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Information flow in reverse logistics: an industrial information integration study

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Abstract With the coming of low-carbon society, the reverse logistics of used batteries for lowering the carbon emission becomes an important research topic; in which, information integration of reverse logistics is the key for implementing reverse logistics systems. Currently there are not many enterprises that are capable of using enterprise systems or e-business systems to manage reverse logistics. In the framework of industrial information integration engineering, this research investigates the process of reverse logistics of used batteries, with an emphasis on the information integration of reverse logistics of used batteries.

Keywords Reverse logistics · Industrial information integration engineering (IIIE) · Information integration · Logistics · Energy · Environmental protection · Information technology management

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1 Introduction

1.1 Background

For many years, the consumption of industrial or non-industrial batteries has been increasing sharply, whereas the market for rechargeable batteries is still low due to their relatively high cost in comparison to disposable batteries. Therefore, the production of disposable batteries is setting a new record year after year. According to statistics, the production and use of batteries worldwide have increased more than 20 % for the past 2 years. China is the world's largest battery producer and consumer with an annual production capacity of 15–16 billion pieces, accounting for 1/4 of the production of various types of batteries worldwide.

If the used batteries are not properly disposed, the hazardous material they contain may lead to environmental pollution and affect human health. Research shows that one battery of the primary used battery category, if not treated and left rotten in soil, can make one square meter of land useless; and one battery of ordinary button battery category can pollute 600 thousand liters of water, which is the total amount of water that a person can drink in his or her lifetime [76].

According to the battery industry statistics, for every 1 billion batteries produced, 16 thousand tons of metal zinc, 23 thousand tons of manganese dioxide, 210 tons of other metals, 4,300 tons of carbon rod, and 7,900 tons of ammonium chloride will need to be used [4]. Most of these components are valuable metal substances that can be recycled. Although the resource consumption of a single battery is not very significant, given the massive amount of disposable batteries extensively used, their resource consumption is very significant [15, 30]. If we do not take the issue of reverse logistics of used batteries into consideration, the metal and nonmetal resources will be wasted by littering or non-thorough treatment of the used batteries. By definition, reverse logistics is the process of planning, implementing, and controlling the efficient and cost-effective flow of raw materials, in-process inventory, finished goods, and related information from the point of consumption to the point of origin to recapture value or proper disposal [34, 36, 38].

Reverse logistics of the used batteries not only protects the natural environment, but also promotes the important economic value of the used batteries. The reverse logistics activity involves more participants, a wider region, and stronger randomness than forward logistics. Therefore, in the entire management process, information sharing, transaction coordination, decision support, and the allocation of resources are reasonably inseparable from the support of the information systems or e-logistics systems. It is obvious that the integration of the information flow of reverse logistics is significantly important in order to realize the environmental and economic value of the used batteries.

In 2005, a new discipline called Industrial Information Integration Engineering (IIIE) was developed [69]. IIIE is a set of foundational concepts and techniques that facilitate the industrial information integration process. As such, new research opportunities in industrial information management were discovered. With the above-mentioned motivation, and in the framework of IIIE, this study will analyze the processes and models of the reverse logistics of used batteries, contemplate the integration of related information flows in reverse logistics, as well as examine the contents, sources, and collection of the reverse logistics of used batteries. It will also discuss the information platform and the future development of e-logistics systems for reverse logistics of used battery as an industrial application example of IIIE in industrial sectors including energy and environmental protection.

1.2 Used batteries

1.2.1 Analysis of the processes of reverse logistics

The process of reverse logistics for used batteries encompasses collection, transportation, storage, sorting, loading/unloading, recycling, and final disposal. This process also includes a series of physical and chemical reactions to get large quantities of recycled metals and nonmetals. The process of the reverse logistics of used batteries is illustrated in Fig. 1.

Through the collection step, used batteries are put together by brand or region, and enter the used batteries processing plant after transportation and short-time storage. In the plant, used batteries are further classified according to their basic components, and go through the corresponding physical breakdown, chemical smelting or leaching steps depending on the requirements of the processing technologies. In this process, large quantities of reusable metals and nonmetals can be obtained, and liquid and solid wastes that will need to be finally disposed will also be generated. After recycling, a majority of the materials will be used for the production of new batteries or other products and enter the new cycles, and a small amount of the materials will enter the final disposal process.

1.2.2 Aspects of the reverse logistics

In this research, the classification of used battery reverse logistics is based on different collection models and their processing technologies adopted. This section analyzes all the aspects of the reverse logistics of used batteries models.

1.2.2.1 Collection of used batteries The collection of used batteries [48] refers to the process in which used batteries are put together through the various channels from

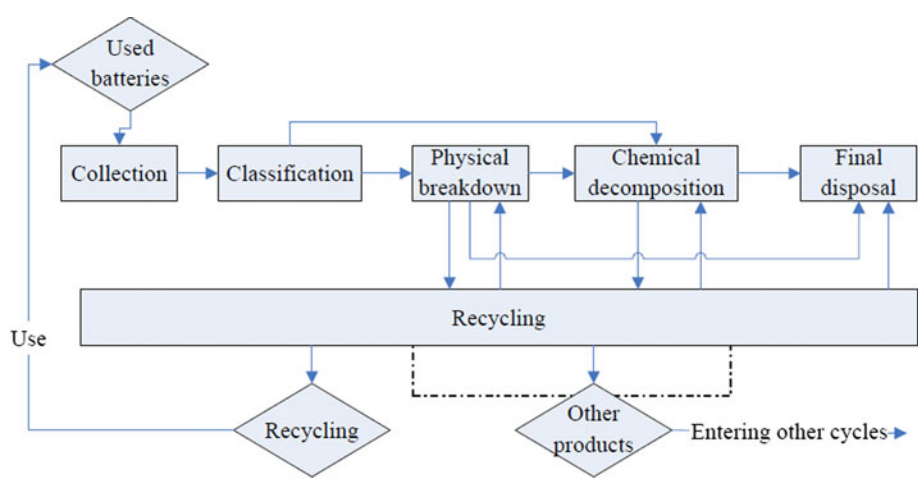


Fig. 1 Process of the reverse logistics of used batteries

individual consumers via their manufacturers or by regions to reach a certain quantity. This process includes logistic aspects of transportation, handling, and storage. The participants for the collection may be diverse as government workers, social and environmental organizations, individuals, and manufacturers.

There are three used battery collection models: industry-led collection, government-led collection, and spontaneous collection by the public. Under industry-led collection, there are three types organized activities: individual manufacturer led collection, consortium led collection and third-party vendor led collection. In addition, this study analyzes the logistic process of these collection models from qualitative perspectives.

A. Industry-led collection

In the industry-led collection models, manufacturers who sell batteries will also collect the used batteries, or third-party vendors lead the collection effort. There are three main types of collection such as collection by each individual manufacturer, collection by a consortium of manufacturers, and collection by third-party vendors. The common drawback of industry-led collection models is that the cost of collection will eventually be transferred to consumers.

