa 2** (Lower section n. 2) *Dante - Garibaldi - (Brin shaft)*	4.3	6*	2011 - 2015
TA **TC -Tratta Aeroporto** (Airport section) *Centro Direzionale - Capodichino Aeroporto*	4.0	4	2025
TR **TC -Tratta Regionale** (Regional section) *di Vittorio - Piscinola*	3.0	4	2025

** Duomo station will open in fall 2021*

figure 39. Line 1's different phases with opening years.

Table 6.	MC - Project's Timeline summary
1976	**A Design-Build concession contract called "concession of sole construction"** is awarded to the joint venture **Metropolitana di Napoli S.p.a (MN)** composed of local construction firms and supported by Metropolitana Milanese.
1978	**Design is finalized** for a 11km line connecting the hilly area of Vomero to the city center and the central station.
1980	**The Iprinia earthquake** hits Naples. Construction is halted to update design to seismic regulations and address the city's financial troubles.
1984 -1985	**Work resumes** thanks to EU funds and a special law granting Naples the right to borrow more money with the central government guarantee as matching funds.
1985	**A 5 km mostly elevated extension** to the outlying social housing neighborhoods of Scampia and Frullone is approved.
1986	**The first consistent grant** from the central government (500 billion liras) boosts the construction pace, previously limited by the scarcity of local financial capacity. **Construction starts on the sections between Vanvitelli-Dante and Colli Aminei-Piscinola**
1992	Further funding is secured to complete the section reaching the city center at Dante
1993	**The first "hilly" section** (*tratta colllinare*) of line 1 **is inaugurated** between Vanvitelli and Colli Aminei
1992 - 1996	After MN is implicated in Tangentopoli-era scandals, its contract with the city is revised and unit costs are reduced by 30%.
1995	The elevated section between Colli Aminei and Piscinola enters revenue service.
1997	**Major redesign of line 1**: the city center (*tratta bassa*) section is extended to reach a new exchange node with line 6 and ferries at Municipio, A new ring section is devised to connect Capodichino airport and Piscinola. The **"Stazioni dell'Arte" (Art stations)** concept is adopted.
1998	Grants from the central government are secured together with matching EU funds. **Preliminary works start in the Dante-Garibaldi section of line 1** (the so called *tratta bassa*) across the city center
2001 - 2003	**The Vanvitelli-Dante section of line 1 is opened.**
2011 -2012	**The Dante-Università section of line 1 is opened**
2012	Major project revision for the section between Centro Direzionale and Capodichino airport: the line is shortened, urban realm improvements are descoped, and one station is removed to save some 300 million euros.
2013 - 2014	Funding is secured for the Centro Direzionale-Aeroporto section and preliminary works start
2013 - 2015	**The Università-Garibaldi section of the TB.2 is opened**
2021	Duomo station is partially opened

8.3 Cost Detail: grand and deep stations, bad geology, and an archeological Eldorado.

The central section of Naples's line 1 is by far the most expensive metro section ever built in Italy, with a total capital cost of **€ 1.748 billion in nominal value, that is almost $635 million per km in PPP real terms**. The detailed breakdown of the capital costs of the "tratta bassa" (see figure 40) provides a good insight into the main drivers that makes this project an outlier in the Italian context in terms of construction cost.

Line 1's design was overhauled during the 1990s. The new design called for a deeper, hook-shaped route instead of the originally planned cut-and-cover tunnel following 19th and early 20th century large Haussmann-style thoroughfares, such as the *Rettifilo* Vittorio Emanuele. This change in construction technique and alignment had a major impact on costs (see section 8.4 for more details): The five deep and **partially mined stations** that replaced the shallower cut-and-cover stations cost **€667 million or 38.1% of the project total and represent that largest project expense**. As we will see in greater detail in the following section, this high cost is the result of six factors: First, the construction technique; second, the depth; third the additional access shafts; fourth, new designs that called for vast mezzanines and "hypogeum plaza;" fifth, the extensive public realm improvements and, sixth, an overall "grandeur" characterized by ample volumes and high quality architectural finishings.

Tunnelling accounts for €286 million (including shafts) for 3.9 km of twin bored tunnels and about 400 meters of cut and cover and open trenches at the Eastern end, mostly built under the wide throat of Garibaldi station and along the Circumvesuviana suburban rail alignment. At **€65 million per km in nominal terms or $103 million in real terms**, the central section of Line 1's tunneling costs are by far the highest per kilometer cost of tunneling among the cases studied in this report. **Naples' difficult geology** and high-density urban area is another important driver of costs: soil consolidation and freezing techniques, using liquid nitrogen to consolidate the excavation front of incoherent soil and prevent dangerous soil settlement, in a context characterized by underground brackish water, accounted for **€74 million**. Finally, **archeology** has been another major driver of costs. In one sense, the decision to incorporate some of the findings into the stations was a clever embrace of inevitable preservation concerns. No matter what, however, **the excavation, removal, restoration, and transport of these items added an additional €266 million** to the project and ensured each station would be unique.

Finally, even though the V.A.T. is more than 75% of the soft costs, the overall accounting structure of the Design-Build concession scheme makes it difficult to identify accurately the soft costs, as MN applies a fixed 3.5 % fee for design and management on top of the itemized costs negotiated in the contract (see section 8.5). This structure makes it difficult to quantify what counts as design and management as compared to the other cases that explicitly break out those costs in their financial documents.

