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TOPICAL REVIEW

A Comprehensive Review of Reverse Logistics in the Automotive Industry

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ABSTRACT Reverse logistics (RL) of automobiles has received wide attention in recent years with the innovation of resource utilization and the increase of environmental awareness. Many research papers have been published in the RL discipline focusing on the automotive industry. However, no review article is available on product-specific issues. To bridge this gap, 91 papers published in the Web of Science (WOS) database between January 2013 and March 2023 were selected and analyzed using content analysis to classify the articles into survey, evaluation, decision making, framework, modeling and review. The main findings of this paper are as follows: (1) Research on RL activities has mainly focused on recycling and remanufacturing, and insufficient research has been conducted on activities such as dismantling and waste management. (2) In terms of research objects, End-of-Life Vehicles (ELVs) and automotive batteries have received a lot of attention, while less research has been done on automotive tires, engines, waste oil, etc., which need further attention. (3) Integrated economic, environmental and social considerations are research opportunities for future evaluation and decision making. (4) The establishment of multi-objective problems and the innovation of solution methods may be the future research direction. (5) Green and sustainability themes are the main trends in the development of RL in the automotive industry in the future.

INDEX TERMS Automotive industry, literature review, reverse logistics, sustainability.

I. INTRODUCTION

Due to the rapid development of the economy and the continuous improvement of people's living standards, the automotive industry has entered a phase of rapid development, and the global production and sales of automobiles are growing rapidly. Based on the statistics from the International Organization of Motor Vehicle Manufacturers (OICA), we have plotted the car production shown in Figure 1. As can be seen from Figure 1, vehicle production shows an upward trend from 1999 to 2021, with the largest vehicle production in 2017. 2019 and 2020 show a decrease in vehicle production due to COVID-19, but an upward trend is seen again in 2021. In the vehicle sales data counted by OICA, 91,227,182 vehicles were sold in 2019, while in 2020, sales dropped to 78,774,320 due to the epidemic, but in 2021, it started to rebound with 82,684,788 units sold [1]. With the growth of technological development and economic growth, people's demand for vehicles is increasing, and the speed of vehicle replacement is accelerating, resulting in an increase in the amount of waste, which has caused many environmental and resource problems. In Europe, 8-9 million tonnes of waste are generated by ELVs every year [2]. Currently, the waste generated by the automotive industry, whether from

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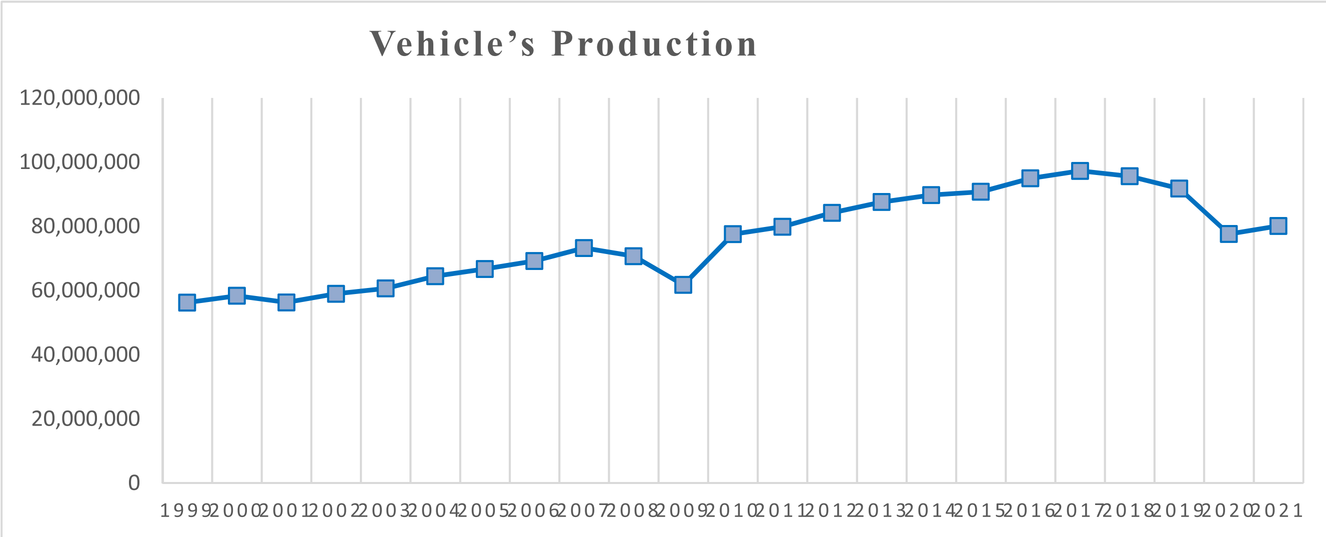


FIGURE 1. The vehicle's production between 1999 and 2021.

