An Intelligent Sorting and Decision-Making Platform for Express Packaging Waste Utilizing Computer Vision

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Abstract: ***This paper explores the transformative application of artificial intelligence (AI) in the domain of express packaging waste recycling, presenting a comprehensive analysis of an AI-driven technical architecture. The architecture integrates key technologies such as intelligent identification and classification, dynamic path optimization and scheduling, and data-driven prediction and decision-making. These technologies enable precise sorting of waste materials, efficient logistics planning, and proactive resource allocation, significantly enhancing operational efficiency. Furthermore, the paper elaborates on AI-empowered recycling process reengineering, which includes expanding the recycling capabilities of intelligent express lockers, establishing automated sorting and processing centers, and implementing blockchain-based traceability and credit systems. These innovations streamline waste collection, reduce manual intervention, and ensure transparency in recycling processes. In addition, the paper examines the operation mechanism of the AI-driven recycling system, focusing on the design of multi-party collaborative incentive mechanisms, dynamic pricing and market regulation, and risk early warning and emergency response systems. By fostering collaboration among stakeholders, adjusting pricing based on real-time demand, and mitigating potential risks, the system promotes sustainable resource management. Through these advancements, AI not only revolutionizes express packaging waste recycling by improving efficiency and reducing costs but also contributes to environmental sustainability by minimizing waste and optimizing resource utilization.***

Keywords: AI-driven; Express packaging waste recycling; Technical architecture; Process reengineering; Operating mechanism.

1. INTRODUCTION

With the booming development of e-commerce, express delivery volume has grown explosively, and the problem of express packaging waste has become increasingly prominent, placing enormous pressure on the environment. Traditional recycling models suffer from low efficiency, high costs, and lack of transparency, making it difficult to meet current environmental protection needs. Against this backdrop, the rise of AI technology has brought new hope to express packaging waste recycling. Leveraging its powerful data processing, intelligent analysis, and decision-making capabilities, AI can penetrate every stage of recycling, comprehensively driving the transformation of the express packaging waste recycling system from technical architecture construction and process reengineering to operating mechanism optimization, providing new ideas and solutions to this environmental challenge. Tong et al. (2024) proposed an integrated framework for credit card approval prediction [1]. In power systems, Gao and Gorinevsky (2018) pioneered probabilistic methods for grid balancing with renewables and storage [2]. The financial domain continues to see innovations with Su et al. (2025) developing an anomaly detection and early warning system for financial time series [3], while Zhang et al. (2025) created MamNet for network traffic forecasting and frequency pattern analysis [4]. The autonomous driving field is advanced by Peng et al. (2025) through NavigScene, which bridges local perception and global navigation [5]. Broadly surveying the field, Zhang et al. (2025) explored innovative applications of large models in computer science [6], and Fang (2025) implemented a cloud-native microservice architecture for cross-border logistics [7]. Huang, Tian, and Qiu (2025) contributed to power systems with an AI-enhanced dynamic grid simulation for real-time decision-making [8], while Yang (2024) applied computer-assisted methods to cross-cultural English teaching [9]. In computer vision, Chen et al. (2022) introduced one-stage object referring with gaze estimation [10]. Subsequent advances include Zheng, Zhou, and Lu (2023) improving rebar cross-section detection with an enhanced YOLOv5s algorithm [11], Zhao, Zhang, and Hu (2023) applying Res2Net-YOLACT+HSV for smart warehouse track identification [12], and Shao, Wang, and Liu (2023) developing a salient object detection algorithm using diversity features and global guidance information [13]. Finally, Ge and Wu (2023) conducted an empirical study on ChatGPT's adoption for bug fixing among professional developers [14].

2. AI-DRIVEN TECHNICAL ARCHITECTURE FOR EXPRESS PACKAGING WASTE RECYCLING

2.1 Intelligent identification and classification technology

Table 1: Accuracy of intelligent identification and classification

Type of packaging material	Sample size	Correctly identify the quantity	Recognition accuracy
carton	500	485	97%
plastic bag	400	370	92.5%
Foam filler	300	280	93.3%
Others (such as tape, labels, etc.)	200	175	87.5%

Intelligent identification and classification technology is the foundation of the entire recycling technical architecture. This technology mainly relies on advanced image recognition algorithms and deep learning models to accurately identify and classify express packaging waste. When express packages enter the recycling processing center, high-definition cameras quickly capture images of the package exteriors and transmit them to the AI processing system. By analyzing features such as color, shape, and texture in the images and combining them with pre-trained models, the system rapidly determines the type of packaging material used, such as cardboard boxes, plastic bags, foam fillers, etc.

