Study mission experience also helps to better evaluate current and proposed transit improvements and can serve to identify potential public transportation research topics.

Study missions are normally conducted in the spring and fall of each year. Study teams consist of up to 15 individuals, including a senior official designated as the group's spokesperson. Transit properties are contacted directly and requested to nominate candidates for participation. Nominees are screened by a committee of transit officials, and the TCRP Project J-3 Oversight Panel endorses the selection.

Study mission participants are transit management personnel with substantial knowledge and experience in transit activities. Participants must demonstrate potential for advancement to higher levels of public transportation responsibilities. Other selection criteria include current responsibilities, career objectives, and the probable professional development value of the mission for the participant and sponsoring employer. Travel expenses for participants are paid through TCRP Project J-3 funding.

For further information about the study missions, contact Gwen Chisholm-Smith at TCRP (202-334-3246; gsmith@nas.edu) or Kathryn Harrington-Hughes at the Eno Transportation Foundation (202-879-4718; khh@enotrans.com).

About this Digest

The following digest is an overview of the mission that investigated transit design, construction, and operation in the Mediterranean region. It is based on individual reports provided by the team members (for a roster of the team members, see Appendix A), and it reflects the views of the team members, who are responsible for the facts and accuracy of the data presented. The digest does not necessarily reflect the views of TCRP, TRB, the National Academies, APTA, FTA, or the Eno Transportation Foundation.

TRANSIT DESIGN, CONSTRUCTION, AND OPERATIONS IN THE MEDITERRANEAN REGION

The theme of this study mission was "Transit Design, Construction, and Operations in the Mediterranean Region." Over a 2-week period, the study team met with senior management transit staffs in Athens, Greece, and Naples, Rome, and Milan, Italy (for a list of host agencies, see Appendix B). The group learned how these transit agencies have been successful in constructing rail transit systems when faced with geotechnical issues and archaeological challenges, observed how the stations serve as intermodal connectors and cultural centers, and studied the measures provided for the safe and secure transport of riders. In addition, the team received presentations on the planning strategies and approaches of the agencies and the operations of each system.

PROJECT PROFILES

Athens, Greece

Athens, the capital of Greece, is located on the southernmost part of Mainland Greece, known as the Attica plain.

With its metropolitan population of approximately 4 million people, Athens has built a state-of-the-art transport system. It is the largest and most complex transportation project in modern day Greece, as well as one of the largest built in Europe during the years of its construction.

The public transport agency, Attiko Metro (AM), was established in 1991 to design, construct, and operate a new metro system in the Attica region. Currently, the system, known as the base project, consists of two metro lines, Line 2 (Red) and Line 3 (Blue); runs 19 km; and encompasses 20 stations. (Line 1 has been in operation since 1904.) The system transports approximately 500,000 passengers daily and 140 million passengers annually. The agency is currently working on an additional 14 km of extensions to Lines 2 and 3 as part of a two-phase expansion plan that was envisioned when the base project was originally designed.

The first phase, which is currently under construction, entails extending Lines 2 and 3 a total of 8.4 km and adding four new metro stations and one depot. As part of this effort, Line 3 will be extended to the airport by sharing the right-of-way (ROW) with a suburban rail line; a station will also be constructed at the Athens international airport. Line 2 will be extended 1.2 km south from the Dafni station to Ilioupoli, with one new station added, and 1.5 km west from Sepolia to Agios Antonios, also with one new station. Line 3 will be extended about 6 km from Ethniki Amyna to Stavros; the extension features two new stations and one new train depot. This phase is expected to be completed in time for the Olympics in August 2004.

The second phase entails 11 km of line extensions, nine new stations, and one depot; it is scheduled for completion in 2007.

Naples, Italy

Naples is situated along the Tyrrenia coast at the innermost point of the Bay of Naples, between Mt. Vesuvius and the Phlegrean Fields volcanic region. It is the third most populated city in Italy (after Rome and Milan), having more than 1 million inhabitants. Together with its suburbs, the population of the metropolitan area totals 3 million.

Metropolitana di Napoli, SpA (MN), is a private company composed of 10 Italian and international construction companies. MN is responsible for completing the city's circumferential ring of Line 1, which began operation in 1993 with 4 km of underground track. The line, when completed, will total 21.2 km in length, have 26 stations, and connect the suburban residential areas to the city's primary business centers, seaport, central train station, and airport, as well as traverse the historic center. Currently, 13.2 km of Line 1 have opened with 14 stations. The Dante-Centro Direzionale segment, roughly 5 km in length, is now under construction. The Centro Direzionale-Capodichino (Airport) tract, covering a distance of approximately 3 km, is in the final stages of planning.

Line 1 intersects many of the rail lines within the Campania region. The Line 1 ring will be closely integrated with Line 6—a new underground light rail line, which will operate along the central waterfront corridor—and with Line 2. Line 2 will share two major passenger interchanges with Line 1 at Museo, a major central city destination, and at Garibaldi, the intercity rail station.

By 2011, the public transport network in Naples will encompass 90 km of rail, 98 stations, 18 rail interchange nodes, and 16 park-and-ride nodes. The third phase of the construction project was begun in 1998 and is expected to be completed by 2011.

Rome, Italy

Rome, the capital of Italy, is located on the Tiber River, in the central part of the country, near the Tyrrhenian Sea. Vatican City, the seat of the central administration for the Roman Catholic Church, is an independent state located within the city of Rome. Rome has 3 million inhabitants.

Metropolitana di Roma (Met.Ro) manages the public transportation services of Lines A and B and the new Line C. Lines A and B form an X-shaped network of 37.5 km of rail over a 1,286-sq-km area, with the lines meeting at the Central Railway Station, Termini.

Line A crosses in a southeast to northwest direction from Anagnina to Ottaviano, near Vatican City. The first 14.5-km segment of Line A was opened in 1980 and is almost all underground. In May 1999, the first stretch of a 4.5-km extension to the northwest was put into service from Cipro–Musei Vaticani to Valle Aurelia, the final three stations opening in January 2000.

Line B crosses in a south to northeast direction from Rebibbia to Termini to Laurentina. The first segment was constructed as an 11-km line, 6 km of which were underground, for the World Exhibition in 1955. Many years later, in 1990, the 8-km northern branch to Rebibbia was opened, with 7 km of the extension underground.

Met.Ro anticipates that the overall number of passengers per hour served by Lines A and B will increase from 36,000 to 42,000 in the next 20 years. To accommodate this increase in ridership, Met.Ro is constructing a new line, Line C, that will encompass 25 km, 30 stations, 36 vehicles, and a maintenance yard. Line C has three distinct construction segments:

- At-Grade Segment (8 km): a 9-station segment within the eastern suburban area; it primarily follows a previous rail corridor.
- Middle Segment (10 km—Giardinetti to S. Giovanni): a 12-station underground segment.
- Core Segment (7 km—S. Giovanni to Ottaviano): a 9-station underground segment; this particular segment crosses the Tiber River and sensitive historical areas, including an alignment adjacent to the ancient Coliseum.

Milan, Italy

Milan is a modern city with a population of 1.5 million people. The urban area encompasses about 4 million people.

The Azienda Trasporti Milanesi (ATM), a joint-stock company, is the main transport provider in the city and the surrounding metropolitan area. The company manages all aspects of public transport service and development. Within this urban and interurban network, the public transport system consists of three metropolitan railway lines as well as 18 tram, 3 trolley-bus, and 96 bus lines. In addition, a unique "people mover" called Radiobus provides a fifth mode of public transport. (Radiobus is described more fully at the end of this digest.) The overall transit network includes 70 km of heavy rail, of which 45 km is underground. The system reaches 86 municipalities and covers nearly 1,400 sq km with 85 stations. ATM has 29 facilities, 26 of which are depots and workshops located throughout the city and region.

Milan's rail transit network comprises Lines 1 (Red), 2 (Green), and 3 (Yellow). Line 1 opened in 1964 and was developed along traditional transit routes. Continuous expansion occurred throughout the 1970s and 1980s. Only Line 1 is third-rail powered. A 2.5-km extension, with two additional stations, is being planned for Line 1; completion is scheduled for 2006. Line 2's initial segment, between Caiazzo and Cascina Gobba, opened in 1969. Continuous expansion has also occurred along Line 2, most recently to the southern end. Line 3 was first opened in 1990, with expansion occurring throughout the 1990s. The most recent addition is a 1.2-km extension from Zara to Maciachini, completed in 2003.

Currently, two expansion projects are underway, and two new lines are under development. These extension projects include expanding Line 3 to the north by 3.9 km, converting the southern end of Line 2 from a light rail to heavy rail, and adding one new station to Line 2. The Line 2 project is expected to be completed by December 2004. The expansion for Line 3 is expected to be completed by 2007.

PLANNING APPROACHES AND STRATEGIES

Athens

In order to ensure the future of transit in the Attica region, AM determined that a need existed for strategic planning after the completion of the base project. A strategic plan was developed that focused on finalizing the design and operating characteristics for the base project, determining expansion needs for the metro network and other feasible projects, and developing a 20-year business plan, which financers required for future funding requests.

As part of the planning process for the extension project, AM reconfigured its management structure. For the base project, a construction consortium of 23 individual companies, composed of nine French, nine German, and five Greek construction firms, was formed under the umbrella of the Olympic Metro Consortium (OMC) to design and construct the project. Project oversight and management was provided by AM and Bechtel, who came under contract to the transit agency in 1992.

