

Research on Integrated Design of Urban Arterial Road ITS based on Co-location and Co-line Mode

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Abstract

With the acceleration of urbanization, urban arterial road traffic management faces prominent problems such as redundant poles, information silos among multiple systems, and repeated investment. This paper takes the Luoshuiwan Road (Puwu Road-Binjiang Avenue) Construction Project in Jiangbei New District, Nanjing as the research object, and proposes an integrated design solution for urban arterial road Intelligent Transportation System (ITS) based on the co-location and co-line model. This model integrates traffic engineering and lighting engineering through co-location and co-line construction, and on this basis integrates five major subsystems including traffic signal control, traffic violation capture, video monitoring, illegal parking capture, and truck right-turn stop safety management, while achieving data sharing and collaborative management through a unified center platform. Case analysis shows that the co-location and co-line model effectively reduces redundant pole installation and lowers engineering construction and operation & maintenance costs; the multi-system collaborative management architecture improves the overall efficiency of traffic management. The research results of this paper can provide reference for similar urban arterial road ITS construction.

Keywords

Co-location and Co-line; Intelligent Transportation System; Urban Arterial Road; Integrated System Design; Traffic Management.

1. Introduction

Urban arterial roads are the backbone channels of urban road networks, bearing a large amount of traffic collection and distribution functions. With the continuous growth of urban motor vehicle ownership, urban arterial road traffic management faces increasingly severe challenges. Traditional urban arterial road traffic management systems usually adopt the approach of independent design and independent construction of each subsystem, resulting in prominent problems such as redundant pole settings, visual pollution, and repeated investment waste. In addition, there is a lack of effective data sharing and collaborative mechanisms among subsystems, forming "information silos" that make it difficult to realize the overall benefits of the system.[1]

Intelligent Transportation System (ITS) as an important means to solve urban traffic problems has received widespread attention and application in recent years. Domestic and international scholars have conducted extensive research on ITS system design, covering many fields such as signal control optimization, traffic violation detection, and video monitoring analysis. However, existing research mostly focuses on technical optimization of single subsystems, and research on how to carry out integrated design at the engineering implementation level for multiple systems is relatively insufficient. Especially in Chinese urban road construction, traffic engineering and lighting engineering are respectively responsible by different specialties, with

pole settings independently, causing a large amount of resource waste and management difficulties.[13]

Co-location and co-line, as an intensive construction model, can effectively solve the above problems by uniformly planning and setting poles and pipelines of multiple specialties. This model has application precedents internationally, but its application research in urban arterial road ITS system integration design in China is still in its infancy. Nanjing Jiangbei New District, as a national-level new district, has carried out active exploration in urban road construction, among which the Luoshuiwan Road (Puwu Road-Binjiang Avenue) Construction Project has carried out innovative practice in the co-location and co-line of traffic engineering and lighting engineering.[15]

This paper takes the Nanjing Luoshuiwan Road project as a case study, and systematically discusses how to carry out system integration design and management of ITS around the core construction model of "co-location and co-line". This paper proposes an ITS intensive construction model of co-location and co-line between traffic engineering and lighting engineering, achieving "one pole for multiple uses, shared trenches", reducing the number of poles by 75.0% and saving investment of approximately 3.12 million yuan. At the same time, a multi-system collaborative management architecture based on a unified platform is constructed to break data silos and achieve cross-system linkage, reducing daily inspection workload by 50% and shortening fault response time by 40%. The two innovations systematically solve the fundamental problems of pole redundancy and low operation and maintenance efficiency in traditional ITS construction, from physical integration to digital collaboration.[3]

2. Study Area and Project Overview

2.1. Project Basic Information

The Luoshuiwan Road (Puwu Road-Binjiang Avenue) Construction Project is located in Jiangbei New District, Nanjing, situated between the Yangtze River Third Bridge and the Yangtze River Fifth Bridge, and is an east-west oriented urban arterial road. The road starts from Puwu Road in the west and ends at Binjiang Avenue in the east, with a total length of approximately 4.3 km. The project is divided into two construction sections: the section from Puwu Road to Pubin Road is an old road renovation section, approximately 2 km long, with an existing red line width of 50 m; the section from Pubin Road to Binjiang Avenue is a new road section, approximately 2.3 km long, with a planned red line width of 62 m, adopting a main-and-side road cross-section form.