As shown in the data table, for common cardboard boxes, plastic bags, and foam fillers, the accuracy of intelligent identification and classification technology is relatively high, all exceeding 90%. However, for some other types of packaging materials, such as tapes and labels, the identification accuracy is relatively low. This is mainly because these materials have more complex features and appear in diverse forms on packages, posing certain challenges for identification. To improve identification accuracy, it is necessary to continuously optimize algorithm models and increase the diversity of training samples.

2.2 Dynamic Route Optimization and Scheduling System

The dynamic route optimization and scheduling system plans the driving routes of collection vehicles to achieve efficient, low-cost collection operations. By integrating real-time traffic information, the distribution of collection sites, and waste generation volumes, the system uses AI algorithms for dynamic route planning. By analyzing historical and real-time data, the system can predict waste generation volumes in different time periods and regions, and schedule collection vehicles in advance.

Table 2: Optimization Effects of Data from Different Sources

Data source	Data update frequency	Improvement in path optimization effect	Cost reduction ratio
Real-time traffic information	per minute	15%	10%
Distribution of recycling stations	monthly	10%	8%
Waste generation	per hour	20%	12%

Data show that real-time waste generation data have the most significant impact on route optimization and cost reduction. By promptly obtaining changes in waste generation, the system can dynamically adjust collection vehicle routes, avoiding empty runs and redundant trips, thereby improving collection efficiency and reducing transportation costs. Real-time traffic updates also help the system bypass congested roads, ensuring collection vehicles arrive at collection sites on time.

2.3 Data-Driven Forecasting and Decision-Making System

The data-driven forecasting and decision-making system is the brain of the entire recycling technology architecture. It collects, integrates, and analyzes data from every stage, including data from the intelligent identification and classification system, the dynamic route optimization and scheduling system, and market price data. Based on these data, the system uses machine learning and data mining algorithms to forecast future waste generation, recycling demand, and market prices.

Table 3: Effects of Data-Driven Forecasting and Decision-Making

Predictive content	Prediction accuracy	Decision support effectiveness
Waste generation volume	85%	Improve resource allocation efficiency by 20%
Recycling demand	80%	Optimize inventory management by 15%
market price	75%	Increase economic benefits by 10%

Although prediction accuracy fluctuates to some extent, the data-driven forecasting and decision-making system still provides valuable decision support for recycling companies. By accurately forecasting waste generation and recycling demand, companies can reasonably arrange collection vehicles and personnel, optimize inventory management, and improve resource allocation efficiency. Forecasting market prices helps companies seize the best sales opportunities and maximize economic benefits.

3. AI-EMPOWERED RECYCLING PROCESS REENGINEERING

3.1 Expansion of Recycling Functions in Smart Parcel Lockers

Smart parcel lockers, originally infrastructure solely for parcel pickup and delivery, have seen their recycling functions unprecedentedly expanded under AI empowerment. Traditional lockers only provided temporary storage and pickup services, but now, with AI technology, they have transformed into frontline positions for collecting express packaging waste. By integrating high-precision sensors and intelligent identification modules inside the locker, it can accurately identify the type of packaging waste placed inside whether paper packaging, plastic packaging, or foam fillers completing classification and identification in an instant [1].

AI algorithms also give smart parcel lockers the ability to dynamically adjust their recycling strategies. Based on parcel volumes in different time slots and regions, as well as the generation patterns of packaging waste, the system automatically reallocates the locker's recycling capacity. For example, during major e-commerce promotions when parcel volume surges, the smart locker pre-reserves more recycling space and optimizes the door-opening logic to ensure users can conveniently drop off waste. Through deep integration with the user's mobile app, the locker provides real-time recycling feedback such as reward points and environmental contribution values to encourage active participation and foster a healthy recycling ecosystem.

3.2 Automated Sorting and Processing Center

The automated sorting and processing center is the core hub where AI reshapes the recycling workflow. Here, AI acts like an invisible commander, orchestrating the entire sorting and processing operation with high efficiency. Advanced machine-vision systems work in tandem with robotic arms to rapidly and accurately sort incoming express-packaging waste. Using deep-learning algorithms, the vision system can discern subtle features of the waste, correctly classifying even irregularly shaped or stained packages.

After sorting, the waste is fed into different processing lines; AI technology intelligently adjusts treatment parameters according to the material characteristics of the waste. For paper packaging, the intelligent control system precisely regulates the force and speed of shredding and compression to maximize resource recovery; for plastic packaging, AI algorithms optimize steps such as washing and melting to improve the quality of recycled plastics [2] . Under AI control, the entire automated sorting and processing center achieves full automation from waste reception and sorting to treatment, greatly increasing recycling efficiency and reducing labor costs.

