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Big-Data-Based Power Battery Recycling for New Energy Vehicles: Information Sharing Platform and Intelligent Transportation Optimization

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ABSTRACT This paper focuses on the principal problems in the actual transaction of decommissioned power batteries such as the asymmetry of information, huge risk and difficult is sues such as recovery and trace. And constructed a new energy vehicle decommissioned power battery recycling platform based on the big data technology. Integrated characteristics of big data information, this paper analyzes the operating mechanism of the Big-Data-Based power battery recovery platform. The functional module on this platform is designed and investigated for the functional requirements of users and shared in formation based on big data. Based on the analysis of traffic big data, a traction battery dangerous goods transportation optimization system is established by using Baidu map application program interface (API). The improved ant algorithm was used to obtain the shortest path model and decrease the transportation costs and risks, besides, it boosts the value of information resources maximum and gives impetus to the power battery recycling industrial transformation and upgrading.

INDEX TERMS Big data, traceability, traction battery, path optimization, new energy vehicle.

I. INTRODUCTION

In the face of the increasingly tense energy crisis and environmental pressure, the global automobile production powers have launched the new energy vehicle strategy, and the electric vehicle industry has entered a stage of rapid development to reduce environmental pollution and energy consumption, clean electrochemical energy production is a serious consideration [1]. China is the largest consumer of electric vehicles in the world, but there is always a prediction of depletion of oil resources [2]. In 2018, China's new energy vehicle production and sales volume respectively completed 1.27 million and 1.256 million [3], a year-on-year increase of 59.9% and 61.7%, the average annual growth rate of new vehicle sales in the past 10 years had exceeded 24% [4]. Among them, the production and sales volume of pure electric vehicles respectively completed 986000 and 984000 [5], a year-on-year increase of 47.9% and 50.8% [6].

Cost is the most important factor. In the process of daily use of electric vehicles, the consistency, total storage capacity and overall cycle life of power batteries became poorer [7], when it is decayed to a certain extent, the fault occurred and the battery power modules or single body needed to be repaired and replaced [8]. Waste battery pollution is characterized as hazardous waste that must be disposed of appropriately [9]. With the increasing number of uses, the capacity was rapidly declining [10]. When the endurance mileage fails to meet the driver's use requirements, it needs to be replaced as a whole. To avoid unexpected driving malfunction, electric vehicle (EV) batteries need to be replaced before the remaining capacity decreases to 70-80% of their original level [11], and the old battery was discarded and recycled [12]. The power

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battery contains nickel (Ni), cobalt (Co), manganese (Mn) and other heavy metal elements [13] as well as the electrolyte with a low flash point, so the retired power battery had high risk and environmental hazard risk [14]. For this reason, the Chinese government had promulgated the interim management measures for the recycling of new energy vehicle power batteries [15], which strictly managed the whole process of production, sales, use, scrap, recycling and utilization of power batteries [16], monitors the implementation of recycling responsibility by each link subject, and hoped to establish the new energy vehicle operation monitoring and power battery recycling. The integrated management platform realized the information sharing of retired power batteries and achieved the purpose of traceable source, traceable destination and controllable nodes [17].

However, the integrated management platform established by the Ministry of Industry and Information Technology of the People's Republic of China focused on the information collection of power battery to avoid flowing into non-compliance channels [18], which did not involve the economy and feasibility of power battery recycling [19]. The vast majority of power batteries were lithium-ionbatteries [20]. According to the national standard GB12268-2012 *list of dangerous goods*, lithium-ion batteries belong to the ninth category of hazardous products. Spent Li batteries contain heavy metal elements, such as Ni and Co, which were classified as carcinogenic and mutagenic materials, as well as toxic organic electrolytes, which adversely affect human health and the environment [21]. Transport vehicles with corresponding categories of dangerous goods were required [22]. The transportation cost of dangerous goods was 2-3 times of that of ordinary goods [23], and the high transportation cost had become the main obstacle that waste generating units and recycling units were unwilling to take the initiative to bear, which had hit the enthusiasm of relevant units in the industrial chain to carry out compliance treatment of power batteries [24].

The traditional power battery recovery logistics mode was only applicable to the recovery of large quantities of discarded power batteries [25], which was not relevant to the power batteries returned by 4S stores [26], because 4S stores had problems such as the number of single recovery batteries returned for maintenance was small, 4S stores were scattered, the time of battery return is uncertain, 4S stores do not allow long-term storage of batteries, etc. [27], [28]. Through the combination of big data technology, the comprehensive platform and power battery logistics network were established to coordinate the recycling and transportation mode of power battery, and the power battery logistics mode was optimized [29]. A multi-level power battery recovery service outlet with larger battery recycling scale and higher bargaining power is necessary, which directly connects waste producing units and comprehensive utilization enterprises, and a dangerous goods warehouse with the temporary storage function of power battery is important [30], [31]. Relying on the big-data based power battery recycling platform, the recycling outlets optimized the optimal comprehensive utilization enterprise and recycling path according to the geographical location, the distance between the outlets and the bidding price of comprehensive utilization enterprises. The interconnection of pool information and comprehensive utilization enterprise information is due to the optimized power electricity, which allowed to obtain the battery disassembly information and trace of the battery and its treatment products [32], [33].

As we can see from the literatures reviewed, the main difficulties of battery recovery are as follows: there are various types, specifications, models and sizes of power batteries. The cost of recycling power batteries is still high. In addition, the transaction efficiency of traditional logistics method and the traceability of power batteries are very low. According to the above difficulties, the big-data based power battery recovery platform had significant advantages on improving transaction efficiency, reducing transaction cost, increasing battery traceability reliability and user satisfaction [34].

In this paper, based on the principle of piping study, Internet of Things (IOT) technology, global positioning system (GPS) technology, audio and video technology and mobile terminal technology, the intelligent transaction supervision system of power battery is constructed through integrating big data of power battery coding, metal price, automobile operation, 4S shop coordinates, new energy vehicle promotion and application, in which reverse product positioning design is carried out, the decommissioning battery directional circulation is realized and visual intelligent logistics data information management platform is built. Moreover, the whole life cycle traceable supervision mode is established based on the power battery transaction to realize the traceability management of power battery.

II. CURRENT SITUATION OF RECOVERY OF RETIRED POWER BATTERY

A. INFORMATION ASYMMETRY IN ACTUAL RECYCLING

1) UNKNOWN STOCK

According to Fig.1, it can be seen from the whole life cycle recovery pipeline process of the power battery that the waste producing unit of the power battery includes the single production enterprise, pack enterprise and vehicle enterprise in the production link [35], power batteries contain many valuable resources and have a high value of recycling. And the waste, unqualified product and test product [36] are obtained from the scrap in the production link. For these three types of batteries, the processing enterprise can convert them through the relationship between production capacity and scrap rate to master the scrap quantity [37]. When the retired battery is in the after-sales maintenance process, due to the geographical factors inherent in 4S stores, power exchange enterprises and repair garages, it is scattered all over the country, and consumers' maintenance situation and battery quantity in the above areas, vehicle enterprises usually do not have real-time and detailed data, and due to the consideration

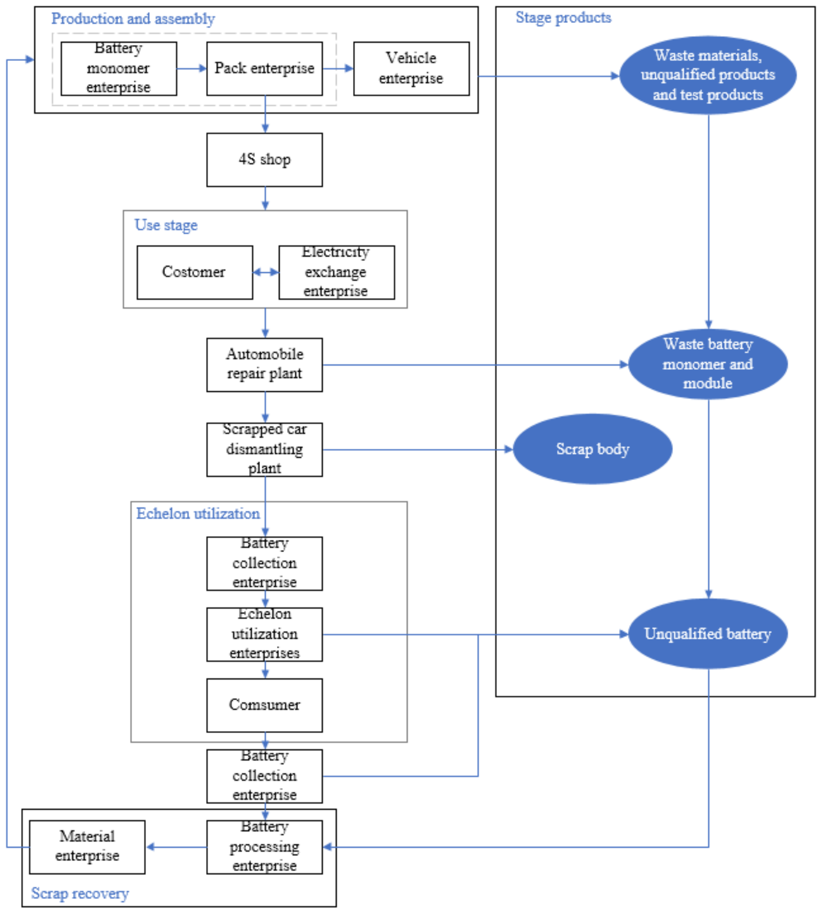

FIGURE 1. Power battery life cycle recovery pipeline process.