1. Collection by each individual manufacturer

Each individual manufacturer only collects batteries they produced and carries out the process of collection and transportation and storage. Commonly, this model involves only the products of single brand or single series.

2. Collection by a consortium of manufacturers

A consortium of battery manufacturers collects batteries they produced by sale volume, region, and product specification.

3. Collection by third-party vendors

A third party vendor other than the manufacturers and consumers collects used batteries within the area they are in charge of.

B. Government-led collections

A governmental entity such as a municipal unit makes efforts to collect used batteries and transport them to the processing site as part of public endeavor.

C. Spontaneous collection by the public

Social organizations or volunteers collect used batteries and transport them to specialized processing sites for processing, with costs being covered by donations from residents, government funding and industry sponsorship. Since various recovery methods are similar, this paper uses third-party recovery collectors in the example shown in Fig. 2.

The main economic costs of the collection process are from the collectors' labor costs, tools, transportation costs, and storage costs. The environmental impact is reflected mainly in the pollution of the environment by the transportation vehicles in the transportation process. Most of the energy consumption is due to the fact that transportation vehicles consume energy, the collection tools consume energy, and the storage facilities consume energy.

1.2.2.2 Classification of used batteries The classification of used batteries will typically be conducted by the processing plant by following the classification standards and utilizing the corresponding devices and technologies [25]. In the reverse logistics of used batteries, classification is simply a sorting process.

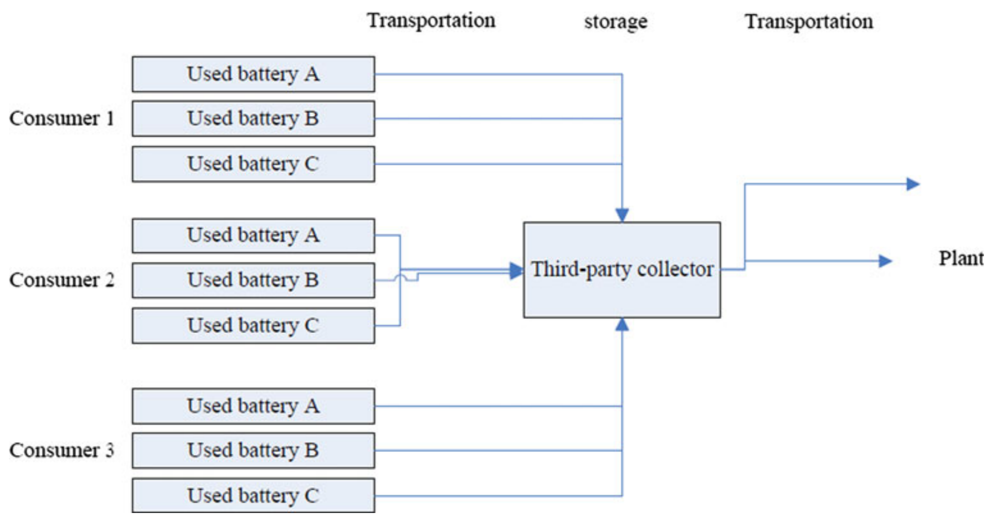
Classification standards have categories by the battery's component, model, or by battery manufacturer. Different collection models, technologies, and devices used during the process will influence the classification of the batteries. For example, using the manufacturers collect model, batteries only need to be classified by battery type and its model, whereas other collection models may need more complex classifications. When batteries are directly crushed, chemically processed, or physically broken down, the classification will be relatively simple.

In terms of components, Zn-Mn batteries will be mainly divided into the acid and alkali Zn-Mn batteries. The processing methods for these two types of Zn-Mn batteries are significantly different and therefore should be thoroughly classified. In the classification process, main processing costs will arise from the classification operators and devices as well as the cost of temporary storage. The environmental concerns are the dust generated in the classification process as well as the pollution from the damaging of batteries in the classification process.

1.2.2.3 Process of used batteries The processing of the used batteries refers to a series of processes in which the batteries after classification are physically broken down, crushed, or chemically leached and smelted to recover large quantities of recyclable metals and nonmetals as well as wastes [62]. The commonly used processing methods for used batteries in China are: breaking down, smelting, direct acid-leaching and crystallizing, roasting acid-leaching and electrolyzing. However, there are also many other methods and new processes derived on this basis.

1.2.2.4 Reuse of used batteries The process of reusing used batteries is involved with the using the recyclable metals, non-metals and various components produced in the process of reverse logistics [66]. In reverse logistic models, the reuse process includes the storage and transportation activities.

Fig. 2 Third-party recovery agency recovery models



After the physical break-down, the outer plastic wrapping and part of the zinc cover can immediately enter the reuse process and then the chemical processing will be started. After that, zinc and manganese metals with their oxides can be formed for new batteries or be used for the processing of other products. This method will promote good recycling of materials that will reduce negative environmental impact.

During this process, the cost of manpower, equipment, transportation, and warehousing will be incurred. The environmental impact is related to pollutants generated in the transportation process. The consumption of resources mainly occurred in the transportation and warehousing processes.

1.2.2.5 Final disposal of used batteries The final disposal involves the various kinds of liquid and solid waste substances generated during the reverse logistics process [67]. The final disposal process involves logistic processes of transportation.

The economic costs are mainly manpower costs and equipment costs. The negative environmental impact is due to pollutants being emitted in the final disposal process. The energy consumption mainly includes the various types of equipment and transportation tools.

1.2.2.6 The process for handling used batteries The entire reverse logistics involves loading, unloading, and handling activities. We analyze and measure them separately. The economic costs involved in the loading, unloading, and handling processes are mainly manpower costs and equipment costs. The energy consumption will be due to transportation involved in the various types of loading, unloading, and handling materials and equipment.

2 Literature review

2.1 Reverse logistics

2.1.1 The connotation of reverse logistics

A research report from the Council of Logistics Management (CLM) points out that reverse logistics is a logistic activity including maintenance, remanufacturing, covering product return, material substitution, material reuse, waste disposal, and reprocessing. In short, reverse logistics refers to the physical flow of the discarded materials that have lost their original value from the point of consumption. Its main purpose is to re-obtain the useful value of the products or to properly dispose of the discarded products [62]. In reverse logistics, there are planning, implementation and controlling processes for the efficient and low-cost flow of materials and the related information from the point of consumption. The main purpose is to realize the value of re-creation and the proper disposal of materials from the starting point of the supply. The Supply Chain Operations Reference (SCOR) model which was introduced by the Supply Chain Council (SCC) benchmarks operational measurement to create a prioritized improvement portfolio tied directly to a company's balance sheet for improving quality performance and profitability. In the SCOR model, Return, which indicates reverse logistics, is considered both an important intra-organizational function and a critical inter-organization process [39].

