Optimization of the Whole Process of Waste Classification: Construction of an Intelligent Monitoring System and Empirical Study on the Effect of Guiding Residents' Participation Behavior

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ABSTRACT To address the insufficient whole-process coordination of waste classification in China, this paper constructs a three-tier intelligent monitoring system integrating textile recycling cycles into the “front-end, middle-end, and back-end” architecture and designs multidimensional guidance strategies for discarded fabric recovery based on the influencing factors of residents' disposal behavior. Supported by wireless sensing and intelligent information acquisition technologies commonly employed in electromagnetic-enabled monitoring environments, the proposed framework optimizes textile resource regeneration through cognition improvement and incentive mechanisms while ensuring systematic management of garment waste alongside general household refuse. The collaborative effect is verified through a quasi-experimental method. Two old communities of similar scale are selected as research objects: the experimental group is equipped with the intelligent monitoring system and implements the guidance strategies, while the control group maintains the traditional model over a six-month experimental period. The results show that the participation rate of waste classification in the experimental group increases to 91%, the accuracy rate reaches 87%, the mixed transportation rate drops to 3%, the resource utilization rate rises by 18 percentage points, and the unit treatment cost decreases by 22.5%. The collaboration between the system and behavioral strategies significantly improves whole-process governance efficiency and demonstrates the value of integrating intelligent sensing, wireless data transmission, and environmental management. This study provides contextually adaptive and replicable technical solutions for waste classification while offering practical references for electromagnetic-assisted monitoring infrastructures and smart urban resource management.

INDEX TERMS waste classification, intelligent monitoring system, wireless sensing, electromagnetic monitoring, textile recycling

I. INTRODUCTION

A. RESEARCH BACKGROUND AND PROBLEM STATEMENT

1) Policy Background: Evolution and Implementation Requirements of Waste Classification Policies at Home and Abroad

Urban domestic waste disposal, significantly impacted by the accumulation of post-consumer garment waste, has become a key factor restricting sustainable development, making the classification of textile materials a vital prerequisite for realizing the resource utilization of waste. Enhancing the systematic recovery of natural and synthetic fibers within municipal waste streams ensures that textile waste is redirected toward regeneration processes rather than landfills [1]. Internationally, countries such as the United States, Japan, and Germany have long established mature waste classification systems, achieving the rational resource utilization of waste through mandatory legislation and public participation [2]. Domestically, in June 2016, the National Development and Reform Commission and the Ministry of Housing and Urban-Rural Development issued the "Draft for Comments on the Compulsory Waste Classification System Plan", proposing the concept of "compulsory waste classification" for the first time; in March 2017, the "Implementation Plan for the Domestic Waste Classification System" was officially promulgated, aiming to basically establish a legal, regulatory and standard system for waste classification by the end of 2020 and form a promotable domestic waste classification model [3]; in 2019, the "Solid Waste Pollution Prevention and Control Law" was revised again, providing legal guarantee for the implementation of the domestic waste classification system, and relevant systems for domestic waste management have been further promoted nationwide [4].

2) Practical Demand: Dilemma of Urban Domestic Waste Disposal and Core Value of Waste Classification

Statistics show that only 13.5% of global waste is recycled and utilized, while about 70% of urban domestic waste is sent to landfills for disposal [5]. Data from the Ministry of Ecology and Environment shows that the output of domestic waste in large and medium-sized cities in China reached 282.625 million tons in 2023, showing an increasing trend year by year, and cities are trapped in the dilemma of "being surrounded by waste". The traditional "mixed collection-centralized disposal" model not only leads to resource waste and increased disposal costs but also exacerbates the load on landfills and environmental pollution [6]. Waste classification can achieve source reduction. To reduce the over-reliance on incineration for terminal disposal and increase the proportion of textile resource recycling, it is crucial to implement precise front-end waste classification that separates discarded fabrics and fiber scraps from general refuse. This proactive categorization at the source ensures that high-value textile materials are preserved for high-quality fiber regeneration rather than being lost to energy-recovery combustion [7].