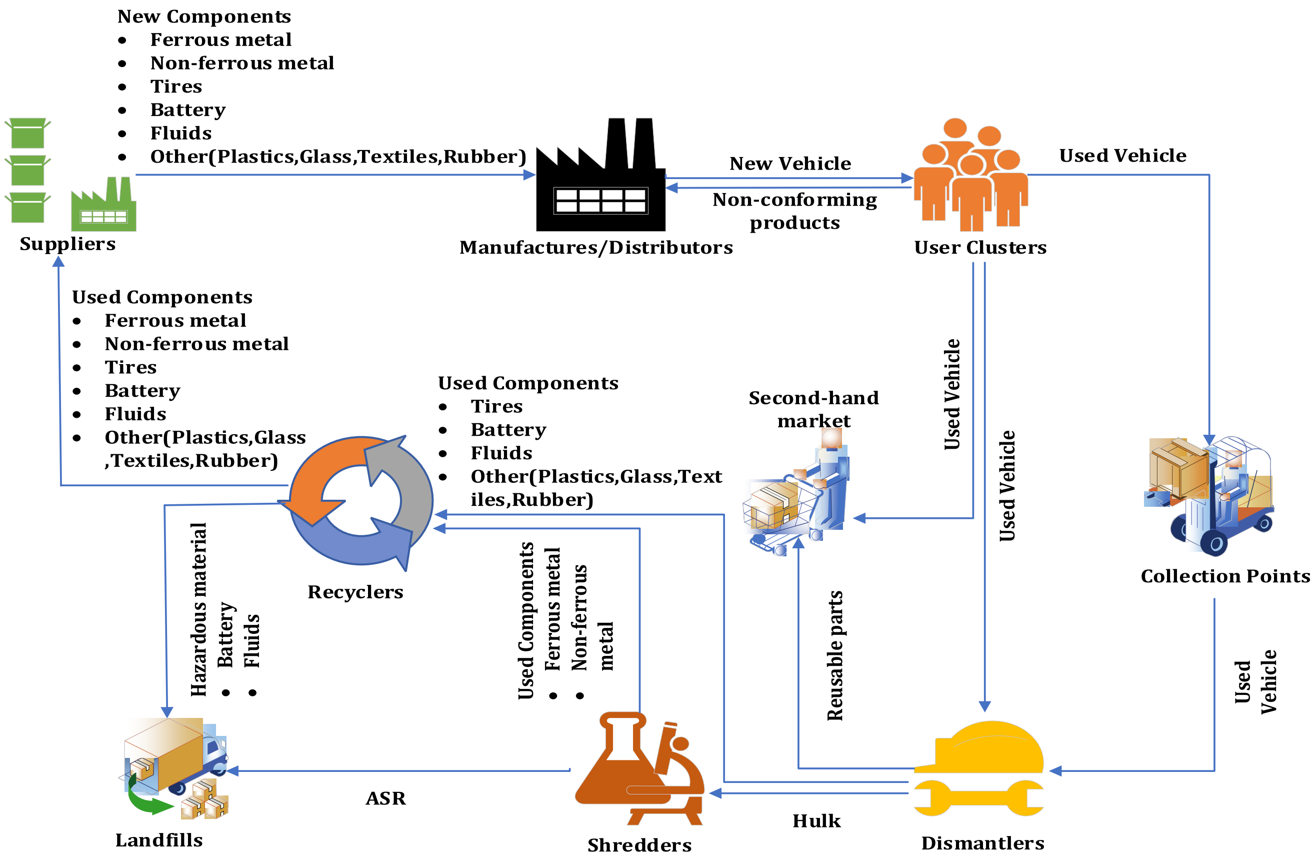


FIGURE 2. CLSC Network for automotive industry.

vehicles or manufacturers, accounts for about 5% of the world's industrial waste [3]. In order to reduce pollution and promote the reuse of resources, many countries have improved environmental protection and automobile recycling systems, and strengthened the management of returned and end-of-life car recycling, and reverse logistics has been more and more recognized and valued. The term reverse logistics was first introduced by Stock in 1992 as a logistics activity that includes processes such as product returns, material substitution, item reuse, disposal, reprocessing, reprocessing, repair, and remanufacturing [4]. With the in-depth development of the logistics industry, the improvement of environmental protection, product recycling system and commodity returns, and the strengthening of recycling and reuse of scrapped products, reverse logistics has become a key factor. Therefore, in today's rapid development of the automotive industry, how to promote the sustainable development of the automotive industry in an environmentally friendly and economical manner has become a hot topic of concern in the global automotive industry, and the management and control of automotive reverse logistics have increasingly become the focus of attention. Based on the study of Ozceylan et al. [5], a network structure diagram of the closed-loop supply chain (CLSC) in the automotive industry was constructed as shown in Figure 2, which contains both forward and reverse logistics.

Globally, in order to be able to comprehensively manage scrap cars, some countries have implemented regulations. On May 24, 2000, the European Union Parliament and Council issued the "2000/53/EC Technical Directive on End-of-Life Vehicles." The Directive requires EU member states to strengthen the management of end-of-life vehicle (ELV) recycling, improve the recycling rate of end-of-life vehicles, effectively reduce the impact of end-of-life vehicles on the environment, and achieve sustainable growth in the automotive industry. In 2002, Japan enacted the Automobile Reuse Law and began to levy various automobile recycling fees on automobile consumers, providing legal protection for the recycling of end-of-life automobiles in Japan The German government adopted the Circular Economy and Waste Act in 1996, which stipulates that vehicles that cannot pass inspection or whose repair costs exceed their own value must be scrapped. In 2007, under the leadership of Ford, General Motors and Chrysler, the U.S. auto industry formulated the "Guidelines for the Future Recycling of End-of-Life Vehicles," which clearly stipulates that The U.S. end-of-life vehicle recycling rate should reach 95% by 2020.

With a large number of national governments issuing corresponding laws and policies on the problem of end-of-life vehicles, many scholars have begun to study the reverse logistics activities of automobiles to explore the economic, environmental and social impact of reverse logistics activities on the automotive sector. The number of articles on the topic of reverse logistics in the automotive industry is increasing significantly. However, there is only one review on the research of reverse logistics systems for end-of-life vehicles [6]. The object of study of this paper is not limited to end-of-life vehicles, but to reverse logistics in the entire automotive field. With the significant growth in the literature, this paper attempts to bridge this gap by reviewing, classifying, and analyzing 91 papers published from January 2013 to March 2023. The rest of the paper is structured as follows: Section II describes the research methodology. Section III provides a descriptive analysis of the selected papers. Section IV discusses the detailed analysis and classification. Research gaps are analyzed and future research directions are addressed in Section V, and Section VI reaches a conclusion.

II. RESEARCH METHODOLOGY

A literature review can help researchers thoroughly explore and construct a specific area of research and can further advance the field. To conduct a systematic literature review, we developed a five-step research methodology framework, adapted from Prajapati et al. [7] with some modifications, for the current literature review (Figure 3).

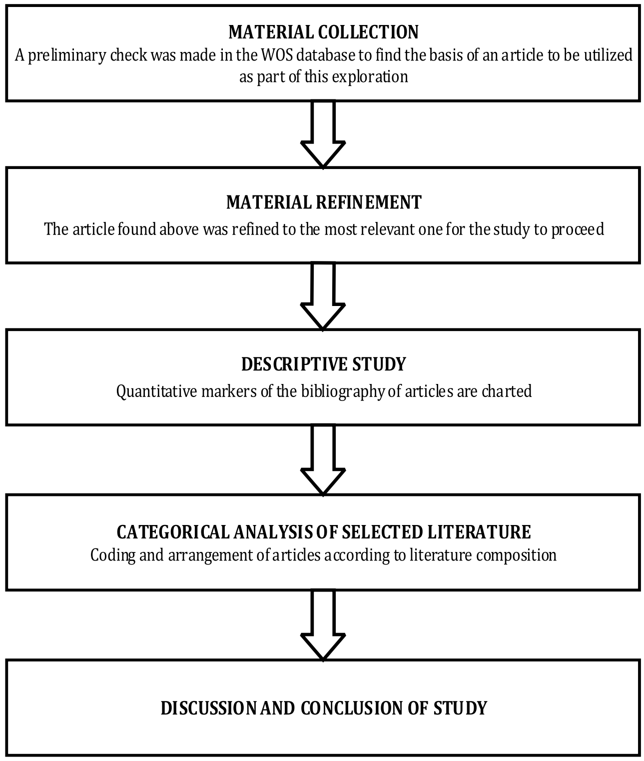


FIGURE 3. Framework for reverse logistics research methodology.

A. MATERIAL COLLECTION

The first step in data collection is to select a database and keywords to find articles. Web of Science (WOS) is the primary source of citation data due to its high reputation and recognition in the scientific community and its independence from the publisher. The WOS is an interdisciplinary and influential database covering the arts, humanities, biomedical sciences, engineering and technology, social sciences and natural sciences. This database can cover the research direction of this paper completely and provide good academic support for the research of this paper. In this paper, we chose to search the WOS database for articles with title, abstract and keywords (at least one of the three elements contains the search term) for "reverse logistics," "closed-loop supply chain" and "automotive." For a comprehensive collection of papers from the automotive industry, we expanded the set of keywords for automotive in the search ["Automotive," "Auto," "Automobile," "Automaker," "Car," "Vehicle"]. The search was conducted in March 2023 and left an initial list of 668 articles.

B. MATERIAL REFINEMENT
In this paper, a data table with the author's name, article title, year of publication, journal information, and full abstract was created for the collection of journal articles. Through a comprehensive review of the papers, we found that the majority of the published papers were concentrated after 2013. As some of the articles were double-accessed when we collected the papers, there were also some papers that were reviewed and were found to be incompatible with the topic of automotive reverse logistics. Finally, after removing the duplicated and non-conforming articles, 91 papers from January 2013 to March 2023 were selected for the study.