Cost breakdown • *line 1 "tratta bassa" Dante - Garibaldi - Brin*

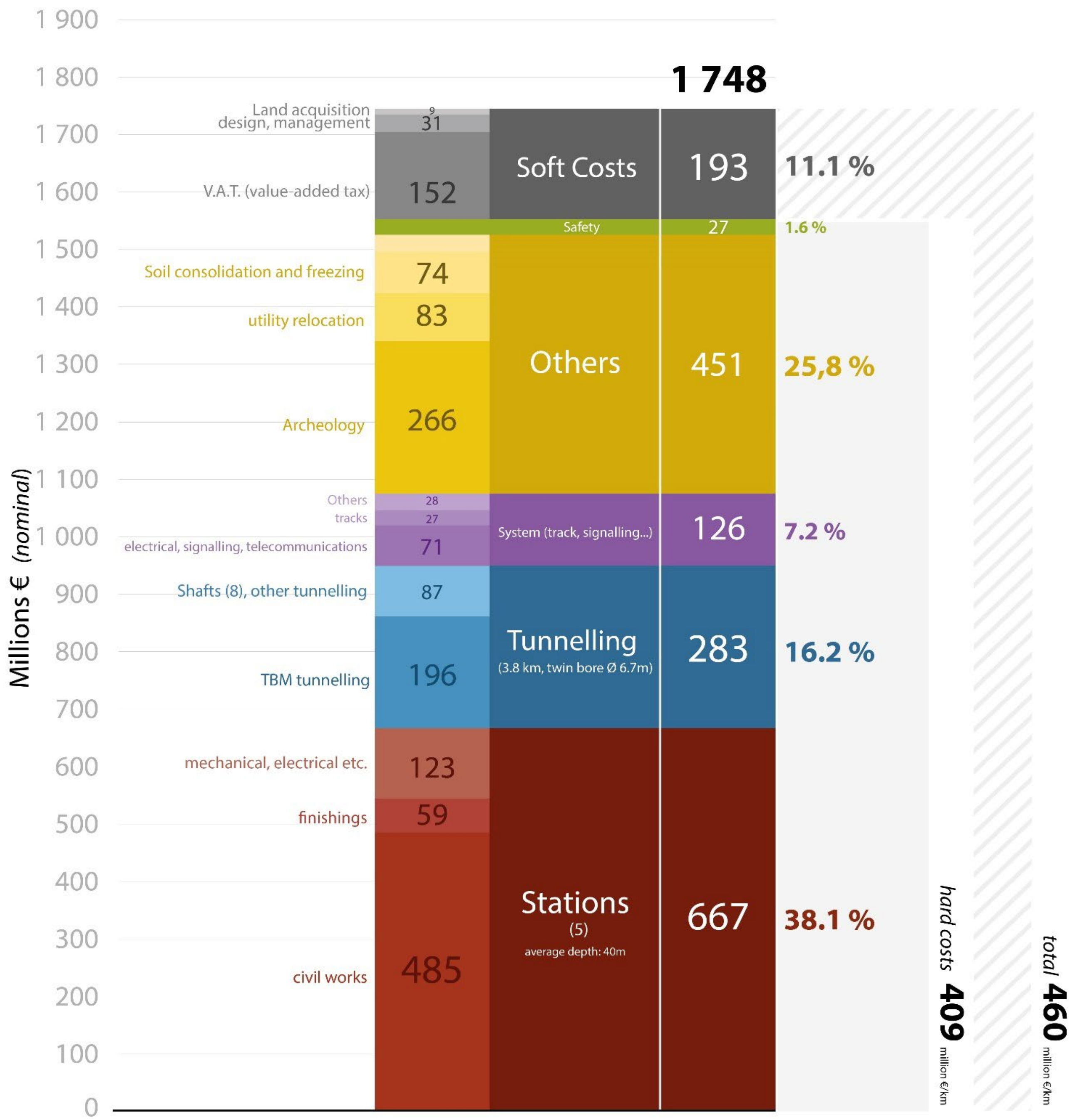


figure 40. Costs breakdown of the city center part of the "tratta bassa" section of line 1 in Naples

8.4 Stations as main drivers of costs: construction technique, depth and 'over-scoping'

The 1997 project revision called for the complete overhaul of the station engineering completed in the preliminary project in the early 1990s. The decision to build the city-center section of the line with a deeper alignment using TBM bored twin tunnels instead of shallow cut and cover[89] necessarily forced **station construction deeper**, requiring a mix of cut-and-cover and mined techniques. Each station has a centrally located main shaft—approximately 16-20 m long, 45 m wide and up to 46 m deep that was built mostly using cut and cover. The shaft contains all vertical circulation elements (escalators, elevators, stairs) from the sub-surface mezzanine to the level situated just above the track level. Platforms were then built by enlarging the 6.7-m wide TBM tunnels to approximately 10.7 m, using various excavation techniques that involve complex operations of soil consolidation and artificial freezing of the excavation front for approximately 50 m on each side of the shaft, while the smaller connecting tunnels from the main shaft to the platforms were built using NATM-ADECO excavation methods[90] (see figure 41).

The choice to build deeper stations was accompanied by **the broadening of the project's scope, associated with the so-called *Stazioni dell'Arte* program**. Famous architects were invited to design not only the stations' layout and interiors, but, in most cases, station construction was accompanied by the complete redesign of the public realm above the stations. Station complexes now included secondary entrances to improve accessibility, while showcasing archeological findings and artwork, based on the concept of the metro as a 'compulsory museum' for travellers.[91] Even though the name of the program (*Stazioni dell'Arte* – Art Stations) might suggest that the art installations themselves had a primary impact on costs, they in fact represent only a tiny fraction of the overall capital budget. It is the associated works for expansive mezzanines, public realm redesign and secondary entrances that drove costs, as we will see in the following three examples: Garibaldi, Municipio and Toledo stations.

[89] The reasons for that choice are multiple and not all linked to NYMBYs opposition to a cut & cover shallow alignment: the 'hook' necessary to reach the future Municipio transit hub (lines 1,6, ferries) envisioned in the 1997, the political will to give direct access to the metro to the disadvantaged communities living in the extremely dense Spanish Quarters, and the hard-to-estimate archeological risk connected with extensive shallow excavation in a multi-layered historical city are all reasons behind that costlier design choice.
[90] For a complete description of the station engineering and excavation techniques see Lunardi, Cassani, and De Giudici (2008, Italian) and Mandolini and Viggiani (2017, English).
[91] The idea of the metro as a *Museo Obbligatorio* (i.e., compulsory museum) has been associated to the *Stazioni dell'Arte* Program by its creator, the art critic Achille Bonito Oliva.

Garibaldi station (€ 166.8 million)

Garibaldi stations is a major transit node where Line 1 connects with the mainline rail terminal (Napoli Centrale), the *passante* cross-city tunnel for regional rail (Napoli Piazza Garibaldi) and the Circumvesuviana suburban rail network (Napoli Garibaldi). The station layout itself follows the design of all city-center stations, with a main access shaft and platforms built within enlarged tunnels. Following the 1997 project revision, the scope was broadened to include a complete overhaul of Piazza Garibaldi, the large 58,000-sqm square facing the main rail terminal, and the construction of a 200m-long "Hypogeum" mall, covered with a pergola designed by the architect Dominique Perrault, that doubles as station access and an "open-air" mezzanine connecting Line 1 to the rest of the transit hub. The hypogeum mall and the complete overhaul of Piazza Garibaldi cost €53.1 million, or approximately a third of the €166.8 million station costs.