3) Key Issues: Bottlenecks in the Whole Process of Current Waste Classification

The whole-process management of urban domestic waste includes four links: waste classification, collection and transportation, disposal, and recycling [8]. Despite increasing policy promotion, China's waste classification still faces the problem of insufficient whole-process coordination: the participation rate and accuracy of residents' classification at the front-end are relatively low; the "mixed transportation of classified waste" exists in the middle-end collection and transportation link, undermining the classification effect; the back-end disposal facilities do not match the front-end classification needs, and the industrial chain for the utilization of recyclable waste is incomplete [9].

B. RESEARCH SIGNIFICANCE

This study constructs an intelligent monitoring system adapted to the whole process of waste classification, which is of great significance both theoretically and practically:

Theoretically, it integrates environmental governance, intelligent technology, and behavioral economics theories, filling the gap in research on whole-process collaborative optimization and technology-behavior collaboration;

Practically, it provides replicable optimization schemes for waste classification for government departments, helps improve governance efficiency, and promotes the transformation of waste classification from "policy-driven" to "public consciousness".

C. LITERATURE REVIEW AT HOME AND ABROAD

1) Research Progress on Whole-Process Optimization of Waste Classification

Existing studies mostly focus on the optimization of a single link, such as the layout of front-end classification facilities [10], the optimization of middle-end collection and transportation routes [11], or the upgrading of back-end disposal technology [12]. Some scholars have proposed the "source-middle-end-back-end" collaborative framework [8,13], but lack specific technical support and implementation paths, failing to form a whole-process closed-loop management system.

2) Research on the Application of Intelligent Monitoring Technology in Waste Classification

Technologies such as the Internet of Things (IoT) and computer vision have been gradually applied in waste classification monitoring, such as intelligent trash cans, video recognition systems, and voice recognition systems [14-16]. However, existing technologies are mostly limited to front-end classification monitoring, lacking whole-process coverage of middle-end collection and transportation and back-end disposal, and the problem of data silos is prominent, making it difficult to support precise decision-making.

3) Research on Influencing Factors and Guidance Strategies of Residents' Waste Classification Participation Behavior

At present, there is a large separation between residents' willingness and behavior in waste classification in China. Residents' classification behavior is affected by factors such as cognitive level, facility convenience, and incentive mechanisms [17,18].

Existing guidance strategies mainly focus on publicity and education as well as material incentives, but have problems such as insufficient pertinence and unsustainable effects, failing to achieve precise guidance combined with monitoring data.

4) Review of Existing Research

In summary, existing studies have three deficiencies:

(1) Lack of systematic research on whole-process collaborative optimization, mostly focusing on a single link;

(2) Fragmented application of intelligent monitoring technology, failing to form a whole-process coverage system solution;

(3) Insufficient research on the collaborative mechanism between intelligent technology and residents' behavior guidance, making it difficult to achieve the dual effect of "technology empowerment + behavior optimization".

D. RESEARCH CONTENT AND TECHNICAL ROUTE

1) Core Research Content

(1) Analysis and bottleneck identification of the whole process of waste classification;

(2) Construction of an intelligent monitoring system covering the "front-end, middle-end, and back-end";

(3) Design of residents' participation behavior guidance strategies based on influencing factors;

(4) Empirical verification of the collaborative optimization effect of the system and strategies.

2) Technical Route

Adopt the research path of "literature review $\rightarrow$ whole-process analysis $\rightarrow$ system construction $\rightarrow$ strategy design $\rightarrow$ empirical research $\rightarrow$ conclusions and suggestions".

Research methods include literature research method, system design method, quasi-experimental method, questionnaire survey method, and data analysis method. Data sources include system monitoring data, questionnaire survey data, and in-depth interview data.

II. ANALYSIS AND OPTIMIZATION FRAMEWORK OF THE WHOLE PROCESS OF WASTE CLASSIFICATION

A. CORE LINKS AND COLLABORATIVE LOGIC OF THE WHOLE PROCESS OF WASTE CLASSIFICATION

The whole process of waste classification covers three core links: front-end source classification, middle-end collection and transportation transfer, and back-end classification disposal. Each link is interlocking, forming a collaborative chain of "source reduction-standardized collection and transportation-efficient disposal". The front-end is the foundation, determining the classification quality; the middle-end is the key, ensuring that the classification effect is not lost; the back-end is the guarantee, reflecting the classification value through resource utilization. The core demand of whole-process collaboration is to achieve "accurate classification, standardized collection and transportation, efficient disposal, and data connection".

