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Invited Review

Reverse logistics and closed-loop supply chain: A comprehensive review to explore the future

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ABSTRACT

Based on environmental, legal, social, and economic factors, reverse logistics and closed-loop supply chain issues have attracted attention among both academia and practitioners. This attention is evident by the vast number of publications in scientific journals which have been published in recent years. Hence, a comprehensive literature review of recent and state-of-the-art papers is vital to draw a framework of the past, and to shed light on future directions. The aim of this paper is to review recently published papers in reverse logistic and closed-loop supply chain in scientific journals. A total of 382 papers published between January 2007 and March 2013 are selected and reviewed. The papers are then analyzed and categorized to construct a useful foundation of past research. Finally, gaps in the literature are identified to clarify and to suggest future research opportunities.

1. Introduction

Initially, the growing attention on Reverse Logistics (RL) and Closed-Loop Supply Chain (CLSC) issues originated with public awareness (discussed in Dowlatshahi, 2000). Then governmental legislation forced producers to take care of their End of Life (EOL) products. For instance, the Waste Electrical and Electronic Equipment (WEEE) directive (directive 2002/96/EC) became European law in 2003, which contains mandatory requirements on collection, recycling, and recovery for all types of electrical goods, with a minimum rate of 4 kilograms per head of population per annum (Georgiadis & Besiou, 2010). WEEE-like legislation was also introduced in Canada, Japan, China, and many states in the US (Quariguasi Frota Neto, Walther, Bloemhof, Van Nunen, & Spengler, 2010). Finally, RL/CLSC is now a revenue opportunity for manufacturers instead of a cost-minimization approach (Guide & Van Wassenhove, 2009). A supply chain, in its classical form (forward supply chain), is a combination of processes to fulfill customers' requests and includes all possible entities like suppliers, manufacturers, transporters, warehouses, retailers, and customers themselves (Chopra and Meindl, 2010). According to the American Reverse Logistics Executive Council, reverse logistics is defined as "The process of planning, implementing, and controlling the efficient, cost effective flow of raw materials, in-process inventory, finished goods and related information from the point of consumption to the point of origin for the purpose of recapturing value or proper disposal" (Rogers & Tibben-Lembke, 1998). Indeed, reverse logistics, in general forms, start from end users (first customers) where used products are collected from customers (return products) and then attempts to manage EOL products through different decisions are undertaken including recycling (to have more raw materials or raw parts), remanufacturing (to resale them to second markets or if possible to first customers), repairing (to sell in the second markets through repairing), and finally, disposing of some used parts.

If we consider forward and reverse supply chains simultaneously, the result network will construct a closed-loop supply chain. Fig. 1 illustrates a generic supply chain for both forward and reverse logistics. In this figure, the classical (forward), and reverse supply chains are presented by solid lines and dashes, respectively. In return evaluation stage, possible decisions on return products are made. (Another illustration of a generic form of closed loop supply chain is found in Beamon, 1999).

Regarding the recent definition of a closed-loop supply chain, we should mention the elevated description of CLSC based on current requirements found in Guide and Van Wassenhove (2009). Based on the new definition, closed-loop supply chain management is the design, control, and operation of a system to maximize value creation over the entire life cycle of a product with dynamic recovery of value from different types and volumes of returns over

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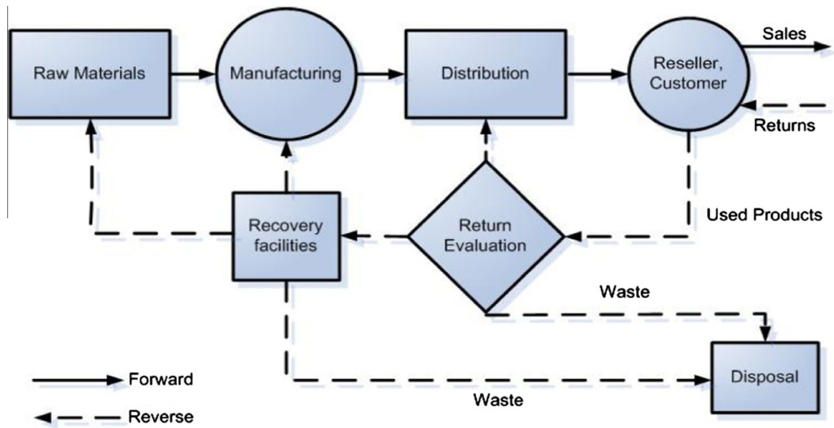

Fig. 1. A generic form of forward/reverse logistics (Tonanont et al., 2008).

time. The importance of this definition is the explicit business point of view instead of other factors like legal, social responsibilities, or even operational and technical details. Indeed, practitioners can focus on the profitability and value of their RL/CLSC instead of cost efficiencies or other costly objectives. Based on the new definitions of the CLSC revealing recent requirements and new situations, it is necessary to have a comprehensive review to help researchers focus on future directions. Recently, no review papers could be found in this field that had undertaken a systematic classified analysis of recent papers to spot future avenues. This paper tries to cover this gap by reviewing, categorizing, and analyzing 382 papers published between 2007 and 2013. The remainder of the paper is structured as follows: Section 2 discusses some earlier review/partial-review papers. Research methodologies are clarified in Section 3. Detailed analyses and classifications of reviewed papers are discussed in Section 4. The current gaps analysis results and future research opportunities are presented and discussed in Section 5. Finally, Section 6 contains the conclusion and future research.