C. DESCRIPTIVE STUDY
In the third step, the bibliographic details of the selected literature are counted. It includes the time distribution of publications, ranking and JCR quartile of journal, distribution of research topics, distribution of research subjects, and geographic location of scholars. This step lays the foundation for content analysis.

D. CATEGORICAL ANALYSIS
The fourth step is to evaluate and analyze the selected literature. The articles selected for this study are now thoughtfully examined. Section IV provides a detailed classification analysis of the selected literature.

E. DISCUSSION AND CONCLUSION
This study provides a direction for the unexplored areas of reverse logistics research in the automotive industry. In the final step of this analysis, the findings of this study, the gaps identified in the literature, and future research directions are discussed. On the last points, the limitations of this literature review are also discussed.

III. DESCRIPTIVE ANALYSIS
The descriptive analysis is presented in the following subsections.

A. TIME DISTRIBUTION OF PUBLICATIONS
The number of articles published per year is shown in Figure 4. The figure shows an overall upward trend in the number of articles published. It is clear from this trend that the number of papers published in the last few years has grown significantly due to the growing interest of researchers in the field of reverse logistics in the automotive industry. 2017 and 2019 saw the highest number of articles published, with 12 published in both.

B. RANKING OF JOURNALS BY NUMBER OF PUBLICATIONS
The number of journals in which the selected papers were published indicates the demand for different journals in reverse logistics in the automotive industry. The number of publications and JCR quartile of these journals are shown in

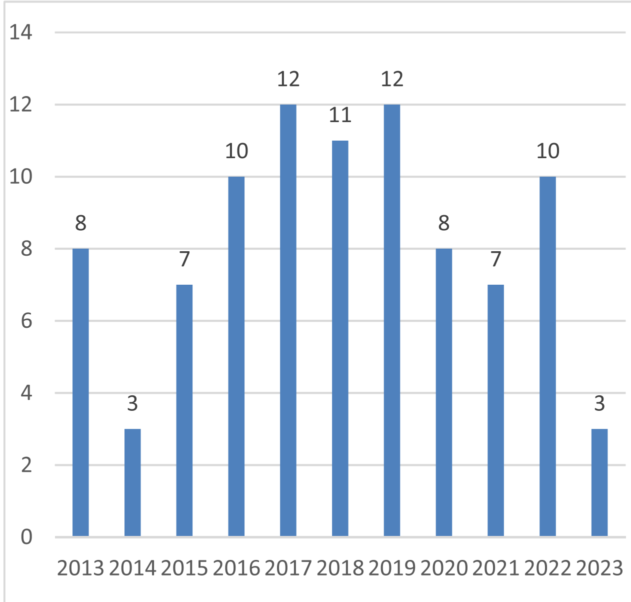


FIGURE 4. Number of papers per year.

Table 1. Because of the different JCR quartile in different subject areas of the journal, this paper selects the highest quartile. From Table 1 we see that there are 24 articles published in the Journal Of Cleaner Production, which is the journal with the highest number of publications, accounting for 26%. In addition, Sustainability (9 papers), and Computers & Industrial Engineering (6 papers) are more active compared to other journals.

C. STATUS OF PUBLICATIONS ON REVERSE LOGISTICS RESEARCH TOPICS
RL and CLSC are two of the most popular research areas in reverse logistics management research. To further understand the statistical information of the papers in reverse logistics research in the automotive industry, we divided the different reverse logistics activities studied by the papers based on the network structure diagram in Figure 2, and Figure 5 shows the number of papers in different areas of reverse logistics.

As shown in Figure 5, of the 91 papers selected, 63 were based on RL topics and 28 were based on CLSC issues. In addition, RL studies were grouped into nine categories of studies (in descending order), including recycling, general, remanufacturing, 3PRLP selection, returns management, reuse, waste management, disassembly, and sustainability and innovation.

D. INDUSTRIES AND OBJECTS OF RESEARCH
A review of publications in the area of reverse logistics in the automotive industry shows that researchers are currently considering the macro automotive industry in addition to a number of papers analyzing ELVs, components and power cells. As we can see in Figure 6, the macroscopic automotive sector accounts for 24% of the papers and the components sector accounts for 13%, which accounts for 37% of the total

TABLE 1. List of journals and the number of papers.

JOURNALS	JCR QUARTILE	N.
JOURNAL OF CLEANER PRODUCTION	Q1	24
SUSTAINABILITY	Q2	9
COMPUTERS & INDUSTRIAL ENGINEERING	Q1	6
RESOURCES CONSERVATION AND RECYCLING	Q1	5
INTERNATIONAL JOURNAL OF PRODUCTION ECONOMICS	Q1	5
INTERNATIONAL JOURNAL OF PRODUCTION RESEARCH	Q1	4
ENVIRONMENTAL SCIENCE AND POLLUTION RESEARCH	Q2	3
TEHNICKI VJESNIK-TECHNICAL GAZETTE	Q4	2
WASTE MANAGEMENT	Q1	2
JOURNAL OF MATERIAL CYCLES AND WASTE MANAGEMENT	Q3	2
INTERNATIONAL JOURNAL OF SUSTAINABLE DEVELOPMENT AND WORLD ECOLOGY	Q1	2
PRODUCTION PLANNING & CONTROL	Q1	2
JOURNAL OF ENVIRONMENTAL MANAGEMENT	Q1	2
EXPERT SYSTEMS WITH APPLICATIONS	Q1	1
ENERGIES	Q3	1
COMPLEXITY	Q2	1
WASTE MANAGEMENT & RESEARCH	Q2	1
OMEGA-INTERNATIONAL JOURNAL OF MANAGEMENT SCIENCE	Q1	1
IEEE ACCESS	Q1	1
JOURNAL OF INTELLIGENT & FUZZY SYSTEMS	Q4	1
EUROPEAN JOURNAL OF INFORMATION SYSTEMS	Q1	1
JOURNAL OF MECHANICAL DESIGN	Q2	1
Ingeniería y Desarrollo	/	1
SUSTAINABLE PRODUCTION AND CONSUMPTION	Q1	1
JOURNAL OF ENERGY STORAGE	Q1	1
ANNALS OF OPERATIONS RESEARCH	Q2	1
POLIMEROS-CIENCIA E TECNOLOGIA	Q4	1
INTERNATIONAL JOURNAL OF ADVANCED MANUFACTURING TECHNOLOGY	Q2	1
JOURNAL OF MANUFACTURING TECHNOLOGY MANAGEMENT	Q1	1
COMPUTERS & OPERATIONS RESEARCH	Q1	1
APPLIED SOFT COMPUTING	Q1	1
IEEE TRANSACTIONS ON ENGINEERING MANAGEMENT	Q1	1
ADVANCES IN MATERIALS SCIENCE AND ENGINEERING	Q3	1
BATTERIES-BASEL	Q2	1
ENVIRONMENT DEVELOPMENT AND SUSTAINABILITY	Q2	1
SUSTAINABLE MATERIALS AND TECHNOLOGIES	Q1	1

publications. Other publications are more clearly studied in reverse logistics, where the most attention is paid to ELVs with 19% of the total publications, followed by automotive batteries with 14% of the total publications. In addition, Figure 6 shows tires, returned products, packaging, car engine, auto timing belts, automotive chassis components, plastic containers for lubricants, used oil, car shell, PET seats, and other research objects.