B. CORE BOTTLENECKS AND CAUSES OF THE WHOLE PROCESS

Combined with practical research and literature analysis [10-12,19], this paper sorts out four core bottlenecks and their causes in the whole process, as shown in Table 1 below:

TABLE 1. Core Bottlenecks and Causes of the Whole Process

Core Links	Core Bottlenecks	Main Causes
Front-end Classification	Low participation rate and insufficient accuracy	Insufficient cognition, inconvenient facilities, lack of supervision, high participation cost
Middle-end Collection and Transportation	Mixed transportation and unreasonable routes	Imperfect collection and transportation system, unscientific scheduling, inadequate supervision
Back-end Disposal	Poor adaptability of disposal technology and low resource utilization rate	Insufficient technical investment, imperfect industrial chain, disconnection between front-end and back-end information
Cross-link Collaboration	Information opacity and poor collaboration	Lack of a unified data platform, unclear division of powers and responsibilities among various subjects

Based on the above bottlenecks, the core objectives of whole-process optimization are clearly defined as: Improve the participation rate and accuracy of residents' classification, standardize the middle-end collection and transportation behavior, increase the back-end resource utilization rate, and reduce the whole-process cost.

C. KEY OPTIMIZATION PATH: COLLABORATION BETWEEN INTELLIGENT MONITORING AND BEHAVIOR GUIDANCE

Following the principles of systematicness, technical adaptability, resident-oriented, and cost-effectiveness, this paper proposes a collaborative optimization path of "intelligent monitoring + behavior guidance". The intelligent monitoring system provides data support for whole-process optimization, realizing precise supervision and decision-making empowerment through real-time collection of data from various links; The residents' behavior guidance strategy focuses on front-end source control, stimulating residents' participation enthusiasm by improving cognition, optimizing the environment, and improving incentives and constraints.

The two form a virtuous cycle of "data supporting strategy optimization and strategies improving data quality", which is the core path of whole-process optimization.

III. CONSTRUCTION OF AN INTELLIGENT MONITORING SYSTEM FOR WASTE CLASSIFICATION

A. CORE REQUIREMENTS AND DESIGN PRINCIPLES FOR SYSTEM CONSTRUCTION

1) Core Requirements

The system needs to meet five core requirements:

(1) Whole-process data collection: covering key indicators of front-end classification, middle-end collection and transportation, and back-end disposal;

(2) Real-time supervision: realizing real-time early warning of abnormal behaviors (such as mixed transportation and incorrect disposal);

(3) Information sharing: breaking data barriers among the government, enterprises, and residents;

(4) Decision support: providing optimization suggestions through data analysis;

(5) Usability: reducing the operation threshold for various subjects.

2) Design Principles

Follow the principles of practicality, compatibility, security, scalability, and low cost.

(1) Practicality requires focusing on core needs and avoiding functional redundancy;

(2) Compatibility ensures that the system can be connected with existing waste classification facilities and government affairs platforms;

(3) Security ensures data security through data encryption and equipment protection;

(4) Scalability reserves functional interfaces to adapt to future technological upgrades;

(5) The low-cost principle requires prioritizing mature technologies and adaptive deployment. For the pilot, hardware density was optimized for data completeness, but large-scale promotion can adopt scaled-down configurations (e.g., shared equipment, batch procurement) to control costs.

B. OVERALL SYSTEM ARCHITECTURE DESIGN

The overall system architecture adopts a three-tier progressive design of "hardware layer-software layer-application layer", with clear functions and collaborative linkage of each layer.

(1) The hardware layer is the basic layer for data collection, covering three types of core equipment: front-end, middle-end, and back-end:

The front-end deploys intelligent trash cans (with infrared sensing and weight sensing functions), high-definition cameras, and environmental sensors;

The middle-end is equipped with GPS positioning modules, video monitoring equipment, and temperature and humidity sensors on collection and transportation vehicles;

The back-end sets up disposal volume statistical terminals, resource utilization rate monitoring equipment, and pollutant emission detection instruments at waste disposal plants.

Notably, the current hardware combination of infrared and weight sensors has a technical limitation: it cannot distinguish mixed waste inside sealed bags (e.g., a plastic bottle placed in a textile bin). Thus, the automated monitoring accuracy primarily reflects external disposal behavior and relative weight distribution, rather than absolute identification of internal waste components.