of confidentiality of vehicle and battery information, vehicle enterprises are reluctant to penetrate most situations. Revealing more related information is unfavorable for battery collection enterprises to layout recycling outlets and battery treatment enterprises to arrange battery recycling facilities and planning capacity [38]. Obtaining the storage data of the waste battery can simulate and accurately calculate the distance between each waste production point and reasonably arrange the transportation shift, time and path in combination with the load capacity of logistics transportation vehicles [39], and avoid passing through the densely populated area under the premise of controlling the driving path as much as possible [40]. The rationality and scientific it y of the layout of recycling outlets are not only the optimization of the logistics transportation path but also the critical factor to keep a safe distance between the masses and dangerous goods [41]. The layout and decision-making of battery recycling outlets caused by information asymmetry, ultimately, lead to further uneconomical battery recycling [42] and unsustainable battery recycling [43]. The information about the amount of discarded batteries is significant for the layout of recycling outlets, which is crucial for the healthy development of the battery recycling industry chain [44].

2) UNKNOWN BATTERY QUALITY

The power battery starts from the material enterprise, and finally goes to the vehicle enterprise [45] after assembly by the monomer production enterprise and pack enterprise. The monomer production enterprise and pack enterprise are collectively referred to as the battery production enterprise, and they may be the same enterprise or two independent enterprises. In order to master the performance information of the battery life cycle, China national standard GB/T 34014-2017 coding rules for automotive power battery require battery manufacturers to trace all parts and components inside the battery before produce battery cells. The eighth to fourteenth positions in the battery code is traceability information code, which are the codes for each enterprise according to their own internal coding rules [46]. In order to avoid information leakage and the expansion of traceability information, some enterprises build longer and richer battery production traceability code and associate the battery production traceability code with power battery traceability information code through certain coding rules. Battery manufacturing information plays a vital role in battery material type judgment, performance evaluation, and life prediction, while coding encryption is complicated for recycling enterprises to obtain battery manufacturing information [47]. The material type judgment, performance evaluation and life prediction of battery are the problems that should be solved by fast and low-cost technology to ensure the development of the echelon utilization industry [48]. By sharing battery information and developing echelon utilization technology, the low-end situation of waste batteries priced by valuable metal element content and weight, endow waste batteries with more possible value by echelon utilization and increase the profits of battery recycling [49], and enable all participants in the battery recycling industry chain to transport dangerous goods in accordance with the regulations in the process of waste battery logistics.

3) UNKNOWN BATTERY VALUE

In China, two national standards in the field of power battery recycling and utilization have been issued, namely GB/T 33598-2017 code for recycling and dismantling of vehicle power battery (hereinafter referred to as the ''disassembly specification'') and GB/T 34015-2017 code for recycling and utilizing vehicle power battery residual energy testing (hereinafter referred to as ''residual energy testing''), in which the national standard for residual energy testing specifies the testing requirements, testing procedures and testing methods of waste power batteries, and does not involve the process and method of residual value evaluation of power batteries [50]. At present, there is no standard or specification for the residual value evaluation of waste power batteries [51]. Each enterprise estimates the residual value of waste power batteries based on the experience of engineers or using some common testing tools (such as a multimeter) for simple testing [52]. Due to the asymmetric information, and based on the treatment experience of waste lead-acid batteries, waste batteries have a high residual value, which can be sold to any unit or even individual at a high price [53]. Finally, the unreasonable phenomenon of some waste producing units bidding for the treatment of waste batteries in the way of the higher price [54]. Under the mechanism of high price, it is inevitable that some waste producing units will give up their social responsibilities, resulting in waste batteries flowing into enterprises without treatment qualification [55], and will not transfer waste batteries by means of transportation of dangerous goods under the law, which seriously affects the healthy development of waste battery recycling industry [56].

B. OUTLETS DISPERSION

China has 34 provincial administrative regions and 334 prefecture level administrative regions [57]. According to the statistics of China Automobile Circulation Association, China has 29664 authorized 4S stores in 2018 [58]. It can be measured that each provincial administrative region in China has an average of 872 authorized 4S stores, and each prefecture has an average of 89 authorized 4S stores [59]. On October 31, 2019, the Ministry of Industry and Information Technology issued the guidelines for the construction and operation of new energy vehicle power battery recovery service outlets (Announcement No. 46, 2019 of the Ministry of Industry and Information Technology), stipulating that new energy vehicle manufacturers should establish collection type recovery service outlets in the administrative areas (at least prefecture level) where new energy vehicles are sold, and the number of new energy vehicles in the enterprise should reach 8000. The storage and safety guarantee capacity of the recycling service outlets cannot meet the recycling requirements of waste power batteries, and the centralized storage recycling service outlets should be established in the administrative areas (at least at the prefecture level) [60]. The location of collection type recycling service outlets should consider regional factors, which can be set up in 4S stores, maintenance outlets, power stations, recycling and dismantling enterprises of end-of-life vehicles and other places with convenient transportation, so as to facilitate the recycling of used power batteries [61]. In the current network construction mode, vehicle enterprises are more willing to set up some 4S stores authorized by them as special repair shops for electric vehicles, and as the consumer-oriented terminal network for power battery recovery [62], the number of outlets is huge and very scattered, the core of which is that these 4S stores often do not have the professional evaluation ability for the decommissioning status of these high-voltage dangerous power batteries. It is very difficult to optimize the path of battery recovery.

C. COMPLEX PROCESS

The process of battery recovery is very complicated. It can be seen from Fig.1 that since the consumer purchased the electric vehicle, the power battery has entered the circulation link from the production link [63]. During the use process, the maintenance is carried out in 4S shop, power exchange enterprise and auto repair factory. The waste power battery generated after maintenance is generally monomer and module, and may also contain a small number of battery packs [64]. Generally, 4S stores, power exchange enterprises and repair garages do not have storage sites and conditions specifically for class IX dangerous goods. In order to control safety risks, storage time and storage amount need to be strictly limited [65]. On October 31, 2019, the Ministry of Industry and Information Technology issued the guidelines for the construction and operation of new energy vehicle power battery recovery service outlets (Announcement No. 46, 2019 of the Ministry of Industry and Information Technology), stipulating that the storage capacity of waste power battery in the collection type recovery service outlets shall not exceed 5 tons. Different storage methods shall be adopted for the storage of waste power batteries according to the classification results of waste power batteries [66]. The storage time of the waste power battery with sound structure and function in the collection type recycling service outlet shall not exceed 30 days, and the storage time of the waste power battery with risk determined by the test in the collection type recycling service outlet shall not exceed 5 days [67]. The treatment requirements of a small amount and rapid transfer put forward a huge challenge to the logistics transportation of waste batteries and the construction of recycling outlets. At the same time, it will complicate the recycling process, resulting in a sharp increase in the recycling frequency of waste power batteries, the number of recycling outlets, and the number of battery recycling participants [68]. Therefore, how to find the shortest transportation radius and cover the whole recycling process of the network pipeline system becomes an urgent matter.

D. DIVERSIFIED DISPOSAL

Before the logistics and transportation of waste power battery, it needs to be packaged. For example, for waste power battery with electrolyte and coolant leakage, firstly, we need to find the leakage point, seal the leakage part, then seal the inner packaging, and finally use the special logistics box of anti-leakage waste power battery for packaging [69]. Basically, a battery consists of an anode, a cathode, an electrolyte, separators and the external case. For the above-mentioned packaging disposal of power battery leakage, because the power battery is usually in an irregular shape with many edges and corners, and the inner packaging is usually PVC plastic film, it is easy to be punctured by edges and corners, resulting in the loss of the anti-leakage function of the inner packaging [70]. To solve the problem that the inner packaging has been damaged, the packaging disposal method has been investigated to absorb a small amount of coolant or electrolyte that may leak through the absorption and solidification technology in the logistics box [71]. For the waste power battery with electrolyte and coolant leakage, first, it is necessary to find the leakage point and seal the leakage part, and then install the waste power battery into the waterproof, insulated and explosion-proof box with water storage tank [72]. After the battery is put in, the power battery is fixed in a special logistics box by means of a fast strap, and then an adsorbent is put in the storage tank. Usually, vermiculite, expanded perlite and other materials with insulation, low density and large porosity are used as the adsorption and solidification materials [73]. At present, the special logistics box for waste power battery has formed the industry standard technical requirements for waste power battery logistics box (Plan No.: 303-2017-008) in China and it has been widely used [74].