Toledo Station (€ 143.6 million)

Toledo station is situated in the core of the densest part of the historic center of Naples. It provides access to Via Toledo, one of the city's main shopping thoroughfares, the Spanish Quarter and connection to the Central funicular. Because of the lack of aboveground space for the construction of a sufficiently large shaft, the station construction involved an even larger proportion of mining: a smaller lateral shaft was built instead, and platform access is provided by a deep mined cross-cavern. This alone resulted in greater mining costs (€46.2 million) compared to other comparable stations in the central section. Moreover, the decision to build a second access point from Montecalvario square in the heart of the dense Spanish Quarter involved the construction of a second deep 50-m shaft and an 80-m long inclined deep bored tunnel connecting to the station's mined cross-cavern. This complex civil engineering feature alone added €37.8 million, increasing the overall station costs by a fourth.

Municipio station (€ 185.3 million)

The 1990s redesign of the central section of Line 1 identified Municipio as another main node in the city's transit network, connecting Lines 1 and 6 to the ferry and cruise terminal (*Stazione Marittima*). The redesign expanded the station's footprint and called for a full reconstruction of Piazza Municipio and the creation of a vast, fully underground mezzanine spanning more than 300 m from the station shaft to the ferry terminal. Together, these two elements added €91.3 million, almost half of the entire construction cost of the station. Copious archeological findings, such as Greek and Roman harbor structures and three boats and the foundations of the Aragonese walls of the Castel Sant'Angelo, delayed construction and forced additional redesigns of the mezzanine structure several times during construction.

Cost by station, line 1 *"tratta bassa"* - Naples

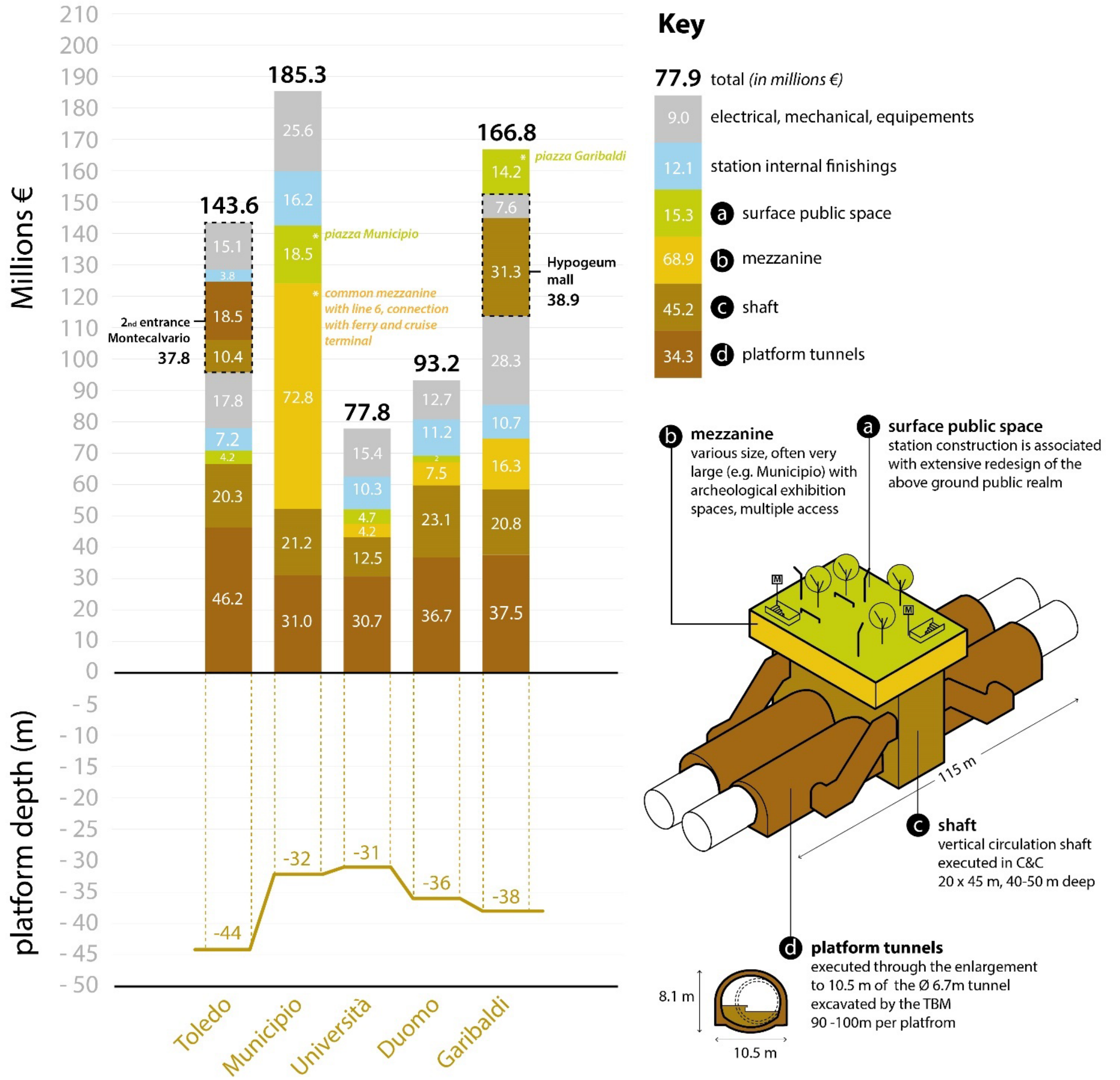
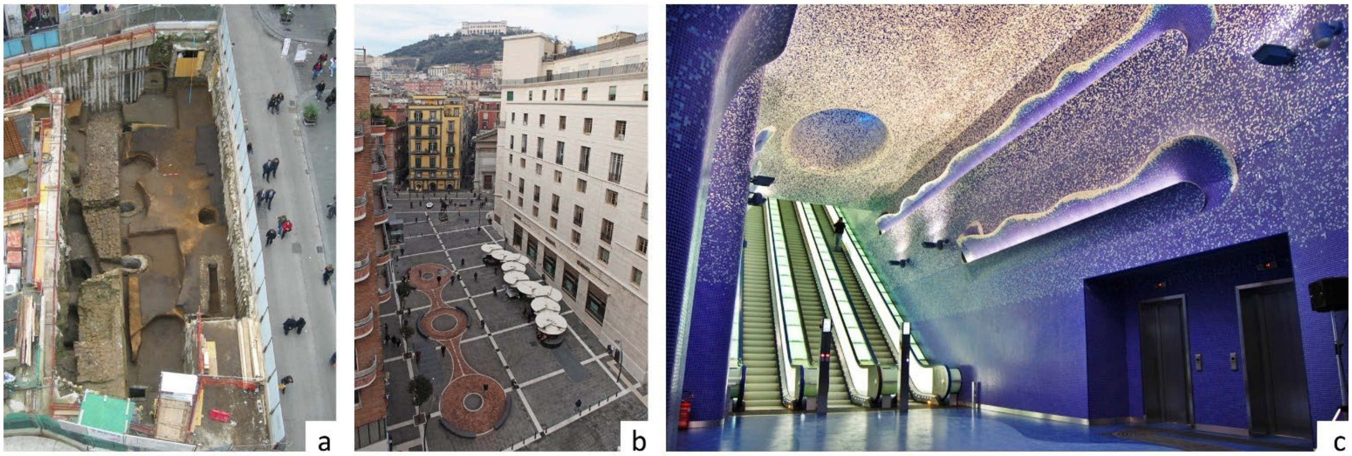