The final destinations of the materials in the reverse logistics generally include: direct reuse, repairing, recycling, re-manufacturing, and other sales channels [18]. Nowadays, the width and depth of reverse logistics is expanding. According to European Reverse Logistics Committee, reverse logistics is a summary of words, which has broad and narrow sense in its meaning. From a narrow sense, the reverse logistics is the process which collects and processes products through a distribution network. In a broad sense, the reverse logistics represents the activities of the reused materials, resources saved, and environmental protections. Therefore, the reverse logistics should include reducing the material used such as fuel, raw materials, edges, packing materials, and defectives reformed. Its purpose is to reduce material backflow and forward logistics and reverse material flow rate.

2.1.2 The reverse logistics of solid domestic wastes

Urban solid domestic wastes mainly refer to the ones generated in citizens' normal daily life. Their main components include kitchen leftovers, waste paper, waste plastics, waste textiles, waste metals, waste glass, pottery and porcelain shards, debris, garden twigs (grass), used batteries, and discarded appliances. Urban domestic wastes also include city's commercial facilities, travel and service industries, city's public works maintenance and management, as well as business or non-business organizations, governmental organizations, schools, military establishments, and social organizations [33].

Song et al. [58] proposed the quantity analysis for the outflow of solid wastes and used it in the logistics of the wastes of electronic products. Arena et al. [3] analyzed the logistic process of industrial solid wastes. Beullen [5] studied and analyzed the reverse logistics models of efficiently recovering useful materials from wastes and created the related quantity model. Chang and Liu studied the reverse logistics in industrial production and analyzed and evaluated it from the technical perspective [8]. Cheng et al. [11] designed the logistics solution for solid wastes of packing materials through modeling. Rodríguez-Iglesias [53] evaluated and analyzed the lifecycle of urban solid wastes. Chang [7] compared various physical and chemical research methods for urban solid wastes.

2.1.3 The reverse logistics of used batteries

China has become one of the largest producers of used batteries in the world. While creating convenience to our lives, batteries also have negatively impacted our environment. Batteries contain many hazardous substances including heavy metals such as lead, mercury and cadmium. There hazardous substances have proposed tremendous threats to human beings and the natural environment. Zhang et al. [82] analyzed the harm of various used batteries to the environment and human health. They reviewed the latest technologies currently being applied to the collection and treatment of used batteries in China and abroad, as well as predicted the possibility of used battery treatment technologies.

Tao [60] warned about the tremendous harm used batteries have on the environment and human health. They analyzed and discussed the problems with the prevention of environmental pollution from used batteries and proposed that preventing the pollution from the used batteries needs to take many different measures including improving laws and regulations, enhancing environmental management, and increasing the recycling effort.

Some researchers proposed the use of the technologies for reverse logistics to integrate the current recycling systems of discarded appliances to increase the recycling rate and reduce environmental pollution. They also suggested the adoption of reverse logistics through the guidance of governmental economic policies, the enhancement of reverse logistics management by enterprises and the active participation and supervision by the general public.

In the study of the collection process of the reverse logistics, Xie [68] introduced the current state of the reverse logistics of used batteries abroad and China. They proposed the three basic preconditions and models for the ideal collection logistics of used batteries. Its purpose is to improve the environmental awareness of the general public. In addition, improving related laws and regulations, enhancing industrial orientation and policy/taxation support, and building a public platform for the reverse logistics are emphasized. Designing a refined agency mechanism for reverse logistics on the condition of making clear the dominating and organizing role of the government are also included in their target goals.

Zhao et al. [83] introduced the planning method for the collection of used batteries in other countries and identified issues that deserve attention in the collection of used batteries in China. He designed a model for the collection of used batteries and estimated their costs [23]. Ren and Liu [49] analyzed the current state of used battery collection in China and proposed the used battery collection models for China by drawing on foreign experiences. They follow the collection model with an extension of the responsibilities of the manufacturers, the government-led collection model, as well as the collection model led by nongovernmental organizations and volunteers. They also analyzed the advantages and disadvantages of various collection models and proposed the implementation strategies.

Tong and Chen analyzed the shortcomings of the used battery collection process advocating—"keep used batteries by individuals and collect them centrally", in connection with the consumption features of batteries and the special nature of used batteries [61]. Du [17] conducted a comparative analysis to the current state of the recycling of lithium ion batteries in China and abroad using a questionnaire survey and expert workshops. They explored the necessity, feasibility, demand and benefits of recycling. They also evaluated the value of recycling and provided suggestions on the management of the recycling process on the basis of the investigative analysis of the current state of recycling. Furthermore, they created the economic model and calculated the benefits of recycling lithium ion batteries in Beijing.

In the study of the technologies used in the processing operation of the reverse logistics of used batteries, Yang et al. [75] explored the experimental methods and experimental conditions for preparing zinc sulfate using the zinc cover of used Zn-Mn batteries as the raw materials to achieve a zinc recovery rate of up to 77. 4 %. Gao [20] studied the method of opening up and burning the used Zn-Mn batteries to remove mercury and carbon powder and then leaching them with sulphuric acid and separating zinc and manganese from the filtrate by precipitation. In this method, the recovery rate of zinc and manganese is 94.5 and 93.6 % respectively.

2.2 Integration of information flow in the reverse logistics

2.2.1 The necessity of the integration

In the study of information integration in the reverse logistics, improving service levels, Daugherty et al. [13] believed that the information system would not only help the collaboration among enterprises but also conduct the effective treatment of returned products. Furthermore, such validity will promote the desirability of customers to buy their products again in the future. Daugherty et al. [14] discovered that investing in information technology resources to improve the level of application performance is important. The more companies invest in information technology, the better the economic benefits of reverse logistics and the higher level of customer service through the empirical analysis in the automotive parts market.

In the study of information integration in the reverse logistics, Richey et al. [52] studied the characteristics of reverse logistics systems. They presented that outsourcing or using package software has drawn the positive effect of reverse logistics especially to operation and management sections. However, it should be based on the reverse logistics of companies which should have a certain format, stringent recovery conditions and on constant technological innovation through empirical research in the auto parts market.

Andel et al. [2] proposed that information technology is productive in rapid decision-making, new product designing, forecasting and budgeting, and product recalls. Deng [16] believed that by using information technology, the enterprises can improve the processing speed of the return to achieve the shortest possible time and save a lot of inventory costs and transportation costs.

Xu [73] insisted that the information system applied in the recovery of waste materials can greatly improve efficiency, not only for manufacturers but also public sectors in monitoring the process and environmental accountability.