(2) The software layer is the core layer for data processing, including four functional modules:

The data collection and transmission module is responsible for real-time collection and encrypted transmission of multi-source data;

The data storage and management module adopts a cloud database to realize the secure storage and structured management of massive data;

The data analysis and early warning module completes data mining, index calculation, and abnormal behavior early warning through algorithm models;

The visual display module presents the processed data in the form of charts.

(3) The application layer is the functional output layer, providing differentiated services for different subjects:

The government-side supervision and decision-making platform supports whole-process index monitoring and policy formulation assistance;

The enterprise-side collection, transportation and disposal scheduling platform realizes vehicle route optimization and task allocation;

The resident-side classification guidance APP provides classification knowledge inquiry, point inquiry, and feedback interaction functions.

C. DETAILED DESIGN OF CORE FUNCTIONAL MODULES OF THE SYSTEM

The core functional modules of the system cover whole-process monitoring and management. The specific functions and technical support are shown in Table 2 below:

TABLE 2. Specific Functions and Technical Support

Functional Modules	Core Functions	Technical Support
Front-end Classification Monitoring	Recognition of residents' classification behavior, accuracy statistics, early warning of incorrect disposal, early warning of trash can overflow	Computer vision, infrared sensing, weight sensing
Middle-end Collection and Transportation Monitoring	Vehicle trajectory tracking, route optimization, recognition of mixed transportation, statistics of collection and transportation efficiency	GPS, GIS, video recognition, big data analysis
Back-end Disposal Monitoring	Disposal volume statistics, calculation of resource utilization rate, monitoring of pollutant emissions, evaluation of disposal effect	Sensors, data fusion technology
Data Integration and Analysis	Multi-source data fusion, whole-process index statistics, trend analysis, generation of decision suggestions	Big data analysis, machine learning
Information Interaction	Residents' classification guidance, enterprise task scheduling, government supervision reports, feedback interaction	Mobile Internet, cloud platform

D. KEY TECHNICAL SUPPORT AND IMPLEMENTATION PATH OF THE SYSTEM

1) Key Technologies

The core technologies of the system include:

(1) Internet of Things (IoT) technology: realizing interconnection of equipment and real-time data collection;

(2) Computer vision technology: accurately identifying residents' classification behavior and mixed transportation phenomena;

(3) Big data analysis technology: mining data value to support route optimization and strategy adjustment;

(4) GIS technology: realizing visualization of collection and transportation trajectories and regional management.

2) Implementation Path

Adopt the implementation path of "technology selection-development and testing-pilot deployment-iterative optimization":

(1) Give priority to mature IoT modules and computer vision algorithms to reduce development difficulty;

(2) After completing the system development, conduct a one-month indoor test to optimize functional vulnerabilities;

(3) Select 2 communities of different scales to carry out a 3-month pilot, collect feedback and debug;

(4) For large-scale replication, the hardware deployment will be adjusted based on scenarios: high-rise commercial apartments can share monitoring equipment per building, while rural areas can adopt mobile monitoring stations to reduce hardware density and costs.

At the same time, ensure the security and stability of the system through data encryption, physical equipment protection, redundancy design and other measures.

IV. DESIGN OF GUIDANCE STRATEGIES FOR RESIDENTS' WASTE CLASSIFICATION PARTICIPATION BEHAVIOR

A. ANALYSIS OF INFLUENCING FACTORS OF RESIDENTS' WASTE CLASSIFICATION PARTICIPATION BEHAVIOR

Based on the "cognition-attitude-behavior" theory and field research, this paper divides the influencing factors of residents' classification behavior into three levels: individual, external environment, and institutional policy, as shown in Table 3 below:

TABLE 3. Analysis of Influencing Factors of Waste Classification Participation Behavior

Influence Levels	Specific Factors	Influence Description
Individual Level	Cognitive level, environmental awareness, behavioral habits, perception of costs and benefits	Insufficient cognition and weak environmental awareness will directly reduce participation willingness; bad habits increase classification difficulty; participation enthusiasm is low when perceived benefits are lower than costs
External Environment Level	Facility convenience, publicity intensity, neighborhood demonstration, community management	Unreasonable layout of trash cans and unclear signs reduce participation convenience; insufficient publicity leads to lack of cognition; neighborhood demonstration and community management strengthen behavioral constraints
Institutional Policy Level	Incentive mechanism, constraint mechanism, policy implementation capacity	Reasonable incentives enhance participation motivation; appropriate constraints standardize behavior; inadequate policy implementation weakens trust and participation willingness

The research finds that insufficient cognition, inconvenient facilities, and lack of incentives are the core factors affecting residents' classification behavior, and targeted guidance strategies need to be designed.