2. Literature review

Some review studies should be mentioned here to clarify the need for this study. In order to manage a structured review, the characteristics of the earlier review/partial review papers are illustrated in Table 1.

In the light of Table 1, no comprehensive review study in RL/CLSC, which analyzes state-of-the-art recently published papers, is found in the literature. Apart from the duration of the study, the limitation of most review papers in Table 1 is the scope of their studies. Some cover either RL or CLSC, and some are partial reviews with specific aims, for instance in JIT (Chan, Yin, & Chan, 2010) or reviewing network design models (Chanintrakul, Coronado Mondragon, Lalwani, & Wong, 2009). Among all mentioned review/partial review papers in Table 1, the papers of Pokharel and Mutha (2009) and Sasikumar and Kannan (2009) can be mentioned as they analyzed the whole area on reverse logistics. However, both covered papers were published before 2008 and they did not include closed-loop supply chain publications. On the other hand, Pokharel and Mutha (2009) just try to make a good selection among all publications in their review paper so the number of publications in their paper is low. Fang, Cote, and Qin (2007) studied the state of eco-industrial development in China. They reviewed reports on a range of case studies and provided a synthesis of type and scale of experimental eco-industrial development, supply chains and symbioses in eco-industrial development and the CE, and major constraints to eco-industrial development. Following this synthesis, they presented an analysis of the opportunities and constraints with respect to making further progress in eco-industrial development in China.

Consequently, after 2007, we cannot observe an integrated review in RL/CLSC, which can present a comprehensive (not partial) review in this field despite the vast number of published papers (see Fig. 2). Besides, in order to have an overall view of the future directions in RL/CLSC studies, it is now necessary to reconstruct a new literature review study based on recent publications in the area. This last line of the Table 1 can present the role of this paper in covering the presented gap of the literature.

3. Research methodology

According to Mayring (2003) content analysis and description of research methodology should include four steps: material collection, descriptive analysis, category selection, and material evaluation. This paper utilizes the steps mentioned in Mayring (2003) to discuss and clarify the research methodology of the paper.

3.1. Material collection

The material of the literature review and the unit of analysis are detailed in this part. The study was conducted from December 2012 to May 2013 covering the accepted papers (available online) in scientific English language journals from January 2007 to March 2013. The search procedure was managed in three stages with the "reverse logistics and closed loop supply chain" keywords in the Google-scholar search engine (www.scholar.google.com) with these modifications: searching for articles in English language, and custom time range between 2007 and 2013, sorted by relevance. It should be mentioned that the search engine is updated periodically due to the acquisition of new publications, relevance, citations, and so forth, so the process of collecting papers is undertaken in a short period of time. The three stages of the research procedure are as follows:

- In the initial search from Google Scholar, 66 pages of search results of 660 papers from various publishers were obtained. The list includes work from Elsevier (www.sciencedirect.com), Informs (http://journals.informs.org/), Emerald (www.emeraldinsight.com), Springer (www.springerlink.com), Taylor & Francis (www.tandf.co.uk/journals/), Wiley (http://www.wiley.com), JSTORE (http://www.jstor.org/), Inderscience (www.inderscience.com), Hindawi

Table 1
Characteristics of earlier review/partial review studies.

Paper	Area	Scope	Year	Number of papers
Meade, Sarkis, and Presley (2007)	RL	Definitions, research, and research opportunities	Until 2006	–
Sasikumar and Kannan (2008b)	RL	End of life product recovery and inventory management	Until 2008	–
Sasikumar and Kannan (2008a)	RL	Reverse distribution	Until 2009	170
Rubio et al. (2008)	RL	Production and operations management	1995–2005	186
Pokharel and Mutha (2009)	RL	The whole area in RL	1971–2008	151
Akçalı, Çetinkaya, and Üster (2009)	RL and CLSC	Network design models	Until 2008	22
Sasikumar and Kannan (2009)	RL	The whole area in RL	1967–2008	543
Chanintrakul et al. (2009)	RL	Network design papers	2000–2008	–
Ilgin and Gupta (2010)	RL and CLSC	Environmentally conscious manufacturing and product recovery	1998–2009	540
Chan et al. (2010)	RL	Just-in-time (JIT) and reverse logistics	Until 2009	125
Akçalı and Cetinkaya (2011)	CLSC	Quantitative models for inventory and production planning	Until 2009	–
Jayant, Gupta, and Garg (2012)	RL	Almost whole area	1990–2009	113
Carrasco-Gallego, Ponce-Cueto, and Dekker (2012)	CLSC	Case studies	Until 2010	10
Fang et al. (2007)	Sustainability	Case studies	Until 2005	13 Eco industries
Our Study	RL and CLSC	The whole area in RL and CLSC	2007–2013	382