There are various requirements for different types of power batteries with different hazards. The guidelines for construction and operation of new energy vehicle power battery recovery service outlets (Announcement No. 46, 2019 of the Ministry of Industry and Information Technology) stipulates that waste power batteries should be stored independently and should not be mixed with other goods and wastes, and should not be placed sideways, upside down or directly stacked [75]. The waste power battery with intact structure and function should be cleaned, and the waste power battery with risk should be insulated, leakproof, flame-retardant, heat insulation and other special treatments, and the treated waste power battery should be placed upright on the shelf [76].

There are a variety of storage methods. Different storage methods should be adopted according to the classification results of waste power batteries. The waste power batteries with sound structure and function should be stored separately, the waste power batteries with risk shall be stored separately after detection, and the waste power batteries with special national regulations should be stored independently [77]. The waste power battery with intact structure and function, the power battery with risk determined by inspection and the waste power battery with special national regulations should be stored in isolation. If isolation storage cannot ensure safety, separation storage should be used. The storage mode should meet the requirements in Table 1 [78].

E. DIFFICULTIES IN TRACKING AND TRACING

On July 2, 2018, the Ministry of Industry and Information Technology issued the Interim Provisions on the Traceability Management of New Energy Vehicle Power Battery Recycling (Announcement No. 35 of the Ministry of Industry and Information Technology in 2018), stipulating the establishment of the ‘‘national monitoring and traceability comprehensive management platform for new energy vehicle power battery recycling’’ (hereinafter referred to as ‘‘the traceability management platform’’) for the production, sale, use, scrap, recovery, and use the whole process of information collection to implement traceability management for new energy vehicle products newly obtained ‘‘road motor vehicle production enterprise and product announcement’’ (hereinafter referred to as ‘‘announcement’’) and imported new energy vehicle products newly obtained compulsory product certification [79]; for new energy vehicle products that have been produced and imported but not included in traceability management, the relevant information should be collected within 12 months after the implementation of the provisions. The traceability information should be supplemented and transmitted to the traceability management platform. The automobile manufacturer should upload the information within 15 working days after the issuance of the factory certificate of domestic new energy vehicles, and the importer should upload the information within 15 working days after the customs clearance of the imported new energy vehicles and the completion of the inspection and quarantine. The seller cooperating with the automobile manufacturer should timely submit the record information to the automobile manufacturer after the vehicle sales, and the automobile manufacturer should upload the information within 30 working days after the vehicle sales license plate and the vehicle owner record information are updated. The repairers and battery rental enterprises cooperating with the automobile manufacturers should submit information to the automobile manufacturers in time after the maintenance and replacement of the power battery. The automobile manufacturer should upload the traceability information within 30 working days after the maintenance and replacement of the power battery [80]. The recycling service outlet should submit information to the automobile manufacturer after the recycling and handover of

TABLE 1. Storage mode.

Storage method requirements	Cut-off storage	Segregated storage	Detached storage
Storage space/m	0.3-0.5	0.5-1.0	0.5-1.0
Channel width/m	1-2	1-2	5
Wall width/m	0.3-0.5	0.3-0.5	0.3-0.5

the waste power battery. The automobile manufacturer should upload the information within 30 working days after the waste power battery is recycled, put into storage and transferred out of the warehouse. The scrapped vehicle recycling and the dismantling enterprise should upload the information within 15 working days after receiving the scrapped new energy vehicle and issuing the scrapped vehicle recycling certificate; the information should be uploaded within 15 working days after the scrapped power battery is disassembled and handed over to the warehouse. The echelon utilization enterprises should upload the information within 15 working days after the echelon utilization battery products are delivered out of the warehouse; the waste power battery generated in the production, detection, and use of echelon utilization battery should upload the information within 15 working days after its recycling and warehousing and delivery out of the warehouse. The recycling enterprise should upload information within 30 working days after receiving and warehousing the waste power battery, and within 30 working days after completing the recycling and final treatment [81].

It is required by the policy that the corresponding responsible subject should be responsible for the submission and traceability of its information throughout the life cycle of the power battery. In fact, some responsible topics study the loopholes of traceability information management systems, wash the waste battery in various ways, and make the waste battery flow back into the market, which makes the traceability management of waste power battery becomes very difficult [82]. For example, since China has not implemented the supervision and dismantling mechanism similar to the dismantling of end-of-life vehicles for the dismantling of power batteries, and there is no penalty in the Interim Provisions on the management of the recovery and traceability of power batteries for new energy vehicles, it is difficult for the management department to impose penalties on the illegal enterprises. The illegal cost of enterprises is relatively low. The comprehensive utilization enterprises make a false report on the number of dismantling, and some of them will be falsely reported as the battery coding is polished and removed, the human set obstacles to avoid the supervision of the traceability management system, and the battery is manufactured into the fields with low requirements for battery performance and considerable consumption, such as rechargeable batteries, vehicle refrigerators, energy storage cabinets, etc., which flow back into the market [83]. The battery capacity in the above-mentioned fields is low, and the number of battery cells in battery products is small, which leads to the scattered battery falling into the hands of a large number of consumers, so it is tough to trace and recover. In other words, China's current policies, regulations and standards are not mandatory documents. In the absence of constraints in the social credit system, the legal cost of not complying with the provisions of the materials safety risk control of retired batteries will become very important.

F. SENSITIVE ISSUES SUCH AS TRANSPORTATION HAZARDS IN THE WHOLE PROCESS

As the waste power battery belongs to the ninth class of dangerous goods, the number is 3480. According to the provisions of the Regulations on the Administration of Road Transport of Dangerous Goods (Order No. 42 of the Ministry of Transport in 2019), road transport enterprises or units of dangerous goods shall strengthen the management of production safety and formulate emergency plans. Road transport enterprises or units of dangerous goods should require drivers and escorts to strictly abide by the relevant departments' regulations on dangerous goods when transporting dangerous goods, relevant regulations on freight transportation route, time and speed. Under the requirements of relevant policies and regulations, and under the comprehensive constraints of multiple factors such as emergency plan, transportation line, time, speed, etc., a lot of preparatory work needs to be done in the early stage of each recovery of power battery [84]. At the same time, different risk levels of waste power batteries need to be packed, loaded, unloaded and transported at corresponding levels. The whole process is very dangerous. It is difficult to find operators and relevant equipments with the same level of qualification in each link of battery recycling, and the whole process of recycling is compassionate [85].

Lithium-ion batteries contain a lot of organic matters and corrosive liquids. The electrolyte of Li-ion power battery is typically a mixed solution of $LiPF_6$ dissolved in the organic solvent [86]. $LiPF_6$ can decompose at 80 °. The widely used electrolyte solvent systems are carbonate mixed solvents with a low flash point, including vinyl carbonate (VC), diethyl carbonate (Dec), dimethyl carbonate (DMC), ethyl carbonate (EMC), etc. generally, propylene carbonate (PC), ethylene glycol dimethyl ether (DME) and other organic solvents mainly used for primary lithium (Li) battery are not used [87]. The flash point, melting point and boiling point of the above solvents are shown in Tab.2. When the shell of Li power battery is damaged due to improper storage, electrolyte leakage

