Practices for Energy Sustainability Enhancement in Metro Systems
Acknowledgments

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Outline/Agenda

• General figures and “green” statistics on Athens Metro Lines 2 & 3
• Electromechanical and Railway Systems consuming energy in a Metro system
• Quantities and percentages of energy consumption profile
• Passive and active methods for energy sustainability enhancement
• Conclusions and future strategies / goals for energy sustainability
ATHENS METRO PROJECTS in operation, construction, design
ATHENS METRO LINES 2 & 3
PROJECTS SUMMARY TABLE

<table>
<thead>
<tr>
<th>PROJECT</th>
<th>COMPLETION TIME</th>
<th>PROJECT LENGTH (km)</th>
<th>STATIONS</th>
<th>OVERAL PROJECT BUDGET (€)</th>
<th>DAILY RIDERSHIP (passengers)</th>
<th>REDUCED TRAFFIC OF PRIVATE VEHICLES PER DAY</th>
<th>REDUCED CO₂ EMISSIONS PER DAY</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. BASE PROJECT LINES 2, 3</td>
<td>2000-2003</td>
<td>17.6</td>
<td>19</td>
<td>2.2 b</td>
<td>490,000</td>
<td>90,000</td>
<td>400</td>
</tr>
<tr>
<td>2. EXTENSIONS PHASE A’</td>
<td>2004-7</td>
<td>12.4 (*)</td>
<td>11(*)</td>
<td>1.5 b</td>
<td>180,000</td>
<td>18,000</td>
<td>150</td>
</tr>
<tr>
<td>3. EXTENSIONS PHASE B’</td>
<td>2009-13</td>
<td>8.5</td>
<td>10</td>
<td>855 m</td>
<td>210,000</td>
<td>63,000</td>
<td>180</td>
</tr>
<tr>
<td>4. LINE 3 EXTENSION TO PIRAEUS</td>
<td>2018</td>
<td>7.6</td>
<td>6</td>
<td>730 m</td>
<td>130,000</td>
<td>23,000</td>
<td>120</td>
</tr>
<tr>
<td>TOTAL</td>
<td>-</td>
<td>46.1</td>
<td>46</td>
<td>5.3 b €</td>
<td>1,010,000</td>
<td>194,000</td>
<td>850 tons</td>
</tr>
</tbody>
</table>

(*) + 21 Km & 4 stations - Airport link on the suburban railway tracks, with dual voltage trains
GREEN TRANSPORT STATISTICS EXAMPLE

From the **36 underground stations of Lines 2 & 3** the following benefits are obtained on a DAILY basis:

- 870,000 passengers served
- 171,000 less cars in the city streets
- 2.94 million car-Km saved
- 29.9 MWh of energy saved
- 784 tons of CO$_2$ not emitted into the city’s atmosphere

While on a YEARLY basis there are **230 less car accidents**, leading to:

- 3 less deaths
- 13 less heavily wounded citizens

Also, when a citizen uses the Metro, in comparison to a car trip,

- He consumes $1/16$th of the energy used
- He produces $1/4$th of the CO$_2$ pollution
Electromechanical and Railway Systems - I

There are approximately 50 electromechanical systems in operation in a Metro network. These are substantial energy consumers:

**MECHANICAL**
- Tunnel ventilation
- Heating, Ventilation and Air Conditioning (HVAC)
- Lifts / Escalators
- Fire detection, fire fighting, fire protection
- Drainage, sewage, pumping stations
- Water supply
- Platform Screen Doors

**ELECTRICAL – POWER SUPPLY**
- Traction Power,
- 20 KV Power Supply.
- Auxiliary Power Supply System 110 V.
- Earthing and Stray Currents Protection.
- Lighting
- Power Remote Control System (PRCS-SCADA).
Electromechanical and Railway Systems - II

ELECTRICAL - LOW VOLTAGE

• Automatic telephones
• Direct telephones
• Clock system
• Close Circuit Television (CCTV)
• Public Address system (PA)
• Traction Circuit Removal System (TCR)
• Intercom system
• Safety / Security / Access control / Intrusion alarm system
• Wi-Fi networks
• Fibre Optics Networks and Data Transmission System
• Uninterrupted Power Supply Systems (UPS)
• Signaling systems
• Public Information System (PIS)
• Fare collection system
• Radio telecommunication system (TETRA)
• Building Automation and Control System (BACS)
Metro Network Energy Consuming Systems

There are three (3) Main Categories of Energy Consuming Systems

1. Building Facilities
2. Railway systems
3. Depots

6 E/M and Railway Systems
Consume 95% of the energy spent

Athens Metro Lines 2 & 3
Yearly Energy Consumption: 230 GWh

50 E/M systems

6 E/M systems
Metro Systems Energy Consumption Distribution

- Traction Power: 54.8%
- Station/Tunnel Ventilation/HVAC: 22.8%
- Lifts/Escalators: 11.8%
- Lighting: 5.8%
- Low Voltage: 2.7%
- Other: 2.1%
Train Traction Power (typical example)

- Passengers per train (approx.) = 1000
- Weight per passenger = 75 Kg
- Train tare weight = 180 tons
- Total Weight = 255 tons
- Train max speed = 80 km/hr
- Train acceleration = 1.1 m/s²
- Max tunnel gradient = 4%
- Operational Voltage = 750 V dc

Motor Power per Train = 2.7 MW = 4 cars x 4 motors x 170 kW each

3.2 MW Traction Power Substations along the Line at approx. 1.5 km intervals
Traction energy saving

- **Regeneration of train braking energy** - train motors become generators when braking and feed back the 750 V dc power network for use by other trains (10-25 % saving). Non regenerated braking energy is turned into heat, expelled in tunnels and stations.
- **Tunnel vertical alignment “humped” profiles** (5-8% saving)
- **Train coasting between stations** accepting a 5 sec/km delay (10-12% saving)
- **Traction motor max current limitation**, leading to smaller accelerations, accepting a 5 sec/km delay (8-12% saving)
- **Synchronization of the trains movement through the signaling systems** - ATO (eg when a train decelerates, another train in the vicinity accelerates and hence better utilizes regenerated energy (10-15% saving)

Above percentages are not cumulative, but substantial energy savings of > 35 % can be achieved and this translates into several million € of operational cost, and significantly reduced CO₂ emissions.
“Humped” profile in tunnel alignment

Gravity assists acceleration when trains are departing a station, and assists deceleration when braking and arriving at the next station.