B. DESIGN OF SPECIFIC GUIDANCE STRATEGIES

Following the framework of hierarchical guidance and classified policies, combined with core influencing factors, four types of guidance strategies are designed:

1) Cognition Improvement Strategy

Adopt a multi-channel publicity model of "online + offline":

Carry out community lectures, home visits and guidance, practical training on classification skills offline, and distribute graphic manuals;

Push classification knowledge and typical cases through community WeChat groups and short video platforms online.

Arrange volunteers to provide one-on-one guidance for special groups such as the elderly to improve the popularity of cognition.

2) Incentive Guidance Strategy

Build a dual incentive system of "material + spiritual":

In terms of material incentives, residents who meet the classification accuracy standard can obtain points, which can be exchanged for daily necessities or deduct garbage disposal fees. For the garbage fee deduction incentive, this study proposes a pilot collaboration mechanism: the third-party app would interface with municipal billing systems through authorized data sharing with local urban management departments, aligning with existing flat-rate or property-included fee structures. This administrative logic requires cross-departmental coordination, which is feasible in pilot scenarios and can be scaled with policy support;

In terms of spiritual incentives, select "model households for classification" every month, publicize and commend them, and issue honorary certificates to strengthen positive guidance.

3) Constraint and Supervision Strategy

Establish a dual supervision mechanism of "intelligent monitoring + volunteer supervision":

Identify incorrect disposal behaviors through front-end cameras, give reminders for the first time, and impose small fines for repeated violations;

Organize community volunteers to conduct on-site supervision, cooperate with neighborhood mutual supervision, and form a constraint atmosphere.

At the same time, disclose supervision results to strengthen behavioral norms.

4) Environmental Optimization Strategy

Optimize the layout of classification facilities, configure 1 set of intelligent trash cans for every 30 households, clearly mark classification standards and disposal guidelines, and regularly maintain equipment; Set up classification exhibition areas in communities to create a good atmosphere of "everyone participates in classification" and reduce the psychological cost of participation.

C. COLLABORATIVE ADAPTATION BETWEEN GUIDANCE STRATEGIES AND INTELLIGENT MONITORING SYSTEM

The intelligent monitoring system and guidance strategies form in-depth collaboration:

The system locates groups with weak classification (such as the elderly with insufficient cognition and tenants with irregular disposal) through data analysis, providing a basis for precise publicity and training; Real-time statistics on the implementation effect of strategies, such as the improvement range of participation rate by point incentives, and dynamically adjust incentive intensity and publicity focus.

At the same time, guidance strategies improve residents' cooperation, reduce malicious damage to equipment and incorrect disposal behaviors, ensure the accuracy and stability of system data collection, and improve system operation efficiency.

V. EMPIRICAL STUDY: VERIFICATION OF THE APPLICATION EFFECT OF THE INTELLIGENT MONITORING SYSTEM AND GUIDANCE STRATEGIES

A. EMPIRICAL RESEARCH DESIGN

1) Research Hypotheses

Three research hypotheses are proposed:

H1: The intelligent monitoring system can significantly improve the whole-process supervision efficiency and data transparency of waste classification;

H2: Residents' guidance strategies can significantly improve the participation rate and accuracy of residents' classification;

H3: The collaborative application of the system and strategies can realize whole-process optimization, improve resource utilization rate, and reduce disposal costs.

2) Selection of Pilot Areas

Two communities of similar scale in a city are selected as research objects: Community A is the experimental group (equipped with the intelligent monitoring system + implementing guidance strategies), and Community B is the control group (maintaining the traditional classification model).

Both communities are old communities with similar resident structures and waste classification foundations, with a permanent population of about 1,200 people, which is in line with the representativeness principle.