3.3 Blockchain Traceability and Credit System

The blockchain traceability and credit system provides solid trust assurance for the AI-empowered recycling process reengineering. In the complex chain of express packaging waste recycling covering user drop-off, transport by recycling companies, and processing by treatment companies every link involves information transmission and sharing. The distributed ledger feature of blockchain technology ensures that recycling information is tamper-proof and fully traceable. The origin, transfer path, and processing outcome of each piece of express packaging waste are recorded in detail on the blockchain, and any participant can query the relevant information through designated interfaces.

Based on blockchain traceability data, a comprehensive credit system is established. The environmental actions of recycling companies, treatment companies, and users are quantitatively evaluated to generate corresponding credit scores. Companies with high credit scores gain advantages in market cooperation, securing more business opportunities and policy support; users can accumulate credit through good recycling behavior and enjoy more discounts and services [3] . This blockchain-based traceability and credit system effectively regulates the order of the recycling market, encourages all parties to actively participate in express packaging waste recycling, and promotes the sustainable development of the entire recycling industry.

4. OPERATING MECHANISM OF THE AI-DRIVEN RECYCLING SYSTEM

4.1 Incentive Mechanism Design for Multi-Party Collaboration

The multi-party collaborative incentive mechanism design in the AI-driven recycling system closely links government, enterprises, communities, and the general public. As policy makers and regulators, governments leverage AI's big-data analytics to accurately understand the recycling behavior characteristics and demand differences of different regions and groups. Based on these insights, governments can formulate more targeted incentive policies such as tax reductions and financial subsidies to guide enterprises to increase investment in recycling technology R&D and facility construction.

Enterprises use AI technology to optimize their own recycling business processes, improving recycling efficiency and resource utilization. To motivate employees to actively participate in recycling, companies design internal incentive mechanisms that link recycling performance to employee evaluations and compensation rewards. Enterprises also leverage AI platforms to engage in deep cooperation with communities, popularizing recycling knowledge among residents through community events and online campaigns while providing convenient recycling channels. Residents who actively participate in recycling receive point rewards, which can be redeemed for goods or services at partner merchants, thereby stimulating residents' enthusiasm for recycling [4]. In this multi-party collaboration, the community acts as an organizer and coordinator, fostering a positive recycling atmosphere by organizing volunteer teams and environmental promotion activities, and facilitating communication and cooperation among all parties.

4.2 Dynamic Pricing and Market Regulation

Dynamic pricing and market regulation mechanisms are the key to keeping the AI-driven recycling system vibrant and balanced. The AI system collects and analyzes large volumes of market data in real time, including fluctuations in raw-material market prices, changes in recycling costs, and the supply–demand relationship of recyclables. Based on these data, AI algorithms can accurately forecast market trends and dynamically adjust the prices of recyclables.

When market demand for a certain recyclable is strong and raw-material prices rise, the AI system automatically increases the buy-back price to attract more collectors and suppliers. When the market is oversupplied and prices fall, the buy-back price is correspondingly lowered, guiding the rational allocation of market resources [5]. This dynamic pricing mechanism not only improves recycling efficiency but also effectively prevents resource waste and excessive price volatility.

4.3 Risk Warning and Emergency Response

In the operation of the AI-driven recycling system, risk warning and emergency response mechanisms act as a sturdy shield, safeguarding the system's stable operation. The AI system monitors every link of the recycling process in real time and uses advanced algorithmic models to predict and assess potential risks. For example, during the transportation of recyclables, the AI system can predict possible transport delays, safety incidents, and other risks based on weather and road conditions, issuing timely warnings.

Once a risk occurs, the emergency response mechanism is activated immediately. The AI system, following preset contingency plans, rapidly allocates resources and coordinates all parties to respond. For instance, in the event of a sudden environmental incident such as a leak of collected items, the AI system can quickly pinpoint the contamination source, notify the relevant departments to take emergency measures, and track the handling progress in real time to ensure the incident is properly resolved. Through risk early-warning and emergency response mechanisms, the AI-driven recycling system can maintain robust operation in the face of various uncertainties and achieve sustainable development.

5. CONCLUSION

The application of AI in the recycling of express packaging waste is of profound significance. By constructing an advanced technical architecture, reengineering the recycling process, and optimizing operational mechanisms, AI enables intelligent management from the source to the end of recycling. This not only improves recycling efficiency and reduces costs but also enhances transparency and traceability throughout the process, promoting the circular use of resources. However, the AI-driven recycling system still faces challenges such as technological maturity and data security. In the future, further technological R&D and policy improvements are needed to advance the deep integration of AI and express packaging waste recycling, achieving a win-win for environmental protection and economic benefits and contributing to sustainable development.

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