



# People's Republic of China Luoyang Metro Project

## *Annexes*

**ANNEXES**

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# Annex 1. Peer review of Asia-Pacific Finance and Development Institute

This report has provided a very good framework for independent evaluation, although there is no Project Completion Report currently. Especially the key questions in the matrix are highly relevant to the objectives and scope, and the methodology is also very appropriate. My personal recommendations are as follows:

## **1. Relevance**

Project design and decision-making are very important for the success of a project. So maybe it is better to interview the local transportation authority and external experts to verify to what degree the metro's line and station design is reasonable. After the pandemic, people's travel habits have undergone tremendous changes, which may affect the line's ridership as well as the revenue. There is some first-hand data from the local public transport association or from field surveys.

## **2. Effectiveness**

The Metro is always very welcome for the local citizens to improve their happiness, which could be presented by first-hand data from questionnaires. So, it is better to show the samplings and draft questionnaires. The results could directly prove that the NDB input is very worthwhile. In Luoyang city, maybe the elderly and students are free to take the metro, so their satisfaction is also very important, not only women or minorities.

## **3. Efficiency**

Maybe we can also discuss Luoyang Rail Transit Corporation's (LRTC') management efficiency to check that the NDB has brought not only funds but also valuable management knowledge to the local public transportation administration.

## **4. Sustainability**

Metro usually highly relies on the local government's subsidy, so financial sustainability is very important for both the NDB and Luoyang Municipal governments. How much is the ridership compared with other lines and buses during the rush hours? How much is the ticket revenue? Can the line be financially sustainable? NDB also invested in equipment, which is usually very expensive and needs a lot of money to maintain, frame repair or depreciation. So if possible, the local financial bureau could be interviewed.

In conclusion, it is a very well-organised evaluation framework that could produce valuable findings in the future.

## Annex 2: Project area map



## Annex 3. Summary of Key project data

Project name	Luoyang Metro Project
Country	The People's Republic of China
Area of operation	Transport infrastructure
Board approval date	July 20, 2018
Actual completion date	March 28, 2021
Total project cost	USD 2,775 million
Approved NDB financing	USD 300 million
Commercial banks	USD 1,311 million
People's Government of Luoyang	USD 1,164 million
Borrower	The People's Republic of China
Implementing agency	Luoyang Rail Transportation Co. Ltd.

## Annex 4: Rating scale

Rating	Score (Rating) descriptor
Highly Successful	Under the concerned criterion, the project achieved or surpassed all main targets, objectives, expectations, and results and can be considered as a model within its project typology.
Successful	Under the concerned criterion, the project achieved almost all (indicatively, over 80-95%) of the main targets, objectives, expectations, and results.
Moderately Successful	Under the concerned criterion, the project achieved the majority (indicatively, 60 to 80 %) of the targets, objectives, expectations, and results. However, a significant part of these was not achieved.
Moderately Unsatisfactory	Under the concerned criterion, the project did not achieve its main targets (indicatively, less than 60%), objectives, expectations, and results.
Unsatisfactory	Under the concerned criterion, the project achieved only a minority of its targets, objectives, expectations, and results.
Highly Unsatisfactory	Under the concerned criterion, the project achieved almost none of its targets, objectives, expectations, and results.

## Annex 5: Project design and monitoring framework

#	Indicators for result monitoring	Unit	Baseline	Target value				Frequency	Data source/ methodology	Data reporting	Responsibility for data collection
				2021	2022	2023	2024				
1	Successful operation		0	100				One time	Test run assessment summary in progress	LRTC	LRTC
2	Passenger flow intensity	10,000 / km·d	0	-	0.6	0.9	1	Annually	Operation statistics in the comprehensive progress report	LRTC	LRTC
3	Average travel time saved	10,000h	0	-	3.46	5.89	7.44	First year of operation	Daily passenger flow multiplied by the time saved for a passenger traveling by line 1 compared to traveling by bus for a distance of 7.3	LRTC	LRTC
4	Share of metro in motorised travel	%	0	-	6	9	10	Annually	Comprehensive progress report	Luoyang Transport Bureau and LRTC	LRTC
4.1	Share of metro in public transportation	%	0	-	12	16	20	Annually	Comprehensive progress report	Luoyang Transport Bureau and LRTC	LRTC
5	Rate of passenger satisfaction of Line 1	%	0	-	97	97	98	Annually	Satisfaction survey report	LRTC	LRTC

## Annex 6: Evaluation framework

Evaluation criteria	Evaluation questions	Sources
<p><b><u>Relevance</u></b></p>	<ul style="list-style-type: none"> <li>• How is the project’s objective relevant to the national, provincial, and municipal priorities in the country?</li> <li>• Were the expected outcomes of the project aligned with NDB’s policies and strategies at the sector and project levels?</li> <li>• Was the project design appropriate in addressing the envisaged impact (improvement of the productivity of workers and reducing carbon emissions), outcome (a safe, efficient, speedy, and comfortable metro line for passengers; decongestion of roads), and outputs (Luoyang Metro Line 1 (LML1) from Gushuixi Station to Wenhuajie station with a total of 22.34 km in length including 18 stations complete with ancillary facilities)?</li> <li>• Did the design of the inputs, outputs, and outcomes of the project follow the logical results chain to achieve the project objective?</li> <li>• To what extent has the project been compatible with the interventions of the other multilateral development banks, international financial institutions, and local funds in Luoyang City and the metro transportation sub-sector in PRC?</li> </ul>	<p>National/Provincial/Municipal policies, strategies, and plans</p> <p>NDB Strategies and Policies</p> <p>Interviews with the Government, project staff, NDB Management and staff</p>
<p><b><u>Effectiveness</u></b></p>	<ul style="list-style-type: none"> <li>• To what extent have the project outcomes and outputs been achieved as indicated in the design framework at the appraisal?</li> <li>• To what extent has the project integrated with the planned metro</li> </ul>	<p>Project documents</p> <p>Data/Information from the Project Implementation Agency</p>