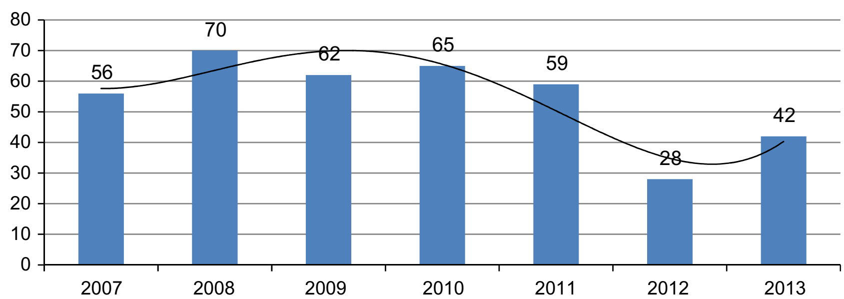

Fig. 2. Distribution of publications per year across the period of the study (382 papers: 2007–2013).

(www.hindawi.com), IEEE (ieeexplore.ieee.org/xpl/periodicals.jsp/), and some library services (e.g., Scopus www.scopus.com, Metapress www.metapress.com). The related papers in the fields of RL and CLSC are selected and reviewed.

- In the second stage, to ensure coverage of recent publications, the same search is run to locate papers published in 2013 with the same keywords. At this stage, 200 new papers are considered, and related papers, which belong to previously mentioned publishers (related to scope of this research), are selected and reviewed.
- Thirdly, papers selected in the first two stages are cross-checked with results of the same keywords in Web of Science (WOS) database to ensure the reliability of the process of finding and selecting papers. In the evaluation process of selecting related state-of-the-art papers in this area of study, all collected papers in the first two phases are considered. At the conclusion of this stage, the most appropriate papers are selected based on the relevance of subjects (the papers which present a topic in RL/CLSC and not just mention similar keywords in non-related topics), rank of journals (there are some papers in local journals, which they cannot count on an international level), and citations (in few cases, there are some papers with high citations in low-level journals, which we considered them in final list). Then, the rest are selected to review and analyze in this study.

Finally, 382 papers are reviewed and classified in the literature review study. They are reviewed, and their differing characteristics are distinguished and recorded in a prepared spreadsheet to be analyzed holistically. Rigor in validity is achieved by validation tests performed by two researchers who also undertake the deductive and inductive approaches simultaneously.

3.2. Descriptive analysis

This study attempts to analyze 382 scientific papers[1] published between 2007 and 2013 as illustrated in Fig. 2.

The distribution of journals in which the selected papers are published indicates the desires of different journals in RL and CLSC management. The publications and distribution of the journals are presented in Table 2 and Fig. 3.

Reviewing Table 2 and Fig. 3 reveals that the subjects of RL/CLSC are considered by many journals. We find 143 papers in various journals with few publications (4 and fewer) in these fields; the list of journals in this category is illustrated in Appendix 1 (Alinovi, Bottani, & Montanari, 2012; Alshamrani, Mathur, & Ballou, 2007; Alumur, Nickel, Saldanha-da-Gama, & Verter, 2012; Amaro & Barbosa-Póvoa, 2009; Amin & Zhang, 2012a; Amin & Zhang, 2012b; Ao, Xu-ping, Bo-jie, & Wu-wei, 2007; Aras & Aksen, 2008; Atasu, Guide, & Van Wassenhove, 2010; Atasu & Souza, 2012; Atasu, Toktay, & Van Wassenhove, 2013; Atasu, Van Wassenhove, & Sarvary, 2009; Barbosa-Póvoa, 2009; Benedito & Corominas, 2013; Besiou, Georgiadis, & Van Wassenhove, 2012; Bogataj, Grubbström, & Bogataj, 2011; Buscher & Lindner, 2007; Cagno, Magalini, & Trucco, 2008; Carter & Rogers, 2008; Chandiran & Surya Prakasa Rao, 2008; Chen, 2011; Chen & Bell, 2011; Chen & Chang, 2012; Cheng & Lee, 2010; Chung, Wee, & Yang, 2008; Cristina Santos Amaro & Barbosa-Póvoa, 2007; Cruz-Rivera & Ertel, 2009; Das, 2012; Das & Chowdhury, 2012; De Brito, Dekker, & Flapper, 2005; de Brito & van der Laan, 2009; Demirel & Gökçen, 2008; Diabat & Simchi-Levi, 2009; Du, Wu, & Hu, 2009; Easwaran & Üster, 2010; Efendigil, Önüt, & Kongar, 2008; El Saadany & Jaber, 2011; El-Sayed, Afia, & El-Kharbotly, 2010; Faccio, Persona, Sgarbossa, & Zanin, 2011; Farzipoor Saen, 2009;

[1] This work considers only papers written in the English language.

Table 2
Distribution of literature based on the source of publication.