After the completion of the base project, AM changed its management style. For the first-phase extensions, instead of a lump sum/turnkey contract, smaller design/build contracts for specific construction projects were awarded. The contracts are prepared with each rail extension subdivided into multiple civil works contracts. The mechanical and electrical contracts are structured not by segments but by systemwide scopes of work for all the line extensions. AM provides incentive to the contractors by offering a 4% to 5% bonus for work completed ahead of schedule.

These changes have resulted in AM assuming more risk but retaining direct control over project management and design. Staff reported that overall costs for the first phase extensions have been lower due to these contracting changes. AM dedicates these savings to archaeological excavations and displays. In addition, this approach puts the design-build process on a fast track. Roughly speaking, there are 6 months for design, 6 months allotted for contract tender, 24 months designated for civil works construction, and then 24 months for mechanical and electrical construction (see Figure 1).

In addition, the AM's planning department conducted a Metro Development Study (MDS) once the base project was completed. This study evaluated the existing transit modes (rail, commuter rail, and tram) by formulating transportation models to determine demand characteristics for additional transit. The MDS came at a time when the agency needed to assess the additional capacity needed to handle the ridership increases expected during the summer 2004 Olympics. As a result, AM developed its two-phase extension plan.

Following the completion of the extension phases, and in preparation for future improvements, AM is conducting design studies for 26 km of line extensions, 21 new stations, and an additional train depot. By the year 2010, at final commissioning, the

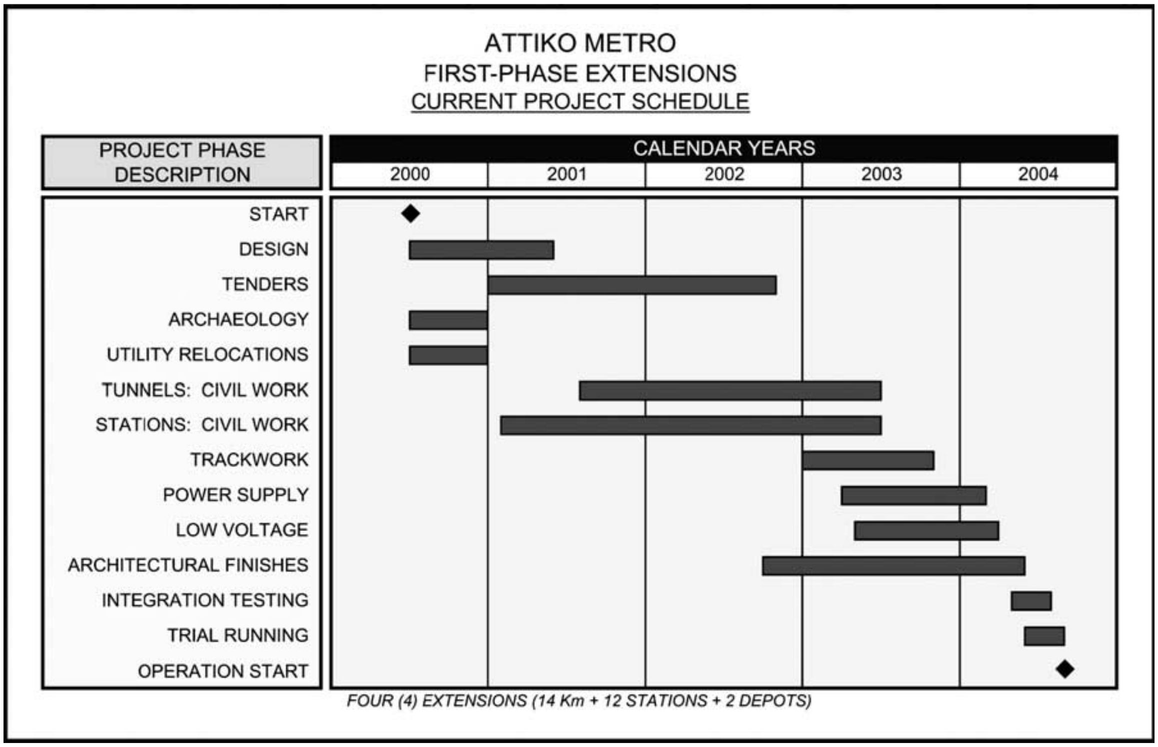

Figure 1 Project schedule for Attiko Metro's first-phase extensions.

system will comprise 83 km of alignment, 76 stations, and 654 train cars.

Naples

In 1994, the city of Naples began planning the integration of four separate operating railways into an underground public transport network. The Campania Regional Metro System (CRMS) first developed a transportation plan for the city of Naples and then a regional plan for the Campania region. Politicians at the local and regional levels who are engineers by trade were the major proponents for developing an integrated urban and regional public transport network.

The Metropolitan Transport Plan of Naples (MTPN) was adopted in 1996. The plan also included integrating the infrastructure through park-and-ride nodes, bus and metro interchange nodes, and connections between rail lines. Finally, the transportation plan was used to drive land use planning through new lines supporting the location of new socioeconomic activities and new stations to encourage the regeneration and renewal of urban areas. As a result of this plan, the construction and extension of Line 1 began.

In 2002, the CRMS adopted its strategic plan. The regional agency initially focused on determining what new components would be vital to the expansion and upgrade of the system and then determined the funding available for those components. Consideration was also given to the uncertainties inherent in the design of the system. In addition, CRMS had the added benefit of learning the national railroad was building a new high-speed line from Rome to Naples. This segment will be completed by 2005, with a connection to Solerno added by 2008. As part of its plan, the CRMS will integrate these railway lines into the regional network.

Different simulation models were created to measure urban traffic zones, regional traffic zones, and peak- and off-peak-hour passenger flows on Line 1 and within the stations. The data provided by these models showed the major challenges to creating the regional network. CRMS concluded that regional services needed to be designed according to schemes conceptually similar to those of the urban underground network.

The primary planning goal for the region's transportation system is to increase the percentage of the population living within 2 km of a station. Once these regional rail lines open and begin operation, by 2010, it is estimated that approximately 76% of the Campania population will live within a 10-minute walk from a transit station. Currently, there are over 1,000 km of existing rail in the region; in 6 years, there will be nearly 1,400 km of rail and 83 new regional stations. As a result of the regional network, CRMS expects the number of riders using public transit to increase by 120% by 2010. In some areas, the increase could be as high as 500%, assuming future transit modification will provide better intermodal connections between lines.

Rome

The city of Rome is experiencing a tremendously high level of traffic congestion. As part of its planning strategy, it, in cooperation with the European Union (EU), developed a mobility plan to address traffic congestion. The plan outlined the establishment of three tools and a new agency:

- A planning tool called the General Plan to improve the supply of collective transport;
- A technological tool called Intelligent Transportation Systems (ITS) that allows an integrated, efficient way to improve transportation by using new technologies; and
- An organizing tool and an agency called Societa Trasporti Automobilistici (STA) to provide design and operating solutions to help improve mobility objectives.

Met.Ro has an extensive in-house engineering and planning staff. The current planning efforts for Line C have centered on preparing the three segments for construction contract tender. The solicitation is scheduled for March 2004. One general contractor will be selected for all three construction phases. As part of its planning process, the agency carefully balances providing efficient public transit access throughout the city with protecting historical monuments.

Milan

The focus of ATM's planning efforts is to achieve an integrated mobility system for the city of Milan by ensuring the efficiency and reliability of public transport so more people choose to ride than drive. To this end, ATM has set several strategic planning goals:

- Consolidate and develop the area served by ATM,
- Guarantee easy access to the system throughout the city,
- Increase the professionalism of the ATM staff in dealing with customers,
- Keep the public informed,
- Listen and respond to the needs of the customers, and
- Continually improve the entire network by making it cleaner and more efficient.

To support these goals, several mobility projects are currently being implemented. They include an extension of the rail network, the construction of two new rail lines, the introduction of an electronic-magnetic ticketing system, and the extension of the Radiobus service.

Other improvements consist of the purchase of "intellibuses," which are fitted with new telecommunications technologies that perform vehicle diagnosis. Information is collected in real time and analyzed continuously in order to detect the deterioration of components. The technology makes it possible for the operations division to prevent or minimize vehicle breakdown during service, and it automatically informs the operations room of any emergency situation.

ATM is also focusing on refurbishing train vehicles (see Figures 2 and 3). New equipment is fully articulated, and older cars are undergoing major

Figure 2 Car remanufacturing with new articulation in Milan.

Figure 3 An example of a new articulated car interior in Milan.

structural modifications, including the installation of gangways for full articulation and rooftop air conditioning. One of the goals of refurbishment is to standardize all of the trains so that the cars can effectively be used on any line. These upgrades are expected to add another 20 to 30 years of life to trains that are currently 15 to 20 years old. ATM expects to refurbish approximately 100 trains in the next 5 years.

FUNDING

Greece and Italy are both members of the EU, whose legislation requires that urban public transportation be open to competition in order to increase efficiency and reduce costs. In effect, the EU mandates that all transportation services be subject to tender.

As a result of the EU actions, Italy enacted laws to create a free market-based system in the early 1990s. Italian law requires that services provided by local governments be subject to a competitive procurement process. Regions award contracts either directly or through tenders based on commuter costs.

Capital

Hosting the 2004 summer Olympics has placed Athens in a unique position to improve mobility at the local level. The EU, banks, and Greece have all contributed funds to building and expanding the public transportation system. In addition, the Athens area is in one of the EU's regional development areas, making much-needed capital investment available to its transportation system.