Table 1. Road Basic Information

Road Name	Road Class	Red Line Width (m)	Design Speed (km/h)	Road Length (km)	Traffic Facility Class
Luoshuiwan Rd (Puwu Rd-Pubin Rd)	Arterial	50	Main 60/Side 40	2.0	B
Luoshuiwan Rd (Pubin Rd-Binjiang Ave)	Arterial	62	Main 60/Side 40	2.3	B

Note: The traffic facility class is determined according to the Code for Design of Urban Road Traffic Safety Facilities (GB 50688-2011).[4]

The main road has 6 lanes in both directions, built according to urban arterial road standards with a design speed of 60 km/h; the side road has 4 lanes in both directions, built according to urban secondary road standards with a design speed of 40 km/h. The road alignment is straight and curved, with a standard cross-section of bilateral cross slope, where the motor vehicle lane

and non-motor vehicle lane slope is 2% toward the roadside; the sidewalk slope is 2% toward the center of the road. The basic information of the designed road is shown in Table 1.[5]

2.2. Design Principles

This project, under the premise of meeting national and Nanjing municipal relevant standards, follows five guiding principles for design: (1) Forward-looking and advanced-traffic management facility construction should closely follow the future construction direction of the city, the technologies and systems used should have sufficient expansion room, ensuring the system has good compatibility and forward-looking nature, fully embodying the "four combinations" concept of "combining short-term and long-term, construction and management, function and landscape, nature and culture";[1][13]

(2) Open architecture and scalability-adopting and following industrial standards of the International Organization for Standardization, focusing on open design with good flexibility, compatibility and portability, adopting scalable design solutions and open architecture for convenient future functional expansion;[11][13]

(3) Operability and uniformity-following the principles of "unified management, unified mode, unified standards, unified interfaces" at the technical level, ensuring that the overall system benefits can be exerted during the layered and gradual implementation process;

(4) Reliability and stability-taking effective measures to ensure system reliability, including improving system redundancy capabilities, increasing fault tolerance of key equipment, fully considering the maturity of adopted equipment to ensure stable system operation;[11][13]

(5) Security and confidentiality of system operation-the data system should have high security and confidentiality, backing up important materials and information, preventing illegal intrusion through system classification protection and control of data storage permissions.[13]

2.3. Engineering Interface (Co-location and Co-line Model)

The overall project plan adopts the co-location and co-line construction of traffic engineering and lighting engineering specialties, which is the most significant feature distinguishing this project from others. According to the conventional requirements of Nanjing Street Light Management Office, the pole design for combined facilities is uniformly implemented by the lighting specialty, and communication pipelines and reserved pre-embeddings are designed by the lighting specialty, which should set up communication pipelines, power supply pipelines, and various pre-embedded parts and reserved holes according to the design of this project.

In specific implementation, the lighting specialty is responsible for providing one circuit from the street light box-type substation for traffic engineering, and the power capacity required by equipment is submitted by the traffic engineering specialty to the lighting engineering specialty. The power supply lines from the outgoing end of the street light box-type substation to the traffic engineering field equipment are designed by the traffic engineering specialty. For equipment attached to street light poles, the traffic engineering specialty provides position and wiring requirements, and the lighting specialty reserves positions and wiring, with the equipment installation method designed by the traffic engineering specialty.

For sections that do not meet the conditions for co-location and co-line, independent pole setting, excavation and pipe burial treatment are carried out by this project. This implementation strategy of "co-location and co-line as main, independent pole setting as supplement" not only ensures the dominant direction of intensive construction but also takes into account the flexibility of actual engineering conditions.

2.4. Pole Statistics of Co-location and Co-line Plan

In order to quantitatively evaluate the implementation effects of the co-location and co-line integrated design model, this study systematically statistics the equipment layout of various

Intelligent Transportation System (ITS) subsystems along the route based on the construction drawing design documents of the Nanjing Luoshuiwan Road (Puwu Road-Binjiang Avenue) Construction Project. This project involves six major ITS subsystems, with specific equipment configuration including: traffic signal control system covering 11 intersections, of which 9 are equipped with signal controllers, configuring 28 circular lights, 17 arrow lights, 24 countdown timers, 76 integrated pedestrian lights, 20 attached pedestrian lights, and 8 post-mounted pedestrian lights; traffic violation capture system covering 17 approach lanes in the Jiangbei section (including 31 intelligent electronic police capture units, 62 LED stroboscopic environment fill lights, 52 environmental checkpoint capture units, 82 environmental checkpoint fill lights) and 3 approach lanes in the Pukou section (including 6 red-light automatic recording system capture units, 17 LED stroboscopic environment fill lights, 11 reverse environmental checkpoint capture units, 17 environmental checkpoint fill lights); traffic video monitoring system with 13 monitoring points configured with 32 dome surveillance cameras; illegal parking capture system with 11 dedicated dome cameras configured at 7 locations; truck right-turn stop safety management system with 1 radar-video integrated device; non-motorized vehicle management system installed on electronic police poles, sharing the electronic police pole mounting box.