	<p>lines, Line 2, Line 3, and Line 4, to form the main artery of Luoyang’s public transportation networks to develop an efficient, green, safe, and accessible comprehensive public transportation system in Luoyang?</p> <ul style="list-style-type: none"> <li>• To what extent has the project achieved the following: <ul style="list-style-type: none"> <li>- mitigated tariff congestion in the urban by transforming traveling people in the urban from taxis and private motor vehicles to public transportation;</li> <li>- reduced carbon emissions by providing a greener transport mode and increasing its transport density;</li> <li>- improved urban resilience by providing a more all-weather mode against extreme climate conditions (e.g., extreme ice and snow freeze, massive rainfall, heave fog, etc.);</li> <li>- enhanced passengers’ efficient movement and worker’s productiveness; and</li> <li>- reduced personal casualties by comparing with and without the project to assess the effectiveness of a more safe transport mode provided?</li> </ul> </li> <li>• To what extent the environment safeguard-related plans have been implemented? Did the project interventions have any negative impacts?</li> <li>• What are the other factors that contributed to the achievement or non-achievement of expected outputs and outcomes?</li> </ul>	<p>Interviews with the Government, project staff, NDB Management and staff</p>
<p><b><u>Efficiency</u></b></p>	<ul style="list-style-type: none"> <li>• Were the Loan Agreement and the Project Agreement signed off and</li> </ul>	<p>Project documents</p>

	<p>effective in a timely manner, which was in line with the estimated sound project readiness at the appraisal stage?</p> <ul style="list-style-type: none"> <li>• Have the financial resources been used to achieve the intended outcomes?</li> <li>• Was the project procurement (contracts awarded) and disbursement performance in line with the appraisal estimates and the project design profile?</li> <li>• Have the project components been implemented as envisaged at the appraisal?</li> <li>• Has the project been put into operation as planned at appraisal?</li> </ul>	<p>Data/Information from the Project Implementation Agency</p> <p>Interviews with the Government, project staff, NDB Management and staff</p>
<p><b><u>Sustainability</u></b></p>	<ul style="list-style-type: none"> <li>• What is the likelihood that project benefits will be sustained within and beyond the life of the project?</li> <li>• Are there provisions for generating or gathering adequate revenue or funding for maintenance?</li> <li>• Are there any institutional issues that affect the performance of the project?</li> <li>• Are there any risks that may degrade environmental protection and social benefits?</li> <li>• Are there any issues with resettlement after the operation?</li> <li>• Are there any risks that affect the sustainability of the project?</li> <li>• Has LRTC trained its workers and staff and employed qualified personnel for the Operation and Maintenance (O&amp;M) of the project?</li> <li>• Has LRTC sufficient funds to meet the requirements of the O&amp;M?</li> </ul>	<p>Project documents</p> <p>Data/Information from LRTC</p> <p>Interviews with the Government, project staff, NDB Management and staff</p>
<p><b><u>Impact</u></b></p>	<ul style="list-style-type: none"> <li>• What are the socioeconomic impacts of the project? To what extent will the</li> </ul>	<p>Project documents</p>

	<p>project reduce the emissions of public urban transport, increase disposable income per capita, and increase the Gross Domestic Product (GDP) per capita in Luoyang City?</p> <ul style="list-style-type: none"> <li>• To what extent is the project likely to contribute to Luoyang City’s overall development objectives, including (1) a provincial sub-central city, (2) an advanced manufacturing base in the central part of the People’s Republic of China (PRC), (3) internationally renowned tourist city, and (4) an environment-friendly livable city (refer to Luoyang City Master Plan: 2011-2020)?</li> <li>• In what ways has the project demonstrated its commitment to encouraging women and ethnic minorities in the area to participate in the project’s planning, implementation, public awareness, and education programs and providing project-created job opportunities to women and ethnic minorities as a priority?</li> <li>• Did the project have any unintended or adverse impact on society and the economy?</li> <li>• Did the project comply with safeguard requirements? Are there any issues left or new issues after completion?</li> </ul>	<p>Data from LRTC</p> <p>Interviews with the Government, project staff, NDB Management and staff</p>
<p><b><u>Performance of partners</u></b></p>	<p><b>NDB:</b></p> <ul style="list-style-type: none"> <li>• How well were the comments and recommendations for quality enhancement and assurance processes included in the final project design?</li> <li>• Was adequate supervision and implementation support provided in a timely manner, and portfolio performance monitored on a continuous basis?</li> </ul>	<p>Project documents</p> <p>Interviews with the Government, project staff, NDB Management and staff</p>

- Did the Independent Evaluation Office exercise its developmental and fiduciary responsibilities adequately, ensuring that projects had sound financial management systems and audit reports were submitted in a timely manner, as required?

**The Government**

- How were periodic progress reports used, and was the Project Completion Report provided in a timely manner and of the required quality?
- Were counterpart resources (funds and staffing) provided in line with the agreement at the design stage?
- Were the flow of funds and procurement procedures suitable for ensuring timely implementation?
- Did the government have the required capacity at all levels to implement the project as per schedule?

## Annex 7: Innovative patents on energy saving and published papers

Based on the result of patent novelty searching, Luoyang Metro Line 1 (LML1) Project Construction has yielded the following technological achievements, including five awards of different categories, 16 patents undergoing applications, 11 of which have been granted (including five invention patents, and six utility model patents), five invention patents under public examination, one software copyright undergoing application, and five published research papers (four of which have been published, and one has been confirmed for publication).

Table 2: Five awards					
#	Item	Award date	Award name	Award level	Awarding department
1	Water-cooled direct expansion magnetic levitation air conditioning unit for subway stations	September 2020	“Innovative Zhuhai” science and technology award	First prize	Zhuhai municipal bureau of science and technology innovation
2	Control methods and devices of air conditioning unit (ZL201810141010.5)	June 2021	China national invention patent award	Gold medal	China national intellectual property administration
3	Demonstration project for magnetic levitation direct expansion air conditioning Units on LML1	March 2022	Best Practice Case for Energy Efficiency in Public Buildings		Tsinghua University Building Energy Research Center
4	Overall design for LML1 project	July 2022	Henan Province Excellent Survey and Design Award	First prize	Henan provincial survey and design association
5	Overall design for phase 1 of the LML2 project	July 2023	Henan Province excellent survey and design award	First prize	Henan provincial survey and design association