Funding for the base project came from three sources: 50% from the EU, 40% from a European Investment Bank (EIB) loan, and 10% from the Greek state. The amount of funding was determined by the needs of the metro system in negotiations with the Greek government and the EU. As part of these deliberations, funding levels incorporated the potential costs associated with changes in the construction alignment and delays associated with the archaeological excavations. The total cost of the base project was €2.2 billion. Funding sources for the first-phase extensions are the same as for the base project. To date, the total cost of the archaeological excavations has totaled €50 million.

When calculating the pay-back projections for the 25-year EIB loan, AM has assumed a fare increase to match inflation. However, fare increases have not corresponded with the initial projections because the regional government controls fare policy. To compensate for this shortfall, AM focuses on increasing ridership, minimizing operating costs, and generating advertising revenue. Advertising accounts for 8% of the total revenue.

Capital funding for the construction of Line 1 in Naples comes mostly from the Italian national government, some from the EU and regional government, and a very small amount from the city of Naples. The total estimated cost of building the underground network is €3.757 million. Of this total, €1.257 million is available to use for improvements to the system and the purchase of new rail cars. The budget for each station includes 3 to 5% for art.

The construction of Line C in Rome is being funded by the Italian government (70%), the regional government (12%), and the municipal railway company (18%). Projected construction costs for Line C are 29 million Euro/km for the at-grade segment, 105 million Euro/km for the middle segment, and 150 million Euro/km for the core segment. Revenue collected by STA from parking fees, fines, and permits contributes to the funding of the ITS program.

In Milan, funding for the various improvement projects comes from the state, regional, and local governments as well as from ATM. ATM officials noted conversion of the 1.6-km light rail segment to an at-grade heavy rail operation is approximately 8 times more cost effective than an underground expansion would have been. The cost of implementing an electronic-magnetic ticketing system is estimated at €100 million, of which 75% is provided by ATM and 25% by the regional and local governments.

Operational

In 2000, the AM formed a subsidiary operations company, Attiko Metro Operations Company (AMOC), to operate and maintain the new lines. By the second year of operation, the operating cost/recovery ratio exceeded 100%. The first-year recovery ratio totaled 83%; it then increased to 148% in 2001 and declined to 139% in 2002. The operational surplus used to pay back the loan went from €12.7 million in 2001 to €17.0 million for the period between January and September 2003. The operations company credited low maintenance costs and high ridership for the gains in revenue. Also, to be more cost efficient, AMOC contracts out certain functions, such as cleaning the trains and stations and maintaining the escalators and elevators.

In Naples, revenues are lower than operating costs for the section of the metro system currently operating. The Italian government provides funding to cover the difference.

As part of the regional transportation plan in Naples, an integrated, distance-based fare policy was implemented on January 1, 2003. A consortium of 13 train and bus companies or agencies, Unicocampania, was formed to carry out this initiative. To get the companies to agree to the new policy, a system to guarantee that companies would not lose money as a result of the change had to be established. To do this, the ratio between transportation usage revenue and profits was established for each company; and subsidies based on those ratios would be made, with the subsidies to end in the fourth year of implementation.

To increase fare-box revenue, marketing and promotional campaigns are aimed at getting riders to purchase a monthly pass, versus daily or single-use tickets. MN officials reported that this effort helps to prevent fare evasion, which was estimated at 9.5% in 2000. In addition, MN collects 5% of its revenue from concession stands and advertising fees.

Since 2000, Met.Ro has been required to cover 35% of its maintenance costs. The remaining amount is funded by the state. Plans to increase revenue include concessions and advertising in the stations and on the trains. Efforts to increase operational efficiency focus on the competitive procurement of maintenance and operational contracts.

ATM currently has a fare-box recovery rate of 53% with the remaining costs covered by the state. To increase the fare-box recovery percentage, ATM has instituted competitive bidding for contracts. Contracts are based on cost per kilometer to operate the system exclusive of maintenance costs.

The region that encompasses Milan also contributes to the operation of the public transport system. It provides approximately 46% of ATM's operating costs. ATM has agreed with the regional government to decrease operating costs and increase ridership so the amount the region contributes will decrease. Officials at ATM stated that the region's contribution to supporting the public transport system has declined since 2002.

ATM devotes an average of over €50 million a year in renewing its fleets of buses, trolley buses, trams, and metro trains.

CONSTRUCTION

Environmental Process

Greek law requires that every construction project obtain an environmental permit. In order to obtain the permit, the transit agency is required to prepare a preliminary Environmental Impact Assessment (EIA) during the design phase of a project and then a final EIA report.

These reports cover technical, operational, and project characteristics, such as demography, traffic, climate, geology, hydrology, archaeology, air quality, flora, fauna, and land use issues, as well as the potential impacts related to local businesses, vibration, dust, traffic, water and power supply networks, and urban environment aesthetics. Any major impact is addressed with proposed mitigation measures. For AM, archaeological concerns are a significant component of these reports.

These reports are then sent to multiple government agencies, including the affected local governments, for review, comment, and approval. As part of the comment period, the local government informs the public and solicits input. If the project is approved, a permit is granted. In some instances, projects are approved with conditions attached. Once the permit is granted, environmental auditors monitor compliance with the environmental requirements and conditions. The public can challenge the approval of a project by appealing to the judicial system.

EIA reports are also required in Italy. In 1996, a presidential decree was issued to increase the authority of the regions and decrease that of the central government. In the past, conflicts between these two levels of government have caused delays in the development of EIAs.

An EIA in Italy covers the description of the project, an evaluation of the installation methods, impacts on existing systems, assessment of technological and technical solutions, quantification of the various technical impacts associated with the construction and operation of the system, evaluation of the socioeconomic impacts, screening and comparative analysis of different alternatives, and the identification of the major modifications needed to minimize or eliminate unacceptable impacts, as well as environmental sustainability issues. Due to the significant archaeological issues facing these ancient cities, developing the EIA reports are an important step in the construction process.

Geotechnical and Tunneling

Athens

Before the OMC began constructing the base project in Athens, the geology and geotechnical conditions along the 19-km alignment were extensively investigated, analyzed, and evaluated. The results of these investigations were used to develop the geotechnical parameters required for the safe design of the tunnels, stations, and other underground works. The OMC was responsible for all geotechnical work and assumed 100% of the responsibility and risks.

The geology of the Attica region is a complicated stratigraphy of sedimentary formations and a variety of magmatic types. The subsoil has a complex structural geology that varies significantly both vertically and horizontally.

Initial planning had assumed that layers of hard rock would be tough to penetrate but easy to stabilize. However, once tunneling began, engineers found variations in the solid rock, very soft soil conditions, and other anomalies, such as illegal underground sewage connections, deteriorated sewer lines, old riverbeds, and ancient wells. In order to protect the safety of the construction crews and the structural integrity of the ancient historical sites above ground, a series of pilot tunnels about 3 m wide were constructed to allow engineers to test the soil and determine its condition before proceeding with the actual tunneling excavations.

Geological conditions also required consideration of vibration mitigation. As a result, AM provided noise and vibration protection of the trackway. The track work is a concrete ballast system with elastic pads specified between the rail and the two block concrete sleepers. A special rubber boot is also provided between the sleeper and roadbed. For the alignment near the ancient Acropolis, a full floating slab was constructed.

Several tunneling methods that included different structural lining configurations were employed to satisfy the requirements of the site-specific geological formations: Tunnel Boring Machine (TBM), Earth Pressure Balance (EPB), Open Face Shield (OFS), and New Austrian Tunneling Method (NATM). Cut & Cover was used for selected areas of single, double, and triple track configurations. In the majority of cases, the tunneling was within an average depth of 20 m.

Softer areas required NATM, a slower process, but better suited for shallower points under weak structures. In the NATM excavations, narrow tunnels were carved out and supported with metal arches and shotcrete applications. The tunnels were broadened with specialized machinery; then a waterproofing membrane was laid along with a permanent concrete lining.

At deeper locations with stable soil, computer-operated, hydraulic TBMs were utilized. These machines had a 9.5-m diameter with a full-face cutter head. The TBMs were designed to bore through the hardest ground at depths ranging from 8 to 28 m below the surface. Rotating cutter heads, fitted with excavating bits and disk rollers, broke up the rock and soil. Conveyor belts removed the debris. Immediately after each forward push, eight precast concrete segments were installed around the perimeter of the tunnel to form a closed ring, leaving behind a nearly completed tube. Afterwards, grout injection was used to fill gaps in the soil and form the final walls of the tunnel.

For the Line 2 project, tunnel production was in three phases:

- Early period (June 1994 to July 1995): 1.4 m/day
- Archaeological Study Phase (July 1995 to June 1997): 0.4 m/day
- Final Production Period (June 1997 to January 1999): 8.4 m/day

For the extension project, EPBs were used for tunneling. These machines have a 9.5-m diameter with full-face cutter heads. Cut and Cover methods were used almost exclusively for station construction. However, NATM was used for five stations that had limited street availability.

Monitoring was performed throughout the construction of the metro system. Extensive instrumentation was used to monitor the behavior of both the adjacent buildings and the construction sites. Vertical and horizontal displacements were recorded. Appropriate actions were taken when required to address local deformations.

In 1999, Athens experienced an earthquake that registered 6.2 on the Richter scale. Accelerations of the earthquake up to 0.6 *g* were recorded in a localized area due to abnormalities in the ground. No tunnels suffered any damage, even though they were designed for 0.16 *g*.