In terms of pole demand estimation, the traditional separate plan follows the principle of independent pole setting for each subsystem. It is calculated that traffic signal poles need 23 (9 intersections x 2.5 poles/intersection), traffic sign poles need 22 (4.3 km throughout the line, one group per 200 m), video monitoring poles need 13, violation capture poles need 14 (20 approach lanes x 0.7), illegal parking capture poles need 7, post-mounted pedestrian signal poles 8, truck right-turn control poles 1, totaling 88 poles in the traditional plan. In comparison, the co-location and co-line plan fully utilizes street light poles as the main mounting carrier, and independently sets 22 poles only for special positions that do not meet co-location conditions (such as curves, special positions at intersections, and places where street light pole structure does not meet requirements, accounting for about 15% of total equipment points).

Through the above comparison of the two plans, the co-location and co-line model can reduce 66 poles, with a reduction rate of 75.0%. In terms of engineering cost, calculated at a comprehensive unit cost of 45,000 yuan per pole (including pole material, foundation construction, cable laying, handholes and installation labor, etc.), the traditional plan costs 3.96 million yuan, the co-location and co-line plan costs 990,000 yuan, directly saving 2.97 million yuan in pole engineering costs. In addition, the significant reduction in the number of poles effectively avoids repeated excavation and pipe laying, with an estimated saving of approximately 150,000 yuan in pipeline engineering costs. Comprehensive calculation shows that this project can save approximately 3.12 million yuan in construction costs through the implementation of co-location and co-line design. The specific comparison data is shown in Table 2.

Table 2. Comparison of Pole Quantity and Cost between Traditional Separate Plan and Co-location & Co-line Plan

Comparison Indicator	Traditional Separate Plan	Co-location & Co-line Plan	Difference/Saving	Change Rate
Number of Poles (pieces)	88	22	-66	-75.0%
Pole Engineering Cost (10,000 yuan)	396.0	99.0	-297.0	-75.0%
Pipeline Engineering Cost (10,000 yuan)	15	5	-10.0	-66%

3. ITS System Integration Design based on Co-location and Co-line

3.1. Traffic Signal Control System

The traffic signal control system is one of the core subsystems of ITS, mainly responsible for regulating intersection signal timing plans, balancing network traffic flow operation, and minimizing stop times, delay time, and environmental pollution. The system adopts a multi-level distributed control structure, divided into three layers: center control layer, communication layer, and intersection layer.[2][12]

The system has basic control functions including multi-period fixed cycle control, arterial coordinated control, and area coordinated control, as well as special control functions such as designated phase control, simulated manual, guard route control, and manual function. It also supports traffic information collection function and equipment fault automatic alarm function.[8][9]

This project sets up signal control design at 11 intersections, of which 9 intersections are equipped with traffic signal controllers. The layout of signal control equipment at each intersection is shown in Table 3.

Table 3. Layout of Signal Control Equipment at Each Intersection

No.	Intersection Name	Signal Controller	Circular Light	Arrow Light	Countdown Timer	Integrated Pedestrian Light	Attached Pedestrian Light	Post-mounted Pedestrian Light
1	Luoshuiwan Rd-Puwu North Rd	1	1	1	1	12	0	0
2	Luoshuiwan Rd-Yuhei Rd	1	4	4	4	16	0	0
3	Luoshuiwan Rd-Yanxin Rd	1	4	0	2	4	0	0
4	Luoshuiwan Rd-Puyun Rd	1	4	4	4	12	0	0
5	Luoshuiwan Rd-Xiangxian Rd	1	4	4	4	12	0	0
6	Luoshuiwan Rd-Pubin Rd	1	2	3	2	0	8	4
7	Luoshuiwan Rd-Huagu Rd	1	4	0	2	4	0	0
8	Luoshuiwan Rd-Huigu Rd	1	2	0	2	16	0	0
9	Luoshuiwan Rd-Hengjiang Ave	0	0	0	0	0	0	4
10	Luoshuiwan Rd-Nanjing Agricultural Univ.	1	3	1	3	0	10	0
11	Luoshuiwan Rd-Binjiang Ave	0	0	0	0	0	2	0
Total		9	28	17	24	76	20	8

3.2. Traffic Violation Capture System

The traffic violation capture system is installed at each signal-controlled intersection to continuously and automatically detect and record motor vehicle driving behavior in designated lanes. The system consists of three parts: intersection front-end subsystem, network

transmission subsystem, and center management platform subsystem. System functions cover traffic violation detection and capture (running red lights, not driving in designated lanes, illegal driving in opposite direction, illegal lane changing, etc.), vehicle detection, vehicle passage information detection, automatic license plate recognition, traffic parameter detection, signal light status video detection, traffic event detection, high-definition recording, vehicle color recognition, data storage, image synthesis and anti-tampering functions.[14]

The Jiangbei section violation capture system is installed at 17 intersection approach lanes, with 31 intelligent electronic police capture units, 62 LED stroboscopic environment fill lights, 52 environmental checkpoint capture units, and 82 environmental checkpoint fill lights. The Pukou section is installed at 3 intersection approach lanes, with 6 red-light automatic recording system capture units, 17 LED stroboscopic environment fill lights, 11 reverse environmental checkpoint capture units, and 17 environmental checkpoint fill lights.