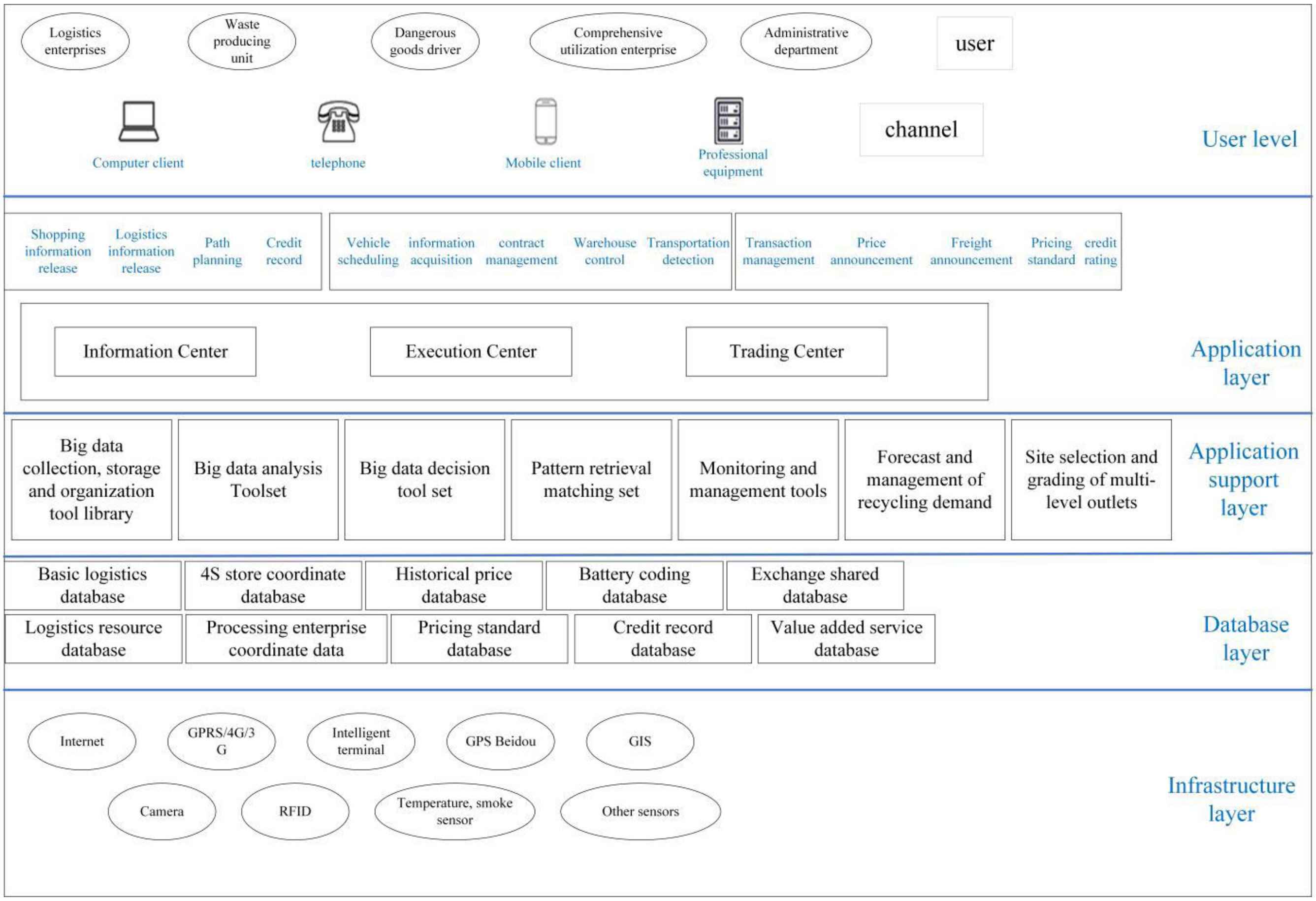

FIGURE 2. Theoretical model of a power battery recovery platform based on big data.

and contact with oxygen in the air will cause the battery to burn and even explode [88]. Therefore, the transportation risk of batteries with a damaged cell shell is very high. Once the electrolyte inside the battery leaks in the transportation process, it is straightforward to catch fire, resulting in the burning of logistics vehicles. Electrolyte leakage may not only occur after battery collision but also after the battery has experienced chemical discharge. The galvanic effect caused by chemical discharge causes electrochemical corrosion and dissolution of battery shell and battery positive terminal [89]. After the components are dissolved, the electrolyte inside the battery can be connected with the outside, and the electrolyte is exposed to the air, which is very dangerous [90]–[92]. Also, to avoid electrolyte leakage caused by battery collision during handling and transportation, the battery should be handled carefully in strict accordance with the operation instructions, and a command and management personnel who has been trained and familiar with the dangerous characteristics of Li battery and precise emergency handling methods should be provided during handling [93]–[95]. Based on the analysis, it is not hard to see that the management and control tasks of safety risk sources of large-scale decommissioned power batteries in China in the future are very arduous and need to be prepared in advance.

III. OPERATION MECHANISM OF POWER BATTERY RECOVERY PLATFORM BASED ON BIG DATA

Based on the typical input-output logic from decommissioning battery to recycling, according to the pipeline theory, the power battery recycling platform of intelligent big data is used to connect the waste production unit, comprehensive utilization enterprise, logistics enterprise, storage unit and regulatory department, and five technologies of cloud computing, IOT, Internet of vehicles (IOV), Internet and big data are integrated into the power battery recycling field, which is expected to be realized for information sharing, resource docking, process design planning, process tracking feedback, business integration optimization and decision-making intelligence. Zhang *et al.* [96] proposed an efficient approach to build a multi-dimensional index for the Cloud computing system, which can process typical multi-dimensional queries including point queries and range queries efficiently. The uniqueness of APP usage via large-scale empirical measurements was systematically quantified by Tu *et al.* [97], and by collaborating with a major cellular network provider, they obtained a city-scale anonymized dataset on mobile app traffic. Guo *et al.* [98] first proposed a crowd-powered event model and a generic event storyline generation framework based on which a multi-clue-based approach to fine-grained

TABLE 2. Flash point, melting point and boiling point of electrolyte solvent for Li batteries.

Solvent	VC	DEC	DMC	EMC	PC	DME
Flash point/°C	160	31	18	25	131	1
Melting point/°C	36.4	74.3	4.6	53	48.8	69
Boiling point/°C	248	126	91	110	242	83

event summarization is presented. The operation mechanism of the power battery recovery platform based on big data is shown in Fig.2.

(1) Infrastructure layer: the infrastructure layer is the data source of the platform operation. Through radio frequency identification (RFID), geographic information system (GIS), GPS, intelligent terminal, camera, temperature and smoke sensor and other methods, the data of all parties are acquired and saved in the recovery process, providing an interface for data collection [99]. On this basis, the infrastructure layer relies on the Internet, the IOT, the IOV and the database layer to build data interaction media, and has the functions of cleaning the collected data and automatic data correction.

(2) Database layer: with the application of PC terminal, Internet of Things and other information technologies, a number of data sources provide rich and diverse research samples for the analysis, mining and prediction of big data and also ensure the objectivity of the results. In addition, the thinking of data collection and extraction is also changing, data collection from the traditional capacity limited premise of targeted acquisition and screening of static data, into from massive dynamic data cleaning and re-selection; data analysis from the conventional calculation method with reduced flexibility, into possess the ability to carry out association analysis of unstructured data, and insight into a large number of hidden data Tibetan information.

(3) Application support layer: the application support layer processes the database layer, mainly carries out data self-configuration processing such as big data real-time analysis and decision-making, provides transaction cooperation and supply-demand matching tools for battery recovery management, realizes transaction recommendation, site selection of recovery outlets, intelligent information push, enterprise blacklist screening, enterprise/driver capability evaluation, vehicle reliability early warning, route planning, capable stowage and other decision-making functions.

(4) Application layer: the application layer is oriented to battery recovery service, supporting the technical requirements of the management layer, service layer and interface layer. The management layer mainly deals with the massive data connected to the platform and provides application services to users through the platform. The service window includes three modules: information service center, battery trading center and value-added service center. The service layer is primarily responsible for the essential services and value-added services of battery recovery. Through the integration of waste production units, comprehensive utilization units and logistics resources, it cooperatively participates in the whole process of battery recovery services. The interface layer is a port to provide information interaction between users and the platform. It is primarily responsible for the output and visual display of data results, so that users can directly access platform information resources.

(5) User layer: the user layer is the platform user. The power battery recovery platform is no longer just to meet the needs of waste production units, comprehensive utilization enterprises and logistics enterprises, but based on the height of openness, diversity and sharing, according to different user groups with different needs, to open data applications with different requirements, integrating management departments, environmental protection departments, safety supervision departments, transportation departments, tax departments, statistical departments, insurance service enterprises, etc. Since then, it has provided various heterogeneous services in the form of a platform to realize data resource sharing, equipment resource optimization and transaction decision optimization.