Naples

The city of Naples occupies land with a particularly variegated morphology attributed to the volcanic nature of the region. The subsoil beneath the city primarily comprises pyroclastic material, such as ashes, lapillus, cinders, pumice, pozzolana, and tufa. Because yellow tufa is a very common soft rock in the region, its presence played a major role in determining the construction methods used to build the alignment and stations.

The soils overlying the tufa formation are loose cohesionless materials, while the tufa itself is generally a soft rock with low permeability, 10.4 to 10.5 cm/s. Throughout the urban area, the tufa rock is permeated by an intricate system of caverns. Prior to the tunnel mining excavations, these caverns were carefully filled with cement grout. The area also has a relatively shallow water table.

The alignment for Line 1 is characterized by relatively deep tunnels, which are located within the base formation of the tufa. The top of this formation is found at depths below the ground level ranging from 15 m at the Dante station to 32 m at the Toledo station. Except for a short stretch near the Dante station, the tunnels are below the water table.

The line consists of two circular tunnels with an inner diameter of 5.85 m and an excavation diameter of 6.75 m. The tracks are generally parallel, with a center distance between tunnels of 11 m. The tunnels are being excavated by a pressurized shield using the EPB approach. The platform tunnels, with an outer diameter of 10.9 m, will be excavated by traditional means after improvements to, and waterproofing of, the surrounding soil.

The tunnels are given a lining, which is formed by using prefabricated concrete segments that are installed inside the shield and then sealed against the soil by extruded concrete. The lining is made watertight by gaskets, housed along the whole perimeter of the lining segments, and then tightened with special bolts. In the stretches above the water table, a shield that performs open-faced advance tunneling is used.

In addition, steep grades and stations deep below the surface have become a necessary design feature of Line 1. Several areas of the system have required grades as steep as 5.5%. Construction of five planned stations requires 20 × 45 m excavations at depths between 35 and 55 m.

The lower stretch of the Line 1 subway is at present under construction; archaeological studies are currently proceeding at the open cut stations (see Figure 4).

Because of the shallow water table in Naples, the effects of possible subsidence are monitored constantly. Systematic monitoring is carried out during construction, with vertical and horizontal movements monitored at strategic points at both grade and below-grade levels and at cross-sectional areas of the tunnels and station wells.

Figure 4 Station open cut in Naples.

Rome

The central core of the underground segment of Rome's Line C will be constructed using two 10-m-diameter TBMs to minimize impacts to sensitive historic areas and reduce congestion resulting from construction. The twin 10-m-diameter tunnel sections will be constructed with a centerline distance between tunnels that generally ranges from 24 to 33 m and is as wide as 42 m. The crossing at the Tiber River will have a centerline distance of 33 m. It will be approximately 127 m deep with the top elevation of the tunnels set at approximately 10.8 m below normal water elevation. Open cuts will be necessary for the central core stations to allow for the necessary archaeological studies. Planners expect that the archaeological study zone will be more than 8 m thick.

Gallery spaces above the platform are excavated by cut and cover. The construction of gallery levels and entrance corridors above the platform adds flexibility in placement and size in relation to platform spaces because the platform level is evacuated by a larger boring machine. Entry/exit corridors are built from these gallery levels, with extreme sensitivity to archaeological considerations and historical monuments above.

Geological studies, in conjunction with subsidence studies, have determined that due to volcanic fissures and a 10-m upper zone of geological voids, the central core segment will require extensive backfill. A bore hole monitoring program is also needed to confirm the proper backfilling of voids. An extensive grout injection program has also become one of the major factors in higher than expected construction costs for the central core segment.

The middle underground segment will be constructed using four 6-m-diameter TBMs. This segment is characterized by previous excavations that must be addressed to avoid future subsidence concerns. Engineers have utilized camera technology to assess the areas that need to be backfilled.

A major concern with the construction of Line C is the possible detrimental effect of vibrations on ancient monuments. Local universities have provided extensive monitoring of existing buildings to review current levels of vibration. The universities used computer model analysis to establish behavior of adjacent buildings, verification of behavior on existing building cracks during tunnel excavation, and investigation of subsidence both transverse and longitudinal to the tunnel alignment. In particular, using the computer-aided Finite Element method, stress analysis was performed on an existing basilica to determine whether the tunnel excavation would adversely impact the church. It was determined that tension stress was very low and well within the appropriate accepted tolerance levels. The summary of the studies indicated that the underground vibration levels will be well below the ambient levels that currently exist for street level traffic. Therefore, the designers set the vibration criteria at 2 mm/sec. To further minimize the effects of vibration, the agency has specified special trackway designs that employ a floating bed concept with rubberized dampening (see Figure 5).

Milan

Milan's subsoil includes sands and clays in the upper layers. The subgrade water elevation changed throughout the construction period. This change required adjustments to the construction methods employed for tunnel excavation. Traditional boring log investigation was performed to establish design parameters and construction requirements.

Archaeology

Athens

The archaeological excavations in Athens are a joint venture of AM, the construction contractors, and the Ministry of Culture (MoC). The MoC has the responsibility for supervising all archaeological activities. Trained archaeologists oversee each proj-

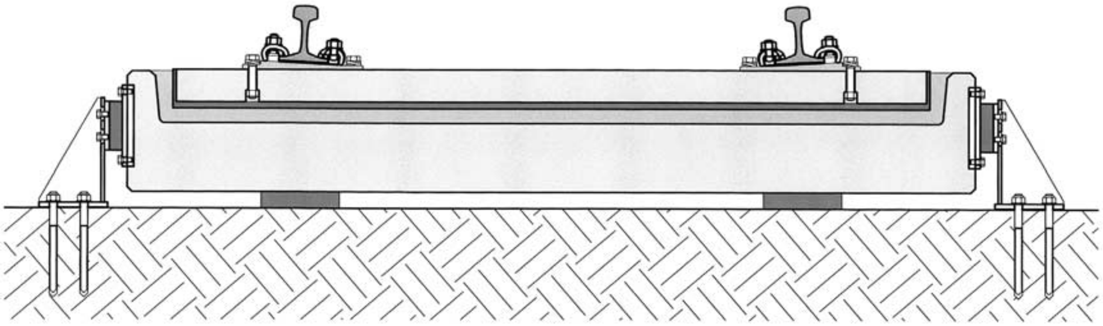

Figure 5 Rome's rail configuration for vibration mitigation.

ect from start to finish. This includes the design of the project, the safeguarding and exhibition of any objects found, and the publication of reports documenting the excavations. The transit agency provides funding and coordinates the archaeological activities with other phases of the construction project.

Before soil was turned, engineers with the MoC determined which points along the planned subway routes were likely to be declared archaeologically significant. While historians searched for clues using the ancient writings of Herodotus, engineers used georadar, a process that records underground images by sending energy into the earth and interpreting reflections. By using both these methods, ancient sites were located.

Approximately 70,000 sq m have been excavated (see Figure 6), unearthing more than 50,000 archaeological findings dating from the Neolithic period to the modern era. Discoveries include public baths, cisterns, ancient roads, city walls, drains, cemeteries, tombstones, statues, and pots and other household items. For example, an ancient aqueduct was discovered; it has been rebuilt by archaeologists for display at the Monastiraki station.

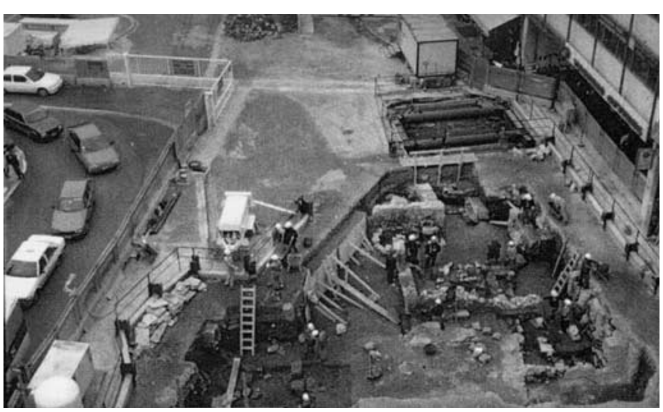

Figure 6 An excavation site in Athens.

Priority was given to preserving the antiquities over maintaining the original plans of the construction project and its schedule. For example, in the early phase of constructing a new station, 700 graves were found. Instead of trying to excavate that area, the construction of the station was stopped and the line rerouted. Further, it took 11 years to build the Monastiraki station because of the location of a Byzantine church. One station and adjacent tunnels were deleted from the scope of the project due to archaeological risks. In addition, the Akropoli, Monastiraki, and Panepistimio stations were built using tunneling methods instead of the traditional surface excavation because these stations are located in the heart of the ancient Greek civilization. Over the course of building the base project, the archaeological delays slowed construction by 2 years.

Naples

In Naples, archaeological surveys are conducted before any construction begins. The team visited two excavation sites in Naples. At the first site, Municipio, excavations are being conducted 3 m below sea level. At this site, special pipes were used to draw water out before the excavation could begin. After draining this site, archaeologists discovered many preserved artifacts.

When antiquities are located at the Municipio site, archaeologists work in two shifts, from 6:00 a.m. to 10:00 p.m., to clean, number, catalog and if possible, restore the items. In the last year, 13 m have been excavated. The amount of time it takes to conduct the excavations depends on the number of artifacts found. Artifacts, dating from the 4th century B.C. to the 10th century A.D. have been discovered. In addition to these discoveries, historians have learned that the coastline was once much farther inland than it is now.