3.3. Traffic Video Monitoring System

The video monitoring system is the most intuitive means of traffic information monitoring and has been widely applied in the field of traffic management. System functions cover traffic condition monitoring, video recording, video control, video storage, backend violation capture, deep learning algorithm, dynamic equivalent pixel enhancement, public security scene deep coverage, and integrated linkage functions.[11][13]

This project installs high-definition surveillance dome cameras on the signal pole integrated poles in the main direction of intersections, covering intersection approach lanes; dome cameras are installed behind bus stops to cover bus stop areas. A total of 13 monitoring points are set up with 32 dome surveillance cameras.

3.4. Illegal Parking Capture System

The illegal parking capture system detects and collects evidence of illegally parked vehicles in no-parking areas along the road. System functions include automatic evidence collection for illegal parking, automatic license plate recognition, automatic evidence collection for other violations, illegal video recording, manual evidence collection, multi-target processing, multi-scenario fast polling evidence collection, evidence image synthesis, image anti-tampering, data breakpoint resume transmission, query statistics and traffic violation processing, expanded front-end audio-video alarm prompting and voice shouting, evidence collection/monitoring automatic switching functions.[14]

This project installs dedicated dome cameras for illegal parking capture at 7 locations, totaling 11 units, covering intersection approach lanes and bus stop areas.

3.5. Truck Right-turn Stop Safety Management System

The truck right-turn stop safety management system is a special system designed for this project targeting the specific safety hazard of truck right-turn blind spots. System functions include stop-free behavior detection and capture, vehicle passage information detection and capture, automatic license plate recognition, high-definition recording, vehicle color recognition, data storage, image synthesis and anti-tampering, networked data transmission functions.[11]

The system sets truck right-turn control measures at intersection directions with high truck right-turn demand, with truck right-turn stop measures supported by radar-video integrated device monitoring. This project installs 1 radar-video integrated device at the north approach of Luoshuiwan Road-Binjiang Avenue to achieve automatic detection and recording of large truck right-turn behavior.

3.6. Power Supply and Communication Plan

The power supply system provides electrical protection for ITS field equipment. The power supply required by the ITS system is drawn from the nearby street light lighting box-type substation, with each lighting box-type substation reserving one circuit for monitoring, and the interface division at the air switch of the lighting box-type substation. This design installs 1 set of traffic signal controller and 1 set of distribution box at each signal-controlled intersection, with power supply for intersection equipment and nearby section equipment drawn from the intersection distribution box. The power cable from the lighting box-type substation to the distribution box uses YJV5x16mm² cable, and the cable from the distribution box to field equipment varies depending on the equipment type.

The network system adopts intelligent ubiquitous perception network (image private network) for data transmission of various systems. The Luoshuiwan Road (Puwu North Road-Hengjiang Avenue section) adopts self-built fiber optic method, with the main optical cable being 1 single-mode 48-core optical cable; the Luoshuiwan Road (Hengjiang Avenue-Binjiang Avenue section) uses the signal control intersection integrated cabinet as the information aggregation node, and then transmits to the Pukou Traffic Police Monitoring Center Platform through rented operator network.

3.7. Center Hardware and Software

The command center is the technical core of the intelligent transportation system. The field equipment of Luoshuiwan Road (Puwu North Road-Hengjiang Avenue section) is connected to the existing platform of Jiangbei New District Public Security Branch Bureau according to national standard GB 25280, industry standard GA/T 1049.2 and other standards; the field equipment of Luoshuiwan Road (Hengjiang Avenue[8][9]-Binjiang Avenue section) is connected to the existing platform of Pukou Brigade. For storage, combined with the current status of Jiangbei New District Traffic Police Detachment computer room, 1 set of video cloud storage (configured with ≥ 40 10TB enterprise hard drives) and 1 set of image cloud storage (configured with ≥ 35 8TB enterprise hard drives) are added; combined with the current status of Pukou District Traffic Police Brigade computer room, 1 set of video cloud storage (configured with ≥ 38 10TB enterprise hard drives) and 1 set of image cloud storage (configured with ≥ 35 8TB enterprise hard drives) are added.