3) Research Methods and Data Collection

(1) Research methods: Adopt the quasi-experimental method, with an experimental cycle of 6 months (the first 1 month is the basic data collection period, and the latter 5 months are the implementation period).

(2) Data collection:

Collect objective data such as classification accuracy and collection and transportation efficiency through system monitoring;

Collect residents' cognition and attitude data through questionnaire surveys (once every 2 months, with a sample size of 200 each time);

Supplement qualitative data through in-depth interviews (selecting 30 community staff and resident representatives).

B. PILOT IMPLEMENTATION AND PROCESS CONTROL

1) Pilot Preparation Stage

Deploy the intelligent monitoring system in Community A, including 30 sets of intelligent trash cans, 15 front-end cameras, and 5 on-vehicle monitoring equipment, and complete system debugging;

Refine guidance strategies, carry out the first round of publicity and training, and establish a point exchange mechanism. The control group, Community B, only maintains the original classification facilities and regular publicity.

2) Implementation Stage

Real-time track the operation of the system and optimize strategy details every month; Control interfering factors, such as avoiding cross-impact of policies between the two communities and excluding short-term impacts of major events on classification behavior.

To address seasonal variations in waste composition (e.g., increased fruit waste in summer), the study collected monthly waste component data and included seasonal adjustments in the accuracy calculation, minimizing the impact of natural fluctuations on experimental results.

C. EMPIRICAL RESULT ANALYSIS

1) Descriptive Statistical Analysis

Basic data show (Table 4) that before the experiment, the participation rate of residents' classification in both communities was about 62%, the accuracy rate was about 51%, the mixed transportation rate reached 28%, and the back-end resource utilization rate was only 23%, with no significant difference (P>0.05), ensuring the validity of the experiment.

TABLE 4. Basic Data

Statistical Indicators	Experimental Group (Community A)	Control Group (Community B)	Statistical Test Result (P-value)
Classification Participation Rate	62.3%	61.8%	0.82
Classification Accuracy Rate	51.2%	50.7%	0.79
Mixed Collection and Transportation Rate	28.1%	27.9%	0.91
Back-end Resource Utilization Rate	23.1%	22.8%	0.87

2) Comparison of Core Indicator Effects

After the experiment, there are significant differences in the core indicators between the two groups. The specific comparison results are shown in Table 5 below.

From the perspective of static data, the experimental group has achieved significant optimization in key indicators: the classification participation rate and accuracy rate have exceeded 90% and 85% respectively, the mixed transportation rate has dropped to 3%, the resource utilization rate has increased to 41%, and the unit waste disposal cost has decreased by more than 20%. In contrast, the indicators of the control group have only fluctuated slightly, and the optimization effect is not obvious.

For clarity, "unit waste disposal cost" is defined as the comprehensive cost per ton of waste, including equipment depreciation, electricity consumption, labor (collection, transportation, disposal), transportation fees, and landfill/incineration charges, consistent with municipal waste management accounting standards.

TABLE 5. Comparison of Core Indicator Effects

Evaluation Indicators	Experimental Group (Community A)	Control Group (Community B)	Improvement/ Reduction Range
Classification Participation Rate	91%	65%	+29%
Classification Accuracy Rate	87%	55%	+32%
Mixed Collection and Transportation Rate	3%	25%	-22%
Resource Utilization Rate	41%	25%	+18%
Unit Waste Disposal Cost	182 yuan/ton	235 yuan/ton	-22.5%

3) Verification Results of Research Hypotheses

The results show:

The supervision efficiency of the experimental group has increased by 40% (the abnormal early warning response time has been shortened from 2 hours to 30 minutes), verifying that H1 is established;

The residents' participation rate and accuracy rate have been significantly improved (the participation rate and accuracy rate of the experimental group have increased by 29% and 32% respectively compared with before the experiment), verifying that H2 is established;

The resource utilization rate has increased by 18 percentage points, and the disposal cost has decreased by 22.5%, with significant whole-process collaborative effect, verifying that H3 is established.

4) Empirical Conclusions and Problem Discussion

(1) Core Conclusions: The collaborative application of the intelligent monitoring system and residents' guidance strategies can mitigate the observed bottlenecks in the whole process of waste classification, significantly improve classification quality, supervision efficiency, and resource utilization level, reduce disposal costs, and is an effective path for the whole-process optimization of waste classification in similar old communities.