**Table 3: A list of 11 granted patents, including five invention types and six utility models**

#	Name	Year	Category	State	Notes
1	Automatic cleaning device for air conditioning unit filters	2013	Utility model	Granted	
2	An energy-saving air conditioning ventilation device for transitional seasons	2013	Utility model	Granted	
3	Magnetic levitation air conditioner	2015	Utility model	Granted	
4	A control method and the corresponding device for air conditioning units	2019	Patent	Granted	
5	Fan system and its control methods for air conditioning unit	2020	Patent	Granted	
6	Ventilation and air conditioning system for subway underground stations	2020	Patent	Granted	
7	Control device for subway fresh air systems	2020	Patent	Granted	
8	A control method, the corresponding device, and AC unit for a direct expansion air conditioning system	2021	Patent	Granted	
9	Control method and device for an air conditioning water system with a pressure-equalizing bypass valve	2022	Patent	Granted	
10	A single-sided supply and return air ventilation and air conditioning system for subway stations	2022	Utility model	Granted	
11	Optimal control method and apparatus for air conditioning systems, electronic devices, and storage media	2023	Patent	Granted	

**Table 4: 1 Granted software copyright**

#	Name	Year	Category	State	Notes
1	Energy-saving control software for ventilation and air conditioning systems based on staged mode control	2021	Software copyright	Granted	

**Table 5: Five research papers, including four published and one accepted**

#	Name	Year	Category	State	Notes
1	Experimental study on direct-cooling air handling unit based on automatic optimization for variable air volume control	2019	Scientific paper	Published	
2	Application of water-cooled direct expansion air conditioning units in rail transit	2019	Scientific paper	Published	
3	Application of water-cooled direct expansion magnetic levitation air conditioning units in a subway project	2020	Scientific paper	Published	
4	An experimental study on the performance of maglev direct expansion air conditioning units for subway stations	2023	Scientific paper	Published	Core journal
5	Analysis method for cooling source scheme in subway stations based on annual hourly energy consumption simulation	2023	Scientific paper	Accepted	Core journal unpublished
6	On the combination of single-end large system and new cooling source for subway stations	2020	Scientific paper	Published	
7	Research on single-end air supply technology for subway stations	2022	Scientific paper	Published	

Table 6: Five invention patents, published and undergoing substantive examination					
#	Name	Year	Category	State	Notes
1	A control method and the corresponding control device for subway fresh air systems	2019	Invention patent	Published	In examination
2	Ventilation and air conditioning system for subway stations	2020	Invention patent	Published	In examination
3	A control method, device, and air conditioning system for air conditioning water systems	2021	Invention patent	Published	In examination
4	An energy-saving wind valve mechanism for platform screen doors	2021	Invention patent	Published	In examination
5	A staged regulation method of subway HVAC system based on numbers of departing train pairs	2022	Invention patent	Published	In examination

## Paper origins

- Mingsheng Zhuo, Peisheng Chen, Qi Cheng & Yang Liu. (2019). Experimental Study on Direct-cooling Air Handling Unit Based on Automatic Optimization for Variable Air Volume Control. *Refrigeration and Air Conditioning* (4).
- Haoming Hu. (2019). Application of Water-Cooled Direct Expansion Air Conditioning Units in Rail Transit. *Theoretical Research in Urban Construction* (35).
- Haiyang Yu, Shuaiyang Bao. (2020). Application of Water-Cooled Direct Expansion Magnetic Levitation AC Units in a Subway Project. *Architecture Engineering Technology and Design* (6).
- Zhuo Yang, Xuedu Wu, Shaoguang Li, Siyuan Chen, Shuaiyang Bao & Xiaofeng Li. (2023). An Experimental Study on the Performance of Maglev Direct Expansion Air Conditioning Units for Subway Stations. *Heating Ventilating & Air Conditioning* (8).
- Dan Zhang. (2020). On the Combination of Single-End Large System and New Cooling Source for Subway Stations. *Low Carbon World*, (11).
- Jipo Wang. (2022). Research on Single-End Air Supply Technology for Subway Stations. *New Technology and New Products of China* (7).

## Annex 8: Energy efficiency in Luoyang Metro project

The PRC government attaches great attention to energy efficiency in the construction and operation of infrastructure and industrial investment projects. As a green, safe, efficient, and comfortable means of transportation, rail transit has been prioritised by both the government and investors at all levels in China as the main pillar of a comprehensive transportation network. Thereby stopping the trend of ecological degradation and promoting socio-economic inclusive and sustainable development.

The NDB-financed Luoyang Metro Line 1 (LML1) project is critical to the urban development of Luoyang City and is listed as a key construction project in the Luoyang City Development Plan (2011-2020) approved by the PRC State Council. Within the design, construction, and operation of the project, GOLY and LRTC have been working to make the project green and energy-efficient in support of Luoyang's goal of building a more livable city.

According to the feasibility study report of the project, the annual electricity consumption during the operation of the project is 87 million kWh (kilowatt hour) in the initial period, 101 million kWh in the near future, and 118 million kWh in the long term. In the future, as the metro network of Luoyang City develops and comes into operation, electricity consumption will increase accordingly. Therefore, as the first metro line in Luoyang, GOLY and LRTC highly valued the project's energy saving and green development. They have carefully organised and adopted a series of measures to provide reference and demonstration for the green development of the upcoming Luoyang metro projects.

### A. Enhancing energy efficiency design

- 1. Energy efficiency architectural design:** The design of station and vehicle section parking lot buildings should adopt an optimised design to reduce energy consumption in terms of building shape, orientation to adapt to natural wind, building materials, and building structure.
- 2. Metro vehicle energy efficiency:** Reduce vehicle weight by adopting lightweight alloy vehicles.
- 3. Energy efficiency in traction power supply system:** Adopt energy efficiency modules, such as low-loss transformers, high-power rectifiers, low-loss rectifier tubes, power-efficient elastic energy-storage operating mechanisms, and other equipment.
- 4. Electricity conservation:** Adopt centralised reactive power compensation modules, set voltage-reducing substations close to electrical load centers to reduce losses, and install smart lighting systems and energy-saving and environmentally friendly lighting equipment.
- 5. Energy efficiency ventilation system:** The energy consumption of the ventilation system accounts for 40% of the total consumption of the station; the ventilation system is the major target of energy saving. The design adopts a closed platform door system to reduce the air-conditioning (air-con) cooling load of the station's grand air-con system during the air-con season, introduces inverter technology in the air-con exhaust in the public area, and utilizes

the train piston wind in the tunnel to regulate the temperature of station.<sup>1</sup>