In the study of information integration in reverse logistics increasing logistics performance, Daugherty et al. [13, 14] studied empirically the relationship between information systems support and reverse logistics performance. The results showed that the information technology capability has a direct impact on reverse logistics management performance and service levels. Yuan and Cheng [77] also analyzed the logistics performance and concluded the application level of information technology has a significant effect on the benefits of reverse logistics.

In the study of information integration in the reverse logistics, some researchers expressed that the uncertainty of reverse logistics can be reduced by having information systems support and the management system can assist predictions. Repoussis [51] stated that using DSS for monitoring online and reporting information of every recycling process brings improved efficiency. Xu and Yang [72] also pointed out that the information technology in reverse logistics management can improve information sharing and management performance.

Chen [10] suggested that the establishment of reverse logistics information system can improve the recovery rate of materials, conduct reverse logistics effectively and control possible risks. Zhang [81] proposed that emergence of regeneration logistics of recycled products requires corresponding information system support. Li [42] pointed out that the delay of using information systems may affect the development of reverse logistics. Timely obtained information and prompt responses are so important that companies should use the electronic data interchange system (EDI) and other information technologies to establish an information sharing platform between the upstream and downstream of the process. Through the well configured platform, enterprises can obtain information and eliminate discontent effectively with customers. It also makes reverse logistics remain in the electronic stage and reduces the actual occurrence of reverse logistics and ultimately accomplishes low-carbon technology improvement of reverse logistics.

Wu and Liu [65] stressed that even though reverse logistics management has a variety of internal and external obstacles, the use of information technology can significantly reduce the disposal of the reverse logistics cycle, particularly through the information tracking from the entrance to the final disposition.

Note that the information management system for the waste recycling process has been significantly important in countries such as China where the country has a relatively weak industrial base and a severe shortage of funds [50].

Zhang et al. [80] stated that information technologies for waste management has important value to the scientific decision-making process where most urban waste is involved with large-scale recycling as well as industrial and scientific practices for reusing.

The complexity of reverse logistics information leads to the demand for information integration of the reverse logistics as well. Yuan [78] explained that 3 PRL including many activities needs an abundance of useful and meaningful information from vendors, manufacturers, consumers, and suppliers. The 3 PRL process requires a series of complex decision-making steps that cannot be completed by manual ones. Therefore, it must establish a logistics information system of reverse logistics.

Some researchers also expressed that the third-party reverse logistics enterprises have large amounts of information flow and act as a transit hub for the exchange of materials. If there is no efficient information processing systems implemented, the reverse logistics operations should be completed manually. Other researchers pointed out that most third-party reverse logistics enterprises in China are still in traditional warehousing and transportation status. When the information systems are faced with the complex business processes, they seemed to be inadequate for their adopting stage. Therefore it is urgent to build an efficient, reliable third-party reverse logistics information system for these emerging third-party logistics companies.

Yan and Sun [74] believed that there is a lot of room to improve the function of reverse logistics information systems so as to speed up the development of reverse logistics. Sun and Shi [59] believed that information technology plays an important role in the reverse logistics operation and it will greatly enhance the level and efficiency of reverse logistics operations and ease the uncertainty and complexity of reverse logistics.

According to the research performed by Jiang et al. [28], a fundamental information model is a prerequisite for the implementation of computer-aided products. She mentioned that the product reverse flow cannot be achieved in the reverse logistics as a competitive means without using information technology in forward logistics [56].

Zhao et al. [84] analyzed the steps of reverse logistics and found out that the biggest problem in the current reverse logistics is the lack of rapid, accurate information. Thus establishing advanced technology systems for the smooth implementation of reverse logistics is necessary.

Chang and Chen [9] stated that the occurrence and development of reverse logistics will inevitably require the support from information systems and information sharing, issues coordination, analysis and decision-making and the reasonable allocation of resources will not be possible without the support of information system.

Zou and Jing [85] stated that the advanced logistics information system plays an important role for the reverse logistics. They also illustrated that the logistics information system of reverse logistics and "forward" logistics are in the direct opposite and the functions and objectives are basically same.

2.2.2 *The method of information integration of reverse logistics*

Yuan [78] analyzed the characteristics of reverse logistics and proposed the structure of third-party reverse logistics management and the various business activities. On this basis, the authors analyzed information system requirements of the third-party reverse logistics management and proposed the functional model of information system as a Web service form.

Some researchers analyzed business processes and data flow of third-party reverse logistics and made a design scheme which mixes C/S and B/S. They also explored how it can be realized by ASP.NET technologies.

Liu et al. [45] researched the third-party reverse logistics business processes. They built the information system of third-party reverse logistics based on J2EE technology and provided the reference for third party reverse logistics and software provider.

Jia [27] proposed a closed-loop supply chain model based on third-party logistics and constructed the closed-loop supply chain information flow network based on the third party logistics by analyzing the reasons causing blockage of information.

Liu and Xiao [46] explained that the importance of the reverse logistics information is greater than the forward logistics one. Strengthened reverse logistics information efforts are important because it provides technical support for sustainable development. Ji and Wang [26] analyzed the business processes of logistics systems and proposed a function model of information integration of reverse logistics. It illustrated the design model of information flow of reverse logistics management system. From the functional integration of information and resources, they provided strategic and tactical guidance to reverse logistics managers for the implementation of information integration. They also stressed that the integration of reverse logistics and forward logistics are very significant to the information function model where information management of logistics are merged into enterprise information management. Due to the fact that the implementation of new systems often faces management challenges, they proposed a synchronization system approach between information integration of reverse logistics and an enterprise management system.

Zhang [81] detailed the platform of logistics information integration of renewable logistics. They explained the conceptual model and function model of the platform and analyzed the support architecture of information integration platform based on Web technology and B/S network model.

Yan et al. [74] illustrated the requirements of reverse information management system needed by reverse logistics and described the Agent and Multi Agent Technology. Based on this, they established an information system model of reverse logistics and researched the working mechanism of the system.

Jiang et al. [28] analyzed the information needs of reverse logistics and proposed an object-oriented hierarchical network graph model. They also discussed the structure and implementation of the model and showed a practical example and validation by illustrating an outdoor air conditioner.

Gu [21] discussed about the integrated logistics and information networks of remanufacturing systems and analyzed three layers of the information network: Internet, Intranet and Extranet layers. Some researchers studied the platform for the information integration of reverse logistics and the characteristics and roles of the reverse logistics information. They also proposed a conceptual model and functional model of the platform for the information integration of reverse logistics, as well as the structural system of the information integration platform.