E. GEOGRAPHY OF SCHOLARS

Table 2 shows the geographical breakdown of the authors. Since many articles were jointly published by scholars from

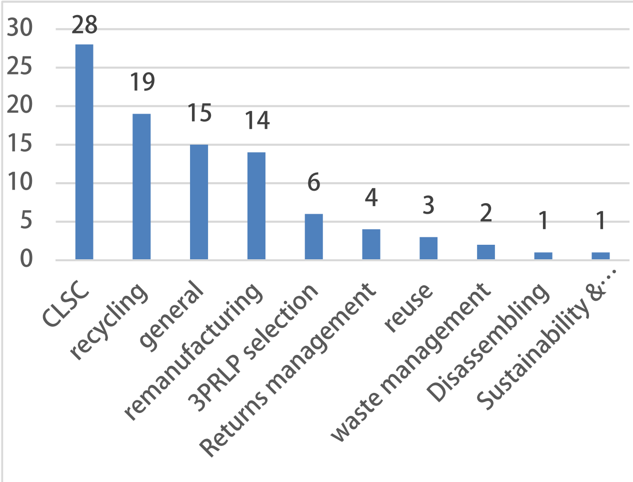


FIGURE 5. Various topics of the dissertation research.

multiple countries, only the countries of the corresponding authors of the articles are listed, and Table 2 shows only the countries with more than five published articles. Academic institutions in China, Brazil, and India have made significant contributions to research on reverse logistics in the automotive industry. China has the highest number of publications on this topic (22), followed by Brazil and India (both 9).

TABLE 2. Geography of scholars.

Country	N.
China	22
Brazil	9
India	9
Denmark	7
Iran	6
Turkey	6
USA	5
Others(Less than 5)	27
Total	91

IV. CATEGORICAL ANALYSIS OF SELECTED LITERATURE

According to Govindan et al. [8] literature classification types, this paper classifies the collected literature into survey, evaluation, decision making, framework, modeling and review categories to reflect the current status of literature research on reverse logistics in the automotive industry. Figure 7 shows the number of publications for each type of study and the percentage of them. This figure may lead researchers into popular areas of research to find future research gaps. In the next six subsections, we will analyze each type of paper in detail.

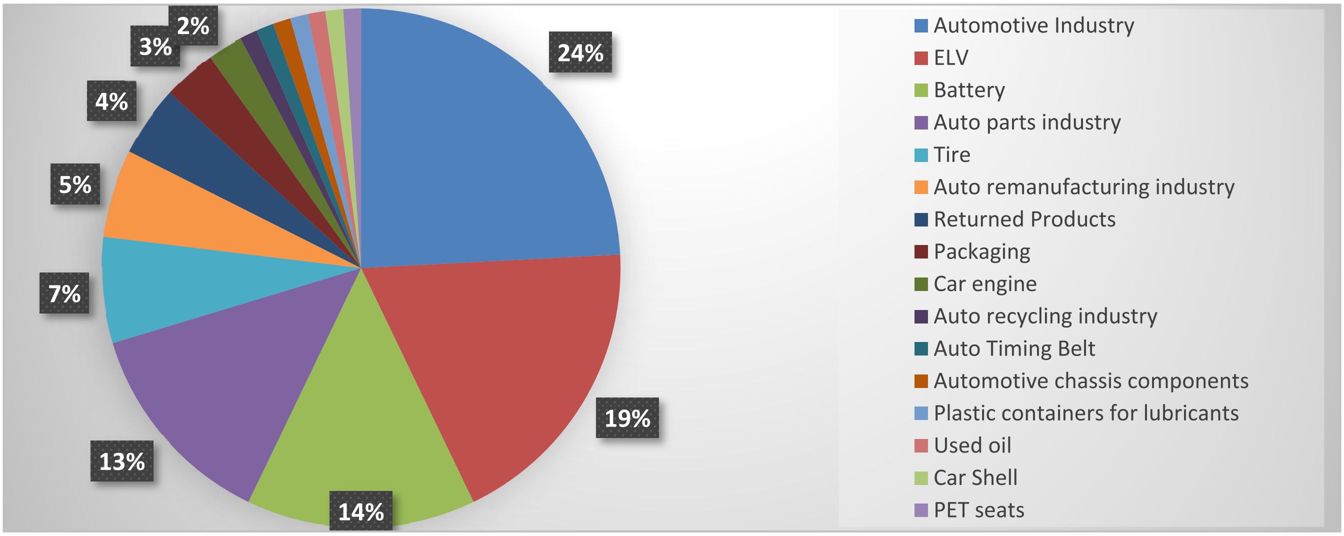
A. ANALYZING THE SURVEYS

Survey study is an important topic that allows valuable theoretical perspectives to be derived through practical research. The surveys are conducted through questionnaires, interviews, case studies or other forms of research to address the main research questions. The illustration of different approaches in survey studies is shown in Table 3. It can be found that about half of the papers use the questionnaire method. Questionnaires are good for collecting data on abstract ideas or concepts that are difficult to quantify. Through the findings of these papers, we discuss the factors influencing reverse logistics activities and closed-loop supply chains.

In response to the aspect of reverse logistics activities, Richnak and Gubova [20] concluded that the biggest obstacle to the implementation of environmental logistics elements in Slovak enterprises is the lack of financial resources. Similarly, Zhang et al. [18] found through their survey results that many remanufacturing firms have low revenues. Pisitsankkhakarn and Vassanadumrongdee [24] obtained from a survey analysis of 200 owners in Bangkok that product and price incentives can significantly increase consumers' purchase intention for remanufactured products. In terms of waste management, Tomasic et al. [9] conducted questionnaires and interviews with the heads of leading brands of cars after sales in Croatia and found that they believe that more resources should be invested in customer awareness and staff education in order to better manage recycled parts. While the main barrier to the adoption of product return management among Malaysian car manufacturers investigated by Zailani et al. [17] was closely related to the availability of resources to support product return activities.

In the context of closed-loop supply chains, Chavez and Sharma [22] considered the impact of current political, social, legal and technological conditions in Mexico on the profitability and environmental friendliness of closed-loop supply chains, demonstrating that the CLSC studied was both profitable and environmentally friendly. Santos and Proenca [23] identified innovation strategies, strategic alliances and government politics as return supply chain facilitators of policy development, while organizational and cultural factors were identified as difficulties. Scur et al. [21] identified the practices of each actor by surveying three key supply chain players (manufacturers, distributors/retailers, and recyclers) and how each actor works in a sustainable manner. The integration of actions and relationships between actors was facilitated from a triple bottom line perspective, highlighting variables for each dimension (economic, social and environmental).

In addition, other surveys collected in the related literature focus on the factors influencing the green or sustainable supply chain, such as environmental pressure [16], [25],



Note: All unlabeled data are 1%

FIGURE 6. Percentage of research subjects.