6. Adopts a kinetic energy recovery system to collect the braking energy generated by the train.

## **B. Implementation of energy efficiency design**

In this project, the energy-efficient work is carried out in accordance with the above design, as follows:

### **(i) Medium-voltage inverter type braking kinetic energy recovery system**

The medium-voltage inverter-type braking kinetic energy recovery system was applied for the first time in the LML1. Installing a braking kinetic energy recovery system in the main line traction substation to achieve the recycling of vehicle braking kinetic energy. At the same time, it effectively improves the DC side grid voltage fluctuation, reduces the tunnel temperature increase, and reduces the slipper damage of vehicle brake tiles (implemented in the main line traction substation of LML1);

### **(ii) Magnetic levitation compressor + terminal water-cooled direct-expansion refrigeration**

For the first time, the magnetic levitation compressor + terminal water-cooled direct-expansion refrigeration (LEV-DER) technology is applied to the air-con compressor unit of the metro for air conditioning and saving energy in the station.

After energy efficiency research, analysis, and demonstration, the air-con and ventilation system adopts key energy efficiency technologies such as "the separation of refrigeration source for air-con of public area (large system) and administrative area (small system), water-cooled modular machine or LEV-DER machine as the cooling source for large systems, air-cooled multi-connected unit for small system cooling source, open-able screen door upper mounting device, Smart control of piston wind, and other key energy efficiency technology. Thus, it achieved significant energy efficiency and consumption reduction. After optimisation of the public area, equipment area, and separation of large and small system loads, there is a reduction of about 40% of energy consumption, which meets the standard of station annual power consumption below 350,000 kWh;

### **(iii) Forced braking slope and train kinetic energy recovery**

The project has installed forced braking slopes at the entrance (exit) section of the Jinghua Road Station, Chang'an Road Station, Wangcheng Park Station, Peony Square

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<sup>1</sup> According to the report of Yi Jiang, an academician of the Chinese Academy of Engineering, the ventilation and air-con system and the traction system energy consumption in the vehicle system in northern China account for about 1/3 and 1/2 of the total energy consumption, respectively. The power consumption of rail transportation systems is mainly concentrated in the ventilation, air-con, and traction systems, accounting for 30-40% of the total energy consumption. Therefore, reducing energy consumption of ventilation and air-con systems is critical of energy efficiency and consumption reduction in the Metro.

Station, Laimaying Station, and Shijiawan Station. Forced braking slopes lengths of about 1,790 m. Energy recovery is achieved through the train kinetic energy recovery system;

**(iv) Mass adoption of lightweight automatic dimming trains and energy-efficient electric traction**

The train weight is reduced, and it is equipped with automatic dimming, lighting system energy consumption logging, and other modules. They can automatically adjust the brightness inside of the wagon according to the change in the lighting environment, which not only reduces energy consumption but also provides a more comfortable environment. Some trains are equipped with permanent magnet traction systems, permanent magnet motors, and inverter air-con systems, which can achieve energy savings of more than 30% compared to asynchronous motor traction systems.

**C. Cooperation with external institutions and suppliers to promote energy efficiency**

Form a project energy efficiency management team led by the construction unit, with the participation of energy efficiency consulting units, design units, equipment manufacturers, engineering units, and expert members. Emphasising the energy efficiency management in the whole project life-cycle, adopting the idea of "target-oriented" whole-process energy efficiency management, and meeting the standard of average annual station energy consumption below 350,000 kWh.<sup>2</sup> From plan optimisation, construction drawing design, equipment bidding and procurement, construction and installation, commissioning and acceptance, O&M re-adjustment, and other stages of comprehensive, multi-angle,<sup>3</sup> intervention, to achieve the successful completion of the energy efficiency solutions and energy efficiency goals of the ventilation and air-conditioning system of the Luoyang Metro.

**D. Major Energy efficiency progress**

Energy Efficiency Progress has been made as the following in LML1:

**1. Energy efficiency of Convertible Ventilation Conservation Module**

The convertible ventilation conservation module reduced energy consumption by 38,554.5 kWh/year, reduced operation cost by 21,590.52 CNY/year, and reduced

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<sup>2</sup> According to Tsinghua University's statistical analysis of energy consumption data of 7 cities and more than 500 stations, the energy consumption of standard underground stations for all-purpose air-con is about 1~1.5 million kWh. The Wuxi Metro demonstration station ventilation and air-con system consumes 370,000 kWh of energy annually through energy efficiency renovation and refined operation. Considering the expected passenger flow and outdoor climate conditions, a target of annual energy consumption of ventilation and air-con in standard stations of Luoyang Metro not exceeding 350,000 kWh was determined.

<sup>3</sup> The LML 1 was conducted air leakage analysis, air-con load study and air-con system scheme optimisation at the design stage. The bidding stage provided detailed parameter requirements for the ventilation and air-con system equipment, and equipment factory inspection verification was carried out. During the commissioning and acceptance phase, equipment performance was evaluated through field testing and optimisation of solutions, recommendations were made accordingly.

carbon emissions by 21.99 tons/year/station. For the LML1, the LRTC can reduce energy consumption by about 732,000 kWh per year, save 410,000 operation costs, and reduce carbon emissions by 418 tons.

## **2. Energy Efficiency of LEV-DER Module Pilot in LML1**

The measured energy efficiency ratio of the pilot station is 6.78, and the highest value of the energy efficiency ratio of the majority of domestic stations is 4. The conservative energy efficiency rate of the pilot station is more than 40%. Taking 600,000 kWh cost station in the same climate zone as the standard, the pilot station reduced 240,000 kWh/station/year, reduced operation cost by 156,000 CNY/year/station, and reduced carbon emissions by 136.9 tons CO<sub>2</sub>/year/station.