Traction power energy savings: 5-8%

Optimum tunnel gradient of 2.5%, offering a compromise between higher construction cost and operational savings, with a breakeven period of approx. 15 years.
Traction energy additional savings (in future projects)

- Feeding back surplus power from train braking to the city Medium Voltage Grid (20KV) (additional saving 5-10% on top of the regenerative braking)

- Use of super capacitors on board the trains. These will charge during braking and discharge during acceleration, assisting the traction power supply and thus reducing the traction power energy needs (20-25% saving)

- Traction power voltage regulation (termed as CBVC – Communication Based Voltage Control) according to the instantaneous energy needs of every train in the network (every sec), as known from the exact kinematic profile of every train from the wireless signaling system (CBTC)
Use of the train induced PISTON-EFFECT for natural tunnel ventilation

Air moves as a result of the moving trains and thus air is constantly exchanged with the atmosphere through open ventilation shafts.

Tunnel fans are typically 2 x 2 x 82 m$^3$/s or 2 x 2 x 100 m$^3$/s per station, bidirectional and fire rated at 250 deg C for 1 hour. Efforts are made to use high aerodynamic efficiency fan blades.

Energy saving in comparison to tunnels forced ventilation: 85%
ADDITIONAL ENERGY SAVING SCHEMES – ENERGY SUSTAINABILITY ENHANCEMENT

• **LED lighting in stations/tunnels** (x 3 life duration, ÷ 3 power consumption)

• **Escalators stopping at zero load** (no passengers, 20% energy saving)

• **Load compensation schemes in power substation**s (5-8% saving)

• **Smart control systems for building facilities management** (ventilation, air conditioning, lighting, etc.)

• **Install extensive photovoltaic cell panels** on the roofs of depot buildings

• **New technologies implementation** (eg. generating energy from the walking of passengers on top of tiles with piezo-electric characteristics)

• **Apply “Condition Based Maintenance”** to trains and E/M systems
Metro Air Conditioning - I

- An air conditioned Metro system attracts more passengers. Note that only 22% of car owners leave their car to take the Metro.
- No air conditioning is provided to the stations, because of:
  - Passengers remain in stations only for a few minutes
  - High cooling loads (estimated at 800 kW for a typical station for a modest 8 °C temperature reduction. Much higher cooling loads for large stations – e.g. Syntagma station 2.7 MW).
  - Excessive air exchange with the atmosphere and tunnels, of the order of 2-3 thousands of m³ of air per train per station arrival, hence the air conditioned air is constantly “lost”
  - Difficult to discharge the hot air into the city. 3-d thermal dispersion simulations for Syntagma station A/C showed an adverse effect on the adjacent National Garden trees
  - Very high operational cost for air conditioning the stations
Metro Air Conditioning - II

- Underground space provisions (200-300m²), equipment routing paths, air conditioning ducts routing and power and control system provisions are foreseen in every metro station. Staff and electronic equipment areas are air-conditioned within metro stations.

- **Power supply** to the (future) station air-conditioning will be provided from the power supply of the large tunnel fans (4 x 130 KW in every station), which remain usually inactive, and if they need to be energized in an emergency, the station A/C will be switched off automatically.

- **In the future Metro Line 4 in Athens** with stations with Platform Screen Doors (see example from Crossrail, London), forming a closed area for the waiting passengers, the A/C option is being examined carefully as the cooling loads are much reduced (< 300 KW per station)
Metro Air Conditioning - III

• **Train air conditioning is implemented** as it is considered worthwhile for the passengers comfort and attracts more passengers. More Metro passengers imply less cars in the streets.

• **Tunnel ventilation systems (civil works and equipment) are sized considering also the train A/C loads** (heat expelled) that are imposed on the tunnels and stations
Conclusions

• Metro projects, although heavy in construction and very expensive (100 m € per Km), they do provide Green Transportation and contribute to sustainable development

• Metro Lines 2 & 3 in Athens, consume approx. 230 GWh of energy yearly, through 50 operational Electromechanical and Railway systems

• The traction power system consumes > 50% of the total energy spent and tunnel ventilation consumes approx. 23% of that energy, hence most efforts are directed in reducing their energy footprint. Also 6 electromechanical systems consume approx. 95% of the energy spent and energy sustainability enhancement efforts are focused on those systems.

• Metro stations in Athens are not air-conditioned for passengers due to environmental considerations for the heat rejected in the city environment and due to high operational cost.

• Metro trains in Athens are air conditioned (excluding the older trains which will eventually be substituted with air conditioned trains). This upgrades the Metro environment and attracts more passengers.
Future goals – short and long term

• Further elaborate and utilize energy saving techniques and new technologies, for traction power, tunnel ventilation and lighting
• Gradually convert all the train fleet into one with air conditioned trains
• Specify and procure trains with reduced weight
• Consider the use of super capacitors on board the trains for further reduction of the traction energy
• Install photovoltaic panels at the depot buildings roofs, wherever possible
• Explore the possibilities of geothermal energy for use in air conditioning the stations
Questions?

Dr George Leoutsakos
gleoutsakos@ametro.gr