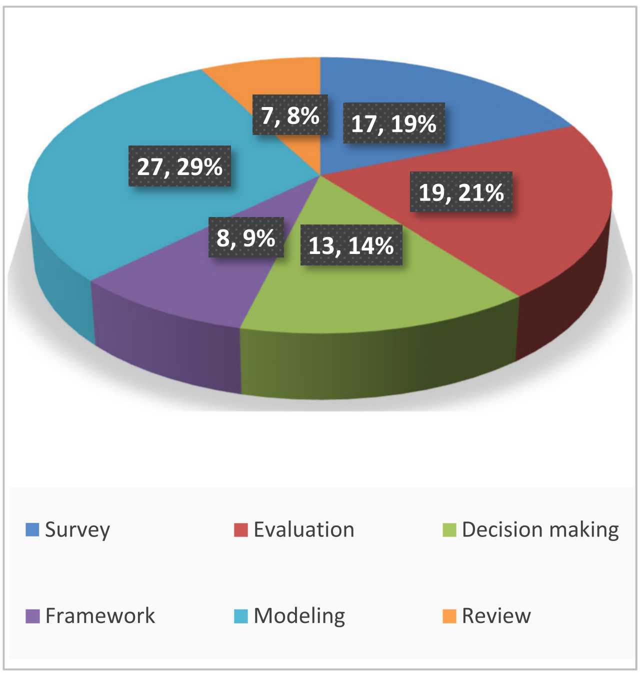


FIGURE 7. Distribution of research articles for different categories.

asset turnover ratio of the company [15], regulations [14], value chain [25], operational concerns [12], management [13], [19], [21].

B. ANALYZING THE EVALUATION STUDIES

A significant area of research in RL is the study of performance evaluation and management strategies for various networks. There are various types of research in the RL of the automotive industry focusing on the evaluation of the RL processes, the economic and environmental performance of organizations and businesses, and supply chain management. The researches considering different objectives, approaches and sustainability dimension can be analyzed in various ways. The papers are summarized in Table 4.

The main objectives of the paper evaluation are divided into 13, battery recycling is the most discussed. Supply chains performance, sustainable supply chain, the economic and environmental advantages of remanufactured products, sustainable end-of-life vehicle management, life cycle assessment, the environmental impact of reverse logistics, barriers to reverse logistics, ELV recycling management, remanufacturing supply chain management, evaluate the performance of returned products, CLSC barriers and economic feasibility of remanufacturing were also discussed.

Sustainability is a highly researched topic that focuses on its social, economic and environmental impacts. Silva et al. define economic, environmental and social factors as the three dimensions of sustainable development [45]. In the sustainability dimension analysis, there are 7 papers that consider economic, social and environmental dimensions at the same time, 5 papers consider both economic and environmental dimensions, 2 papers consider only the economic dimension and 5 papers consider only the environmental dimension. Figure 8 shows the incremental trend of considering sustainability dimensions in the evaluation of papers from 2013-2023. Between 2020 and 2023, the same number of papers considered economic benefits as environmental benefits, causing the line charts to overlap during this period. As can be seen, economic benefits have been the focus of research. However, after 2015, papers considering environmental benefits show an upward trend, indicating that environmental issues are receiving increasing attention from researchers.

TABLE 3. Survey methodology.

Reference	questionnaires	interviews	case studies
Tomasic et al. [9]	√	√	
Lagarinhos and Tenorio [10]			
Tian [11]			√
White et al. [12]			√
Kumar and Rahman [13]	√		
Luthra et al. [14]	√		
Tippayawong et al. [15]	√	√	
Seles et al. [16]		√	√
Zailani et al. [17]	√		
Zhang et al. [18]		√	
Mathivathanan et al. [19]	√		
Richnak and Gubova [20]	√		
Scur et al. [21]			√
Chavez and Sharma [22]			√
Santos and Proenca [23]		√	
Pisitsankkhakarn and Vassanadumrongdee [24]	√		
Mayyas et al. [25]			√
Total	8	5	6

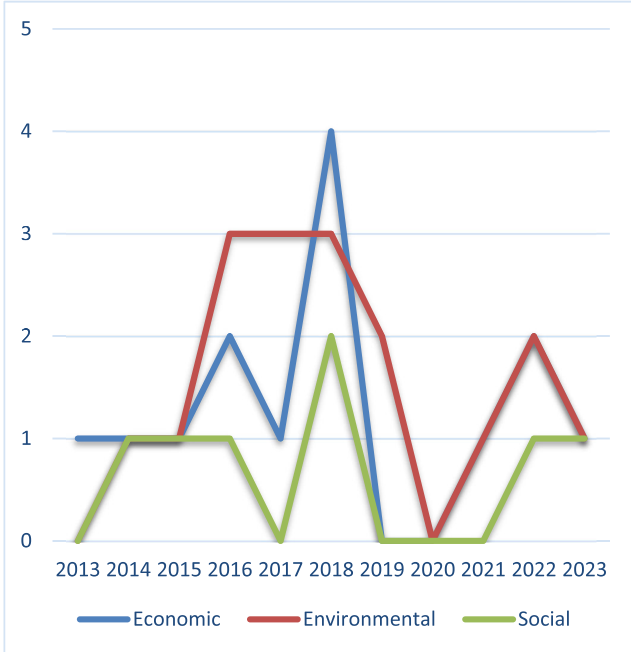


FIGURE 8. Sustainability dimension number trend.

C. ANALYZING THE DECISION MAKING STUDIES

Some studies focus on decision making frameworks and tools which are illustrated in this subsection of the paper.

The selection of third-party reverse logistics provider (3PRLP) is a very important research direction in reverse logistics, which can directly improve the quality of the product and have a significant impact on the cost price of the product [59]. From Table 5, we can obviously see that there are 6 papers that study third-party reverse logistics supplier selection. In the selection of sustainability 3PRLP, there are different dimensions of selection criteria in different cases, such as some papers consider three dimensions: economic, environmental, and social [50], while others add risk dimensions to the analysis based on the three dimensions [46], [47], [48], [56], while Govindan et al. [54] propose a multi-step process to select a third party reverse logistics provider. The common economic criteria include quality, cost, delivery, and capability of research and development. Environmental criteria are green design, reuse, remanufacture, refurbish, recycle and disposal. As the world attaches importance to environmental issues, "low carbon" has gradually become the development goal of various countries. Kannan et al. [50] added low-carbon and environmental management systems to environmental indicators. Zarbakhshnia et al. [47] also added air emissions and management for hazardous substances as environmental indicator criteria. The social criteria are mainly health, flexible working arrangements, the voice of the customer, and policy. In terms of risk and safety criteria, Zhang [48] and Yang [56] considered only operational and financial risks, while Mohamed et al. [46] and Zarbakhshnia [47] also considered organizational risk and safety.

For the recycling decision aspect, Tian et al. [49] developed a new standard system for selecting the best recycling model for end-of-life vehicles. A producer-responsible organization (PRO) recycling model based on a manufacturer's union organization was found to be most suitable for China. Byung-soo et al. [51] conducted simulations to determine the optimal number of returnable packages to purchase. Kai et al. [52] investigated a decision problem involving a choice between end-of-life product remanufacturing and disassembly in order to improve the performance of product recycling. A quality-dependent multi-objective optimization model was developed and validated to determine the optimal or near-optimal

TABLE 4. Summary of evaluation studies.