4. Synergistic Design of Traffic Safety Facilities and Non-motorized Vehicle Management

4.1. Traffic Safety Facility Design

Traffic safety facilities are the basic guarantee for the normal operation of the ITS system. This project, according to the Code for Design of Urban Road Traffic Safety Facilities and other relevant standards, has established a complete traffic safety facility system.[4]

For traffic signs, 16 types of signs including prohibition signs, instruction signs, warning signs, and guide signs are set up throughout the line, including intersection advance guide signs, lane direction signs, combined prohibition signs, pedestrian crossing signs, motorized/non-motorized lane indication signs, right-turn stop signs, etc. The main information Chinese character height of sign panels adopts 35 cm, retroreflective film adopts Class IV retroreflective film, and sign panels adopt 3004 type aluminum alloy plates. In the co-location design, small signs such as pedestrian crossing signs, motorized/non-motorized lane indication signs, and street name signs are attached to the street light pole, while intersection advance guide signs and combined prohibition signs are set on the crossbeam of the co-location street light, with co-location poles, structures and foundations provided by the street light.[6][10]

For traffic markings, 17 types of markings including road center lines, lane edge lines, stop lines, pedestrian crossing lines, guide arrows, and lane division lines are laid out throughout the line, all adopting hot-melt reflective marking coating with marking thickness ≥ 2 mm.[7]

For traffic isolation guardrails, according to the actual needs of existing traffic management, motorized/non-motorized isolation guardrails (Beijing-style round steel guardrails, 0.75 m high) are installed at intersections with future planned roads and at openings of planned roads to prevent vehicles from crossing.

4.2. Non-motorized Vehicle Management System Integration

This project fully considers the traffic safety needs of non-motorized vehicle users in mixed traffic environments and has established non-motorized vehicle management equipment and facilities. The design principle is motorized/non-motorized vehicle separation, with non-motorized vehicles and motorized vehicles having their own rights of way. At intersections with high traffic volume where conflicts between non-motorized vehicles, motorized vehicles, and pedestrians are prominent, management equipment should be conveniently located for management personnel to carry out on-site management and services.[10]

System functions include: (1) Motor vehicle encroachment capture function-real-time monitoring of non-motorized vehicle lanes, capturing motor vehicles illegally occupying non-motorized vehicle driving space; (2) Non-motorized vehicle wrong-way driving capture function-monitoring non-motorized vehicle wrong-way driving behavior, capturing and identifying riders; (3) Remote voice broadcast function-broadcasting intersection traffic light status, supporting emergency remote voice broadcast.

This project's non-motorized vehicle management equipment and facilities are installed using electronic police poles, sharing the electronic police pole mounting box, fully embodying the intensive concept of co-location and co-line. Non-motorized vehicle management equipment is installed at the east and west approaches of the non-motorized vehicle intersection of Luoshuiwan Road and Nanjing Agricultural University, and IoT voice broadcast system equipment is installed at the intersections of Luoshuiwan Road and Nanjing Agricultural University, and Luoshuiwan Road and Binjiang Avenue.

5. Discussion

5.1. Advantages Analysis of Co-location and Co-line Model

The urban arterial road ITS integrated design solution based on the co-location and co-line model proposed in this paper, compared with the traditional independent construction model, has the following significant advantages:

(1) Reducing pole redundancy and saving land resources. In the traditional model, traffic signal poles, monitoring poles, sign poles, etc. are independently set, causing road space waste and visual pollution. The co-location and co-line model attaches traffic engineering equipment to street light poles, significantly reducing the number of poles and improving road space utilization.

(2) Reducing engineering construction costs. In the co-location and co-line model, communication pipelines and reserved pre-embeddings are uniformly designed and constructed by the lighting specialty, avoiding repeated construction and road damage caused by multiple specialties separately excavating and laying pipes. The power supply system shares street light box-type substation circuits, reducing the investment in independent power supply facilities.

(3) Simplifying operation and maintenance management. The unified pole and pipeline system reduces the number of operation and maintenance points, lowering daily maintenance workload and management complexity. The lighting specialty is responsible for pole and

pipeline maintenance, while the traffic engineering specialty is responsible for equipment maintenance, with clear division of responsibilities.

(4) Improving system scalability. The open architecture design facilitates future functional expansion and capacity expansion, reserving space for the development of future intelligent transportation technologies.

5.2. Value of Multi-system Collaborative Management Architecture

The multi-system collaborative management architecture based on a unified platform constructed in this paper achieves unified access, unified management and data sharing of five ITS subsystems (signal control, violation capture, video monitoring, illegal parking capture, truck right-turn stop). The value of this architecture is reflected in:

- (1) Data sharing breaks information silos. Data from various subsystems converge to a unified platform, achieving multi-source fusion of traffic flow data, violation data, and video data, providing more comprehensive information support for traffic management decision-making.
- (2) Collaborative control improves management efficiency. The signal control system can obtain traffic flow data provided by the violation capture system and video monitoring system to achieve dynamic optimization of signal timing; the illegal parking capture system and truck right-turn stop system can link with the signal control system to form a complete traffic violation management closed loop.
- (3) Unified operation and maintenance reduces management costs. Various subsystems are managed through a unified platform, enabling operation and maintenance personnel to monitor the running status of all equipment on the same interface, improving fault response speed and management efficiency.