IV. DESIGN OF RECOVERY AND TRACEABILITY PIPELINE MODULE BASED ON BIG DATA

The design requirements of logistics information platform are mainly embodied in practicability, high compatibility, accuracy, stability and security. According to the pipeline logic and structure design principle, the platform is divided into three modules: basic function pipeline, extended function pipeline and characteristic function pipeline by adopting the pipeline modular design method, as shown in Fig.3 and Fig.4. The basic functions include information service function, battery trading function, value-added service function, platform operation management function, mainly to satisfy the basic service needs. The extended functions include decision-making analysis function and intelligent logistics function, mainly by means of big data, changing the traditional power battery recycling mode, innovating the power battery recycling service mode, improving the all-round service experience, achieving low-cost production and waste units, safety and environmental protection compliance, avoiding single certification, tracing the source of the whole process, and information disclosure control. The featured functions include recycling function and disposal management function, background monitoring function. Mainly with the

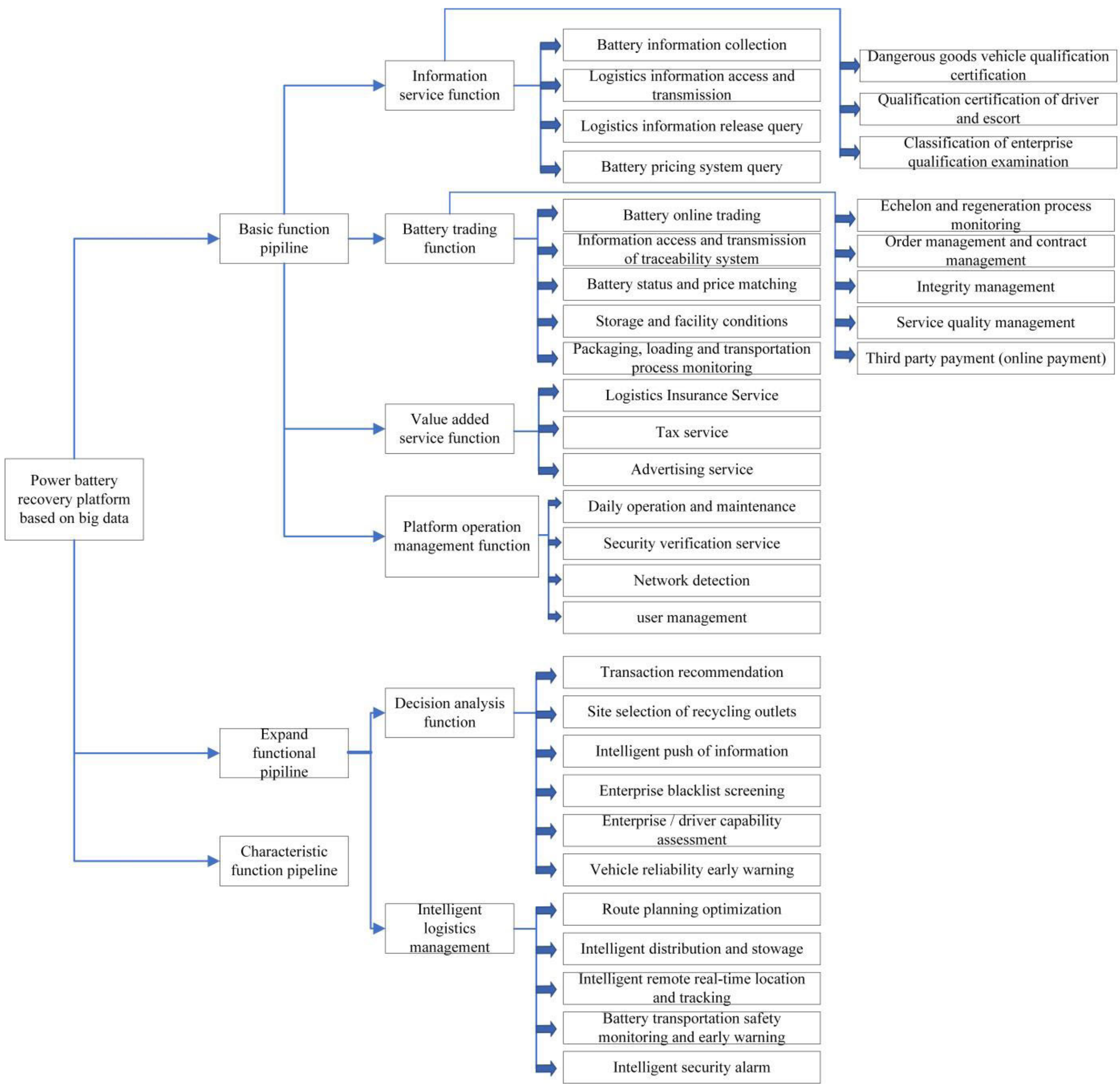

FIGURE 3. Overall logical structure model of a power battery recovery platform based on big data.

help of big data, starting from the waste production link of battery, relying on the power battery's coding, the battery, packaging, vehicle, disassembly products, renewable products, energy consumption, three wastes and other links in the whole life cycle can be connected in series, and the information island, regulatory blind spot, high regeneration cost, poor environmental friendliness, high freight of comprehensive utilization enterprises, and challenging construction of recycling outlets can be opened small/new enterprises are difficult to enter the supplier system of vehicle enterprises.

A. BASIC FUNCTION PIPELINE

Information service function includes the whole process of information collection, transmission, release, and verification of enterprise, battery, vehicle and personnel. The information service function subdivision includes several modules. ① Battery information collection function. Based on the traceability code of power battery and the access of external information system and platform, the information required for pricing is collected from multiple isomorphic or heterogeneous data sources [100] (such as basic information such as battery specification and model, size and weight, positive and negative

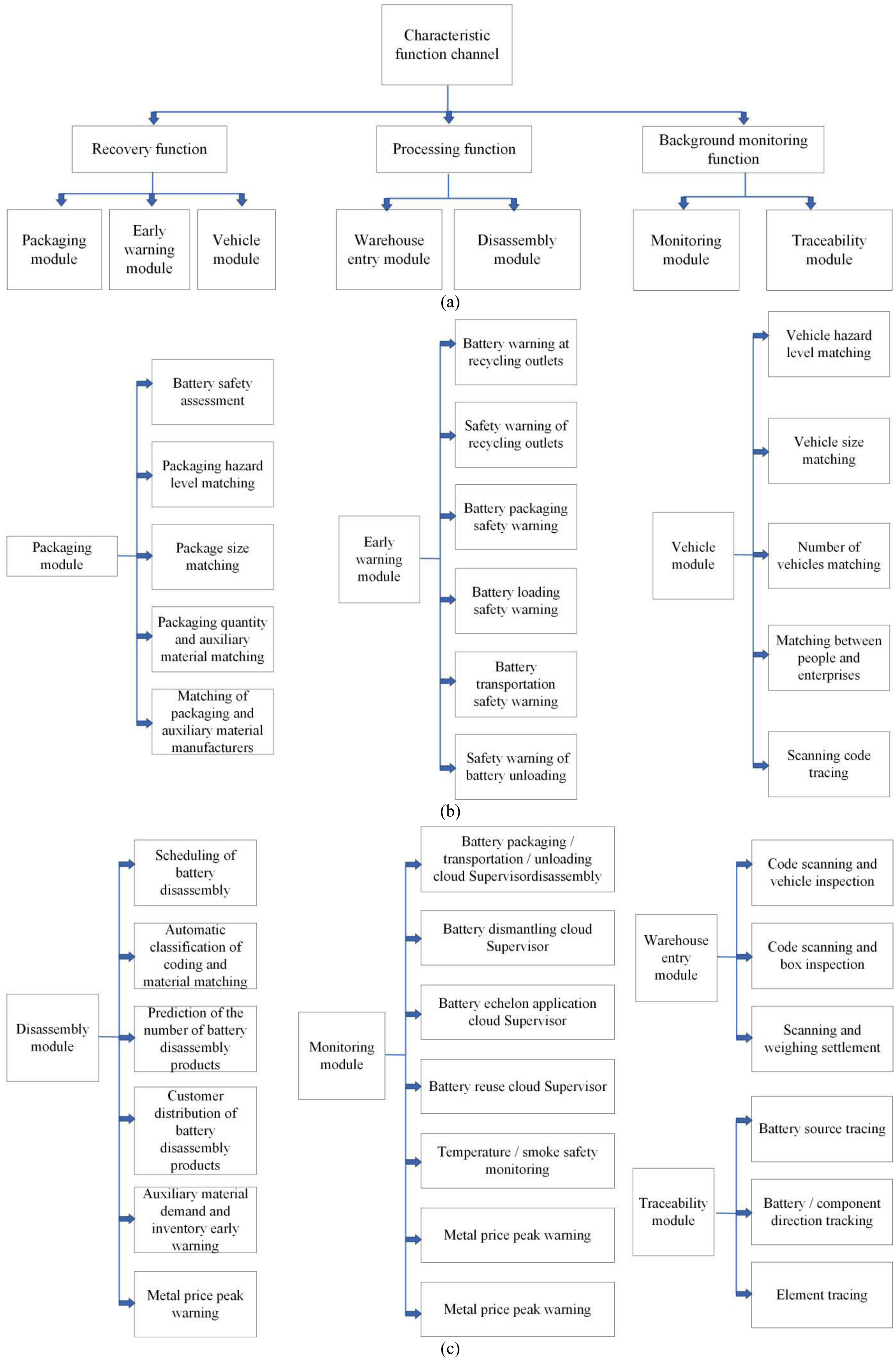

FIGURE 4. **Logic structure model of characteristic function pipeline of power battery recovery platform based on big data.**