Reference	Model focus	Methodology	Sustainability dimension considered
Sabharwal and Garg [26]	Economic feasibility of remanufacturing	A graph theoretic approach	Economic
Guenther et al. [27]	Sustainable supply chain	CPLEX	Economic,social and environmental
Van Loon and Van Wassenhove [28]	The economic and environmental advantages of remanufactured products	Mathematical modeling	Economic and environmental
Klooer et al. [29]	Reuse of electric vehicle batteries	Decision support systems	Economic,social and environmental
Ahmed et al. [30]	Sustainable end-of-life vehicle management	AHP and fuzzy AHP	Economic,social and environmental
Kwak and Kim [31]	The economic and environmental advantages of remanufactured products	Mathematical modelling	Economic and environmental
Oliveira and Magrini [32]	Life cycle assessment	Life cycle assessment	Economic and environmental
Camargo Rodríguez et al. [33]	The environmental impact of reverse logistics	System dynamics	Environmental
Gardas et al. [34]	Analysis of obstacles of reverse logistics	ISM	Economic,social and environmental
Grandjean et al. [35]	Transportation of lithium-ion batteries for automobiles	Flash cryogenic freezing	Environmental
Li et al. [36]	Supply chains performance	Fuzzy network data envelopment analysis	Economic
Zhou et al. [37]	End-of-life vehicle (ELV) recycling management	ISM	Environmental
Govindan et al. [38]	The relationship between supply chain management practices and sustainability	Conceptual model	Economic,social and environmental
Zhu and Tian [39]	Remanufacturing supply chain management	Case study	Environmental
Kuik et al. [40]	Evaluate the performance of returned products	Fuzzy Logic	Environmental
Hu [41]	Supply chains performance	Stackelberg model	Economic and environmental
Joshi et al. [42]	Lead-acid battery recycling	System dynamics	Economic and environmental
Bhatia et al. [43]	CLSC Barriers	AHP and grey-decision making trial	Economic,social and environmental
Lin et al. [44]	Battery Recycling	Stackelberg model	Economic,social and environmental

product recovery solution. While Zhang et al. [58] analyzed three recycling models through a Stackelberg game and investigated the optimal recycling decision of an EV manufacturer by comparing different recycling models. Karagoz et al. [55] used an extension of the additive rate evaluation method in an interval type 2 fuzzy environment to solve the problem of the location of ELV recycling facilities.

There are many methodologies to solve specific decision problems, such as AHP [46], [47], [54], TOPSIS [46], MOORA-G [47], The Dominance Degree-Based Heterogeneous Linguistic Decision-Making Technique [48], Gray DEMATEL [49], VIKOR [49], ELECTRE [50], ANP [54], Interval type-2 fuzzy ARAS [55], Fuzzy MULTIMOORA [56], Linguistic interval value hesitation fuzzy DEMATEL technique [57], Stackelberg game [58] and mathematical modeling [51], [52]. From these papers, it can be seen that the most used method is AHP, and all of them combine it with other methods to make decisions.

TABLE 5. Summary of decision making studies.

Reference	Model focus	Methodology
Mohamed et al. [46]	Third-party reverse-logistics provider (3PRLP) selection	AHP and TOPSIS
Zarbakhshnia et al. [47]	3PRLP selection	Fuzzy AHP and MOORA-G
Zhang and Su [48]	3PRLP selection	The Dominance Degree-Based Heterogeneous Linguistic Decision-Making Technique
Tian et al. [49]	The selection of take-back patterns	Gray DEMATEL and fuzzy VIKOR
Kannan et al. [50]	3PRLP selection	ELECTRE
Byungsoo et al. [51]	Optimal purchase decision	Mathematical modeling
Kai et al. [52]	Product recovery	Mathematical modeling
Joanna et al. [53]	Reverse logistics network design	Life cycle management
Govindan et al. [54]	3PRLP selection	AHP and ANP
Karagoz et al. [55]	ELV recycling facility location	Interval type-2 fuzzy ARAS
Yang et al. [56]	3PRLP selection	Fuzzy MULTIMOORA
Shahidzadeh and Shokouhyar [57]	Sustainability	Linguistic interval value hesitation fuzzy DEMATEL technique
Zhang et al. [58]	Battery recycling decisions	Stackelberg game

D. ANALYZING THE STRUCTURAL FRAMEWORKS

A few studies have attempted to construct and present a problem-related framework to explain the main things that need to be studied - the key factors, barriers or variables and the assumed relationships between them. This section will provide a descriptive analysis of some of the papers in the structural framework category targeting RL systems, remanufacturing, and supply chains.

In terms of reverse logistics systems, Subramanian et al. [66] proposed a conceptual reinforcement learning framework based on a comprehensive literature review and several case studies of Chinese automotive parts companies that show the reverse logistics situation in the Chinese context, highlighting the implementation issues in the automotive parts domain. Kaviani et al. [60] developed a comprehensive framework to identify the key barriers to successful RL implementation in the automotive industry. The results indicate that economic barriers are the most important and knowledge barriers are the least important barriers to successful RL implementation in the automotive industry.

In the context of remanufacturing, Frota and Dutordoir [61] addressed a large gap in knowledge about the key characteristics of the remanufactured product market by using a big data analysis framework. Subramoniam et al. [64] validated a remanufacturing decision framework using hierarchical analysis for the automotive industry. Similarly, Abdulrahman et al. [65] developed a remanufacturing decision framework for strategic decision making of Chinese auto parts manufacturers and used hierarchical analysis to investigate the key factors affecting remanufacturing practices in the Chinese auto parts industry. Govindan et al. [67] proposed a modeling framework for studying the basic barriers to remanufacturing automotive parts in India. The findings show that higher costs and lack of customer acceptance are the basic and most influential barriers to automotive parts remanufacturing.

In the supply chain context, Ferreira et al. [62] conducted a state-of-the-art literature review of environmental management maturity to generate the original integrated framework of GSCM maturity levels. The integrated framework and evidence from multiple cases were then used to determine the relationship between environmental management maturity and the adoption of green supply chain management (GSCM) practices. Luthra et al. [63] developed a sustainability-focused supplier selection assessment system from the perspective of an organization's supply chain.

E. ANALYZING THE MODELING STUDIES

Different models are required to solve different reverse logistics problems. As can be seen from Table 6, these models are most often used to solve reverse logistics or closed-loop supply chain network design problems. A good network structure can bring great value to a firm, not only in terms of cost reduction [5], [68], [69], [70], [72], [73], [86], [88], [92] and revenue increase [5], [75], [83], [84], [90], but some logistics networks can also reduce greenhouse gas emissions [75], environmental impacts [92], [93], social impacts [93] and shortage costs [70]. Ozkir and Basligil [90] in building a closed-loop supply chain network considered maximizing trade satisfaction, maximizing customer satisfaction, and maximizing the total CLSC profit function.

In the study of reverse logistics problems, the determination of the objective function is very important. As can be seen from Table 6, although different models establish different objective functions, the most prominent objective of the models is still cost minimization or profit maximization. 12 of the papers have models that require cost minimization and 9 papers consider maximum profit. And on this basis, researchers have gradually focused on environmental and resource issues and considered environmental impacts and social impacts in model construction.

As can be seen in Figure 9, the number of papers in our study that use single-objective or multi-objective methods in different years (13 single-objective papers and 10 multi-objective papers). In 2013-2021, most of the papers established single-objective functions and only a small number of papers considered multi-objective. Although four papers with multi-objective methods are added in 2022, there are few methods to solve such problems because multi-objective functions are NP-hard problems. It seems that the computational difficulties of the multi-product approach are the reason behind these results.