figure 41. Breakdown of station's cost for the "tratta bassa" of Naples's metro line 1.

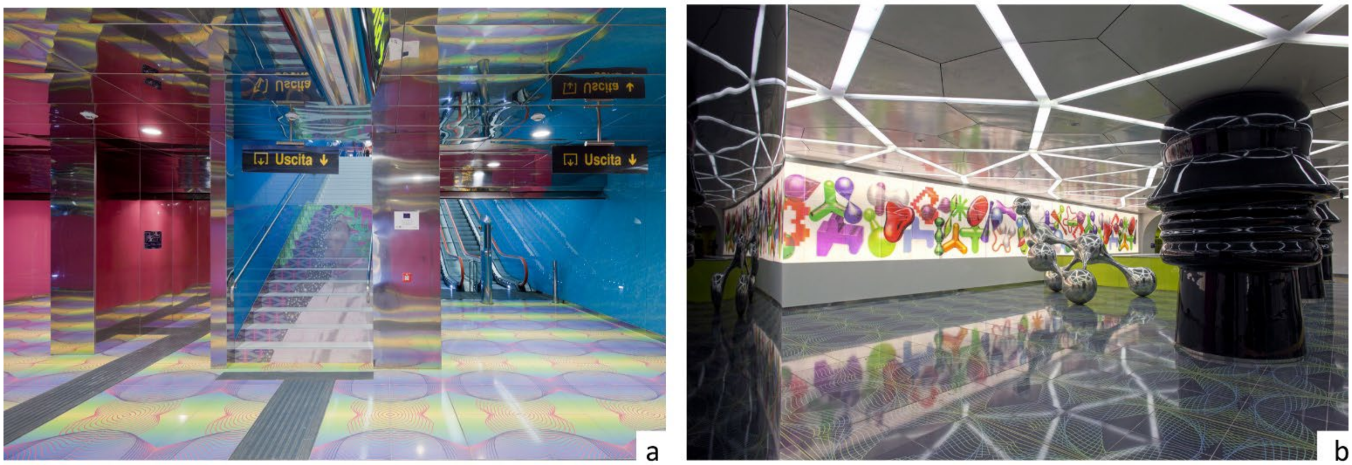
Toledo



Municipio

figure 42. *Pictures of Toledo and Municipio stations. TOLEDO. (a) archeological excavations. (b) Public realm above the main access shaft. (c) Station's internal design by architect Oscar Tusquets Blanca. MUNICIPIO. (d) Station's internal design by architects Álvaro Siza and Eduardo Souto de Moura. (e) Rendering of the long corridor connecting L1 and L6 station complex to the ferry terminal. (f-g) Archaeological excavations. (h) The construction site at Piazza Municipio in 2016.*
Courtesy of Metropolitana di Napoli spa.