Publication	Year of publication							
	2007	2008	2009	2010	2011	2012	2013	Total
Int. J. of Prod. Econ.	1	17	3	3	8	5	4	41
Int. J. of Prod. Res.	5	2	4	7	5	9	7	39
European J. of Oper. Res.	3	3	5	5	3	2		21
Int. J. of Adv. Manu. Tech.	–	1	–	5	2	1	4	13
J. of Cleaner Prod.	2	4	1	2	1	–	2	12
Com. & Oper. Res.	8	1	1	1	1	–	–	12
IEEE Int. Conference	1	2	3	2	2	–	–	10
Int. J. of Log. Sys. & Mgmt.	1	4	–	2	2	–	1	10
Prod. & Oper. Mgmt.	1	1	3	–	3	–	2	10
Resour., Cons. & Recy.	–	–	1	2	4	1	1	9
Com. & Indust. Eng.	–	2	3	1	2	1	–	9
Transp. Res. Part E	–	2	1	1	1	2	2	9
Omega	1	2	2	–	1	1	–	7
Int. J. of Sustainable Eng.	–	3	1	–	–	–	1	5
Int. J. of Physical Dis. & Log. Mgmt.	1	2	–	–	2	–	–	5
J. of Oper. Mgmt.	5	–	–	–	–	–	–	5
J. of Environmental Mgmt.	1	–	–	2	2	–	–	5
An International J.	–	1	2	–	2	–	–	5
App. Math. Mod.	1	–	–	1	1	–	2	5
Expert Sys. with App.	–	–	1	1	1	2	–	5
Others (4 and below)	25	23	31	30	16	4	16	145
Total	56	70	62	65	59	28	42	382

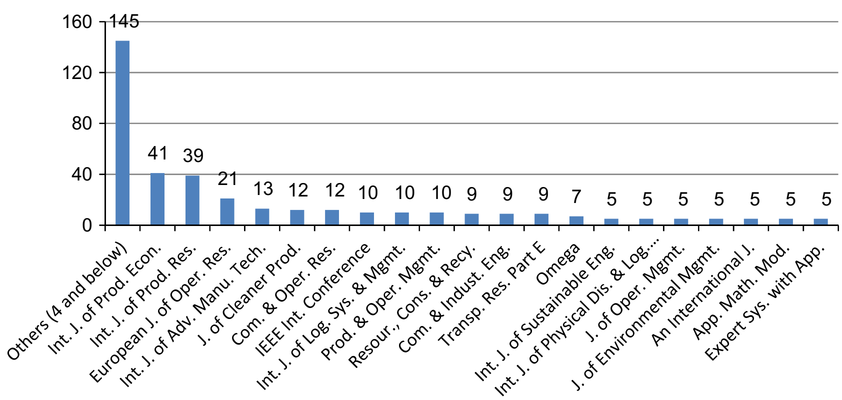

Fig. 3. Distribution of publications based on different journals (382 papers: 2007–2013).