The second site, Duomo, is covered and has lighting so work can proceed regardless of the weather (see Figure 7). There are about 20 workers per shift, working from 6:00 a.m. to 11:00 p.m., Monday through Friday. The workers use shovels and pails and then small tools to scrape the dirt. The work at this site is expected to be finished by May 2004. Archaeologists are currently excavating material from the early period of the Roman Empire, the 1st century A.D. Remains of building columns are being discovered. There are also the remains of wells from later periods at this level.

Rome

When preparing for the construction of Line C, planners knew the underground would need to travel through the heart of the city. This area contains many historic monuments and buildings and archaeological remains. A database was used to determine the route that would cause the least disruption to archaeological sites and monuments. Because tunnels will be excavated underneath the archaeological remains, the most impact to the remains will come from the construction of the stations. Approximately 18 months is set aside for an archaeological excavation at a station site. This is to ensure due diligence in recovery of ancient artifacts and to reduce impacts on project schedule and cost.

Milan

In Milan, archaeological remains are usually found within 6 to 7 m of the surface. They do not have an impact on construction.

Figure 7 Duomo excavation site.

SYSTEM OPERATIONS

Operations Control

Athens

Lines 2 and 3 of the Athens metro system were designed to operate with a central supervisory control concept. Train operators utilize cab signals with automatic train protection (ATP). A supervisory system provides real time information to the control center, an interface for train control, and automatic train identification. Upgrade of the system to fully automatic train operations (ATO) was envisioned as an option in the original design concept. The design and construction of the first expansion phase for Lines 2 and 3 has provided the impetus to begin that process. New cars required for the extensions will be ATO equipped, and an ATO retrofit program is underway for the existing fleet. The control center is located underground at a key station intersection. In the control center, each line has a contemporary operations console with train location and signal indications.

The control center is designed to provide supervisory control and data acquisition (SCADA) for power, ventilation, and other subsystems. Radio and hard wire communication systems also support the control center, as well as extensive closed circuit television (CCTV) applications. CCTV is utilized to assist line operation managers, to provide customer assistance, and to support emergency security response management.

The Line 3 extension to the airport will share the ROW with suburban rail and will be controlled by a new suburban rail system control center. In order for the metro to run on the suburban railway track, the trains must have dual electric traction power and signal equipment. Seven such trains have been specially ordered. At the airport, the metro and railway will have separate dedicated platforms because the dimensions of equipment do not permit joint platform operation. Unlike the rest of the system, where metro trains operate at a maximum speed of 80 km/hr, the metro trains on the suburban line will operate at 120 km/hr to be compatible with suburban railway speeds. The travel time from the airport to the city center will be 27 minutes, with a frequency of three trains per hour.

Naples

The operation of Line 1 in Naples is managed at a central control center. The current center is an interim configuration, and plans are underway to consolidate the central control center for Line 1 with other lines, including Lines 2 and 6. Train movements are supervised from this center with full ATO capability. Train operators perform a supervisory function as trains enter ATO control areas. Fixed communication circuits monitor and control train movements. The center also maintains full communication with train personnel and customers.

As in Athens, power and ventilation systems are centrally monitored at the control center by a SCADA system. CCTV applications are also extensively deployed to assist the control center in operations, emergency response, and security. Command and supervisory functions are centrally supported by hard wire and wireless communication systems.

Rome

The train control systems planned for Line C in Rome will utilize audio frequency circuits and operate with central ATO/ATP. Trains will also have an operator on board, as is the practice with Lines A and B.

A road/vehicle management control center has been implemented in the city center of Rome. The team visited STA's traffic control center to observe the ITS ROMA system in operation. The layout and activity of the control room had many similarities to rail operations centers (see Figure 8).

Information at the center is collected from a distributed system of 2,500 fixed roadway sensors and 60 strategically placed cameras. The cameras have the ability for remote field of vision manipulation to provide greater area coverage. These systems relay information over a fiber optic network, much of which is routed through metro tunnels. Real time traffic flow modifications are achieved through a distributed system of electronic message displays and zone control sensors that regulate vehicles by smart card permits. Improperly equipped vehicles that enter a controlled access point of a limited traffic zone are photographed, and the registered owner is fined. Key traffic signals are also aided by road sensor technology.

Milan

In Milan, train control for Lines 2 and 3 are ATO based with an operator in the cab. Line 1 utilizes a cab signal system with automatic stopping at stations (see Figure 9). The two new lines under development are expected to be driverless. Train control is centralized in a contemporary control center. The control concept provides three major functional divisions: train operations, station operations, and equipment/power supervision. Effective system communication belongs to a separate surface operations center.

Information technology supporting surface modes was also described to the team by ATM. Milan's high degree of functionality in this area and its transit organizational structure has enabled effective service coordination and enhanced customer information between rail and surface modes. The surface control center has the ability to track vehicle locations through a landmark-based system and collect data on vehicle status. In addition, vehicle condition/status data have numerous uses. For exam-

Figure 8 ITS Traffic Control Center managed by STA in Rome, Italy.

Figure 9 Milan's train operator console.

ple, real time statistics permit maintenance personnel to intervene when selected performance tolerance standards are exceeded and before customers are inconvenienced by a vehicle failure. Public address information may be dispatched centrally to the entire system or to an individual service or particular vehicle. Customized announcements are usually entered into a computer console and simultaneously dispatched through a voice simulator. Voice simulation permits improved audio clarity, uniformity of communication, and automated multilanguage capability.

Power Systems

In Athens, traction power is handled by a distributed system of rectifier installations providing 750 volts of direct current (VDC) under normal operation. These substations are supplied by the local power grid and are designed to provide substantial redundancy to protect them from local power outrages. Rolling stock is equipped with regenerative braking systems for energy conservation. Emergency power cut-off switches are also located at regular intervals along the ROW. Power for tunnel lighting, wayside equipment, and stations is provided by separate power feeds controlled at stations. Critical systems are supported by power back-up equipment, generally in the form of increased supply redundancy, battery backups (with a 2-hour reserve capacity), and uninterrupted power supply (UPS) for data/control systems. In addition, electric companies in Athens are provided a separate room for transformers at certain stations.

Traction power for Line 1 in Naples is distributed by an overhead catenary system, thereby leaving the track bed more accessible for maintenance and emergency evacuation. Direct current (DC) power is fed by a distributed system of four rectifier-equipped substations. Separate power feeds supply equipment systems with a hierarchy of reserves and redundancy to ensure power to critical systems in the event of blackouts or local power interruption. Auxiliary power for selected systems includes UPS and/or diesel generators with up to 4 hours of reserve capacity.

In the event of a blackout, the Naples railway system is outfitted with a three-level power supply system. If this situation were to occur, the normal power supply would be automatically switched to a back-up supply source sufficient to operate the system. In the unlikely event of a failure of the back-up system, a diesel generator that is capable of operating the system for up to 4 hours would provide power.

In Rome, power distribution for Line C will employ an overhead catenary system similar to the scheme utilized for Lines A and B.

Power distribution systems for Lines 2 and 3 in Milan are catenary, while Line 1 has third-rail power distribution. Line 2 evolved as a catenary system because a portion of the ROW was already utilized by a regional rail service utilizing overhead power. For Line 3, overhead power was selected as the operational preference. Newer rail cars are equipped with alternating current (AC) propulsion and regenerative braking. Many older cars are being retrofitted with AC propulsion as part of a comprehensive overhaul. Finally, local generators are available to provide power back-up of critical systems.

Ventilation and Lighting

In Athens, routine ventilation of the system is achieved by the piston action of the train and secondary fan equipment at stations.

For Line 1 in Naples, ventilation channels equipped with large reversible fans are typically located about halfway between stations. During normal operations, the ventilation system ensures sufficient air exchange to remove excess heat and create positive airflow, counteracting possible pressure changes due to train movements. Station lighting systems are typically linear, providing a raceway for other wiring and integration with signage components. Light wells for both natural lighting and ventilation are utilized in several locations.

The mechanical ventilation system in Rome utilizes airshafts located between stations and air balance shafts located at either end of the stations. Air ventilation systems are located above and below station platforms.

Tunnel ventilation for Lines 1 and 2 in Milan is provided by a system of vent fans. Additional emergency ventilation capacity is provided on Line 3. Centralized control of power and ventilation systems is supplied at the control center.

Fare Structure

The Athens metro system employs a self-enforced open-type fare control concept. A customer may purchase a ticket from a machine or agent and then proceed through a control line where ticket validation machines are located. The validation is good for a certain trip or period of time depending on the ticket type: one way, daily, or extended pass. This honor system enjoys a high level of customer cooperation and is enforced by ticket checking. The control line is barrier free, with small widely spaced ticket validation devices on waist high pedestals (see Figure 10). This open concept accommodates an exceptionally high two-way volume of customer traffic and greatly enhances the spacious architectural feel of stations. However, the agency is currently considering conversion to a gated control line for improved security and control. Currently, single trips cost €0.70 and can only be used on a specific mode, whereas daily (€2.9) and monthly (€35) are cross-honored among the bus, electric bus, and metro lines. Smart cards are also planned, with system-wide roll out expected after the 2004 summer Olympics.

Fare collection on Line 1 in Naples is accomplished with a closed/gated control line. Tickets and passes are dispensed by machine. The new integrated fare system creates single-ticket destination zones, with complete mode equity and sharing within zones. The zonal concept utilizes time-distance tickets. In the future, it is planned to extend the integrated fare policy to the ferries.