3 Integration of the information flows

3.1 Collection of the information flows of reverse logistics

3.1.1 Main contents of the information flows of reverse logistics

3.1.1.1 System's external information flows The external information flows of the system of the reverse logistics are the information exchange among governments, competitors, consumers, environmental organizations, junk market, etc. The sources of information flows are:

1. The responsibilities and obligations set out in the provisions regarding the recycling of resources by enterprises in the laws and regulations prepared by governments or indicators on the recovery rate and utilization rate that should be met. These provisions promote enterprises to implement the recovery of corresponding products and resources, and thus are also the main drivers for reverse logistics. Therefore, information about the related laws is the imported input element to the information system of reverse logistics. Due to the improvement of resource and environment awareness such laws and regulations, their requirements are increasing as an ongoing basis and even influencing the overall landscape of reverse logistic activities.
2. Competitors may have a significant impact on the development of recycling strategies. Each company needs to make reference to the strategies of competitors to prepare their own recycling strategies, needs and core competitiveness.
3. The information obtained from consumers will be about the use and location of batteries and dynamic. Commonly the information about the use of products can be collected from the users and their retailers. The information has important reference points in the screening and collection of products to be recycled. At the same time it can be utilized for enterprises to improve the quality of information. The information about location refers to the specific location of products and information about the quantity of the products available. Such information is very important to planning and controlling the collection operation and the entire recycling process. In common, retailers and users are the main suppliers of such information.
4. Information obtained from raw materials is also needed. The raw materials which do not meet with specifications or provide an over-supply to the original battery manufacturers will be sold to other enterprises in order to enhance the efficiency and product utilization.
5. The structure information of products of reverse logistics processing includes the ratio and the number of various recyclable resources extracted from used batteries. In addition, government agencies obtain this kind of information to test whether the manufacturers meet with production requirements.
6. Currently environmental protection and resource recycling practices have been increasingly accepted by the general public. Not only consumers are increasingly valuing the green products, but also the establishment of many environmental organizations has played a great role in promoting enterprises to recycle used items. If an enterprise can become the environmental benchmark for its industry, it will improve the potential image of the enterprise in a way that is invisible.
7. The goal of reverse logistics is to maximize the product value while abiding by laws, regulations and supply restrictions. In order to achieve this goal, recycling enterprises must be able to obtain the timely and accurate market prices of the product and information about their availability.

3.1.1.2 System's internal information flows Internal information within a system flows or be transmitted between the enterprises that collect used batteries and manufacturers. Manufacturing companies need to recycle used batteries as well. Enterprises that collect used batteries are located in the middle of the supply chain and their role is to transmit information. The main types of information are:

1. Information about the used batteries collected, such as quality, time and location of collected products, the uncertainty level of collected products in their return, and the collection cost.
2. Information about the processing of used batteries such as product processing options (either direct utilization or modular utilization) after breakdown or recycling, product's processing cost and its level of difficulties.
3. Information about the type and quantity of raw materials or components obtained from used batteries by manufacturers enterprises.
4. Information about the harmfulness of the used batteries. The enterprises may voluntarily build up their environmental consciousness to ensure that all the recycling processes are environmentally complied and pollution free.
5. Information about the assembly styles of different parts or raw materials of used batteries. Accordingly, the useful resources from used batteries can be properly extracted and recovered, and then reuse, before they are finally disposed (Fig. 3).

Both obtaining and processing the information about the reverse logistics of used batteries require the use of information system model. More importantly, the operational management of reverse logistics involves not just an enterprise, but also the used batteries themselves as the source of pollution. Therefore, the model requires the support of more refined, reasonably connected, and reliable information systems. The information integration between enterprises and supply chain is an important basis for implementing reverse logistics. Currently there are very limited numbers of enterprises that can use information systems in the management of reverse logistics. But owing to the peoples' improved environmental awareness of repeated utilization of resources and the development of networking technologies, the advantage of information systems and online data sharing will be helpful for the information integration and management.

3.1.2 Collection of information flows

The collection of the information resources of reverse logistics is the basis for the integration and the input process of reverse logistics information management. As described above, the information about the reverse logistics of used batteries is very discrete. The time and location of information generation are highly random. Therefore, the collection of the information resources of reverse logistics of used batteries is much more difficult than the collection of the forward logistic information. The collection of the information resources of reverse logistics mainly includes three processes: (1) the analysis of information sources, (2) the identification and collection of information resources, and (3) the organization of information resources.

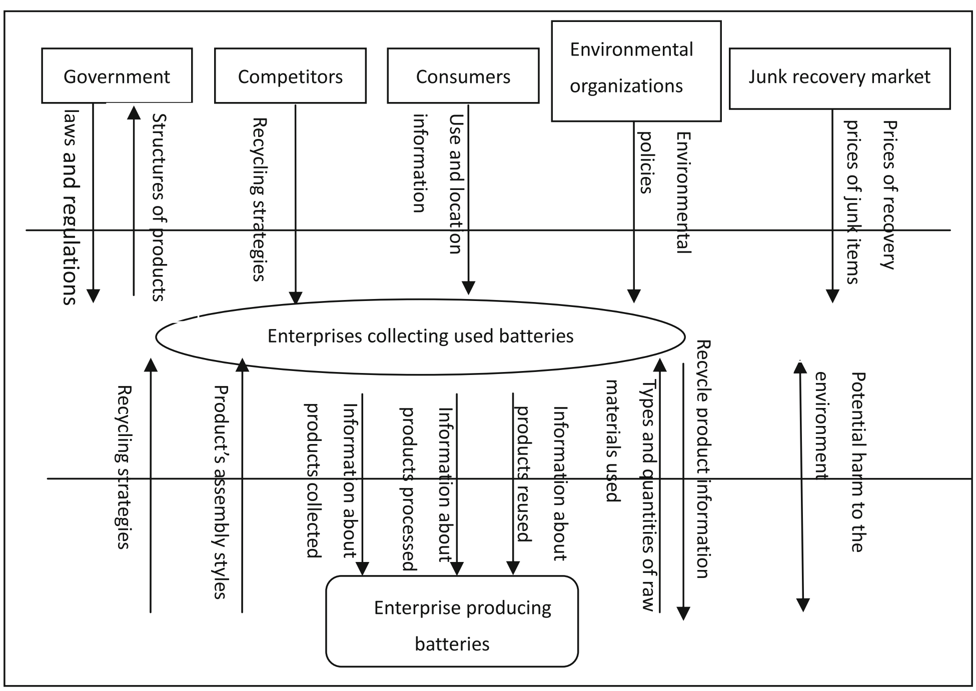


Fig. 3 Information flows in the collection system of used batteries

3.1.2.1 Analysis of information sources The analysis of information sources refers to where information resources are obtained, i.e. the identification of information sources. In fact, the internal sources of the manufacturers of used batteries and every part of the supply chain can be the information sources of the reverse logistic system. For the manufacturers of used batteries, product design unit, production unit and the sales unit of the forward logistic system are all important sources of the information resources of reverse logistics of used batteries. For example, the design unit of used batteries has information about the raw materials used in the batteries, as well as their types and quantities; the production unit and the sales unit provide information about the quantities of batteries produced and sold; and the main locations where the raw materials needed flow to.