Università



Garibaldi

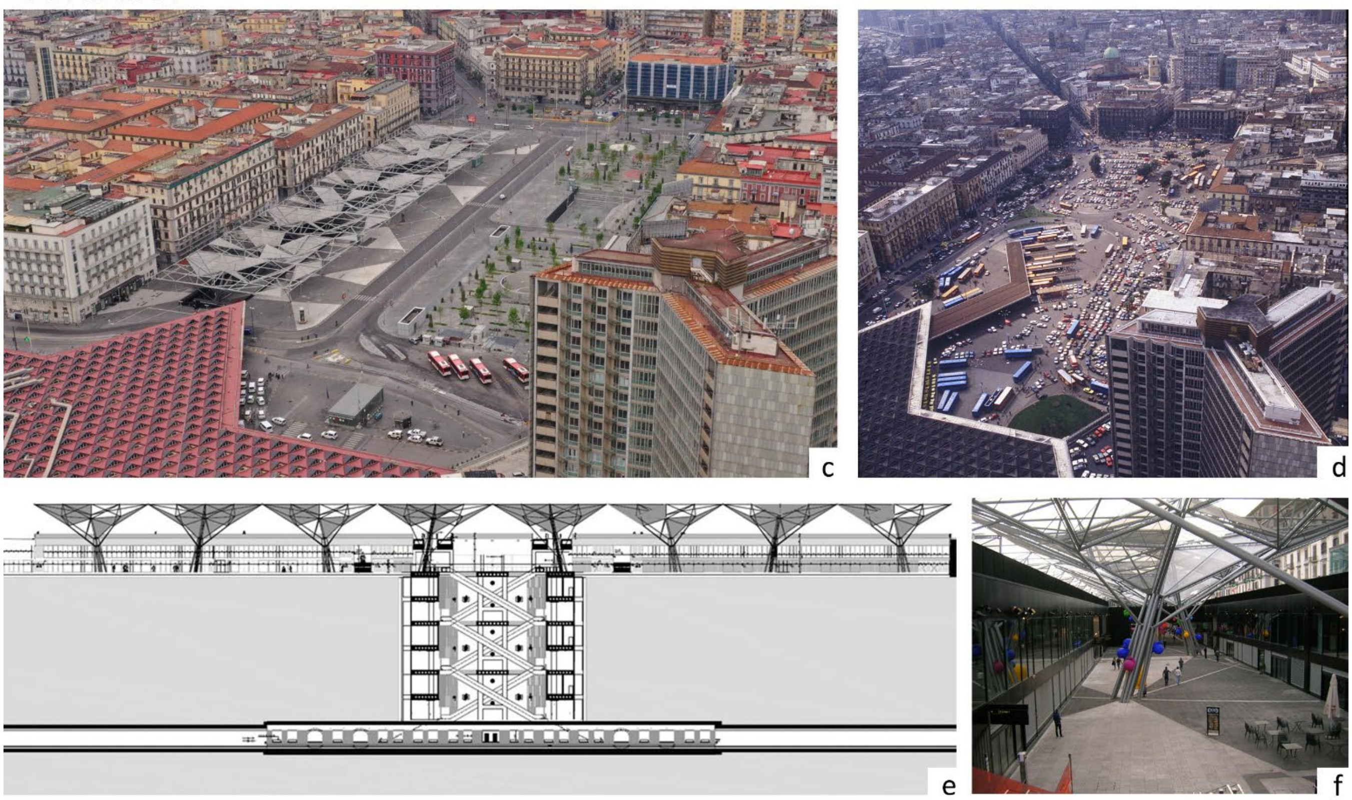


figure 43. *Pictures of Università and Garibaldi stations. UNIVERSITÀ. (a-b) The station's playful interior design by designer Karim Rashid. GARIBALDI. (c-d) Piazza Garibaldi after (c) and before (d) the extensive overhaul linked to the construction of line 1's metro station. (e) Station's longitudinal section across the vertical access shaft and the Hypogeum Mall, both designed by architect Dominique Perrault. (f) The Hypogeum Mall with the triangle shaped pergola.*
Courtesy of Metropolitana di Napoli spa.

8.5 Consistent cost escalation over the years

The initial cost estimate for Line 1's 2.7-km five-station extension through the center city beyond Dante station was approximately €570 million in 1990 (see figure 44). From here, the project twisted and turned as corruption trials led to the election of a new center-left majority in 1993, which renegotiated the project costs down to €500 million.[92] By the close of millennium, however, the costs and scope had changed considerably.

The Municipal Transport Plan of 1997 sketched out a new alignment with deeper stations and a major node at Municipio. It also called for continuing the tunnels beyond Garibaldi to Centro Direzionale to allow a future extension to the airport and, ultimately, the completion of the loop. These changes in scope **added €189 million or 38%** to the D-B contract.

By 2007, the project's cost had nearly doubled from €689 to €1.375 billion because of delays caused by unanticipated archeological discoveries and geological challenges. The €686 million increase broke down along two factors: first, changes in the itemized costs and quantity of inputs between 1995 and 2007 accounted for €335 of the increase, while the remaining €351 million were the result of design and construction-technique changes to adapt to the archeological findings (notably, by changing the excavation methods to the same costly two-step approach described in the Rome case), and, to a larger extent, from changes in the project scope. The decision to build bespoke showpiece stations increased costs by €143 million, and the additional utility-relocation and public realm improvement added another €52 million.

In 2014, there was a €382 million cost increase that brought the final project cost to €1.757 billion. Again, unanticipated archeological findings were partially to blame for these costs, but the other issue was that since the 1990s, technological advances had rendered obsolete design decisions regarding the signaling system.

Overall, the history of cost increases for Line 1 is illustrative of the effects of continuous changes to a project's scope and the challenges of combining broader goals of urban renewal with a transportation project. It was unrealistic to accept the original €500 million estimate as a reasonable guide because it was based on an impossible to implement cut-and-cover approach in one of the most historically significant Italian cities. While this first order problem is clear, the project also suffered from additional scope creep, which is a well established worst practice. Part of the problem here is the exceptionally long timeline, which allowed the goals of the project to shift multiple times. On top of these two significant flaws, the structure of the Design-Build scheme was too opaque

[92] See the acts of the parliamentary commission (CD, 2009), and Calise (2021, pp. 72-73). In 1992, a new electoral law for municipalities, that give more leverage to the mayor vis-à-vis the municipal council, empowered a new generation of politically active and progressive mayors in large cities, a political season that came to be known as "the mayors' spring."

and uncompetitive to keep costs in line and the project on schedule, much like we saw in our Green Line Extension case.