5.3. Quantitative Analysis of Co-location and Co-line Model Benefits

Based on the aforementioned pole statistics and cost estimation data, the co-location and co-line integrated design demonstrates significant economic and spatial benefits in this project. From the perspective of pole quantity comparison, through the co-location and co-line model, the 4.3 km section of this project significantly reduces the 88 poles required by the traditional plan to 22 poles, with a pole reduction rate as high as 75.0%, directly saving approximately 3 million yuan in comprehensive costs of pole and pipeline engineering.

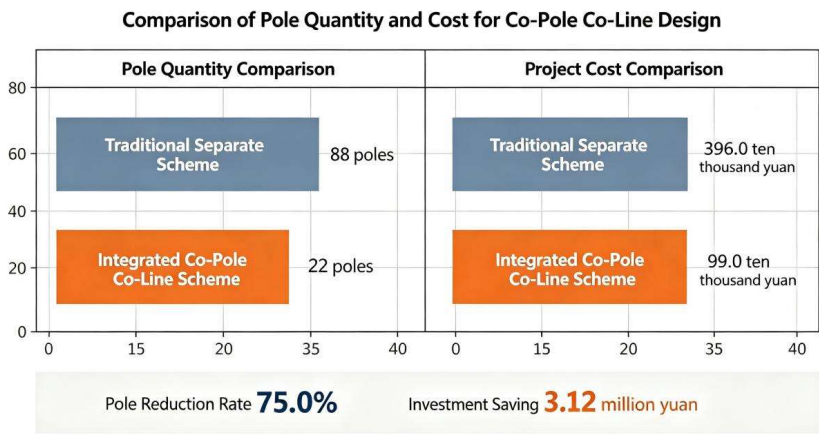


Fig. 1 Pole and cost comparison of co-location and co-line integrated design

In order to quantitatively evaluate the pole saving effect, the pole saving rate is defined as follows:

$$R_p = \frac{N_{trad} - N_{co}}{N_{trad}} \times 100\%$$

N_{trad} is the total number of poles required for the traditional separate scheme (units)

N_{co} is the actual number of poles for the co-location and co-line scheme (units).

Substituting the project data: $R_p = (88 - 22) / 88 \times 100\% = 75.0\%$.

In terms of investment savings, the investment saving amount is defined as follows:

$$S_c = C_{trad} - C_{co} = \sum_{i=1}^n (P_i \times N_{trad,i}) - \sum_{j=1}^m (P_j \times N_{co,j}) + S_{pipe}$$

C_{trad} is the total cost of pole engineering for the traditional scheme (10,000 yuan),

C_{co} is the total cost of pole engineering for the co-location and co-line scheme (10,000 yuan),

S_{pipe} is the saving amount for pipeline engineering (10,000 yuan).

Calculated based on a comprehensive cost of 45,000 yuan per pole:

$C_{trad} = 88 \times 4.5 = 396.0$ (10,000 yuan),

$C_{co} = 22 \times 4.5 = 99.0$ (10,000 yuan),

$S_{pipe} \approx 15.0$ (10,000 yuan),

thus $S_c = 396.0 - 99.0 + 15.0 = 312.0$ (10,000 yuan).

A horizontal comparison of the implementation effects of this project with similar projects domestically and internationally reveals that the pole reduction rate of this project is at the upper limit of the range reported in existing literature. For example, the pole reduction rate for 44 roads in the central urban area of Beijing was 38%, 50% in the Beijing Guomao Bridge area, 58% in the Haidian Zhongguancun West Zone, and 50% in the core area of smart connected intersections in the Beijing Economic-Technological Development Area; in local projects, the intersection pole reduction rate for 3 roads in Shushan Industrial Park, Shou County was over 75%, and the road section rate was over 50%. Generally, the pole reduction rate for conventional multi-pole integration projects ranges from 37% to 58%, with comprehensive construction costs reduced by approximately 25%. In contrast, the 75.0% pole reduction rate and over 60% comprehensive cost reduction of this project are both superior to the industry average.[15][16][17]

The high pole reduction rate of this project can be attributed to the following four aspects: First, this project is a newly constructed road, fully implementing the co-location and co-line concept from the design source, without the restrictions and historical legacy issues of dismantling and renovating existing poles; Second, deep integration of traffic engineering and lighting engineering professional designs was achieved, comprehensively considering pole layout and structural selection during the scheme design phase; Third, the large road red line width (50~62m) provided sufficient physical space and structural margin for mounting multi-system equipment on shared poles; Fourth, this project integrated all 6 ITS subsystems-including traffic signal control, violation capture, video surveillance, illegal parking capture, right-turn control for trucks, and non-motorized vehicle management-into the co-location and co-line scope, with a significantly higher system integration level than conventional projects that typically integrate only 2-3 subsystems.