Ferguson, Guide, Koca, & Souza, 2009; Fernandes, Gomes-Salema, & Barbosa-Povoa, 2010; Ferrer & Swaminathan, 2010; Francas & Minner, 2009; Galbreth & Blackburn, 2010; Gamberini, Gebennini, Manzini, & Ziveri, 2010; Ge & Huang, 2007; Ge, Huang, & Li, 2007; Ge, Huang, & Wang, 2007; Georgiadis, 2013; Geyer, Van Wassenhove, & Atasu, 2007; Golinska, 2009; Golinska, Fertsch, Gómez, & Oleskow, 2007; Gou, Liang, Huang, & Xu, 2008; Govindan & Murugesan, 2011; Hasanov, Jaber, Zanoni, & Zavanella, 2013; Hellström & Johansson, 2010; Hong, Ammons, & Realff, 2008; Hong & Ke, 2011; Hong & Yeh, 2012; Hsueh, 2011; Hua & Lingling, 2010; Huang, Yan, & Qiu, 2009; Hwang, Ko, Yune, & Ko, 2009; Jaber & El Saadany, 2009; Jaber & El Saadany, 2011; Jaber & Rosen, 2008; John & Sridharan, 2013; Kannan, Diabat, Alrefaei, Govindan, & Yong, 2012; Kannan, Murugesan, Senthil, & Noorul Haq, 2009; Kannan, Noorul Haq, & Devika, 2009; Kannan, Sasikumar, & Devika, 2010; Karaer & Lee, 2007; Karakayali, Emir-Farinas, & Akcali, 2007; Kassem & Chen, 2013; Kaya, 2010; Kenné, Dejax, & Gharbi, 2012; Ketzenberg, 2009; Ketzenberg & Zuidwijk, 2009; Kim & Goyal, 2011; Kim, Yang, & Lee, 2009; Ko & Evans, 2007; Krikke, 2011; Krikke, le Blanc, van Krieken, & Fleuren, 2008; Kusumastuti, Piplani, & Hian Lim, 2008; Lee & Chan, 2009; Lee & Dong, 2008; Lee, Dong, & Bian, 2010; Lee, Gen, & Rhee, 2009; Li, Li, & Cai, 2009; Li, Liu, Cao, & Wang, 2009; Lieckens & Vandaele, 2012; Listeş, 2007; Loomba & Nakashima, 2012; Lu & Bostel, 2007; Mansour & Zarei, 2008; Melacini, Salgaro, & Brognoli, 2010; Metta & Badurdeen, 2011; Min & Ko, 2008; Mitra, 2007; Mitra, 2009; Mitra, 2012; Mitra, 2013; Mitra & Webster, 2008; Mukhopadhyay & Ma, 2009; Mutha & Pokharel, 2009; Nenes & Nikolaidis, 2012; Pal, Sana, & Chaudhuri, 2013; Pan, Tang, & Liu, 2009; Panagiotidou, Nenes, & Zikopoulos, 2013; Parlikad & McFarlane, 2007; Peng & Zhong, 2007; Pishvaee, Farahani, & Dullaert, 2010; Pishvaee, Kianfar, & Karimi, 2010; Pishvaee, Rabbani, & Torabi, 2011; Pochampally & Gupta, 2012; Poles, 2013; Ponce-Cueto, Manteca, & Carrasco-Gallego, 2011; Qi & Hongcheng, 2008; Qiang, Ke, Anderson, & Dong, 2013; Qiaolun & Tiegang, 2009; Qin & Ji, 2010; Qingli, Hao, & Hui, 2008; Qiu & Huang, 2007; Quariguasi Frota Neto, Walther, Bloemhof, Van Nunen, & Spengler, 2009; Rangwani, Subramanian, Ramkumar, & Narendran, 2011; Ravi, Shankar, & Tiwari, 2008; Rouf & Zhang, 2011; Roy, Maity, & Maiti, 2009; Rubio & Corominas, 2008; Saen, 2011; Sahyouni, Savaskan, & Daskin, 2007; Salema, Barbosa-Povoa, & Novais, 2007; Salema, Barbosa-Povoa, & Novais, 2010; Salema, Póvoa, & Novais, 2009; Sarkis, Zhu, & Lai, 2011; Schulz, 2011; Schweiger & Sahamie, 2013; Serrato, Ryan, & Gaytan, 2007; Seuring & Müller, 2007; Seuring & Müller, 2008a; Shi, Fan, Gao, & Zhang, 2009; Shi, Zhang, & Sha, 2011a; Shi, Zhang, & Sha, 2011b; Shi, Zhang, Sha, & Amin, 2010; Silva Filho, 2013; Soleimani, Seyyed-Esfahani, & Kannan, 2013; Soleimani, Seyyed-Esfahani, & Shirazi, 2013a; Soleimani, Seyyed-Esfahani, & Shirazi, 2013b; Srivastava, 2008b; Subramanian, Ramkumar, & Narendran, 2010; Tagaras & Zikopoulos, 2008; Tang, Liu, Fung, & Luo, 2008; Teunter & Flapper, 2011; Teunter, Kaparis, & Tang, 2008; Toktay & Wei, 2011; Topcu, Benneyan, & Cullinane, 2013; Toyasaki, Boyacı, & Verter, 2011; Vadde, Kamarthi, & Gupta, 2007; Van Wassenhove & Zikopoulos, 2010; Vidovic, Dimitrijevic, Ratkovic, & Simic, 2011; Vishwa, Chan, Mishra, & Kumar, 2010; Vlachos, Georgiadis, & Iakovou, 2007; Wang, Zhao, & Wang, 2011; Webster and Wei, 2013; Wei & Zhao, 2011; Wikner & Tang, 2008; Wilcox, Horvath, Griffis, & Autry, 2011; Winkler, 2011; Xanthopoulos & Iakovou, 2009; Xiao, Shi, & Yang, 2010; Yang, Min, & Zhou, 2009; Yang, Wang, & Li, 2009; Yang, Wee, Chung, & Ho, 2010; Yingfei, Shuxia, Xiaojing, & Fang, 2011; Yuan & Gao, 2010; Zarandi, Sisakht, & Davari, 2011; Zarei, Mansour, Husseinzadeh Kashan, & Karimi, 2010; Zhang, Huang, & He, 2011; Zhang & Jin, 2011; Zhou & Min, 2011; Zhou & Wang, 2008; Zhu & Xiuquan, 2013; Zikopoulos & Tagaras, 2007; Zikopoulos & Tagaras, 2008; Zuidwijk & Krikke, 2008; Özceylan & Paksoy, 2013a; Özceylan & Paksoy, 2013b; Üster, Easwaran, Akçali, & Çetinkaya, 2007; Mitra, 2007) Besides, the journals with more than five publications are illustrated in Fig. 3. This also clarifies the vast area of review in this study. Among the journals, three were clearly more active than the others in RL/CLSC: the International Journal of Production Economics (41 papers in various subjects), International Journal of Production Research (38 papers), and European Journal of Operational Research (21 papers, which are mostly quantitative and analytical research using various state-of-the-art methodologies).