The analysis of the information sources of used batteries should include the analysis of the time and location of the information generated, but due to the special nature of the reverse logistic system, the space–time attributes of information generation are very uncertain in many cases. This also creates difficulties for the accurate location of information sources.

3.1.2.2 Identification and collection of information After identifying the information sources of used batteries, the information workers will identify the related useful information such as the information demand of each process and each unit in the system. On the one hand, they need to determine the information demand of each part of the reverse logistics of used batteries system and select the information resources needed through the process. By doing this way, they can lay out a solid foundation for the information transmission between the participating enterprises. The identification of the information resources of used batteries is a processing of eliminating information uncertainties.

The gathering of information about used batteries should be followed by identifying the products. The process emphasizes the measures and methods of gathering. Many types of information in the reverse logistic are involved with different attributes, different stages. Therefore, the process of information gathering is a continuous tracking process, especially for the information about different states of products in different stages of their lifecycle; the information needs to be reflected in the reverse logistic information system in real-time. The identification and organization of information resources of used batteries need to take advantage of some logistic technical approaches. Furthermore using advanced logistics identification and gathering technologies can help enterprises collect the accurate and comprehensive gathering of information resources.

3.1.2.3 The organization of information flows Information resources of the reverse logistics obtained through the gathering process are often disordered and discrete. The obtained information would be better off when being classified to some degree before the integration of information. It helps them to form certain information by different levels, different sources and different roles of the information resources, eventually leading to the efficiency of subsequent information management.

3.2 The information flow of reverse logistics of used batteries

From the system perspective, the reverse logistics is a material compensation to the forward logistics, so as to enable the materials in the entire logistic system to be in a relatively stable state. The logistics and information flows of batteries are the links of connecting various functional modules of the entire system. The flow of logistics as a tangible entity receives the most important attention, especially the measurement criteria for the appreciation of the entire supply chain and whether or not it is environment-friendly. To make the entire logistic process smooth, you will need to optimize the information functional structure of the entire process and to develop an information relationship strategy which can provide a guiding direction.

As compared to forward logistics, the information of reverse logistics is more dynamic and unpredictable. Gathering and integrating the reverse logistic information of batteries, integrating and analyzing them with the information of the forward logistics, preparing related production, incorporating the recovery and procurement strategies are critical activities to increase the economic benefits of the entire logistic system. Accordingly, the unnecessary resource wastes will be reduced and the environmental pollution be minimized.

By illustrating the explanation of the external and internal information of the entire supply chain of the entire reverse logistics of used batteries and the description of the information interfaces of the reverse logistics of the forward logistics of batteries, we finally get the integrated information model for the reverse logistics of used batteries as shown in Fig. 4.

The start-point for gathering the information is consumers. Information gathering is implemented through two information flows: return of goods and post-use collection. The quantity and geographic location information of used batteries are gathered from the two lines and then the used batteries collected are classified which requires the support of many types of information, such as the recovered value of the junk recovery market, the quantity of the used batteries and their recyclability. After that, the used batteries

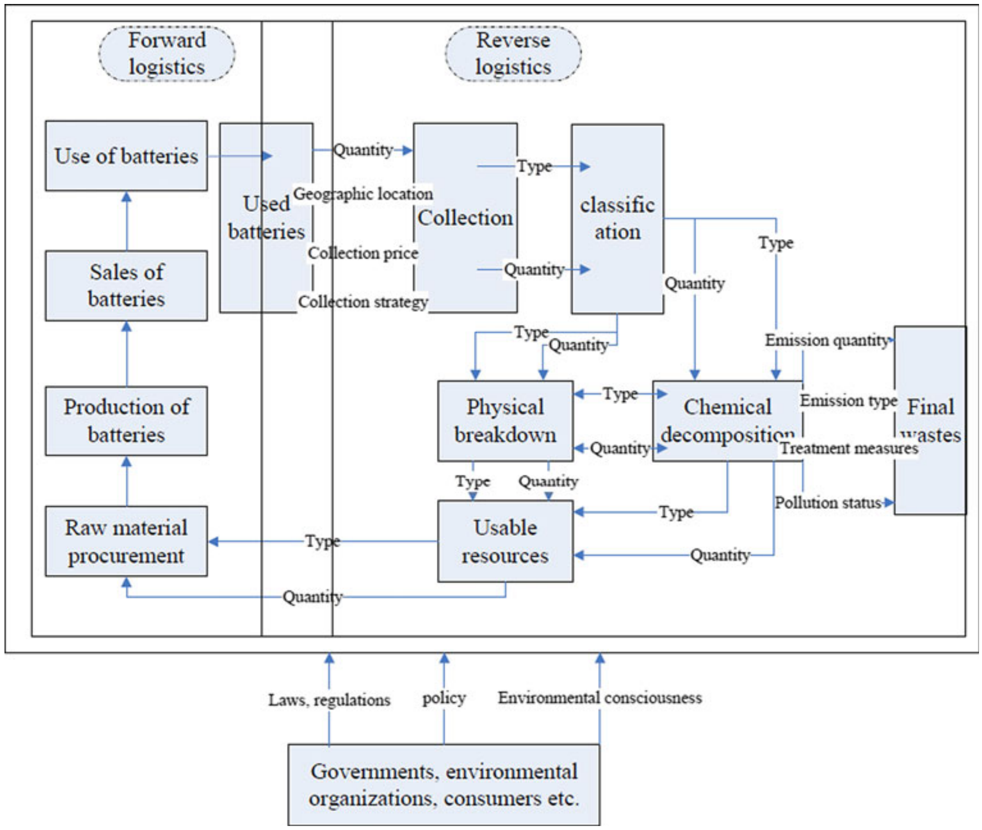


Fig. 4 Illustration of the information flows in various processes of the reverse logistics of used batteries

are preliminarily processed to identify resources that can be reused. The process is also subject to the restrictions of government policies, recycling strategies of competitors, rules & regulations of environmental organizations, as well as information about the junk recovery market. When reusable resources are obtained, the reverse logistics will be connected to the forward logistics of batteries and the product wastes will be disposed.

Integrated information systems applied will ensure the smooth implementation of used battery recycling. For the integration of information flows must be a core enterprise functions in the entire supply chain enough to lead, collect and integrate all the information. Otherwise there will be information asymmetry in the supply chain or the violation of related laws, regulations and policies causing larger damages to the environment.

3.3 Construction of information platform of reverse logistics of used batteries

3.3.1 The logical construction of information platform of reverse logistics of used batteries

The paper has collected the information flow within and outside the system and determined the existence information flow of all aspects. The preceding section mainly analyzed an enterprise part but the reverse logistics of used batteries involved in a number of battery manufacturers. It can carry out the information integration of reverse logistics on the basis of information sharing.