material type, Ni, Co, Mn and Li metal content ratio and electric vehicle operation data), and the data is standardized and sorted out. ② Logistics information access and transmission. Access to the external information system and platform, collect the information of the ninth type of dangerous goods transportation qualification enterprises, vehicles and drivers, and standardize and sort out the data. ③ Logistics information release query. Logistics supply and demand information release and query function is the release and query of source information for vehicles and goods. ④ Battery pricing system query. Collect the pricing strategies of echelon utilization and recycling enterprises, input the vehicle operation data into the battery life calculation model, access the external echelon utilization monomer market procurement platform, and a convenient management platform for query the price of Ni, Co, Mn and Li metal. ⑤ Qualification certification for dangerous goods vehicles. Regularly check the vehicle driving license and road transportation license of dangerous goods vehicles within the validity period to ensure that the operating vehicles on the platform are legal vehicles with real identity, to improve the reliability of the platform. ⑥ Qualification certification of drivers and escorts. The qualification certificates of the drivers and escorts for road transport of dangerous goods and the driving licenses of motor vehicles should be examined dynamically. ⑦ Classification of enterprise qualification examination. The transportation unit qualification verification function mainly refers to the verification of the business license, road transportation business license of the member enterprise; the comprehensive utilization of the business license, hazardous waste business license, renewable resource recovery operator registration certificate, enterprise credit and other information for the nuclear test certificate. If it does not meet the standards set by the platform, the authority will control the corresponding functions. For the comprehensive utilization enterprises, they will also be classified according to the compliance conditions such as the white list of the Ministry of Industry and Information Technology and the enterprise's processing capacity (and the remaining processing capacity of that year).

(2) Battery transaction function: it mainly includes battery transaction, logistics resource transaction, evaluation of battery price, matching transaction, traceability information entry and traceability source cancellation, third-party payment to improve usability, vehicle positioning monitoring of the whole process of battery recovery after order transaction, battery packaging, loading and unloading, in transit tracking and other logistics process monitoring functions.

(3) Value-added services: mainly including logistics insurance services, tax services, advertising services and other features. As the power battery belongs to the ninth category of dangerous goods with high risk, in order to reduce the risk of logistics and improve the anti-risk ability of the platform, the logistics insurance service function is used to protect the rights and interests of three parties, i.e. waste production unit, comprehensive utilization enterprise and logistics enterprise. The value of the power battery of different material types is different. In the transaction, the waste production unit may pay the treatment fee of a global utilization enterprise, or the comprehensive utilization enterprise may pay the waste metal fee of the waste production unit. In addition, tax service is a two-way tax system.

(4) Platform operation management function: the shared logistics information platform based on big data needs a manageable and controllable operation management platform to deploy various services and operate maintenance management. Platform operation management system is a kind of auxiliary management system required to coordinate each subsystem to complete its functions, involving daily operation management and maintenance, security verification service, network detection and user management.

B. EXTENDED FUNCTION PIPELINE

Based on the background of big data, the development of the new generation of information technology makes the expansion function of the platform increasingly rich. The extended function design of the platform in this paper combines the application of big data technology, and mainly lists the following two functions:

(1) Decision analysis function: mainly including transaction recommendation, site selection of recycling outlets, intelligent information push, enterprise blacklist screening, enterprise/driver capability evaluation, vehicle reliability warning. Transaction recommendation is based on the analysis of behavior preference of waste production units (such as treatment cost priority, information security priority, enterprise distance priority, service praise priority, processing capacity priority, etc.), intelligent matching recommendation and comprehensive utilization of enterprises. The site selection of recycling outlets is based on the big data of new energy vehicle promotion and application, analyzing the promotion and application density of electric vehicles all over the country, avoiding densely populated areas and traffic control areas, evaluating the site use/lease cost, analyzing massive data by establishing a model, controlling a single variable to simulate the site selection scheme, so as to find out the optimal site address. The environmental pollution of solid waste has the characteristics of responsibility tracking and tracing. In order to reduce the risk of waste producing units, improve the reliability of the platform, collect the big data of safety and environmental protection accidents in the process of enterprise operation and production published by the government dynamically, and form a blacklist of enterprises. Through sensor or remote control system, the platform can make a unique "personnel analysis" on the data of employees' working status, professional level, driving habits, work enthusiasm, independence and contribution value to the enterprise, so as to make an objective judgment on employees' work performance, and make the reward and punishment system of the enterprise more objective and targeted for employees' training; in addition, according to the excavation analysis, the equipment with potential safety hazards shall be replaced in time, and actions should be taken as early as

possible to nip the hazard source in the bud, ensure the normal operation of production and avoid accidents.

(2) Intelligent logistics management: using big data technology to realize logistics auxiliary decision analysis, mainly including route planning optimization, wise distribution and loading, intelligent remote real-time positioning and tracking, battery transportation safety monitoring and early warning, and smart security alarm. Through machine learning, the platform comprehensively considers vehicle load, route, weather, order, traffic condition, traffic control and other factors to provide prediction and optimization of transportation route. With the application of computer database technology, the application software connecting the owner of goods and the driver of transportation is developed to realize the precise docking of goods and vehicles and the automatic calculation of freight after the transaction of the order. According to the processing cycle required by the waste production unit, the intelligent distribution of goods and loads is realized. Through the installation of GPS/BeiDou equipment, the vehicle and battery can be located and tracked remotely and in real-time, and the camera can be installed to realize the whole process visualization. Install temperature sensor, smoke sensor and infrared imaging equipment to monitor the safety condition of battery during transportation and storage in real-time, and give early warning for fire accident. Echelon utilization of batteries has high value. Sensors are installed in the battery logistics box, and the case is opened for alarm; the electronic fence is set in the transport process, and the transport path is dynamically matched with the electronic fence to realize intelligent security in the logistics process.

C. CHARACTERISTIC FUNCTION PIPELINE

By using big data tools, build a customized service with three specific function modules: recycling function, processing function and background monitoring function, which can enrich the use of the platform with characteristic functions.

(1) Recovery function: mainly including packaging module, early warning module and vehicle module. The packaging module starts from the scrapping demand of the waste producing unit. The waste producing unit enters the basic information and safety information when the battery is scrapped. The platform automatically evaluates the safety status of the battery according to the national laws and regulations or enterprise standards, and matches the required level of the packaging according to the safety status result system. According to the basic information system of battery, the size, quantity and auxiliary materials of the package are calculated. Based on the above evaluation results, the system compares the price of reusable packaging materials and disposable packaging materials delivered by recycling enterprises, selects the optimal scheme according to the optimization strategy, and feeds back to the recycling enterprise.

The pre-warning module is to pre-warning the battery stock in the battery recovery node, using the storage time, battery weight, manual control and other means to pre-warning the battery recovery node stock, and based on the stock to give the safety pre-warning of the battery recovery node, when reaching the pre-warning value, automatically trigger the battery scrap demand, in order to reduce the risk of the battery storage process. In addition to the early warning at the recycling outlets, the whole process of battery packaging, loading, transportation and unloading can also be realized through the configuration of thermal imaging technology, smoke sensing technology, etc.

The vehicle module is based on the number of batteries and safety conditions to achieve vehicle related management. According to the battery safety assessment results, the system automatically matches the risk level of the required logistics vehicles. When the vehicles arrive at the scene, it connects with the public security traffic management system, checks the vehicle transportation risk category and legitimacy, and gives the judgment result of whether to load and release. According to the weight and size information of the battery, combined with the package size information recommended by the system, the system uses ant colony algorithm (ACA) to automatically match the size and quantity of each vehicle under the premise of the lowest cost of all battery transportation.

(2) Processing function: mainly including warehousing function and disassembly function. The warehousing function is to collect the battery, issue the vehicle number plate registered at any time, automatically connect the vehicle information with the gate guard vehicle number plate identification system in the recycling enterprise by using big data and realize automatic release. After the vehicle enters the plant area, the code scanning inspection equipment shall be utilized to check the consistency of the delivered battery, so as to avoid changing the goods halfway. The number and weight of the battery are registered after scanning the code and checking the authenticity. The information is connected with the financial accounting and settlement system to automatically print the payment/payment list and the payment/collection list, rapidly.