While the collaborative model mitigated observed bottlenecks in the pilot old communities, its replication across high-rise commercial apartments or rural settings requires contextual adjustments—e.g., adapting hardware deployment to high-rise density or reducing monitoring costs for rural areas with scattered populations. These adaptations are part of the replicable framework, emphasizing context-specific optimization rather than one-size-fits-all application.

(2) Existing Problems:

During the pilot, it was found that the system's recognition accuracy for complex disposal scenarios (such as nighttime disposal and simultaneous disposal by multiple people) needs to be improved;

The guidance strategy has a more significant incentive effect on low-income groups but insufficient attraction for young groups;

There are barriers to cross-departmental data sharing, affecting the precise adaptation of back-end disposal. In the future, it is necessary to targeted optimize system algorithms, refine strategy design, and promote the construction of cross-departmental collaborative mechanisms.

VI. CONCLUSIONS AND POLICY RECOMMENDATIONS

A. MAIN RESEARCH CONCLUSIONS

(1) There are four core bottlenecks in the whole process of waste classification: low front-end classification quality, poor middle-end collection and transportation connection, insufficient back-end disposal adaptability, and poor cross-link collaboration, which are rooted in the lack of technical support and insufficient residents' participation motivation;

(2) The constructed "three-tier architecture" intelligent monitoring system can realize whole-process data collection, real-time supervision, and decision support, with stable operation and strong adaptability;

(3) The multi-dimensional guidance strategy designed based on influencing factors can significantly improve residents' participation rate and accuracy rate, and its pertinence and sustainability are better than traditional strategies;

(4) The collaboration between the system and strategies can achieve the optimization effect of "1+1>2", greatly improving the whole-process governance efficiency.

B. TARGETED POLICY RECOMMENDATIONS

1) Technical Level

(1) Increase investment in the R&D and promotion of intelligent monitoring technology, and establish a special fund to support algorithm optimization and equipment upgrading;

(2) Formulate unified technical standards, standardize system data interfaces, and promote cross-regional and cross-departmental data sharing;

(3) Establish a technical service system to provide system deployment and operation and maintenance guidance for small and medium-sized cities and rural areas.

2) Institutional Level

(1) Establish and improve the whole-process supervision system, and clarify the division of powers and responsibilities among the government, enterprises, and residents;

(2) Improve the incentive and constraint system, and link classification effectiveness with community assessment and enterprise qualifications;

(3) Build a collaborative governance mechanism to promote the formation of joint forces among departments such as housing and urban-rural development, ecology and environment, and urban management.

3) Resident Level

(1) Build a diversified publicity and education system, and carry out precise publicity through online and offline channels;

(2) Optimize classification facilities and services to improve participation convenience;

(3) Establish a differentiated guidance mechanism, and design adaptive incentive and training programs for different groups.

4) Industrial Level

(1) Improve the industrial chain of waste classification, collection, transportation, and disposal, and cultivate professional collection, transportation, and resource utilization enterprises;

(2) Increase investment in back-end disposal facilities to improve technical adaptability;

(3) Establishing a price linkage mechanism for recyclable textile waste ensures stable income for fiber recovery enterprises and enhances the enthusiasm for high-value resource utilization throughout the textile regeneration sector. This economic framework stabilizes the market value of post-consumer garments and industrial fabric scraps, incentivizing firms to invest in advanced textile recycling technologies.

AUTHOR CONTRIBUTIONS

Conceptualization – Bo Wang, Zhenjing Lin, Zhao Luo and Jing Chen; methodology – Bo Wang, Zhenjing Lin, Zhao Luo and Jing Chen; investigation – Bo Wang, Zhenjing Lin, Zhao Luo and Jing Chen; writing-original draft preparation – Bo Wang, Zhenjing Lin, Zhao Luo and Jing Chen. All authors have read and agreed to the published version of the manuscript.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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ETHICS APPROVAL AND CONSENT TO PARTICIPATE

This study was approved by the Ethics Committee of Hebei University of Environmental Engineering, and was performed in accordance with the principles of the Declaration of Helsinki. All participants were provided with written informed consent forms explaining the purpose, methods, data usage and privacy protection measures of the study. Participants could withdraw from the study at any time without affecting their rights.

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