The fare control system in Rome is a closed design with gated turnstiles. The ticket validation system is time based, and the system is integrated with surface modes.

Figure 10 Athens open fare control line for ticket validation.

Milan utilizes a closed control line fare system. The fare media is a locally dispensed time-based ticket that is validated at the control line. This system employs self- enforcement. According to ATM officials, customers who fail to pay, particularly on surface modes, will be quite visible to their fellow passengers and "punished" by the "blush factor." An integrated fare system for seasonal tickets is currently in operation. An electronic ticket or smart card system is now in the design and testing phase. A system-wide roll-out is expected to begin in 2004.

STATIONS

Facilities/Infrastructure

Athens

In Athens, system control indications are centralized at a station manager control room. The transit agency gives visual and spatial prominence to this function in the station environment. The station manager has indication for local ROW power and signals, as well as a full spectrum of control for systems supporting that station. Controls include station lighting, fire-life-safety, elevators/escalators, fare control, and extensive CCTV and public address/information systems. The stations are equipped with state-of-the-art communication systems that ensure radio and cable communication between the Operation Control Center (OCC) and the various personnel located along the alignment.

Customer information systems in the station are primarily directed to the platform area. Fixed signage is enhanced by audio messages and electronic signage. The base line systems are currently being retrofitted with the more versatile electronic signage that has been developed as part of the line extension projects. Also, cellular phone companies have installed transmission devices in stations and tunnels so customers can receive reception while riding the train. AM charges the cellular companies a user fee for this service.

CCTV is a key element of the station infrastructure. Cameras are deployed throughout a station to monitor crowding, security, and operations. The customer's perception of safety and control was a key criterion in the development of CCTV standards. The newest stations make even greater use of CCTV, deploying in some cases nearly twice as many cameras as the earlier stations.

All 20 stations are supervised by station attendants. Additionally, each station has a station master. The station master's responsibilities are similar to those of the controller in the OCC. The station master has the ability to turn off power to the third rail in the event of an emergency. The station master can control the movement of trains and has the ability to control the ventilation systems within the station.

Special consideration has been given to people with special needs and senior citizens. The metro system has 146 escalators and 70 elevators, emergency telephone sets, and special ramps at critical points. Additionally, stations are equipped with warning striping on the platform floors and special spaces within the train vehicles.

AM places great emphasis on cleanliness in the metro stations. In an effort to keep the sanitation standards high, the consumption of food and beverages is forbidden in the stations and the trains. Smoking is prohibited throughout the network. Littering, graffiti, and destruction of property are prohibited. Pets can be carried on the train only in a pet container.

Finally, much effort in the design of the stations is devoted to complement the local urban streetscape. Where possible, natural ventilation and plant materials have been introduced in a "bio-climatic approach." This includes utilization of adjacent open space elements.

Naples

Station equipment controls for Line 1 in Naples are centralized at the station manager's location. Generally, these booth-type facilities are placed next to the entry control line. The station manager has a direct line of sight of customers entering and exiting the system. The booth has an open appearance, and the manager is readily available for interaction with the customer. Local signal and ROW power indications are provided at the station manager's location, as are comprehensive status indication and control of station equipment systems (see Figure 11). The control function is aided by extensive CCTV, public address, and point-to-point telephone/intercom access located throughout the station complex. Access to most of these systems, including CCTV, is available at the central control center; however, the station manager is expected to act as the first line of supervision and response.

Figure 11 Station manager control booth console.

Detectable strips/guideways are present throughout the stations in Naples. These rubber strips with grooves guide visually impaired customers to train doors and elevators. The passenger simply slides the cane along the grooves (see Figure 12).

Figure 12 Guideways for the visually impaired at a station in Naples.

Rome

On Lines A and B in Rome, station control rooms are located in the area of the fare control line. The station manager has extensive supervisory control of station subsystems. CCTV monitors provide surveillance throughout the station. Line C is expected to utilize more extensive CCTV coverage than do the existing Lines A and B. Also, Line C will mainly have center platforms, whereas Lines A and B have a variety of center-to-side and side-to-side platforms.

Milan

As in Athens, Rome, and Naples, stations in Milan are equipped with a station control room for the management of the station environment; and the station manager is the first line of response to events in the station. Virtually all the local station controls for Line 3, including lighting, smoke detection, equipment indications, and communications, are also available at central command. Plasma screens have been installed at selected locations to provide real time information and for the coordination of surface transit arrival times.

The platform orientation varies at Milan's subway stations, even on the same lines. Some stations are accessible to handicapped passengers; some are not. Accessibility is accordingly depicted on the transit maps. Some stations have guideways for visually impaired customers. There are pay bathrooms at the stations.

Intermodal Connectors

Athens

In Athens, in addition to Lines 2 and 3, an older line, metro Line 1, operates from Kifissia to Piraeus. This line has been in operation since 1904 and is 25.6 km long with 23 stations. Daily ridership totals 330,000 passengers. Although the study team did not participate in meetings with the company that operates Line 1, AM officials did make reference to the importance of providing Lines 2 and 3 with connections to Line 1. For instance, interline transfers exist between Line 1 and Lines 2 and 3 at Attiki, Omonia, and Monastiraki stations. When Lines 2 and 3 opened, the passenger load on Line 1 increased by 15%.

There are 10 bus-to-metro intermodal stations, most of which are on the outlying legs of Lines 2 and 3. Line 2 intermodal stations are Dafni, Sygrou-Fix, Attika, and Sepolia. Line 3 has intermodal stations at Ethniki Amyna, Katehaki, and Panormou. An intermodal station provides for transfer at the Larissa station between Line 2 and the Hellenic Railway. Larissa also serves as a transfer point to diesel and electric buses as well as taxis. In addition, metro riders have numerous informal intermodal transfer opportunities as stations are situated adjacent to major bus routes operating on nearby streets. An effort has been made to relocate bus stops close to station entrances to enhance transfers.

The most unusual intermodal operation involves the metro extension of Line 3 to the airport utilizing the suburban railway. As a result of this line, a major intermodal center is currently being constructed along a toll road median (see Figure 13). This facility will include a station serving both the suburban rail line and Line 3, a bus hub, and a 2,500-car-capacity parking garage.

Intermodal transfers are a key element of AM's immediate and long-range plans for the public transport system. In 2004, intermodal connections will include bus transfers at almost all metro stations, major park-and-ride facilities at five metro stations, interline transfers, intercity rail transfers at Larissa, suburban rail transfer at Plakentras, and tram connections at Sygrou-Fix. By 2007, additional park-and-ride facilities will be constructed, along with a tram connection to a metro transfer point at the site of the old airport. Finally, a metro transfer station at Ag. Savas will connect to the intercity bus terminal.

Figure 13 The intermodal airport station under construction.

Naples

When Naples started planning for an integrated public transportation system, a number of transfer points between the old rail line and new subway lines were established. Beyond the transfer opportunities between the metro rail lines, the metro will eventually extend to the airport, Capodichino Aeroporto. Also, a new metro station is located one block from the ferry terminal, facilitating a relatively easy transfer. In addition, as Line 1 is put into operation, bus routes are reorganized to connect to the stations.

The MTPN emphasizes the importance of intermodal transfers. For example, while the number of railway kilometers increased from 63.5 in 1996 to 75.5 in 2002 (19.8%) and tram kilometers remained static at 15, the number of railway interchange nodes grew from five to eight (60%) and park-and-ride nodes grew from one to four (300%). By 2011, railway kilometers will grow to 90 (19% over 2002) and tram kilometers will double to 30. But railway interchange nodes will grow 125% to 18 over this same time period, and park-and-rides will again grow 300% to 16. The plan for the Campania region projects an 18% increase in railway kilometers (1,179 to 1,392 km) between 2001 and 2010, with 28 new park-and-rides and 21 new bus-to-rail transfer nodes.

The impact on the modal share due to the addition of public transport facilities is expected to increase the public transport share in Naples from 36% today to 51% in 2010. The overall public transportation mode share for the Campania region is expected to increase from 20% to 33%.

Rome

In Rome, suburban bus lines have intermodal transfer points to the two metro lines at six locations mostly located near the end of the lines. Similarly, eight park-and-ride lots are located on the metro lines with adjacent bus facilities. Two regional rail/suburban bus park-and-ride transfer facilities exist, as well as three metro/regional rail transfer facilities. Intermodal transfer facilities between regional rail or the subway and the national railway exist at three locations. Line C will have intermodal transfer facilities with buses, trams, park-and-ride, and regional rail. There will also be four interline metro transfer stations.

As a unique intermodal development and congestion mitigation strategy, Rome has created a ring road around the center of the city. In addition to providing a bypass around the core, it also serves as a checkpoint for tourist buses and for nonresident autos. The tourist buses must pay for a permit (the cost is based on where in the central city the bus is traveling) and nonresidents must pay for an electronic tag for their autos. Autos are permitted to pass through without payment during the night hours, but are precluded from parking. The metro lines operate within the ring. At points on the ring, intermodal transfer facilities exist with city buses, park-and-ride lots, and metro trains.

Within the central city, there are numerous opportunities to transfer between modes due to metro stations being located adjacent to bus stops. In addition, bus stations, usually at grade and open air, are located at metro stations and near rail stations. Finally, access to the international airport is provided by regional rail from the center of Rome.