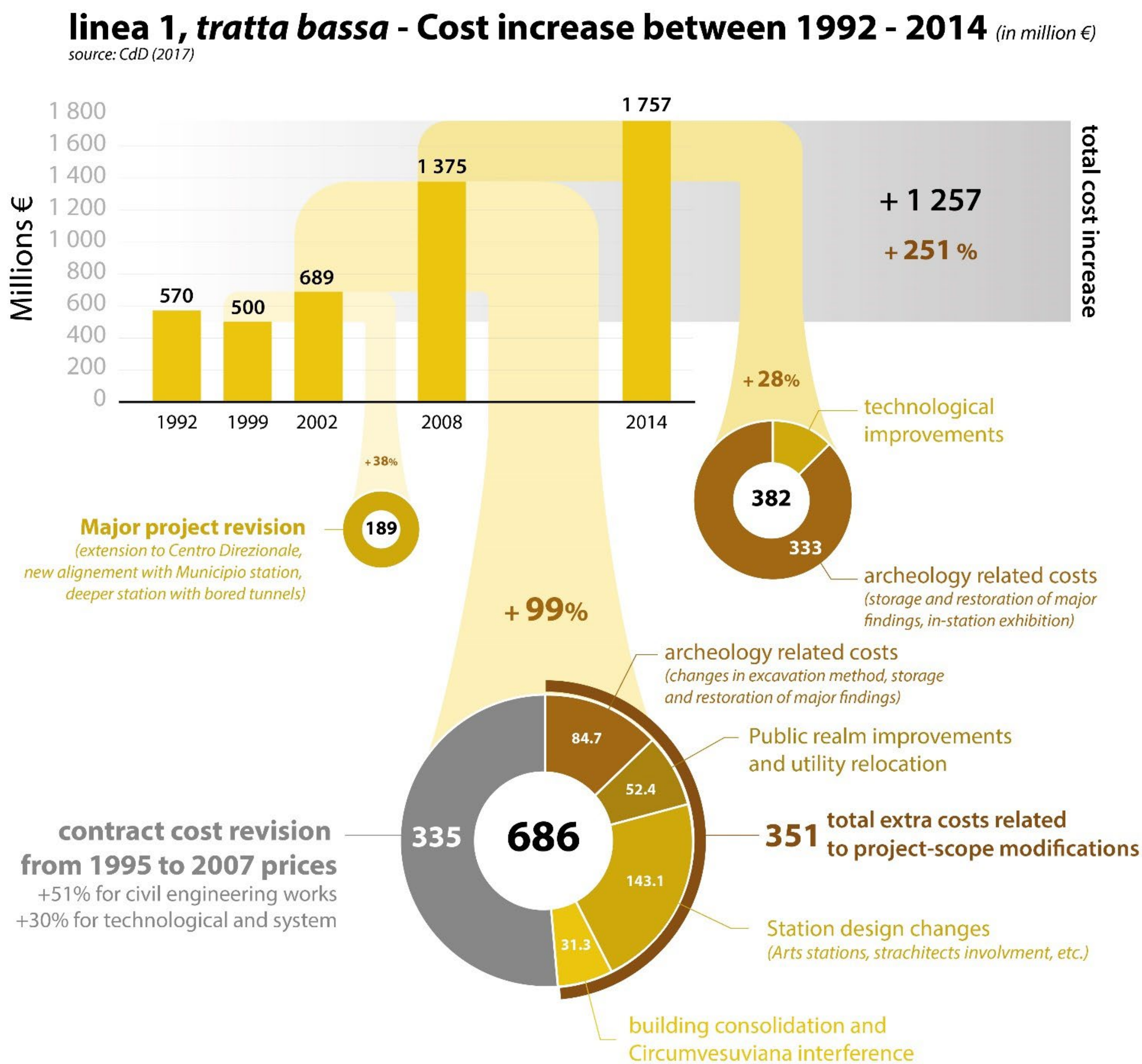


figure 44. Cost increase of the city center section between 1992 and 2014. Based on data from the Court of Auditors (CdC, 2017a).

8.6 The "original sin": a flawed Design-Build scheme

Naples's Line 1 was **delivered under a Design-Built (D-B) scheme called 'Concession of Sole Construction'** (in Italian*: concessione di sola costruzione* or *concessione di committenza*). The general protocol of a D-B delivery is that the grantor, normally a public agency, retains a design-builder to design and build an infrastructure project based on a preliminary feasibility study. The design-builder designs the project to the specifications laid out in the feasibility documents, secures approvals, and then builds it. The Concession of Sole Construction used in Naples and in other Italian projects initiated in the 1970-80s did not specify a project schedule or define a scope in advance of the agreement. The current agreement includes all future extensions of line 1 (and later line 6) for an indefinite term.

The original 1976 contract between the Municipality and the joint venture **Metropolitana di Napoli S.p.a. (MN)** was awarded without a public bidding. Metropolitana Milanese (MM), the public company responsible for Milan's metro, was MN's majority shareholder. At the time, MM was deemed the only national firm with sufficient expertise in metro construction. However, MM sold its stake two years later, in 1978. Moreover, the contract's term and scope have been modified repeatedly since the short initial section of the *Metropolitana Collinare*. As a result, the procurement of new sections, including the city center and airport sections planned after the 1997 municipal transit plan have been awarded to MN through private negotiations of unit costs between the Municipality and the company rather than being bid out to all qualified bidders.

Under this framework, unit prices are set through negotiations between the granting authority and the concessionaire following periodic renegotiations and contract amendments[93] rather than competitive bidding based on the official reference unit prices that have governed other public works since the 1990s. The Court of Auditors ruled that this **opaque and non-competitive D-B concession scheme** had a material role in inflating the overall costs of the project. In addition, Metropolitana di Napoli is compensated for the various project-delivery tasks included in the Design-Build scheme, such as management, design, work supervision, etc., with a fixed percentage of the construction costs, that varies between 22.7% for the civil engineering structure to 8.5% for the rolling stock.[94] An even higher percentage, 30%, has been granted as compensation for dealing with the "high quality" internal finishes of the *Stazioni dell'Arte.*[95] This compensation structure incentivizes cost increases. Furthermore, since the term of the contract is indefinite, there are inevitable conflicts over pricing unit costs, but

[93] The contract has been amended 8 times since 1976, but the general structure of the concession scheme remains unchanged, while the unit cost have been reviewed times and again.
[94] CdC (2017a), page 70, table 8.
[95] CdC (2017a), page 64.

rather than opening up bidding to other contractors and allowing reference unit prices to discipline bids, these changes are negotiated privately. The Court of Auditors estimates that the €335 million increase in unit costs negotiated through this method following the 1995 amendment of the contract represent an excessive increase, outperforming the average sectorial inflation in the 1995-2007 period by at least six to eight percentage points.

Disentangling costs scrupulously in Naples is a challenge because the opaque delivery mechanism and the lack of competition and public oversight makes it difficult to estimate the magnitude of these "original sins" on the final costs. Without question, it has been one of several factors that makes Naples's Line 1 the most expensive metro segment ever built in Italy.

8.7 Gigantism, archeology, uncompetitive bidding, lack of public oversight: the "perfect storm"

The case of Naples Line 1[96] highlights several factors that can drive construction costs upward dramatically, even in the context of a country that has otherwise put in place effective mechanisms to moderate construction costs. The **challenging environmental conditions of the city's old core**, with its high densities, layered history, poor geology, and brackish subterranean waters represent a difficult environment that contributes significantly to increase the technical complexity of excavation and drives costs. Yet, the choice to link the construction of the metro line with an **extensive redesign of the public domain and the construction of the glamorous *Art Stations* designed by renowned *starchitects*** was entirely the choice of political leaders. The city-center section's high station costs are the result of the excavation technique (freezing, consolidation, etc.) prompted by geological considerations and the desire to minimize disruption of the archeological layers. But also, to a large extent, to **the broad scope of using the construction of Line 1 as a catalyst for urban redevelopment** by the city's political leaders, as Municipio's large mezzanine, Garibaldi's hypogeum mall and Toledo's second entrance and public realm improvements highlights.

As in Rome's case, **the rich archeological strata that lies under the city's streets have been a major driver of costs**. Indirectly, because the rigid regulatory framework for heritage protection and the unchallenged veto power held by archeological authorities resulted in conservative design decisions, notably about the tunnel alignment and depth, and about the station's construction techniques that contributed to record-breaking costs. Directly, by adding €266 million to the budget for excavation, removal, storage, restoration and the display of

[96] Similar problems have plagued the construction of line 6, that we do not cover in detail in this report for a matter of space and simplicity.

findings, notably the Isolympic temple unearthed at Duomo station and the Aragonese walls and Roman boats discovered at Municipio.

In addition to the environmental conditions and deliberate political choices, **the D-B delivery mechanism of the Concession of Sole Construction** weakened the contracting authority's oversight capacity and incentivized the concessionaire to add scope and increase costs to reap larger fees.