In terms of methods for model solving, the most common is the use of CPLEX and LINGO solvers. Among the

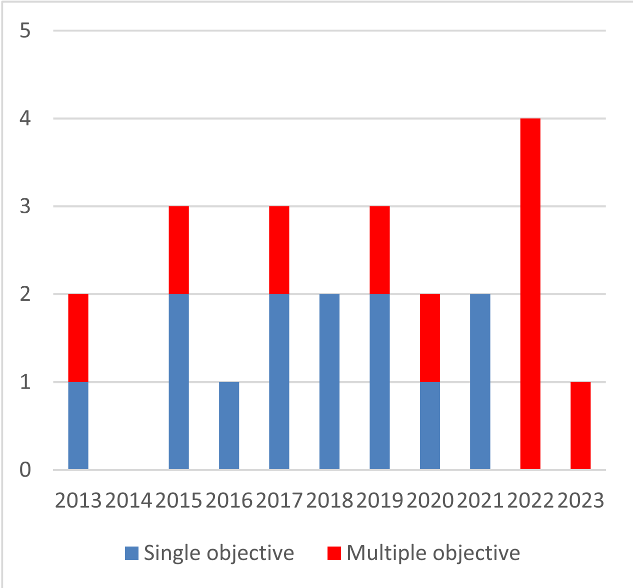


FIGURE 9. Single and multiple objective analyses in different years.

27 selected papers, four applied CPLEX [5], [83], [86], [93], and two applied LINGO [72], [79]. The remaining literature also used other methods or solvers, such as CCRSP and Taguchi-PSO [68], heuristic algorithm [69], two-stage optimization model [70], Excel Solver [71], FISM [74], IMPROVED NSGA-II [75], TFM [76], combined prediction model [78], semi-parametric modeling [81], linear programming with fuzzy parameters [82], GUROBI 5.5.0 solver [84], MOHEV [87], Fix-and-Optimize algorithm [88], DEA and BRPP [92].

F. ANALYZING THE REVIEW STUDIES

A number of reviews and overviews are being published to investigate the current state of development of reverse logistics in the automotive industry.

Due to the increasing governmental attention to environmental and resource issues, the literature on the direction of sustainable supply chains has been produced in abundance. Sustainability reviews for the automotive industry are analyzed in terms of sustainability supply chain management [96], sustainability and innovation [98], and green supply chain management [97]. With the rapid growth of global automobile production, the number of end-of-life vehicles is also increasing year by year, and the issue of how to deal with end-of-life vehicles is getting more and more attention. In the literature collected in the past decade, researchers have mainly analyzed end-of-life vehicle reverse logistics [6], ELV management [95] and ELV recycling [99].

In the latest report, Climate Change 2022: Mitigating Climate Change, published by the United Nations Intergovernmental Panel on Climate Change (IPCC) [100], it is stated that the annual average global greenhouse gas emissions from 2010-2019 are at the highest level in human history, reaching 59 billion tons in 2019, which is a 12% jump from the global emissions of 52.5 billion tons in 2010, i.e. the last an average annual increase of 1.3% over the last 10 years. In order to reduce greenhouse gas emissions, the global demand for electric vehicles is also gradually increasing, so the recycling of lithium-ion batteries is also very important.

As can be seen from Table 7, the keywords most mentioned are "Automotive/Auto/Automobile/Automake/Car/Vehicle," "Supply/Supply chain," "Reverse/Logistics/Logistical/Reverse logistics," "Closed-loop/Closed-loop supply chain," "Sustainable/Sustainability*/Sustainable development," "Green," "Recycl*/Return/Recovery/Collect*" and "EOL." It can be seen that researchers are interested in the literature on supply chains, and there is also currently a greater focus on green and sustainability. In the reverse logistics of the automotive industry, end-of-life vehicles are a key topic, and there are also several articles that provide a review of research on end-of-life vehicles [6], [95], [99]. For the methodological approach, in addition to the common content analysis [6], [95], [96], [99] and bibliometric approach [6], [98], there are also used data analysis [94], empirical studies and mathematic modeling [97].

V. ANALYSIS OF RESEARCH GAP AND FUTURE OPPORTUNITIES

The above description and detailed analysis of the article create a comprehensive knowledge base for the field of reverse logistics in the automotive industry. The results of the study can help researchers interested in reverse logistics in the automotive industry to understand the various topics of accepted papers and future research opportunities.

The analyses of this study originate some future research for authors as follows:

- Although research on reverse logistics for the automotive industry has been increasing in recent years, it can be seen from Figure 5 that only nine categories of reverse logistics activities are currently being analyzed, in addition to CLSC. Researchers have mostly focused on recycling and remanufacturing issues, and there are many activities to be studied in the reverse logistics network structure of automobiles, such as return, disassembly, and reuse. Although there are many papers studying remanufacturing issues, few papers have evaluated the impact of remanufacturing technology, and the impact of technological factors on remanufacturing activities could be considered in the future.
- In terms of research objects, the analysis in Figure 6 shows that, in addition to studying the macro automotive industry, the remaining literature focuses on three main research industries, including ELVs, automotive batteries, and automotive components. Therefore, other papers mentioned tires, automobile engines, and waste oil, which are research objects in automotive reverse logistics management, can receive more attention from researchers.

TABLE 6. Summary of modeling studies.

Reference	Model focus	Objective functions	Methodology	Single/Multiple objectives
Ozceylan et al. [5]	Network design	Sales revenues and costs	CPLEX	Multiple objectives
Shahparvari et al. [68]	Network design	Minimum total cost of network	CCRSP and Taguchi-PSO	Single objective
Chaabane et al. [69]	Vehicle routing	Minimize total cost	Heuristic algorithm	Single objective
Govindan et al. [70]	Supplier selection and network design	Minimize total cost and minimize shortages	Two-stage optimization model	Multiple objectives
Huang [71]	Hypothesis validation	Maximum profit	Excel Solver	Single objective
Xiao et al. [72]	Network design	Minimize total cost	Lingo	Single objective
Kusakci et al. [73]	Network design and optimization	Minimize total cost		Single objective
Chakraborty et al. [74]	Structural relationship analysis		FISM	
Yuchi et al. [75]	Network design	Maximize profit and minimize total CO_2 emissions	IMPROVED NSGA-II	Multiple objectives
Pereira et al. [76]	Forecasting		TFM	
Zhang et al. [77]	Mode Comparison	Minimize logistics cost		Single objective
Hao et al. [78]	Forecasting		Combined prediction model	
Zhou et al. [79]	Cost optimization	Maximum profit	Lingo	Single objective
Shankar et al. [80]	CLSC strategic	Contribution margin or profit		Single objective
Kumar et al. [81]	Remanufacturing	Hazard rate	Semi-parametric modeling	Single objective
Phuc et al. [82]	Reverse supply chain optimization	Minimize total cost	Linear programming with fuzzy parameters	Single objective
Demirel et al. [83]	Network design	Maximum profit	CPLEX	Single objective
Ene and Ozturk [84]	Network design	Maximum profit	GUROBI 5.5.0 solver	Single objective
Shaharudin et al. [85]	Return management			
Mahmoudzadeh et al. [86]	Network design	Minimize cost	CPLEX	Single objective
Govindan et al. [87]	SCND and OAP	Minimize cost and environmental impact	MOHEV	Multiple objectives
Lotfi et al. [88]	The viable closed-loop supply chain network	Minimizes a hybrid of the weighted expected, maximum, and EVaR of the cost function	Fix-and-Optimize algorithm	Multiple objectives
Fander and Yaghoubi [89]	Closed-loop automotive supply chain with the dual-channel sales system	Optimal capacity allocation for vehicle production and storage		Multiple objectives
Ozkir an Basligil [90]	Closed-loop supply chain network	Maximize trade satisfaction, customer satisfaction, and total CLSC profit		Multiple objectives
Xing and Yao [91]	Power battery echelon utilization and recycling strategy	Profit for manufacturers and retailers		Multiple objectives
Ghalandari et al. [92]	Closed-loop supply chain network design	Minimize cost and environmental impact	DEA and BRPP	Multiple objectives
Mu et al. [93]	Network design	Minimize the total network costs, environmental impacts and social impacts	CPLEX	Multiple objectives