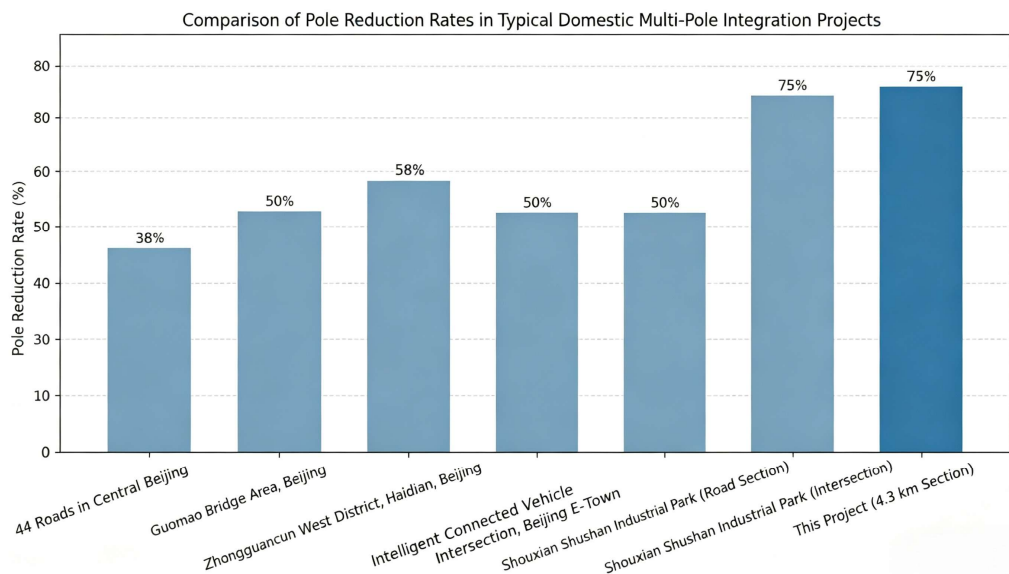


Fig. 2 Horizontal comparison of pole reduction rate of co-location and co-line

Table 4. Data Source Table for Horizontal Comparison of Co-location and Co-line Pole Reduction Rates

Project/Area	Pole Reduction Rate	Data Source
This Project (Nanjing Luoshuiwan Rd)	75.0%	This study
Beijing Central City 44 Roads	38%	Literature [15]
Beijing Guomao Bridge Area	50%	Literature [15]
Beijing Haidian Zhongguancun West	58%	Literature [15]
Beijing E-Town Intelligent Connected Intersection	50%	Literature [16]
Shouxian Shushan Industrial Park	Intersection >75%, Section >50%	Literature [17]

5.4. Multi-system Collaborative Management Effect Evaluation

In addition to physical pole integration, this project constructed a multi-system collaborative management architecture at the logical level, achieving unified access and data aggregation for 6 major ITS subsystems. Specifically, the traffic signal control system, traffic violation capture system, traffic video surveillance system, illegal parking capture system, right-turn mandatory stop safety control system for trucks, and non-motorized vehicle management system are all connected to the management platform through unified interfaces, achieving comprehensive aggregation of signal control data, violation detection data, video surveillance data, illegal parking detection data, truck right-turn behavior data, and non-motorized vehicle management data.[11][13]

In terms of platform architecture and storage configuration, the system fully utilizes existing resources with moderate expansion, relying on the existing platforms of the Jiangbei New Area Public Security Bureau and Pukou Brigade as the central management platform. To meet the storage needs of massive data, the Jiangbei section added video cloud storage (configured with ≥40 10TB enterprise-grade hard drives) and image cloud storage (configured with ≥35 8TB enterprise-grade hard drives); the Pukou section added video cloud storage (configured with ≥38 10TB enterprise-grade hard drives) and image cloud storage (configured with ≥35 8TB enterprise-grade hard drives).

Compared with the traditional independent construction mode, the multi-system collaborative management architecture has significant advantages in operation and maintenance (O&M) efficiency. First, the unified management interface breaks down data silos between subsystems, enabling managers to achieve panoramic perception of traffic operation status across the entire

line on a single platform; Second, the data sharing mechanism provides basic support for cross-system linkage control and comprehensive judgment—for example, data correlation between video surveillance and violation capture can improve law enforcement accuracy; Finally, the centralized O&M management mode significantly reduces fault response time and equipment inspection costs, avoiding management redundancy and efficiency loss caused by parallel maintenance of multiple vendors and platforms.[11][13]

To quantitatively evaluate the O&M efficiency improvement, the O&M efficiency improvement rate η_{maint} is defined as follows:

$$\eta_{maint} = \frac{T_{trad} - T_{co}}{T_{trad}} \times 100\%$$

T_{trad} is the daily inspection workload under the traditional scheme (person-times/month)

T_{co} is the daily inspection workload under the co-location and co-line scheme (person-times/month).