3.3. Category selection

The structural dimensions of this study and major topics of analysis including detail classifications are categorized in Table 3. These are based on analyses of different aspects of reviewed papers and attempts to find appropriate categorization of all papers. We implemented two criteria during our categorization:

1. Each category should contain a huge class of papers, which means that the category at least should cover 50 percent of all papers.
2. The category should be capable of being subdivided into sufficient subcategories. For example, when we discuss about "uncertainty", exactly 62 percent of all papers are covered in this classification which means that the mentioned classification includes a sufficient number of papers. Besides, this category covers many subclasses such as fuzzy, normal stochastic, robust, two-stage stochastic, interval, deterministic, and combinations of these. On the other hand, we had to present a fair categorization in which papers can highlight their contributions. For example, in surveys, we discuss all the papers and we present the contribution for all of them.

Table 3 illustrates the main dimensions of the study and the major topics of analysis. This study considers four main classes of research. Classes 1 and 2 cover papers from all topics in reverse logistics (main class 1), and in closed-loop supply chain (main class 2). Due to the growing importance of sustainability (Gupta & Palsule-Desai, 2011) and green supply chain (Srivastava, 2007), we include papers that study various aspects of sustainability (main class 3) and green issues (main class 4) with sufficient consideration in RL/CLSC. The main fields are descriptively illustrated in Fig. 4, which presents the number of papers in each of the identified main classifications. The detailed presentation of all publications in these four categories is explained in Appendix 2.

The other classifications of Table 3 fall in four categories:

(1) A paper can be a review or survey study or may deal with different types of quantitative/qualitative analyses.
(2) A paper can regard any type of uncertainty for parameters (stochastic, fuzzy, interval, chaos, and scenario approaches), or just include deterministic assumptions.
(3) The modeling (if applicable) can be constructed conceptually or mathematically. There are also different solution methodologies like analytical, exact solvers,[2] approximation, heuristic, meta-heuristic, and other approaches.
(4) A paper can be constructed based on a case study, it can experiment with a case study in its numerical analyses, or it can regard no real case during the study.

Generally, there are three types of decision variables: strategic decision variables (locations, capacities, etc.), tactical decision variables (allocations, planning, etc.), and operational decision variables (lot sizing, inventory, etc.) (Chopra & Meindl, 2010). Finally, in terms of period, product, and objective function (if applicable), a paper can be single-type or multiple-type. As mentioned, these categorizations are based on analysis of the characteristics/content of the selected papers. The detailed clarification of each column is provided in the related section.

It should be pointed out that these classifications are the main categories, and the details of the dimensions of the review study are comprehensively discussed and analyzed in the following sections.

3.4. Material evaluation

Rigor in validity is achieved by validation tests performed by two researchers using the deductive and inductive approaches simultaneously. Besides, using spreadsheet software is helpful in proceeding/minimizing error, and evaluating different aspects of analyses. The materials are crosschecked with other databases to ensure enrichment of the study. Indeed, in this review paper, there are some efforts to ensure whether or not the publications are sufficient and appropriate. Therefore, we design some mechanisms in checking this issue. For example, the material (means collected papers and the search engines) are checked with SCOPUS and WOS to add a few missing papers (fewer than 10 papers). Besides, two researchers investigate the sufficiency of the collected papers through searching and crosschecking publications independently.

4. Detailed analyses of the literature

The selected papers of this literature review are discussed and analyzed in this section to construct a holistic view of the recent and state-of-the-art studies in reverse logistics and closed-loop supply chain. The results can clarify the current gaps and future directions for research.

4.1. Problem classifications

There are various types of study subjects in RL and CLSC. Although the authors undertake research in different areas with special aims, the papers can be classified as follows:

[2] By the term "exact solvers", we mean the researches that utilized general exact solvers such as Lingo, GAMS, and CPLEX.

Table 3
The main classifications of the study.

Main classes	Field of research	Problem type	Regarding uncertainty	Modeling approach	Solution method	Data/case Study	Decision variables	Period	Product	Objective function
Main class 1	RL	Quant. study	Det.	Conc.	Anal. or exact	Case study	Strat.	Single period	Single product	Single obj.
Main class 2	CLSC	Qual. study	Non-det.	Math.	Appr. & heuristic	Case exp.	Tact.	Multi-period	Multiple product	Multi-obj.
Main class 3	Sustainable	Review	NA	NA	Meta-heuristic	Theo.	Oper.	NA	NA	NA
Main class 4	Green	Survey	–	–	Other appr.	NA	NA	–	–	–

Abbreviations: Quant.: Quantitative, Qual.: Qualitative, Det.: Deterministic, NA: Not applicable, Conc.: Conceptual, Math.: Mathematical, Anal.: Analytical, Appr.: Approximation, appr.: approaches, exp.: experiment, Theo.: Theoretical, Strat.: Strategic, Tact.: Tactical, Oper.: Operational, obj.: objective.