(3) Background monitoring function: mainly including a monitoring module and traceability module. The monitoring module includes the real-time monitoring of battery packaging, transportation, loading and unloading as well as on-site disassembly, transfer, echelon utilization (classification, testing, screening, matching, assembly, inspection, etc.) and regeneration utilization (pyrolysis, crushing, separation, dissolution, impurity removal, synthesis, sintering, etc.) of off-site operations. In addition to audio and video monitoring, there are temperature monitoring of thermal imaging technology, safety monitoring of smoke detection technology, and energy consumption monitoring of the whole process of disassembly, echelon utilization and recycling, such as water consumption, power consumption and gas consumption. Based on the monitoring data, backward production capacity is eliminated to achieve industrial adjustment and optimization. At the same time, the real-time monitoring of the typical pollutants discharged from the three wastes in the process of comprehensive utilization, the docking of

networking platform, and the supervision of the whole people are carried out to eliminate the inherent concept of poor environmental protection of waste battery recycling.

According to the battery recovery traceability management system established by the Ministry of Industry and Information Technology, the traceability module traces the battery source to force the production and waste units to fulfill the producer's responsibility [101]. For the vehicle manufacturers whose power batteries have reached the scrapping time but have not been scrapped for a long time, the system automatically checks the accounts to avoid the loss of the battery. After disassembling the battery and its components, each product should be tracked to make sure that all materials are effectively disassembled and damaged in accordance with the specifications, so as to avoid an illegal return to the market. The system can also track all elements of batch power battery atthe atomic level, match the Material Safety Data Sheet of the battery provided by the whole vehicle enterprise according to the battery code, automatically calculate all element types and contents, track the battery source, the direction of battery level components and the three waste emissions to form a boundary closed-loop [102], and feedback and verify the three waste emissions against the trace results of elements whether there is fraud or not.

V. TRANSPORTATION PATH OPTIMIZATION OF POWER BATTERY BASED ON BIG DATA

Dangerous goods transportation of power battery is an important part of power battery recovery. It refers to packaging, route planning, reporting and dispatching vehicles to deliver power battery from 4S shop to recycling outlets according to customer's scrap requirements. The route planning and scheduling effect of dangerous goods transport vehicles have a great impact on the distribution safety, cost, speed and efficiency, and have become one of the factors restricting the development of the power battery recovery industry. Therefore, one of the most important tasks of the power battery recovery platform is to develop the route planning and scheduling function of the dangerous goods transport vehicles.

According to the logic of pipeline science, it is necessary to find the best path in the whole system boundary. The most common method is to use the sum of the straight-line distance between two points as the data basis of the optimal solution. However, the straight-line distance between two locations is often quite different from the actual distance of the road, which makes the calculated optimal path often unable to be applied to the actual road.

A. BASIC MODEL OF ANT COLONY ALGORITHM

ACA is a population-based heuristic bionic evolutionary algorithm [103], [104] proposed by Dorigo *et al.* In the early 1990s, by simulating the behavior of ants in the nature to find their way collectively. In the process of ants crawling, pheromones are left on the road. The more ants passing through the same path, the higher the concentration of pheromones and subsequent ants tend to choose the path with a high concentration of pheromones [105]. Pessin *et al.* [106] presented the application of Swarm Intelligence to a problem of garbage and recycling collection using a swarm of robots. Zhang *et al.* [107] proposed a temporal multi-objective ant colony optimization algorithm to generate the routing plan for electric vehicles to fulfill the various requirements of drivers under a time-dependent stochastic traffic environment.

B. MODEL ESTABLISHMENT

Before building the model, the variables and parameter symbols used in the model should be defined and explained. Set O as the recycling outlet; Z as the total distance of the vehicle to go through all 4S stores; m as the number of 4S stores; n as the number of vehicles; d_{ij} as the distance between 4S stores i and j; q_i as the recycling weight of 4S store customers, $q_0 = 0$; Q as the maximum load of each vehicle; v_i as the recycling volume of 4S store customers, $v_0 = 0$; V is the maximum loading volume of each vehicle; x_{ij} is the 0-1 variable, and the value of vehicle k from 4S shop s_i to s_j is 1, otherwise it is 0; y_{ij} is the 0-1 variable, when vehicle k serves 4S shop i, it is 1, otherwise it is 0.

The model assumes that the coordinates of the recycling outlets and 4S stores are known; the weight and volume of the batteries to be processed in each 4S store are known, and they will not exceed the approved load and volume of a vehicle; each 4S store has and is only served by one vehicle once; the road conditions have no impact on the driving distance of the vehicle; the vehicle models of the recycling outlets are the same, and the number of vehicles is sufficient, and the driving mileage of each recycling task is not more than the vehicle maximum driving distance; the capacity of recycling outlets is large enough.

Based on the parameter setting and model assumption, the objective function is established:

$$\min\ Z = \sum_{i=0}^{i=m} \sum_{j=0}^{j=m} \sum_{k=1}^{k=n} d_{ij} x_{ijk} \tag{1}$$

$$S.t.\ \sum_{i} q_i y_{ik} \le Q, \quad k = 1, 2, 3, \ldots, n \tag{2}$$

$$\sum_{i} v_i y_{ik} \le V, \quad k = 1, 2, 3, \ldots, n \tag{3}$$

$$\sum_{i} y_{ik} = 1, \quad i = 1, 2, 3, \ldots, n \quad k = 1, 2, 3, \ldots, n \tag{4}$$

$$\sum_{i=0}^{i=m} x_{ijk} - \sum_{j=0}^{j=m} x_{ujk} = 0 \ u = 1, 2, 3, \ldots, m \quad k = 1, 2, 3, \ldots, n \tag{5}$$

$$y_{ijk} = 0, 1 \quad i = 1, 2, 3, \ldots, m \quad k = 1, 2, 3, \ldots, n \tag{6}$$

$$x_{ijk} = 0, 1 \quad i = 1, 2, 3, \ldots, m \quad k = 1, 2, 3, \ldots, n \tag{7}$$

In the above formula, Eq.1 is the objective function to minimize the journey; Eq.2 is the vehicle load constraint, and the recovery volume of each 4S shop shall not exceed the approved load capacity of the vehicle; Eq.3 is the vehicle load volume constraint, and the recovery volume of each 4S shop shall not exceed the vehicle compartment volume; Eq.4 is to ensure that each 4S shop has one and only one vehicle for service; Eq.5 is to ensure that each vehicle has served a 4S shop, you must leave after the store; Eq.6 and Eq.7 are variable values.

C. MODEL SOLUTION

Before solving the model problem, the following symbolic definitions are introduced: number of ants K; number of 4S stores L; 4S store set R (r = {i} | i = 1, 2, l); recycling outlet R_0; time t: pheromone quantity $\tau_{ij}(t)$ on the line from 4S shop i to 4S shop j; heuristic information quantity $\eta_{ij} = 1/d_{ij}$, d_{ij} represents the distance between 4S shop i and 4S shop j; each ant only visits each 4S shop once during a tour, controlled by *Tabu* (k), *tabu* (k) represents all 4S shops visited by the k ant in the tabu table; *Allowed* (k) refers to the 4S shop that the k ant is allowed to visit next, that is, all 4S shops that the ant has not visited, *allowed* $(k) = r -$ *tabu* (k); the ant releases pheromones on its route. Therefore, ant k located at 4S store i at time t calculates the transfer probability of 4S store j as the next access node according to Eq.8 [108].

$$P_{ij}^{k}(t) = \begin{cases} \dfrac{\left[\tau_{ij(t)}\right]^{\alpha} \times \left[\eta_{ik(t)}\right]^{\beta}}{\sum \left[\tau_{is(t)}\right]^{\alpha} \times \left[\eta_{is(t)}\right]^{\beta}}, & j \in \text{allowed}(k), \\ & s \in \text{allowed}(k) \\ 0, & \text{otherwise} \end{cases} \tag{8}$$

In Eq.8, α is the information heuristic factor, the larger the value is, the more sensitive the ant is to the pheromone; β is the expectation heuristic factor, the larger the value is, the more sensitive the ant is to the length of the line [109].

Pheromone updating is one of the important factors affecting the convergence of ACA [110]. When all ants have established the access path, pheromones on each side of the path will be updated according to the following rules:

$$\tau_{ij}(t+n) = (1-\rho) \times \tau_{ij}(t) + \Delta\tau_{ij}(t) \tag{9}$$

$$\tau_{ij}(t) = \sum_{k=1}^{k=m} \tau_{ij}^{k}(t) \tag{10}$$

In Eq.9 and Eq.10, ρ is the pheromone volatilization factor, and $1-\rho$ is the pheromone residue factor. In order to prevent the infinite accumulation of information, ρ value range: $0 \le \rho \le 1$; $\tau_{ij}(t)$ and $\tau_{ij}(t+n)$ respectively represent the number of pheromones remaining on the path at time t and time $t+n$ [111]; represent the path (r_i, r_j), The increment of pheromone, $\Delta\tau_{ij}^{k}(t)$ indicates the pheromone amount of the K ant on the path (i, j) in this cycle [112].