## **3. Energy Efficiency of Convertible Ventilation Conservation Module (CVCM) in LML1**

With CVCM, total electricity consumption was reduced by 694,000 kWh/year for the LML1 (without a pilot station). Pilot stations (Jiefang Road Station and Peony Square Station) reduced 480,000 kWh/year, which reduced electricity costs by 657,440 CNY/year. Metro Line 1 carbon emissions were reduced by 669.5 tons of CO<sub>2</sub> /year.<sup>4</sup>

## **4. General Energy Efficiency of the Operating Stations of Luoyang Metro**

After the successful application of the air-con system solution in pilot stations in the LML1, the solution has been fully promoted and applied to Metro Line 2. Within 15 underground stations of Line 2, 14 stations are equipped with LEV-DER modules, and all 15 stations are equipped with CVCM modules.

Currently, LRTC operates two metro lines in Luoyang. With only CVCM, it reduced energy consumption by about 5.1123 million kWh/year, which reduced electricity cost by about 2.863 million CNY/year, and reduced carbon emission by 29,155.5 tons CO<sub>2</sub> /year.

In the design, construction, and operation of the LML1, several technical innovations were adopted to improve energy efficiency. The predetermined target of an average annual energy consumption of less than 350,000 kWh for a standard station was met. The energy efficiency practices of LML1 provide a model for Line 2, as well as the planned Lines 3 and furthermore, the LML1 demonstration provided will help promote low-carbon development and more livable city development in Luoyang.

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<sup>4</sup> Luoyang Metro's electricity rate of \$0.65/kWh and a national grid average emission factor of 0.5703 tons CO<sub>2</sub>/MWh in 2022.

## Annex 9: CO<sub>2</sub> emissions reduced

Indicators	Reduction in carbon emissions (tons)/year
Energy efficiency of convertible ventilation conservation module	<b>418</b>
Energy efficiency of LEV-DER module pilot in LML1	<b>2,601.1</b>
Energy efficiency of convertible ventilation	<b>669.5</b>
General energy efficiency of the operating stations of Luoyang metro	<b>29,155</b>

## Annex 10: Summary from customer satisfaction surveys

In 2022, the China Academy of Safety Science and Technology (CASST) conducted a third-party independent survey and evaluation of passenger satisfaction for Metro operations in Luoyang. The methodology and findings are summarised as follows.

### A. Survey and assessment methodology

The passenger satisfaction survey has seven indicators: station accessibility, environment and order, station operation, interchange, counseling, complaint, and security.

Table 1: Definitions

<b>Station accessibility</b>	The extent of clear and attractive guidance information for entering and leaving the station; convenient and quick ticketing; standardised and orderly security checking and smooth accessing.
<b>Condition and order</b>	The extent of sanitation, well-ventilated, and moderate temperature; order of queuing and boarding, no begging, performing, and advertising behavior.
<b>Station operation</b>	The extent of passenger information services; elevators, escalators, and other facilities that are well maintained and functional; metro trains operation punctuality, stability, and low noise; and barrier-free access and humane facilities that are complete and in good working order.
<b>Interchange</b>	The extent of convenient, fast, and orderly interchange.
<b>Counselling</b>	The extent of friendly and accurate responses from the metro staff.
<b>Complaint</b>	The extent of the open channel of complaint filing, timely and satisfying response.
<b>Security</b>	The extent to which passengers feel safe and secure during the whole process of metro service.

**Survey Sample.** The survey sample size shall not be less than 1% of the line's average daily traffic volume and a minimum of 400. The surveyed stations should be at least 50% of the total stations

on the line, covering the interchange stations, stations with regular flow control, and stations with the highest average daily traffic volume on the line.

**Survey Timing.** The survey would be carried out during the metro's rush hour and regular hours.

**Assessment Methodology.** Survey uses a randomised questionnaire, which categorised into three evaluation levels: satisfactory, fair, and unsatisfactory.

#### **A. Survey Execution**

In addition to the above-mentioned seven indicators of the questionnaire, another 13 additional questions have been added to reflect more accurate passenger feedback. The questionnaire shall be answered with a simple check mark.

Questionnaires were distributed and collected on-site for passengers at LML1 and LML2 on ten selected stations for each metro line between September 20 and 22, 2022. Online questionnaires were also conducted from 22-30 September 2022.

The stations selected at LML1 include Hongshan Station, Qinling Road Station, Chang'an Road Station, Peony Square Station, Wangcheng Park Station, Jiefang Road Station, Zhouwangcheng Square Station, Yingtianmen Station, Qingniangong Station, and South Qiming Road Station. For LML2, the selected stations were Erqiao Road Station, Guohua Road Station, Luoyang Railway Station, Jiefang Road Station, Wenbo Park Station, Sports Center Station, Citizens' Home Station, Kaiyuan Lake Station, Longmen High-speed Railway Station, and Balitang Station.

The QR code of the passenger satisfaction survey was posted at each station for conducting online surveys.

In total, 1,148 questionnaires were collected, including 900 on paper and 248 electronics; of which, 505 were collected for Line 1 (414 papers and 91 electronic copies), and 683 were collected for Line 2 (486 papers and 157 electronics).

Among passengers who completed the survey, 609 were male and 539 were female, accounted for 53% and 47%, respectively. In terms of age distribution, 73% of the passengers were in the age group between 15-40 years, with 37% being 26-40 years old and 36% being 15-25 years old.

The results of the survey indicated that 38% of passengers take the metro 3-10 times per week, which is basically considered as commuter, while another 24% take the metro more than ten times per week. 38% of surveyed take the metro 1-2 times per week. The data shows that more than 60% of the passengers take the metro frequently, and passengers are increasingly choosing urban rail transit in Luoyang.

#### **B. Questionnaire and findings**

The survey has three levels of response: satisfactory, fair, and unsatisfactory, with score coefficients corresponding to 1, 0.5, and 0, respectively. According to the calculation criteria, sum up the passenger satisfaction evaluation scores of the two metro lines. The full score is 300 points.

According to the results, the passenger satisfaction survey of Metro Line 1 scored 294.51, with a satisfaction rate of 98.17%. Satisfaction in all seven indicators, including station guidance, ticketing, security check, overall station conditions, order, service information and facilities,

punctuality, disabled accessibility, professional and friendly staff, and sense of security, reached 95% and above. It shows that passengers are more satisfied with the accuracy and convenience of station guidance, facilities, staff service, and attitude. However, it looks like there is a flaw in the level of train operation noise, with a satisfaction level of 92.7%.