- ***Designing and planning.*** The main subjects of research are assigned to RL and CLSC network designing and planning. The aim of designing is to determine strategic (long-term) decision variables like locations and the capacity of all facilities. In the planning stage, the most important decision variables are the quantities of flows between supply-chain network entities known as mid-term decision variables (discussed in detail later). Some studies regard designing and planning stages simultaneously, and some concentrate on one of them in depth. Besides, some studies just concentrate on designing decisions, which are presented in the category of "***designing***" (row 13 in Appendix 3).
- ***Survey.*** Vast areas of papers try to find practical solutions to scientific questions in an interactive study with practitioners through questionnaires/interviews. These papers provide valuable results for both academia and practitioners in various aspects of RL and CLSC.
- ***Price and coordination.*** Important discussions between two entities of a supply chain network (for instance, a remanufacturer and a retailer of second market) determine the price of products and coordinate win–win strategies to balance profit margins. Usually, in such problems, optimum price and coordination strategies are determined.
- ***Different studies.*** There are different kinds of valuable studies in special categories, which try to elevate scientific research. Some subjects of these studies are: study on business perspectives of RL and CLSC (Atasu, Guide, & Wassenhove, 2008; Guide, Gunes, Souza, & Van Wassenhove, 2008; Guide & Van Wassenhove, 2009; Hsu, Alexander, & Zhu, 2009; Sharma, Iyer, Mehrotra, & Krishnan, 2010), study on the role of Radio Frequency Identification (RFID) in RL and CLSC (Jayaraman, Ross, & Agarwal, 2008; Visich, Li, & Khumawala, 2007), study on redefining the value chain strategy of CLSC (Jayaraman, 2007), study on eco-design methods focused on 'end-of-life' strategies (Pigosso, Zanette, Ometto, & Rozenfeld, 2010) and eco-industrial development (Fang et al., 2007), study on the potential for cannibalization and auction design (Guide & Li, 2010), (to be discussed later).
- ***Production planning and inventory management.*** Some researches in supply chain networks are related to operational decision variables, which play a vital role in supply chain cost efficiencies. Scheduling of products and return products (manufacturing and remanufacturing) simultaneously, and inventory control policies of such production systems are main subjects of these studies. There are some studies that concentrate on production planning and lot sizing decisions without regarding inventory issues. Such studies are categorized in a different class as "***production planning***" (row five in Appendix 3). Conversely, there are some studies which concentrate on the inventory management issues such as finding reorder point, base stock, and economic order quantity without regarding production planning subjects. These studies arranged in the category of "***inventory management***" (row ten in Appendix 3). Finally, in some cases, planning decision variables and operational decision variables are considered in an integrated research called "***hybrid planning***" here (row 15 in Appendix 3).
- ***Planning.*** As mentioned, there are three types of decision levels in supply chain management issues, which are considered by the authors together or individually. Some research studies the planning level decisions such as quantity of flows between network entities without regarding any strategic or operational decisions. In this paper, such publications are assigned to the category of "***planning***".
- ***Conceptual and analytical framework.***These studies analyze some theoretical or practical factors to find a framework for different aspects of RL/CLSC. For instance, Barker and Zabinsky (2008) classified a total of 37 case studies to find a framework and to analyze if the same considerations were valid. Wikner and Tang (2008) developed a conceptual framework for the concept of the customer order decoupling point. Setaputra and Mukhopadhyay (2010) attempted to develop a research framework in reverse logistics by dividing it into six research categories.
- ***Review and partial review.*** These types of research try to review/partial review concentrating on RL and CLSC. For instance, some partial review papers can be added to previously discussed review papers. Melo, Nickel, and Saldanha-Da-Gama (2009) reviewed applications of facility location models to supply chain network design. Rubio, Chamorro, and Miranda (2008) reviewed reverse logistics publications in the field of production and operations management. Chan et al. (2010) reviewed the impacts of Just In Time (JIT) to reverse logistics systems. Ke, Zhang, Liu, and Li (2011) reviewed the subject of remanufacturing engineering.
- ***Different analysis.*** This category is dedicated to different kinds of quantitative and qualitative analyses in various subjects like analysis of long-term behavior of CLSC (Georgiadis & Besiou, 2008), analysis of development of carpet industries (Biehl, Prater, & Realff, 2007), analysis of transportation modes and costs (Kara, Rugrungruang, & Kaebernick, 2007), analysis of three variables influencing reverse logistics (Shankar, Ravi, & Tiwari, 2008), performance evaluation analyses to optimize supply chain operations considering end-of-life operations (Komoto, Tomiyama, Silvester, & Brezet, 2011), and bullwhip measuring (Chatfield & Pritchard 2013; Das & Dutta 2013; Pati, Vrat, & Kumar, 2010), (to be discussed later).

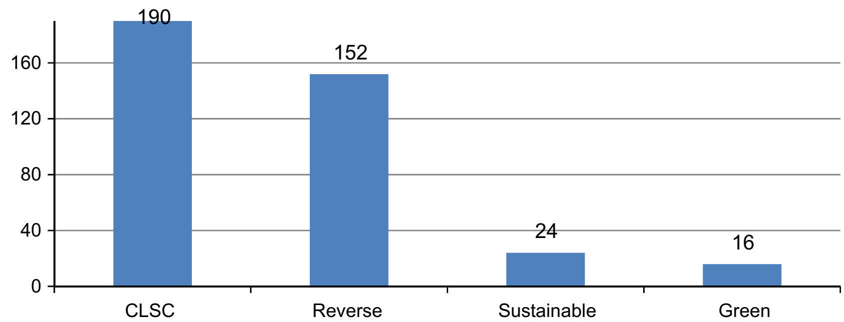

Fig. 4. The main fields of the papers in the study (382 papers: 2007–2013) (see Appendix 2 for detail).