Milan

All three operating metro lines in Milan are radial. There are five park-and-ride lots located at outer stations on metro Line 1 and four interurban bus intermodal facilities, two of which are at park-and-ride lots. In addition, Line 1 has a regional rail connection at Maggio, an urban railway connection at Venezia, and an urban railway system connection at Codorim. It also has interline connections to Line 2 at the Loreto and Cadorna F.N. Triennale stations. Metro Line 2 has six park-and-ride lots and four interurban bus intermodal facilities at the outer stations. Line 2 also has one intermodal connection with the regional railway and interurban buses at the national railway terminal and an intermodal connection with regional rail at Porta Genova. Metro Line 3 originates in the city center and has one park-and-ride at the outermost station, which also has an interurban bus station. In the city center, there are two interurban bus intermodal facilities on Line 3, including one at the central railway station that also permits interline transfer to Line 2 and offers connections to buses to Malpensa, Linate, and Orio Al Serio airports.

In total, there are 12 intermodal park-and-ride lots, 13 interurban bus intermodal facilities (many in combination with other modes), 8 interconnections with the rail system, 3 intermodal connections to airport-bound buses, and 1 rail connection to the international Malpensa Airport. Within the city, there are also many informal opportunities for transfers from the metro to the tram and bus lines. At the main railway station, a passenger can transfer to either of two metro lines and a number of bus and tram lines. Auto parking is also provided at the railway station. Completing the picture for intermodal transfer is the Malpensa Airport express rail line, which stops at the two major railway stations that are also intermodal transfer stops.

Art

Athens and Naples use stations as cultural centers by showcasing archaeological findings and works of art. Art is also displayed at stations in Rome and Milan, but not to the extent of Athens and Naples.

Athens

When it comes to art, AM maintains a philosophy that trains and stations should be attractive and aesthetically pleasing to enhance the riding experience of passengers. AM believes this attitude encourages repeat use and will attract new riders.

Because numerous antiquities were unearthed during the construction of the metro system, AM decided to display significant historical remains at the stations where the artifacts were discovered. Five central metro stations are considered station-museums because of these exhibits. In addition, three open archaeological sites are located next to metro stations. The team visited the Syntagma station, where many significant findings are presented. The items on display range from Submycenaean graves from the 11th century B.C. to terracotta pipes from the Pisistratid aqueduct, which dates back to the end of the 6th century B.C. (See Figures 14 and 15.)

In addition to exhibiting the findings from the excavations, modern artwork by famous Greek artists is on display at 12 stations. Eventually, the art program will be expanded to include all stations. Sculptures, ceramic tiles, silk-screened works, and paintings are located on the platforms, transfer areas, and concourses and outside the stations. A stunning piece of art, *Aethrio (Atrium)* by George Zongolopoulos, viewed by the team at the Syntagma station, consisted of umbrellas and metal stairs inside a large circular area covered in mirrors (see Figure 16).

Figure 14 Display at Syntagma station highlighting the different historical eras of Greek civilization. See Figure 15 for an enlargement of the outlined section.

Naples

Art is an integral component of station design in Naples. Both the Deputy Mayor of Naples and officials at MN stressed the importance of making the public transport system a "living civil monument" and stations "a meeting point between people and art." A priority for MN is creating a design scope that often extends beyond the actual limits of transit infrastructure and into adjacent neighborhoods.

International architects were hired for each new station and the architects were given total responsi-

Figure 15 Terracotta pipes from the Pisistratid aqueduct.

Figure 16 *Aethrio (Atrium)* by George Zongolopoulos.

Figure 17 The escalator that links the Salvatore Rosa station to the neighborhood.

bility for designing the stations. The architects chose the colors, art work, and materials. In addition, the architects took into account the neighborhoods surrounding the stations so that the designs would be both functional and aesthetically pleasing. To illustrate the importance of incorporating art into the stations and neighborhoods, the team received a tour of several new stations.

The Dante and Museum stations were designed by Gae Aulenti. At the Dante station, he incorporated a pedestrian zone, used glass entrances to enhance lighting, and included works by five contemporary artists. A special feature of the Museum station, currently under construction, is a passageway from the station to the national museum. Once completed, it will include an array of photos by four Neapolitan photographers. The Museum station has also restored life to a blighted area and is a good example of the regeneration of neighborhoods. The area now contains a beautiful garden, a café, and a new post office.

The architect for the Salvator Rosa and the Materdei stations was Atelier Mendini. Although he used similar materials, shapes, and construction features at the two stations, he created a unique style for each one. The underground areas are modern, and the above ground design complements and incorporates the surrounding neighborhood. For example, at the Salvator Rosa station, a long enclosed escalator was installed that forms an aesthetic link from the station to the neighborhood (see Figure 17).

The Materdei station has two entrances from the same square. Traffic was redirected to create a square with a pedestrian zone decorated with elliptical forms (see Figure 18). The exterior of the station includes a colored glass spire, colored panels, and a statue (see Figure 19). Again, the surrounding neighborhood was decorated to complement the station design. The interior is enhanced with mosaics, silk-screens, and wall coverings.

The design of the Cilea-Quattro Giornate Station was done by Domenico Orlacchio. Again, traffic was diverted to create a pedestrian area, and much of the art displayed at this station represents the history of Naples' fight for freedom.

Figure 18 Designs along the pedestrian square at the Materdei station.

Figure 19 Example of painted buildings surrounding the Materdei station.

Rome and Milan

In Rome, many colorful mosaics adorn the stations on Lines A and B. At the Magliana station there is a mosaic by Lossonczy Tamas depicting dancers with the sun and clouds. The Colosseo station incorporates a very vibrant mosaic by Piero Dorazio. In Milan, the team observed a large colorful sculpture of a needle and thread outside one station. ATM also incorporates culture into its public transport system by restoring historic trolleys from different eras. These trolleys are used for tours and special events.

Safety and Security

Minimum safety and security standards are defined by the EU for its member states. These regulations require that railway safety be maintained and continuously improved. Each member state is required to establish a safety authority, known as the Ministry of Transportation (MoT), which is responsible for regulating and enforcing the EU safety standards. In addition, the MoT has the authority to impose penalties on transit agencies that violate the safety provisions, and it can authorize amendments to the EU safety standards.

The EU sets Common Safety Targets (CST). These targets represent the minimum safety requirements the member states must meet. They are expressed in terms of risk-acceptance criteria for passengers, staff (including contractors), users of at-grade crossings, unauthorized persons on railways, and other risks that pose a liability. Member states have the option of setting higher target levels.

In addition to the CST, public transit agencies also are expected to comply with the EU's Common Safety Indicators (CSI). These requirements pertain to accidents, incidents, near misses, and technical safety of infrastructure. Examples of the indicators used for technical safety of infrastructure include percentage of tracks with ATP in operation, percentage of train kilometers using operational ATP systems, number of level crossings, and the percentage of level crossings with automatic or manual protection.

The EU standards also require each transit property to possess a Safety Certification Certificate (SCC). A transit agency receives the SCC after developing a safety plan that meets, at the very least, the minimum requirements of the common safety targets and indicators. The EU standards also require the public transit agency to submit an annual safety report to the MoT. The report describes the safety targets, indicators and the results of an internal audit and observations made regarding operation deficiencies and malfunctions.

Athens

In order to avoid any unexpected danger within the transportation system, AM incorporates numerous safeguards into the design and construction of its subway system. In addition, AM will institute new and innovative safety and security procedures during the upcoming Olympic Games.

As mentioned previously, AM utilizes a CCTV monitoring system in all 20 stations. All cameras are supervised at the individual stations and a central operations control center. In addition to camera surveillance, security guards closely monitor stations. These security guards coordinate live surveillance with the transit police station located at a central station. The station security guards are trained not only to deter passengers from fare evasion but also to detect and prevent any other illegal or suspicious activity. There are 80 uniformed security personnel who are available for assistance within the stations and trains. Police personnel positioned in stations also include special guards of the Greek Police. Additionally, trained, nonuniformed members of the Athens State Security Force assist in patrolling Lines 2 and 3. Through the use of video and audio surveillance systems, the police and station security personnel are also able to observe passengers and activity in the tunnels.

Attempting to ensure the safety of the riding public, each station is outfitted with an automatic fire detection system. As a part of the fire detection system, there is an automatic fire extinguishing system in all high-risk areas. These automatic extinguishing systems are located primarily in the walkways and at the entrances and exits of each train platform. The engineers and staff at AM believe that these fire prevention devices create fire-resistant train stations. Emergency ventilation is provided by a system of fans in the tunnels and stations that is designed to direct smoke away from passengers in the event of a fire.

Fire-life safety systems in stations are both passive and active. Automatic protection systems are designed for high-risk areas, and dry standpipes and smoke detectors are extensively deployed. Fire alarms are readily accessible to customers. Fire safety systems are designed to help contain fires within zones, thereby creating “safe zones” for customers in the event of a smoke or fire emergency. “Help-point” intercoms and alarms are also located in stations and train cars.

All stations are equipped with public address systems that allow continuous communication with passengers. In the event of a fire or explosion, the public can be advised immediately. The operations personnel have been properly trained to deal with emergency situations. All stations are equipped with emergency plans.

Because of the large crowds expected during the Olympic Games, public transportation officials will be introducing additional security measures to reduce the risk of harm to passengers. The security force will go through extra drills to better manage crowd control. All stations and the train depot will be equipped with security fencing. New and louder alarms will be installed in the stations. There will be limited access to certain “control critical” areas in the train stations. Additional cameras will be activated and monitored by a new security control room. Explosive and chemical detectors will be installed in all stations, and emergency escape markers will be placed in all train cars. These security measures are targeted to be in place by June 2004 and will be maintained after the Olympic Games.