The case of Naples' Line 1 city-center section shows that its high costs were the product of difficult conditions, poor geology for metro construction and a dense urban environment, and self-inflicted wounds, poor project delivery and management and attaching too many goals to a single infrastructure project. In short, no matter what, Line 1 would have been relatively expensive because of unavoidable challenges, but those challenges were exacerbated by poor decision making.

9 Nine Takeaways

What do the Italian cases teach us about the drivers of construction costs? It is a common refrain in the mega-project domain to say: “once you have done one project, you have done…one project,” meaning that the complexity and specificity of each context doesn’t offer lessons that can be easily generalized. It is true that every project has its own characteristics, and it can be risky to generalize findings and lessons into an easy-to-apply list of Dos and Don’ts of transit-infrastructure projects. Nevertheless, we believe that by reconstructing the historic development of construction costs and detailing the institutional framework in Italy over several decades, together with the four cases of Turin, Milan, Rome and Naples, there are several valuable lessons for achieving a more cost-effective delivery of rail transit infrastructure.

The nine takeaways derived from the cases in this report are meant to help planners, policymakers, and the public better understand and tackle the drivers of construction costs.

1 *Delivery method matters, but the devil is in the details rather than ideology*

The cases feature delivery schemes ranging from General Contractor, PPP concession, traditional Design-Bid-Build, and DBFOM concession. Despite the different labels, Italian legislators who studied project delivery in both the 1994 and 2016 reform found that what really matters is the level of oversight public agencies have over fundamental tasks such as early planning, design, as well as project and construction management. Contracting authorities with sufficient in-house capacity, like Milan’s Metropolitana Milanese and Turin’s InfraTO, are able to implement the more traditional Design-Bid-Build (preferred in Turin and normally used in Milan too) but also to effectively guide projects procured under various PPP structures (like the ones used for M4 and M5), which were set up to limit the public’s ability to exercise effective technical oversight. To ensure that the public can manage projects effectively, key techno-managerial roles need to be enshrined in law such as the RUP project manager position, the DL (work supervision) and the AS (high supervision) detailed in section 3.2. The fact that the most successful contracting agencies are essentially staffed by technical professionals, mostly civil engineers, geologists and architects and almost never managers, suggests that empowering technical experts to manage and supervise are a key to building and nurturing reliable, competent and stable in-house expertise.

2 *Level of design for the RFP: the more detail, the better*

Regardless of the delivery method, it is critical that contracting authorities publish RFPs based on detailed designs to reduce risks and limit cost escalation. In order to evaluate cost estimates effectively, it is necessary to have a detailed final project, especially when considering geological and archeological risks, two key contributors to change orders during construction. As we saw in Rome's case, the different outcomes in terms of absolute costs and cost increases between section T4-T5 and T3 of MC, both contracted out within the same General Contractor's RFP, but based on different levels of design, are linked to the different level of design detail. The transfer of risk implied in PPP schemes, upon which a greater involvement of the private sector is often justified, seems to work more in theory than in reality, especially if the RFP lacks sufficient detail. In general, going into the bidding process with a design that addresses all the possible sources of uncertainty provides a better opportunity to assess risks and divide them between the agency and contractor equitably.

3 *A winning trio: Official unit-price lists, itemized unit-price contracts and best-value-for-money scoring of bids*

Functioning markets need symmetrical and transparent access to information, especially information about key inputs. Italian legislation on public procurements developed over the last three decades, in the aftermath of a national corruption scandal, shows that the "winning trio" of official unit-price lists, itemized unit-price contracts and best-value-for-money scoring of bids has proven to be a successful recipe for more transparent public-procurement markets. **Regional official unit-price lists** (*Prezziari Regionali delle Opere Pubbliche*) are both a tool that provides public authorities with a guide to anticipating how much goods and services cost and a way of disciplining contractors' behavior. **Itemized unit-price contracts**, unlike lump sum contracts, show exactly how costs change when scope or schedule is adjusted. **Best-Value-for-Money scoring of bids** (*regola dell'offerta economicamente più vantaggiosa*) improves the quality of bidders and proposals by de-emphasizing the need beat out the competition solely on cost (or even sanctioning it with exclusion, thanks to the so-called "rule of the anomalous offer"), while emphasizing the technical quality of offers. Naples's ill-conceived Design-Build concession scheme, based on privately negotiated itemized costs and insufficient pre-bid design, resulted in inflated prices and a general lack of transparency and competition. Finally, as some interviewed experts and officials have stated, the official unit-price lists are also an effective tool to counter the growing concentration of large conglomerates that play in the international infrastructure market.

4 *A balance between in-house technical capacity and outsourced design, and how to achieve it*

By examining cases in four cities, we saw different degrees of in-house capacity and varying ways this capacity was mobilized in the planning and delivery process. In Milan's case, the municipal engineering firm **Metropolitana Milanese** has been able to develop its world-class expertise in metro construction because of continuous support from the municipal government to maintain strong in-house capacity in the context of a shrinking public sector, privatization, and international competition. Given Milan's relatively low construction costs in spite of growing private involvement in more recent projects, MM is a blueprint for cities or states engaged in large infrastructure projects that seek to cultivate and maintain technical capacity within the public administration. **Turin's InfraTO** offers another approach to in-house design and technical capacity. InfraTO outsources large parts of the design work due to its much smaller staffing and a lower project output compared to MM, but it does so in a frame of strong in-house technical supervision and continuous non-adversarial collaboration with consultants, something that we also see in our Istanbul case. The InfraTo approach is effective and demonstrates that smaller cities and agencies can achieve similar outcomes to larger, better staffed organizations if properly staffed. In particular, these cases suggest that it's crucial to maintain a strong technical in-house capacity to steer the early planning, design and engineering choices setting the parameters of the project, while downstream detailed engineering and design, which is labor-intensive and more technical, requires fewer choices that explode costs, can be delegated to private firms. Finally, the case of **Roma Metropolitane**, which on paper is similar to MM and InfraTO, shows how political uncertainty to transit expansion and agency oversight powers, notably through the imposition of the GC delivery formula for political reasons, can reduce the effectiveness of in-house technical capacity.