This paper uses information platform of reverse logistics of used batteries to achieve information sharing and integration. The platform makes the recovery strategy and recycling prices to achieve the appropriate economic and environmental benefits.

The enterprises participating in the reverse logistics waste batteries will be divided into four categories: (1) demand enterprises, (2) distribution enterprises, (3) processing enterprises, and (4) collection enterprises according to the reverse logistics process.

The demand enterprises in reverse logistics are battery manufacturers and customers in the reverse logistics which determine the material requirements types and correspond to the stock according to production plan of forward logistics.

Distributing enterprises in reverse logistics delivery products timely and determine the appropriate inventory according to the needs of demand and existing inventory. They play important roles in the information platform to meet with all the needs of enterprises timely through locating products of distribution by GIS, GPS and other advanced information technologies including RFID and IoT [19, 31, 43, 70].

Collection enterprises in reverse logistics determine the collection strategies according to the needs of raw materials of demand enterprises and depending on the location of the used batteries. Collection enterprises play the most important role in information platform of reverse logistics by connecting the end users and processing enterprises. Advances in information technology can significantly shorten the processing time of reverse logistics through the tracking process management. For instance, the use of POS, EDI and RFID technologies can help them collect information of the recycled products, classify them, tract them through the recycling process. The coding of the recycling reason and final disposition, statistics on products return rate, recycling rate, inventory turns will be beneficial for the real-time logistics and evaluation of recovery process. In addition, enterprise systems also enable information sharing of forward logistics and reverse logistics by reducing the uncertainty of recycle process.

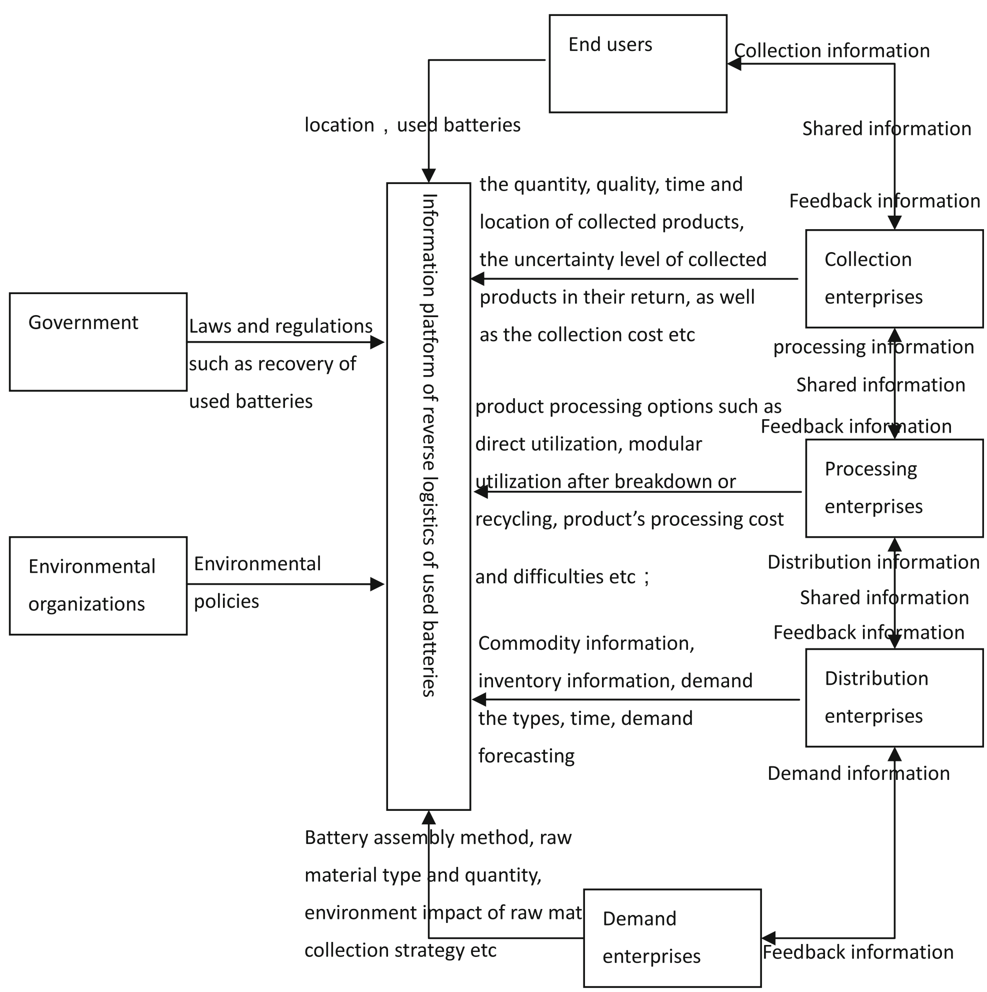
Information sharing of reverse logistics will be fully shared through the Internet information flow by making the enterprises to achieve a "zero distance" communication. Therefore, it is possible for the enterprises to realize the benefits of information sharing, business interaction and enterprise collaboration.

Information integration of reverse logistics of used batteries is on the premise that all the companies in the reverse logistics coordinate the demand, production, sales, purchasing, inventory and other aspects of dynamic information through sharing information of enterprise business information. In view of the integrity and consistency of reverse logistics, it is necessary for them to share information of customers, inventory, logistics and other information in information platform, and set shared services dynamically according to the needs of different enterprises.

According to the information flow diagram of various aspects of reverse logistics of used batteries and enterprises in reverse logistics, this study develops a logical structure of information platform of reverse logistics of used batteries, shown in Fig. 5.

The platform connects government agencies, environmental organizations, end users, and the enterprises in reverse logistics. The platform links processing enterprises with upstream and downstream, processing enterprises can obtain collection information, distribution information, and

Fig. 5 Logic structure diagram of the information platform of the reverse logistics of used batteries



feedback information. This platform connects processing enterprises and other enterprises by realizing the information sharing between these enterprises. On the other hand, processing enterprises also view the information of other enterprises through the platform. For example, they view the information of used raw materials, inventory, and the type and quantity on need delivered by distribution enterprises. From this point, processing enterprises are the beneficiaries of information integration because they can adjust the stock purchase plan and production plan according to the inventory information.

3.3.2 Information platform of reverse logistics of used batteries

The structural design of information platform is shown in Fig. 6.

1. Customer Service Management provides products and business information, orders information and customer feedback service for customers.
2. Collection enterprise management systems provide information service, providing recycling information of used batteries.
3. Processing enterprise management systems provides information services, product information, supply information and process information.
4. Distribution Management System delivers information services provided, providing information including inventory information, order information and customer information.
5. Platform Admin supports the platform and service provided by platform administrators.

The user's home page will be read directly from the back-end database and displayed in the appropriate forum. This module is used to display public information about the platform including four parts: (1) industry trends, (2) business dynamics, (3) policy guidance and (4) financial news. The user will login through the home page.