The passenger satisfaction survey of Metro Line 2 scored 291.01, with a satisfaction rate of 97.01%. Among them, Satisfaction ratings were mainly distributed between 86% and 98%. Satisfaction rate for train orders, service facilities, elevators, punctuality, stability, disabled accessibility, interchange order, staff attitudes, and sense of security all reached 95% and above. Those with relatively low satisfaction were train operation noise, 86.3%; guidance information, 92.1%; disabled accessibility, 92.4%; and security check, 92.8%.

### **C. Comprehensive evaluation**

During the passenger satisfaction survey, both lines were surveyed independently. Accordingly, in this passenger satisfaction evaluation, both Lines were conducted separately, with Line 1 scoring 294.51 and Line 2 scoring 291.01, respectively.

Passengers surveyed on the two metro lines were not the same, but by analysing the final results of the survey, it can be found that the two lines are relatively similar in terms of higher and lower satisfaction feedback. More favorable service mainly involves safety, environmental sanitation, convenient service facilities, good attitude of staff, etc. On the other hand, the relatively low feedbacks are mainly centered on train operation noise, security checks, access to the station, begging, performing, and advertising behavior in the train, etc. Passengers from some stations have an average opinion on the interchange guiding signs, the convenience of interchange, the stability and punctuality of the train operation, and the order of queuing and boarding the train.

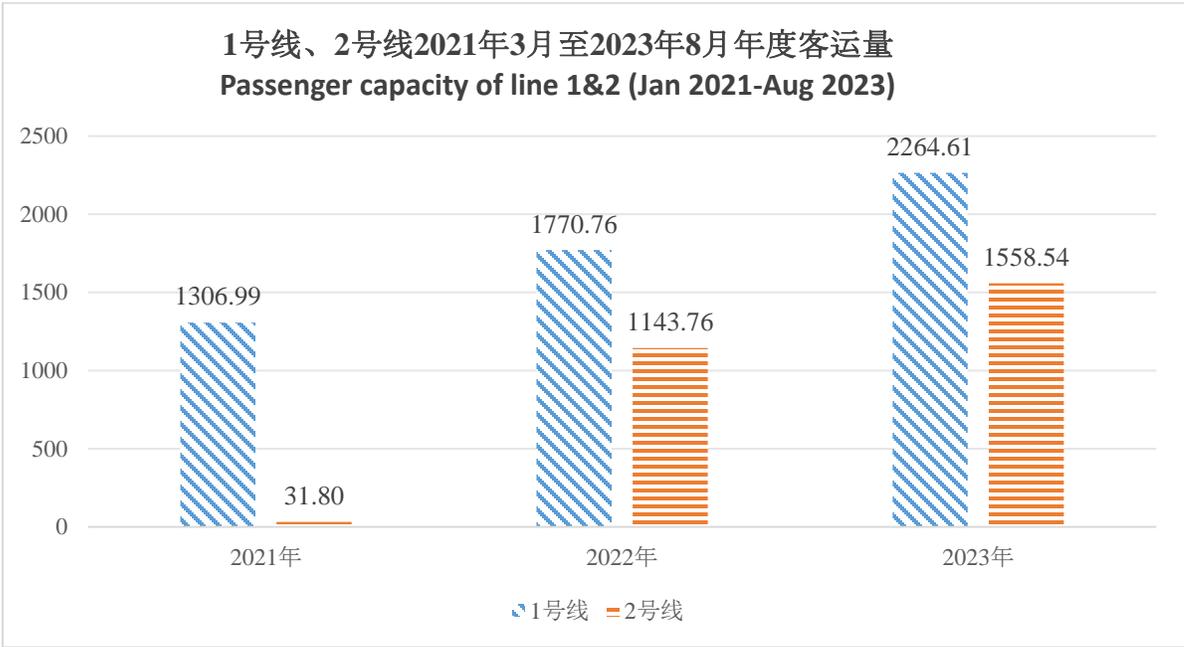
In response to the indicators of low satisfaction in the evaluation, the independent assessment report of CASST recommended that LRTC takes the following corresponding measures:

- (i) It is recommended to study measures to reduce train operation noise, improve stability and punctuality, and enhance the comfort of the environment for passengers traveling and queuing. In addition, the staff should stop some passengers from talking loudly and playing video and music on their cell phones on the train, strengthen the publicity and control efforts, and, if necessary, incorporate the measures to alleviate such issues into the passenger code of the metro and standardise its implementation;
- (ii) It is recommended that the security check should be enhanced to strictly prevent the entering of begging, performing, and distribution of small advertisements. Also, warning signs prohibiting advertising should be posted on the train, and security and dispatchers should stop such behavior on sight and in time to maintain the order of passengers' quiet travel; and

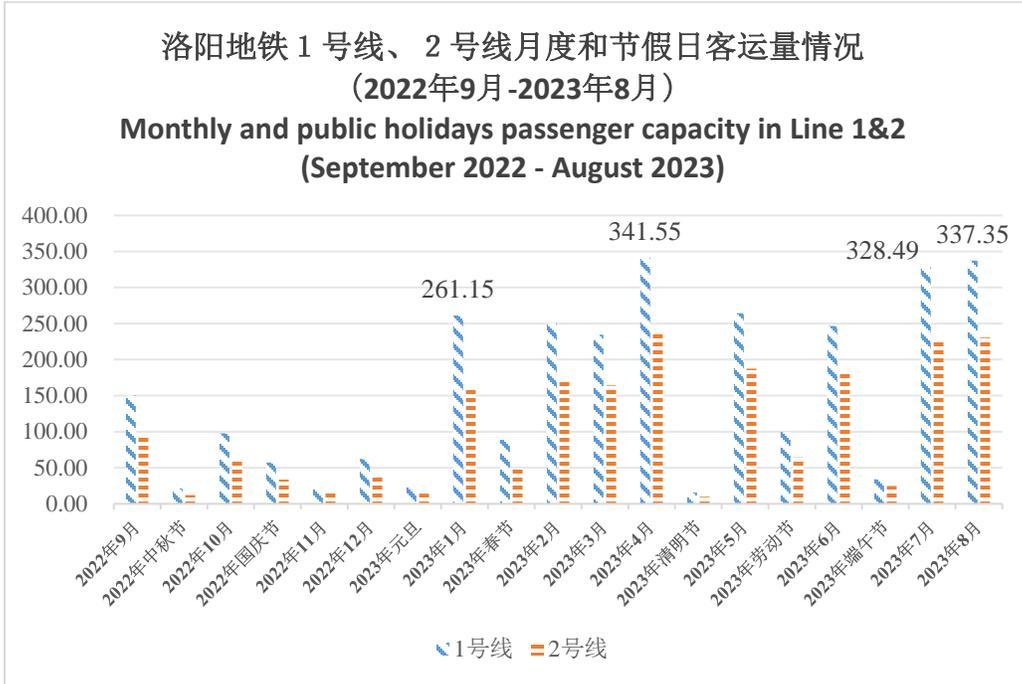
It is recommended to further enhance the passenger flow organisation at the interchange station and increase the number of platform service staff during the morning and evening peak hours.