Ant cycle model is used as the update strategy of pheromone, and the expression is as follows:

$$\Delta\tau_{ij}^{k}(t) = \begin{cases} \frac{Q}{L_k}, & \textit{The } k-\text{th ant goes through the path } (i, j) \\ 0, & \text{otherwise} \end{cases} \tag{11}$$

In Eq.11, Q is a constant, indicating the pheromone strength, which to some extent affects the convergence speed of the algorithm; L_k is the total length of the access path of the k ant in this cycle [113].

According to the path selection information of ants, after updating the global pheromone of the network, the total length of the shortest network path of ants in the process of logistics distribution is calculated. When the number of iteration cycles $N_K > N_{K\max}$, the iteration cycle is stopped and the path and the total path length of ants are output. At this time, the final iteration result is the optimal distribution path [114], [115].

The traditional ACA uses Pythagorean Theorem to calculate the distance between any two nodes [116]. In this paper, we optimize the JSON package returned by Baidu map API to obtain the actual distance matrix between any two nodes. It mainly involves the use of the Baidu map route matrix API to obtain the route distance and time without obtaining detailed route information [117]. After optimization, the calculation accuracy of the system can be improved, so that the calculation result is closer to the actual vehicle driving distance [118].

D. BATTERY RECOVERY ANALYSIS OF A RECYCLING OUTLET

The program is developed based on B/S mode, and the server is developed in PHP language, mainly completing algorithm solving function [119], the client uses Ajax technology to realize asynchronous data interaction with the server [120], and the development language includes HTML, JavaScript, CSS, JSON. [107]. Take a battery recycling and treatment enterprise in Foshan City, Guangdong Province as an example. The location of recycling outlets is R_0 (address: Leping Town, Sanshui District, Foshan City), which provides battery recycling services to 10 nearby 4S stores. The address and weight volume of 4S stores are: Dongfeng Nissan Foshan GuangwuRuixiang franchise store (0.45t, 1.45m^3), Guangzhou Honda Hengxing store (0.83t, 3.06m^3), Guangzhou Automobile Fengfeng store TianfushanYouhong-Guicheng store (0.31t, 0.83m^3), Shilihe automobile Guangqi 4S store (2.11t, 6.15m^3), Foshan Shili automobile and Zhonglian FAW Volkswagen 4S store (0.06t, 0.06m^3), Foshan Sanshui Toyota Automobile Sales Service Co., Ltd. (1.05t, 3.04m^3), Guangqi Toyota ZhongyuanNanfeng store (1.26t, 4.15m^3), Dongfeng Nissan fengri franchise store (0.38t, 1.45m^3))Guangzhou Nanling Toyota Automobile Sales Service Co., Ltd. (0.76t, 2.92m^3), Foshan ShundeY-isheng Toyota Automobile Sales Service Co., Ltd. (1.45t, 4.66m^3). It is assumed that there are enough vehicles in the

TABLE 3. Table of actual road distance between nodes.

i	j 0	1	2	3	4	5	6	7	8	9	10
0	0	31.3	29.1	35	29	19	12	12	35.9	44.9	60.6
1	33.9	0	15	16	21.6	42.1	49	41	36.6	41.7	44
2	31	9.7	0	9.6	15	32.8	34.8	36.8	45.9	54.9	30.9
3	38	17	6.4	0	7.7	33	36	38	42	51.2	23.6
4	31	23	12	8.3	0	25	28.2	29	45	58	30
5	20	46	28	30	24.8	0	6.3	8.6	48.7	57.8	57.5
6	19	51	42	36	31	5.6	0	4.5	44.6	53.7	62.2
7	14	38	35	38	33	9.8	4.3	0	40.2	49	64.3
8	36.2	32.7	40	40.6	44.9	48	42.4	40.2	0	11	69.6
9	45	45.5	49	49.5	53.8	57	51.3	49.2	8.9	0	85.3
10	65.4	40	30	24.5	29	60	62	64	76.3	78.4	0

TABLE 4. Calculation results.

Serial number	Best path	Distance/km	Loading quality/t	Loading volume/m3
S1	0-3-4-5-6-7-0	92.5	4.79	14.23
S2	0-10-2-1-9-8-0	187.1	3.87	13.44
	Total	279.6	8.66	27.67

recycling network to meet the task requirements. Each vehicle has a capacity of 5t and a compartment volume of 24.8m^3. It is required to plan an appropriate vehicle arrangement and driving route to minimize the total distance of distribution and transportation.

The actual road distance of each node (1 recycling network and 10 4S stores) calculated by Baidu map API is shown in Tab.1. According to the approved load of the distribution vehicle is 5T, the car volume is 24.8m^3, the battery mass to be recovered is 8.66t, and the total volume is 27.67m^3. It is preliminarily determined that the number of distribution vehicles can be selected as 2, that is, the number of ants $k = 2$ for distribution. The initial parameters are set as follows: information heuristic factor $\alpha = 1$, expected heuristic factor $\beta = 2$, pheromone volatility factor $\rho = 0.95$, maximum number of iterations $N_{max} = 200$, $K = 2$. Table 3 can be obtained after calculation.

It can be seen from Table 4 that the total mileage of the ACA optimized in this paper is reduced from 310.8km to 279.6km, 31.2km and 11.1% after improvement, and the optimization effect is very obvious.

VI. CONCLUDING REMARKS

The development of big data technology has brought opportunities to the power battery recovery industry. It has become the trend of information development to establish a new energy vehicle retired power battery dangerous goods transportation platform based on big data. At the same time, it is also an innovative achievement of the Internet plus recycling integration and innovation and development. This research has been well applied in the practical engineering, and it has a very realistic reference value for government safety supervision, industry information tracing, national network planning and layout, enterprise investment planning, and recycling enterprise operation. Some researchers have achieved some research progress in using the state-of-the-art deep learning methods for anomaly detection or prediction. Wu *et al.* [121] proposed a LSTM-Gauss-NBayes method, which was a synergy of the long short-term memory neural network (LSTM-NN) and the Gaussian Bayes model for outlier detection in Industrial Internet of Things. Xu *et al.* [122] presented a novel unsupervised deep learning framework for anomalous event detection in complex video scenes, in which they utilized deep neural networks to automatically learn feature representations. This paper builds the battery recycling information platform by the big data, and by analyzing the operation mechanism of the platform and combining with the pipeline logic, it establishes the theoretical model of the power battery recycling platform based on big data, realizes the application model design of ''information sharing, intelligent decision-making, optimization and integration'' of retired power battery, and improves and enriches the application scope of big data. Using the improved ACA, through the secondary development with the help of the internet, map platform and Baidu map API, in order to realize the directional recycling, using the reverse product positioning design technology to find the best way to transport dangerous goods, a power battery recycling network system suitable for the national geographic space is constructed. In addition, the actual case analysis is selected, which shows that the method is feasible and practical. It has innovated the technology and business model of power battery recovery, broadened the win-win road of waste generating units, process logistics enterprises and end recycling enterprises, and provided valuable big data thinking transformation for the industry and government to promote scientific and effective supervision. However, the information processing model is not perfect, and it also has shortcomings, such as slow convergence, easy to stagnation and local best solution. Most of the search time of the algorithm is used to construct the solution, which makes the search time longer and reduces its efficiency. When the scale of the problem is large, the stagnation problem is easy to occur and enter the state of the local optimal solution. The calculation accuracy of the system need to be improved and there is still significant room for improvement in terms of conducting high-quality calculation result.

This paper construct a new energy vehicle retired power battery recycling platform using big data technique, analyzes the operation mechanism of the big data traction battery recycling platform. The shortest path model is obtained using the improved ACA. Provides an effective recycling platform for the safe transportation and cost reduction of the new energy vehicle power battery recycling process, and provides a reference for the transformation and upgrading of the power battery recycling industry. But, there are few areas where further extension of our future research work is needed.

(1)Further optimization research on parameter design and data collection of new energy vehicle retirement power battery recycling platform.

(2)A comparative study on the computing efficiency of the recovery platform based on ACA and that based on other intelligent algorithms [123]–[126].

(3)Application of the established recycling platform and existing research results to actual recycling.

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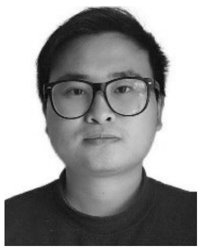

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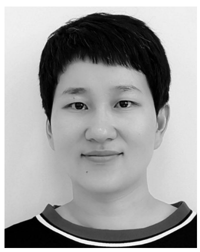

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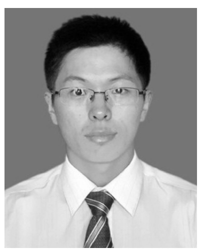

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