5 *Technical requirements: how specific do they have to be?*

Tighter standards and regulations are a major driver of costs. The constant change in standards and regulations about excavated soil classification, fire proofing, seismic standards has triggered costly change orders on several projects. Standards intended to protect archeology and monuments represent one of the largest constraints in the Italian case. The cases of Naples and Rome illustrate plainly the consequences of strict heritage regulations on design choices and, ultimately, on costs. Moreover, even if Italy does not use NFPA 130 as its fire safety standard, but instead a set of local norms established through ministerial technical committees based on EU recommendations, the new standards approved in 2015 will have impacts that are yet to be visible in current projects. In general, technical requirements that on paper look like necessary and savvy improvements, are rarely evaluated by the legislator or the industry from a genuine benefit/cost perspective and are often taken for granted. At the same time the Italian case offers some insight into possible technical approaches to reduce the impact of tighter standards: for example, the complete separation of platforms and tunnels in the new automated metros reduces the need for costly ventilation infrastructure that is common in other cities, such as in New York. Furthermore, new archeological protocols established after 2008-10 in Rome and Naples, shifting from a reactive to a proactive approach to archeological screening, will possibly reduce, if not the upfront costs, at least the delays and cost overruns due to archeological surprises in future city-center projects.

6 *Political hesitancy, difficult funding, cumbersome bureaucracy*

Political intervention, micro-management, and uncertainty all have a negative impact on costs. Large infrastructure projects require enormous upfront preparation and coordination among multiple actors. Well intended political meddling, especially when it affects the project scope or schedule by adopting more restrictive work conditions, something we also saw clearly in our New York case, will inevitably impact costs. At the same time the inability to commit to a project or the avoidance of contentious decisions also increases costs by adding time to the design, redesign, and process of gaining approvals and support, all of which stymies the construction process and opens the contracting authority up to litigation from disgruntled contractors.

7 *Greater public awareness about costs and transparency matters*

The Italian case shows that an increased awareness among the general public and policymakers about the problem of rising costs, corruption, and waste-prone practices is the first step to build the consensus needed to address complex and entangled problems and enact reforms that establish public confidence and curb escalating costs. Based on our review of official reports and interviews with officials and public works experts, there is consensus that better procurement practices and effective oversight authorities, stemming from the public works reforms started in 1994, have contributed to reduce waste and weed out corruption and abusive practices relative to the 1980s and reduce construction costs.

8 *The longer, the better*

Cutting projects into shorter sections to make them more financially palatable in the short run ends up increasing the overall costs in at least four different ways: First, by making economies of scale more difficult to achieve; second, by reproducing expensive construction staging and operational requirements; third, by hindering the learning curve of both management and contractors that is typical of all large-scale complex projects like metro construction, and, fourth, by introducing potential delays that slow down approvals and trigger cost escalations.

9 *Industrial sector expertise*

As a final takeaway, the Italian case points more broadly to the importance of national policy nurturing the development of a construction sector with diverse and broad expertise that can be applied to metro construction. Expertise in tunnel building and design, in particular, stand out as being critical to building underground metros at a relatively low cost. Even though our study doesn't allow us to make any definitive conclusion on that claim, some hints, such as a greater use of prefabrication in construction, which is possibly one of the reasons for a lower incidence of labor costs on hard costs, might suggest that the construction sector in Italy is more "advanced" thanks to a greater capacity built over time. Similar observations can be extended to other countries with low construction costs, such as Spain, Switzerland, Turkey, and Austria. Countries that develop domestic expertise that can adapt solutions to specific constraints, such as geology, and catalyze cost-saving innovations through new techniques will achieve greater efficiency and build transit-infrastructure faster, cheaper, and better than nations that rely solely on importing expertise and consultants.

10 Bibliography

ANAC. (2015). *Deliberazione n. 51 del 24 giugno 2015*. Rome.

Beria, P. (2007). Transport megaprojects in Italy. A comparative analysis of economic feasibility studies into EIAs.

Calise, R. (2021). *La metropolitana europea. La Linea 1 di Napoli nell'ambito della politica comune dei trasporti.*

CD, C. d. D. (2009). *Relazione della giunta per le autorizzazioni. Richiesta di deliberazione in materia di insindacabilità, ai sensi dell'articolo 68, primo comma, della costituzione, nell'ambito di un procedimento contabile nei confronti di Francesco de Lorenzo, Giulio di Donato e Ugo Grippo*.

CdC. (2011). *Metropolitana di Roma (Linea C)*. (Deliberazione n. 21/2011/G). Rome.

CdC. (2017a). *La linea 1 della metropolitana di Napoli*. (Deliberazione 28 dicembre 2017, n. 20/2017/G). Rome.

CdC. (2017b). *Lo stato di realizzazione dei sistemi di trasporto rapido di massa a guida vincolata e di tranvie veloci nelle aree urbane (L. 26 febbraio 1992, n. 211)*. (4/2017/G). Rome.

Lunardi, P., Cassani, G., & De Giudici, C. (2008). La Metropolitana di Napoli. *Strade e Autostrade, 2*, 147-156.

Mai, M. G. (2009). *TRASforma urbis. Metropolitane storiche a Milano 1909-2009*: Maggioli Editore.

Mandolini, A., & Viggiani, G. M. (2017). Experiences gathered from the construction of napoli underground. *Procedia Engineering, 172*, 31-41.

Metropolitana Milanese spa, M. (1980). *MM. Venticinque anni della Metropolitana Milanese spa*.

Minici, G. L. (2018). *La metropolitana milanese. Evoluzione, urbanistica e architettura.*: Silvana Editoriale.

Palma, B. (1972). Metropolitana difficile. *Capitolium, 2-3*, 9-24.

RM. (2019). Le gallerie della linea C tra la stazione San Giovanni e il pozzo di via Sannio. Retrieved from https://metrocspa.it/blog/le-gallerie-della-linea-c-tra-la-stazione-san-giovanni-e-il-pozzo-di-via-sannio/

RM. (2021a). Il nuovo progetto e il sottoattraversamento della linea A. Retrieved from https://metrocspa.it/il-nuovo-progetto-e-il-sottoattraversamento-linea/

RM. (2021b). Roma Metopolitane. La tutela archeologica, ambientale e dei monumenti. Retrieved from https://www.romametropolitane.it/articolo.asp?CodMenu=10760&CodArt=10802#:~:text=Nel%20sottosuolo%20romano%20il%20cosiddetto,profondit%C3%A0%20di%20circa%2020%20metri.

SILOS. (2021). Sistema Informativo Legge Opere Strategiche. from Camera dei Deputati https://silos.infrastrutturestrategiche.it/

Spinosa, A. (2019). *Metropolitane d'Italia*.

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