# Annex 11: Trends in passenger traffic on LML1 and LML2

Figure 1: The Average passenger numbers on LML1 and 2 (2021-2023)  
(‘0000-passenger numbers)

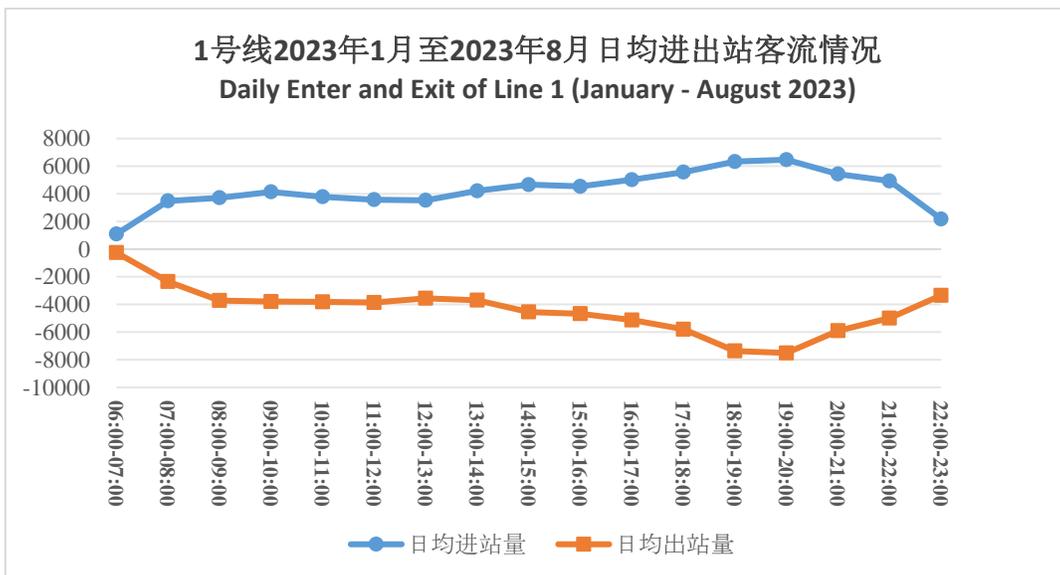


**Figure 2: Passenger capacity during special months and public holidays of Luoyang Metro Line 1 and 2 ('0000 passengers)**



**Figure 3: Daily Utilisation of Line 1**

**Average Entry and Exit Passenger Capacity at Different Intervals of Line 1 from January 2023 to August 2023.**



## Annex 12: Annual key indicators of the maintenance engineering department

Table 1: Statistical table of annual key indicators of Maintenance Engineering Department

Evaluation indicator 评价指标	Indicator value 分公司级指标值	Cumulative value 累积指标
Failure rate of signaling system 信号系统故障率	0.8 time per 10,000 train-kilometers 0.8次/万列公里	0.169 time per 10,000 train-kilometers 0.169次/万列公里
Failure rate of power supply system 供电系统故障率	0.16 time per 10,000 train-kilometers 0.16次/万列公里	0.017 time per 10,000 train-kilometers 0.017次/万列公里
Failure rate of PSDs 站台门故障率	0.8 times per 10,000 times 0.8次/万次	0.015 times per 10,000 times 0.015次/万次
Failure rate of train exiting from main line operation 列车退出正线运营故障率	0.4 time per 10,000 train-kilometers 0.4次/万列公里	0.017 time per 10,000 train-kilometers 0.017次/万列公里
Reliability of automatic recharge ticket vending machine 自动充值售票机可靠度	98.0%	99.27%
Reliability of entrance and exit gates 进出站闸机可靠度	99.0%	99.80%
Reliability of escalator 自动扶梯可靠度	98.5%	99.49%
Reliability of elevator 垂直电梯可靠度	99.0%	99.70%

## Annex 13: Awards for Luoyang Metro Line 1 project

#	Name	Award category	Award
1.	General contracting project of LML1	Excellent survey and design award of Henan province	First prize
2.	Civil design for section 06 of LML1	Excellent survey and design award of Henan province	Second prize
3.	Design of Hongshan Station of LML1	Excellent survey and Design Award of Henan Province	Third prize
4.	Civil design for section 02 of LML1	Excellent survey and design award of Hubei province	Excellent survey and design award of Hubei province
5.	Civil design for section 02 of LML1	Survey and design award of Henan province	Second prize
6.	Design of integrated monitoring, fire alarm system, environmental and equipment monitoring system, access control system, automatic ticketing system, escalators, and platform screen doors for LML1	Excellent survey and design award (municipal engineering category) of Guangzhou city	First prize
7.	Design of integrated monitoring, fire alarm system, environmental and equipment monitoring system, access control system, automatic ticketing system, escalators, and platform screen doors for LML1	Excellent survey and design award (intelligent building) of Guangzhou city	Third prize
8.	Comprehensive application of BIM technology in LML1 project	The 12th China "innovation cup" BIM application competition	Third prize
9.	Comprehensive application of BIM technology in LML1 project	2021 China information technology skill competition, building	Second prize

		information modeling (BIM) category	
<b>10.</b>	Comprehensive application of BIM technology in LML1 project	The 4th "craftsmanship cup" BIM competition of Henan province	Second prize
<b>11</b>	Comprehensive application of BIM technology in LML1 project	5th "central plains cup" BIM application competition for construction projects of Henan province in 2021	Second prize
<b>12</b>	Comprehensive application of BIM technology in LML1 Project	4th Shanghai BIM innovative application competition - project case award (municipal engineering category)	First prize
<b>13</b>	Comprehensive application of BIM technology in LML1 project	7th construction engineering BIM competition	Second prize
<b>14</b>	Key technology research project for construction of urban rail transit in high water level and ultra-thick gravel layer	China urban rail transit scientific and technological progress award	Second prize
<b>15</b>	Key technology research project for construction of urban rail transit in high water level and ultra-thick gravel layer	Science and technology award of China railway engineering group	First prize