After the users' log in, they can access these function: information query including releasing information of demand, viewing information and retrieving information; demand management including demand records and contract management, and other management tasks. It includes management of strategic cooperation and tactical operation.

(2) This paper illustrates the module structural design of collection management system as shown in Fig. 7.

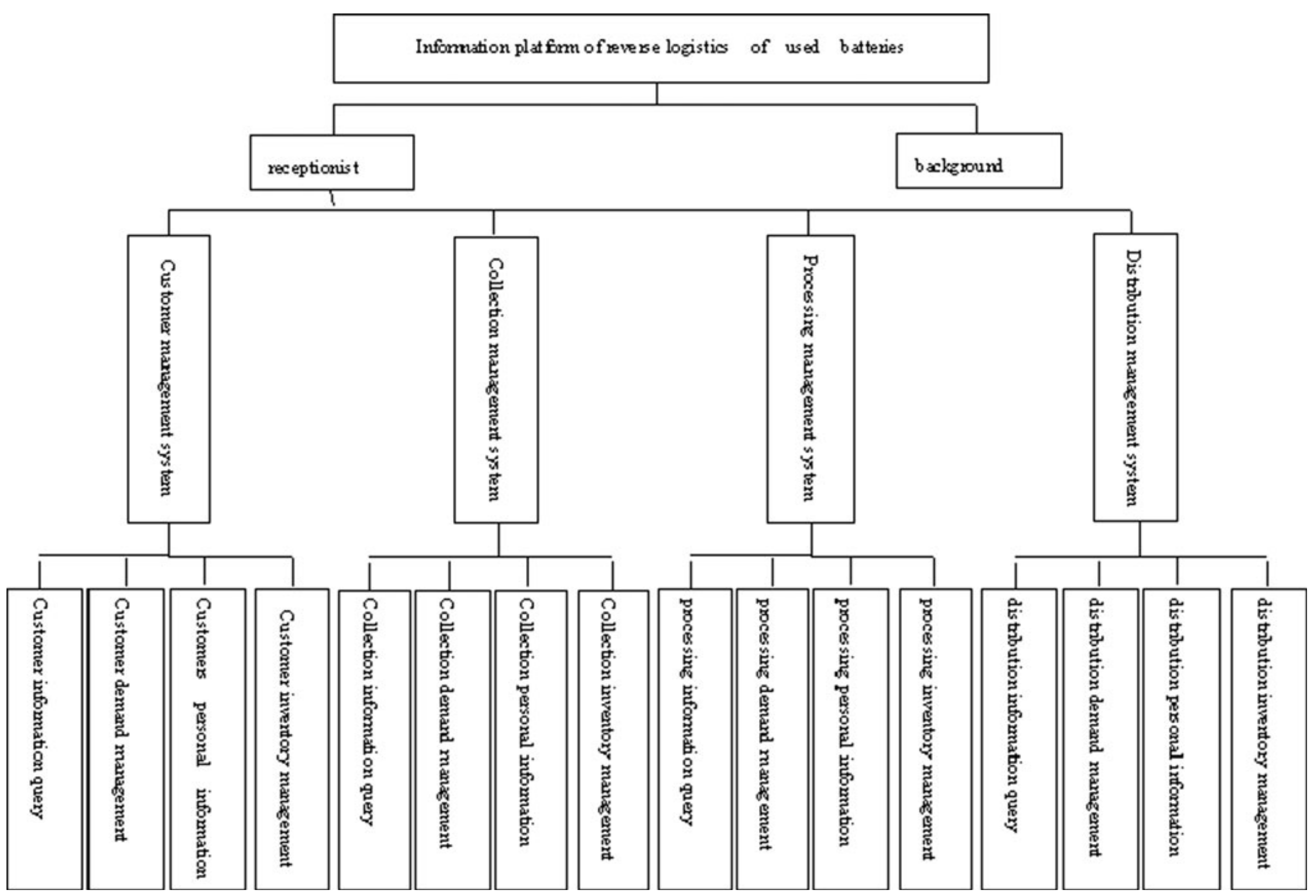


Fig. 6 Logic structure diagram of the information platform of the reverse logistics of used batteries

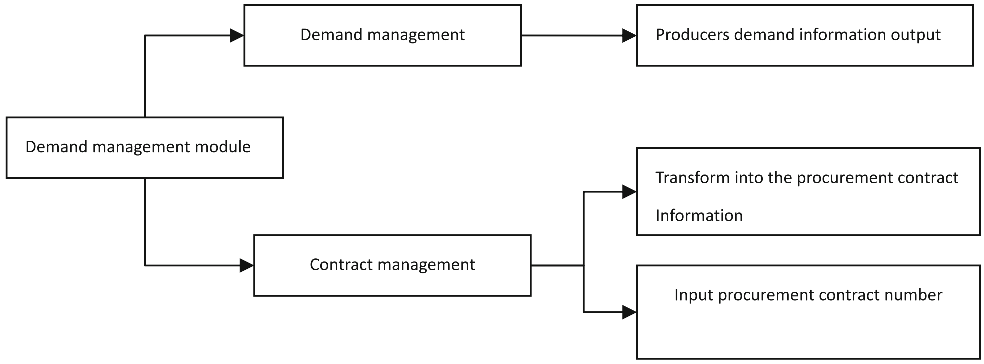


Fig. 7 Collection management system—demand management module structure

Requirements Management Module includes two submodules: contract management and demand management. Contract management includes two parts: input procurement contracts and transforming into procurement contract information. Contract management first obtain contract number from the input part and have access to contract information from the transformation part, then return the specific contract information to the module demand management. Demand management includes the output of the producer information. Demand management first obtain contract information returned from contract management module and then pass procurement contract information to the output of information of producer demand.

4 Summary

So far there are very limited number of studies that have examined information integration of reverse logistics as well as that in used battery reverse logistics. In 2005, a new discipline called Industrial Information Integration Engineering (IIIE) was developed [69]. IIIE is a set of foundational concepts and techniques that facilitate the industrial information integration process. As such, many new opportunities in industrial information management were discovered. In the framework of IIIE, this study analyzes the processes and modeling of the reverse logistics of used batteries, and investigates the integration of related information flows in preparation of developing industrial informatics systems that are implementable. Based on a comprehensive examination, this paper is the first to analyze the main information integration issues and information collection method of the reverse logistics of used battery from both internal and external perspectives, in the framework of IIIE [1, 54].

There are still many challenges and issues that need to be resolved in order for an e-logistics system to become applicable for the reverse logistics of used batteries [6, 12, 22, 24, 29, 32, 35, 37, 40, 41, 44, 47, 55, 57, 63, 64, 71, 79]. Our future research includes developing an e-logistics system for reverse logistics of used battery as an industrial application example of IIIE in industrial sectors including energy and environmental protection.

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