- Quantitative research methods such as mathematical modeling, simulation, and survey methods are the main methods used in research. Qualitative research methods are generally used such as case studies and expert opinions. Through the detailed analysis of the papers, we found that most of the papers used quantitative research methods. In the classification analysis in Figure 7, we can find that the number of papers in the modeling category is the largest, accounting for 29% of the total number of papers. And most studies using

TABLE 7. Summary of keywords.

Keyword	References
Reverse/Logistics/Logistical/Reverse Logistics	[6][96]
Closed-loop/Closed-loop supply chain	[6][96]
Sustainable/Sustainability*/Sustainable development	[96][98]
Green	[96][97]
Environment	[96]
Ethics/Ethical	[96]
Social	[96]
Economic	[96]
Supply/Supply chain	[6][96][97]
Waste management	[96]
Recycle/Return/Recovery/Collect	[6][96]
Remanufacture	[96]
Reuse	[96]
Life cycle assessment	[96]
EOL	[95][96]
Automotive/Auto/Automobile/Automake/Car/Vehicle	[95][96][98]
Innovation	[98]

questionnaires and mathematical models are found in the survey papers and decision papers, respectively. Therefore, in future studies, researchers can pay more attention to qualitative research methods to solve research problems.

- Most of the research studies in the survey category analyze the impact factors of supply chains in terms of economic, social and environmental dimensions in closed-loop supply chains. In contrast, in terms of reverse logistics barrier factors, the focus has been on economic benefits, while environmental and social benefits have been neglected. Future researchers can consider environmental and social impacts when studying reverse logistics barrier factors. In papers considering product waste management, Tomasic [9] and Zailani [17] analyzed the perspective of retailers and manufacturers, respectively, and future research scholars can analyze the perspective of other firms in the supply chain network, such as suppliers and logistics companies for product return management.
- It is obvious from Figure 8 that the sustainability dimensions (social, economic and environmental) are considered by many articles, with environmental issues being the most prominent dimension (considered by 17 papers), which indicates that environmental issues are getting more and more attention. This is followed by the economic dimension, which considers issues such as cost, price, and income. And the social dimension was considered in the least number of studies. In further studies, all three dimensions should be introduced in the evaluation of automotive reverse logistics, especially the social impact, to understand the overall intrinsic benefits of reverse logistics activities in the automotive industry in a given region and/or country.
- The 3PRLP selection is the most studied decision class problem. To determine the optimal 3PRLP, some papers have analyzed the risk dimension in addition to considering the triple dimension of sustainability. Different dimensions require the identification of different relevant criteria, and more new criteria can be explored in future research to construct the full sustainability dimension and thus improve the quality of decision making.
- AHP is popular for its ability to combine qualitative and quantitative decision making in a reasonable way. A number of literature have mixed AHP with other methods for decision making. Although this approach has wide applicability, it may not be suitable for all decision problems. Therefore, future literature can be more about choosing suitable decision methods or improving them based on existing methods to make them more reasonable and effective in solving problems.

- Among the studies based on the framework structure, there are more papers on remanufacturing and relatively less attention to RL recycling and reuse processes. The impact of these two activities on the automotive market could be an interesting research direction for the future. In addition, barrier-influencing factors are mostly considered in the studies and the facilitation factors of reverse logistics activities could be considered in the future.
- The most common research approach for network design and optimization is to build mathematical models. Future researchers may consider qualitative research on this topic, and through surveys or case studies, be able to reach a deeper understanding of the actual problem in order to build the most suitable reverse logistics network.
- As can be seen from Table 6, most of the existing studies consider the cost optimization of the enterprise when building the model, and a number of studies have been conducted from the perspective of increasing the profitability of the enterprise. However, there are very few papers that consider the aspects of customer satisfaction, social impact, and the degree of impact on the environment and resources. Future scholars may consider further research on these aspects.
- Figure 9 illustrates the single/multi-objective trend situation. Although there are still gaps in multi-objective analysis compared to single-objective analysis in different studies. However, since real-world problems are rarely single-objective, it is necessary for researchers to focus more on multi-objective functions rather than single-objective functions. For multi-objective complex problems, researchers can also try some innovative algorithms to solve them in the future.
- The research on uncertainty problems is the focus and difficulty, and also the weak point in the existing research. Most scholars put forward the importance of the research on uncertainty factors, but few of them are really integrated into the research at present. There are many uncertainty factors in the real situation, which will become a hot issue for research in the future.
- In the review analysis, in addition to automotive reverse logistics and supply chain topics, a number of papers focus on green and sustainability. Green and sustainability may be the main trend for the future development of reverse logistics in the automotive industry. End-of-life vehicles are the main object of researchers, and how to better handle ELVs is a problem that needs to be solved in the future.

VI. CONCLUSION

This paper presents a comprehensive literature review of papers published in different journals in the field of reverse logistics in the automotive industry in the WOS database. 91 papers published between January 2013 and March 2023 were selected, reviewed, classified, and analyzed to identify gaps in the literature and discussed comprehensively to identify future research opportunities for the authors.

The current paper research mainly focuses on recycling and remanufacturing issues, and other reverse logistics activities are yet to be further studied. In terms of research subjects, researchers have mainly focused on considering ELVs and automotive batteries, and the rest of automotive components are also future research directions. In order to understand the trends of specific companies, it is recommended to conduct qualitative research, especially survey-based research. Economic, environmental and social aspects should be considered when evaluating or making decisions on problems, and more decision dimensions and criteria can be studied in the future. In terms of model building, focusing on multi-objective problems and using new methods may be the direction of future research. Green and sustainability remain the main trends for the future development of reverse logistics in the automotive industry. In summary, this study reviews reverse logistics activities in the automotive industry and analyzes future directions for this research area.

However, this study also has limitations. Firstly, only the WOS database was selected for the collection of materials in this paper, and there may be some good articles that were left out, and multiple databases could be selected to collect literature in future studies. Secondly, the collected papers are only classified into six types according to their nature, and the paper analysis can also be subdivided according to the topic of the problem studied in the article, and through the multi-perspective analysis, a better understanding of future research opportunities can be achieved. These limitations need to be further improved in future studies.

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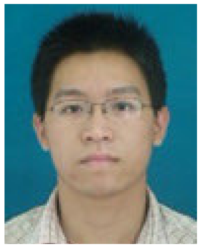

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