## Annex 14: List of key persons met

### Government Departments

Yunjian Mao, Deputy Secretary General, Luoyang Municipal People's Government

Menghui Zhao, Director, Department of International Economic Cooperation, Department of Finance of Henan Province

Qingyuan Duan, Section Chief, Department of International Economic Cooperation, Department of Finance of Henan Province

Lixia Zhang, Deputy Director, Luoyang Municipal Finance Bureau

Zhen Sun, Section Chief, Department of International Economic Cooperation, Luoyang Municipal Finance Bureau

Hansheng Zhuang, Section Chief, Rail Transit Operation Management Division, Luoyang Transportation Bureau

Wenbing Wei, Deputy Chief, Department of Infrastructure Development, Luoyang Municipal Development and Reform Commission

Xiaoyu Jiao, Chief, General Division, Luoyang Municipal Bureau of Statistics

### Luoyang Rail Transit Group Co. Ltd.

Chaoxin Ma, CEO & Chairman

Haobo Li, Deputy General Manager

Xuedu Wu, Chief Engineer

Haiyang Fang, Manager, Finance Department

Xiang Ji, Manager, Dispatching and Ticketing Department, Operation Company

Min Luo, Manager, Vehicle Department, Operation Company

Yantao Chu, Manager, Maintenance Engineering Department, Operation Company

Jie Liu, Deputy Manager, Passenger Transport Department, Operation Company

Liang Sun, Staff Member, Land Acquisition and Resettlement

Yanwei Shen, Manager, Human Resources Department

Hongwei Li, Manager, Corporation Management Department

Hongjun Zhao, Manager, Contract and Legal Department

Jingfeng Jing, Manager, Chief Engineer's Office

Yanmin Wang, Manager, Safety and Quality Department  
Jile Ren, General Manager, Property Management Company  
Lianfeng Zhang, General Manager, Construction Management Company  
Taoliang Zhang, General Manager, Development Company  
Shaofeng Song, Deputy General Manager, Operations Company  
Peng Li, Development Company, Deputy General Manager, Development Company  
Tong Zhang, Manager, Human Resources Department, Operation Company  
Haiyang Yu, China Railway Design Corporation  
Shimeng Wang, Senior personnel, Finance Department  
Jianbo Cao, Director, Human Resources Department  
Na Wang, Senior Director, Enterprise Management Department  
Weili Li, Legal Affairs Officer, Contract and Legal Department  
Xurun Ye, Director, Chief Engineer's Office  
Guojin Li, Manager  
Guobin Sun, General Manager, Construction Management Company  
Shiyang Jin, Manager, Development Company  
Liang Guo, Business Manager, Development Company  
Qianqian Ren, Operations Branch Assistant Operation Company

**Metro Line 1 Passengers**

Zhenling Zeng  
Xiuju Xing  
Honglin Wang  
Zhongliang Du  
Yuping Wang

## Annex 15: List of documents reviewed

### Section A. NDB Policies, Guidelines, and General Strategies

- NDB (2016). New Development Bank Country Partnership Plan
- NDB (2016). New Development Bank Procurement Policy
- NDB (2016). New Development Bank Environment and Social Framework
- NDB (2017). New Development Bank General Strategy: 2017-2021
- NDB (2018). Project Implementation Guidelines
- NDB (2016). Policy on Sovereign Loans & Loans with Sovereign Guarantee

### Section B. Project Documents

- NDB (2017) Luoyang Metro Project Environmental Impact Assessment, February 2017
- NDB (2017) Luoyang Metro Project Feasibility Study Report (Chinese), June 2017
- NDB (2017) Luoyang Metro Project Feasibility Study Report (English), June 2017
- NDB (2017) Project Document to the Board, September 13, 2017
- NDB (2018) Appraisal Mission Memorandum of Understanding Between New Development Bank, Henan Provincial Department of Finance, and Luoyang Rail Transportation Co. Ltd.
- NDB (2018) Luoyang Metro Project Loan Agreement Between New Development Bank and People's Republic of China, August 16, 2018
- NDB (2018) Loan Agreement between People's Republic of China and New Development Bank, August 16, 2018
- NDB (2020) Request for the Amendment to Legal Agreement, April 10, 2020
- NDB (2020) Amendment No.1 to the Loan Agreement, May 07, 2020
- NDB (2020) Project Progress Report (September 2018-June 2020), July 24, 2020
- NDB (2021) Aide Memoire, Environmental and Social Implementation Review Mission, June 25, 2021
- NDB (2021) Aide Memoire, Review Mission, April 27, 2022
- NDB (2021) Project Progress Report (July 2020-June 2021), September 06, 2021
- NDB (2022) Project Performance Assessment, August 17, 2022
- NDB (2022) Project Performance Assessment, November 9, 2022
- NDB (2022) Project Progress Report (July 2021-December 2021), March 21, 2022
- NDB (2022) Project Progress Report (January 2022-August 2022), September 30, 2022
- NDB (2022) Structure of Project Completion Report
- NDB (2022) Aide Memoire, Review Mission, April 25, 2022

## Annex 16: Photos from the Evaluation Main Mission to Luoyang



The Independent Evaluation Office team visited the Luoyang Metro Line 1 in September 2023.

## Abbreviations

<b>CVCM</b>	Convertible Ventilation Conservation Module
<b>LML1</b>	Luoyang Metro Line 1
<b>LML2</b>	Luoyang Metro Line 2
<b>LRTC</b>	Luoyang Rail Transit Corporation
<b>NDB</b>	New Development Bank
<b>O&amp;M</b>	Operation and Maintenance
<b>PRC</b>	People's Republic of China
<b>kWh</b>	kilowatt hour