Naples

MN officials stated that safety issues and security concerns are an integral part of the planning, design, and construction of the system. Because of this, no accidents have occurred since 1993, when the original 4-km line opened.

All stations are monitored via video surveillance. There are approximately 40 cameras in each rail station. The cameras record a 6-day period. If an accident is reported within that time, it is likely that it will be on record with the central control center. This system not only serves to protect against false accident claims but also serves to deter crime. Future improvements to the metro system include transmitting CCTV images directly to the police.

Although the EU has issued safety standards for public transport systems, MN officials indicated there is no specific legislative language pertaining to intentional attacks on the system. Regardless of the lack of EU requirements, transit agency personnel indicated they plan for such events. In an effort to be proactive regarding handling a sudden emergency, the agency was in the process of conducting its first emergency evacuation simulation. By simulating a worst-case scenario, the agency planned to assess management response and its ability to evacuate passengers safely and quickly. Agency officials also indicated that periodic simulations of emergency situations are conducted that focus only on coordination and collaboration between the police and fire departments and emergency medical services.

At each station there is a safety officer on duty 18 hours/day. In the event of a fire or bomb, designated safety personnel direct the evacuation. Stations are equipped with emergency exits and ventilation systems. There are also evacuation routes. Oxygen tanks are available for emergency personnel.

Fire-and-smoke safety systems in stations include fire alarm areas, which are locally activated smoke control barrier systems that aid in compartmentalizing station areas as safe zones for evacuation (see Figure 20). The stations have a fire detection system that is connected to a sprinkler system. In the event of a fire, air is forced throughout the ventilation system to keep smoke away from passengers. Fans are regulated to perform in a complementary series of pushing or pulling actions in the event of a fire or smoke emergency to help provide a safe evacuation path for customers.

The timely detection of a fire or smoke emergency is fostered by thermo-sensitive cables in tunnels. Fire detection information is integrated with the continuous train identification and location data supplied by the control system. Ventilation systems are also complemented by active fire suppression systems. A system of hydrants is distributed at regular intervals along the alignment.

Figure 20 Station smoke/fire barrier in a station in Naples.

Nothing in the Naples metro stations is made out of flammable material, and all stations are constructed to resist earthquakes. Even luggage rooms are built to withstand dynamite. To illustrate the priority of safety at MN, even an art display of three old Fiat automobiles is totally nonflammable; all flammable materials, including the tires, have been retrofitted with appropriate look-a-likes.

Rome

In Rome, monitoring and making improvements to the transportation system is an ongoing effort to ensure the safety of the riding public from intentional attacks or dangerous situations. To ensure compliance with the EU requirements, the designers, engineers, and operations personnel implement more restrictive safety standards. Trains and stations are equipped with sophisticated surveillance systems. The control center is utilized to inform passengers of emergencies or dangerous situations. Inside train stations, evacuation routes are clearly marked.

Milan

Like the other public transportation systems around Europe, Milan actively monitors and records the activities and movement of people within the public transport system. The network of video cameras has been increased to more than 300 on Line 1, approximately 440 on Line 2, and 580 on Line 3. Emergency interphones connecting passengers with the operation control center have been installed inside the passenger compartments of all the underground cars: 330 cars on Line 1, 264 cars on Line 2, and 123 cars on Line 3. In particular, Line 3 also utilizes intelligent imaging processing that provides a signal to the station agent or command center in the event of an unusual occurrence. Indicators and SOS signs have been installed in all stations (see Figure 21). Video surveillance is utilized to assist the response process. Patrolling the system is the responsibility of the police.

Fire protection in Milan's stations is similar to that in Naples. Compartmentalization systems utilizing water are deployed to create safe zones in the event of smoke and fire conditions. If a train catches fire, smoke detectors activate sprinklers at the top and sides of the doors and passageways at the platform. This system creates a wall of water to prevent smoke from traveling from the train tunnels into the passageways beyond the platforms.

As a key component to ensuring safety, the agency requires safety training for all operators. The training

Figure 21 Milan's station SOS intercom.

covers the operator's role and responsibilities in the event of an emergency. It also familiarizes the operators with the agency's policies and procedures for tunnel safety, fire prevention, and evacuation.

ATM was one of six public transit systems in Europe to participate in a program designed to develop innovative security management systems for public transport systems. The project, Pro-active Integrated Systems for Security Management by Technological Institutional and Communications Assistance (PRISMATICA), was conducted from April 2000 to March 2003 and funded by the EU. As part of the technical component of the project, ATM used video cameras and audio systems to automatically detect vandalism, trespassing, fare evasion, fires, and suspect packages. If an abnormality in the system was detected, a signal was sent to the station manager and operations control center. As a result of this project, best practices in prevention techniques and security management will be developed for public transport operators throughout Europe.

Finally, to provide a safe environment to public transport riders between the hours of 8:00 p.m. and 2:00 a.m., ATM instituted a service called Radiobus. Radiobus is a variable-route transport service that minimizes waiting times, walking distances, and journey times. It uses a geographic information system that continuously adjusts the route according to the travel requests received from customers. ATM uses seven controllers during the evening hours to oversee the service and one controller during the day to record the travel requests. The controllers provide customers with the approximate time, location, and number of the bus that they will ride. The bus accommodates 2 wheel chairs and contains 16 seats. The service has an on-time performance rate of 80 to 85% and the ridership configuration is approximately 50% workers and 50% pleasure travelers. Currently, this service is available only in certain sections of the city; but, by the end of 2004, the service will be provided throughout Milan. The cost to ride is €3 compared to the usual single-ride fare of €1.

APPENDIX A—STUDY MISSION TEAM MEMBERS*

Michael DePallo, Team Leader, Director/General Manager, Port Authority Trans Hudson Corp. (PATH), Jersey City, New Jersey

Jack Boda, Director of Mobility Management and Project Implementation, San Diego Association of Governments (SANDAG), San Diego, California

Reed Caldwell, Deputy Public Transit Director, City of Phoenix-Public Transit Department, Phoenix, Arizona

Robert Cumella, Deputy Chief, Capital Planning and Budget, MTA—New York City Transit, New York, New York

Ranord Darensburg, Director, Risk Management/In-House Counsel, Transit Management of Southeast Louisiana, New Orleans, Louisiana

Kelly Felty, Manager, Engineering, Metrolink, Los Angeles, California

Erin Fletcher, Segment Manager, Seattle Monorail Project, Seattle, Washington

Kimberly Johnson, Manager, Michigan Department of Transportation, Lansing, Michigan

Gary Lemley, Director of Engineering, Houston Metropolitan Transit Authority, Houston, Texas

Levern McElveen, Manager, Office of Safety and Risk Management, Maryland Transit Administration, Baltimore, Maryland

Shirley Ng, Deputy Project Manager, San Francisco Bay Area Rapid Transit District, Oakland, California

Richard Sarles, Assistant Executive Director, NJ Transit, Newark, New Jersey

Eduardo Ugarte, Assistant Vice President, Facilities Engineering, Dallas Area Rapid Transit, Dallas, Texas

Margaret Mullins, Mission Coordinator, Program Manager, Eno Transportation Foundation, Washington, DC

*Titles and affiliations are as of the time of the study mission.

APPENDIX B—STUDY MISSION HOST AGENCIES/COMPANIES

ATHENS, GREECE
Attiko Metro (AM)
Attiko Metro Operations Company (AMOC)

NAPLES, ITALY
Metropolitana di Napoli, SpA (MN)

ROME, ITALY
Societa Trasporti Automobilistici, SpA (STA)
Metropolitana di Roma (Met.Ro)

MILAN, ITALY
Azienda Trasporti Milanesi (ATM)

APPENDIX C—LIST OF ABBREVIATIONS

AC	Alternating current
AM	Attiko Metro
AMOC	Attiko Metro Operations Company
ATM	Azienda Trasporti Milanesi
ATO	Automatic train operations
ATP	Automatic train protection
CCTV	Closed circuit television
CRMS	Campania Regional Metro System
CSI	Common Safety Indicators
CST	Common Safety Targets
DC	Direct current
EPB	Earth Pressure Balance
EIA	Environmental Impact Assessment
EIB	European Investment Bank
EU	European Union
ITS	Intelligent Transportation Systems
MDS	Metro Development Study
Met.Ro	Metropolitana di Roma
MN	Metropolitana di Napoli, SpA
MoC	Ministry of Culture
MoT	Ministry of Transportation
MTPN	Metropolitan Transport Plan of Naples
NATM	New Austrian Tunneling Method
OCC	Operation Control Center
OFS	Open Face Shield
OMC	Olympic Metro Consortium
PRISMATICA	Pro-active Integrated Systems for Security Management by Technological Institutional and Communications Assistance
ROW	Right-of-way
SCADA	Supervisory control and data acquisition
SCC	Safety Certification Certificate
STA	Societa Trasporti Automobilistici
TBM	Tunnel Boring Machine
UPS	Uninterrupted power supply
VDC	Volts of direct current

These digests are issued in order to increase awareness of research results emanating from projects in the Cooperative Research Programs (CRP). Persons wanting to pursue the project subject matter in greater depth should contact the CRP Staff, Transportation Research Board of the National Academies, 500 Fifth Street, NW, Washington, DC 20001

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