Based on the equipment deployment statistics of this project (Table 2), calculations were made for signal controllers, signal lights, various cameras, fill lights, radars, display screens, and other equipment deployed along the Lushuiwan Road line. The benefit calculation table is shown below. Under the traditional separate mode, the above equipment was dispersedly mounted on approximately 88 independent poles. O&M personnel needed to inspect each pole point by point. Calculated based on an average inspection time of 15 minutes per pole and completing one full coverage inspection per month, the monthly inspection workload of the traditional scheme was approximately 22 times/month. After adopting the co-location and co-line mode, equipment was centrally mounted on 22 comprehensive poles. O&M personnel could complete inspections and maintenance for multiple types of equipment at the same pole location at once. Calculated based on an average inspection time of 30 minutes per comprehensive pole, the monthly inspection workload of the co-location scheme was approximately 11 times/month. Considering additional advantages of the co-location mode such as shared trenches for power and communication pipelines, concentrated fault points, and high spare parts universality, the actual O&M efficiency improvement can be further amplified. Comprehensive estimation shows that the co-location and co-line mode can reduce daily inspection workload by approximately 60%, shorten fault response time by approximately 40%, and improve O&M efficiency by 50%.

Table 5. Calculation Table for O&M Workload and Efficiency Improvement

Workload and Efficiency Improvement	
Traditional Monthly Inspection Workload	$T_{trad} = 88 \times 0.25 = 22$
Daily Inspection Workload under Co-location & Co-line Scheme	$T_{co} = 22 \times 0.5 = 11$
Operation-Maintenance Efficiency Improvement Rate η_{maint}	$\eta_{maint} = \frac{22 - 11}{22} \times 100\% = 50\%$

5.5. Limitations and Prospects

Although this study has carried out systematic exploration in co-location and co-line integrated design and multi-system collaborative management, there are still certain limitations. First, the benefit analysis in this paper is mainly based on engineering design parameter estimation, and still lacks actual traffic data after project operation (such as changes in accident rates, improvements in traffic efficiency, etc.) for effect verification. Subsequent research can combine operational data for quantitative evaluation. Future studies can further track the

[1][13]operational data of the project throughout its lifecycle, and conduct more in-depth empirical research on the comprehensive benefits of co-location and co-line integrated design from dimensions such as traffic operation efficiency, carbon emission reduction, and long-term operation and maintenance costs.

Second, the applicability of the co-location and co-line model under different road conditions (such as narrow roads, historical districts, etc.) needs further research. Third, the actual operational effects of the multi-system collaborative management architecture need long-term tracking verification. Future research directions include: (1) carrying out quantitative evaluation research on ITS system operational effects under the co-location and co-line model, establishing effect evaluation index system; (2) studying adaptive analysis methods of the co-location and co-line model in different urban road types; (3) exploring ITS multi-system intelligent collaborative control algorithms based on artificial intelligence and big data; (4) studying the evolution direction of the co-location and co-line model in the vehicle-infrastructure cooperative environment.

6. Conclusion

This paper takes the Luoshuiwan Road (Puwu Road-Binjiang Avenue) Construction Project in Jiangbei New District, Nanjing as a case study, and systematically discusses the integrated design solution for urban arterial road intelligent transportation systems around the core construction model of co-location and co-line. The main conclusions are as follows:

(1) An ITS intensive construction model of co-location and co-line between traffic engineering and lighting engineering is proposed. This model effectively solves problems such as pole redundancy and repeated investment in urban arterial roads by attaching traffic engineering equipment to street light poles, sharing communication pipelines and power supply systems, providing a buildable construction model for similar projects.

(2) A multi-system collaborative management architecture based on a unified platform is constructed. On the basis of co-location and co-line, unified access, unified management and data sharing of five subsystems including traffic signal control, violation capture, video monitoring, illegal parking capture, and truck right-turn stop are achieved, improving the overall efficiency of traffic management.

(3) Project practice verifies the feasibility of the solution. The Luoshuiwan Road project sets up signal control at 11 intersections, installs 32 monitoring cameras and 11 illegal parking capture cameras, and achieves multi-disciplinary collaborative construction through the co-location and co-line model, providing technical support for urban road intelligent traffic management in Nanjing Jiangbei New District.

The research results of this paper have certain reference value and practical significance for promoting intensive construction of urban arterial road traffic engineering and improving the overall efficiency of intelligent transportation systems.

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