- ***Decision making and performance evaluation.*** One of the important research categories in RL/CLSC is studying performance evaluation of various networks, recovery strategies, etc. These researches are completely studied in this category.
- ***3PRLP selection.*** Third Party Reverse Logistic Provider (3PRLP) selection is another important subject, which can improve the quality of products directly and it can have noticeable impacts on the product cost price.
- ***Vehicle routing problem.*** As distribution systems and the related strategies are one of the most effective parts of the network and the total costs are closely dependant to the transportation costs, Vehicle Routing Problem (VRP) is an effective issue in RL and CLSC. There are some studies which directly consider this problem mostly in proposing efficient algorithms.

The general categorizations of different studies are analyzed and a portion of each is illustrated in Fig. 5 showing the percentage (*X*-axis) of various categorization portions from all papers. The papers are classified in Appendix 3, which aims to precisely assign the papers in different subjects of research in RL/CLSC.

Appendix 3 presents various studies in each identified category. As stated, designing and planning research are the most popular research topics. Survey studies are other important subjects, which can lead to valuable theoretical points through practical research. The other vital and influential area of research is price and coordination studies, which generally contain complicated mathematical and analytical approaches.

An overview of the different surveys is necessary to identify the various subjects in this research area in RL/CLSC. In order to organize the various papers in this category, the publications are discussed in the four main classifications: RL, CLSC, green, and sustainability.

4.1.1. Surveys in reverse logistics

Srivastava (2008a) conducted informal interviews with 84 stakeholders in a reverse logistics study, which included excellent statistics of different industries. The interviews are used to develop a conceptual model for simultaneous location–allocation of facilities for a cost effective and efficient RL network Kocabasoglu, Prahinski, and Klassen (2007) used a survey of plant managers to empirically assess linkages between supply chain investments, organizational risk propensity (willingness to take risks), and business uncertainty. Seitz (2007) took a case-study approach with more than 130 interviews conducted across the RL of five European vehicle manufacturers. Li and Olorunniwo (2008) reported a case study that focuses on key strategic issues that a firm may need to consider to be excellent in its RL efforts. Álvarez-Gil, Berrone, Husillos, and Lado (2007) was a survey, which proved that the probability of firms implanting RL systems depends on stakeholder salience, availability of resources of the firm, and a progressive strategic posture of the manager. Verstrepen, Cruijssen, de Brito, and Dullaert (2007) was a survey of shippers and logistics service providers in Flanders which is one of the leading logistics regions in Europe. This paper empirically investigates reverse logistics in Flanders, reporting the results of a cross-sector survey of 250 Flemish logistics service providers and shippers with a response rate of 22.5%. Lau and Wang (2009) was a survey in the electronic industry of China. The cases selected in this study include four major companies and they discussed important issues such as driving forces of reverse logistics, barriers to reverse logistics, and improvements measures for reverse logistics implementation in China. Janse, Schuur, and de Brito (2010) performed some interviews with PricewaterhouseCoopers (PwC) consultants on performance improvement. They summarized barriers and facilitators in managing RL in the consumer electronics sector and provided a diagnostic tool to assess a consumer electronics company's RL practices and to identify the potential for RL improvement from a business perspective. Field and Sroufe (2007) interviewed the top chart of a selected case (Paper Co) identifying and explaining relationships between key constructs through application of qualitative data collection and analysis, and development of testable propositions as an early foundation for later empirical work in environmental management and reverse supply chain systems. Dowlatshahi (2010) studied critical cost-benefit sub-factors needed to develop effective RL operations. They investigated ways in which a firm should use these sub-factors and insights gained for managing and implementing the reverse flow of parts/products. Geyer and Blass (2010) presented detailed economic data on cell phone collection, reuse, and recycling. The results proved that many mobile phones are not disposed of properly (through reuse or recycling) but are instead stockpiled. Reuse and recycling operations in 2003 in the UK and in 2006 in the US show that while cell phone reuse has a healthy profit margin, handset recycling is currently a by-product of reuse. Zoeteman, Krikke, and Venselaar (2010) studied interviews with managers of companies to analyze gaps between policy objectives and the actual global WEEE-flows and the scale of OEMs operations and government enforcement (global/regional) through case studies and surveys of successful business applications in recovery. Rahman and Subramanian (2012) surveyed eight factors: legislation, customers, strategic cost, environmental concerns, volume and quality, incentives, resources, and integration and coordination. The results presented factors such as government legislation, incentives, and customer demand as the major drivers. Erol et al. (2010) surveyed the current state of reverse supply chain management (RSCM) initiatives in several Turkish industries. They considered Turkish automotive, white goods, electric/electronics, and furniture industries. Bernon, Rossi, and Cullen (2011) was a survey using grounded theory approach aimed at providing a conceptual framework to manage retail reverse logistics. Kapetanopoulou and Tagaras (2011) studied drivers and obstacles

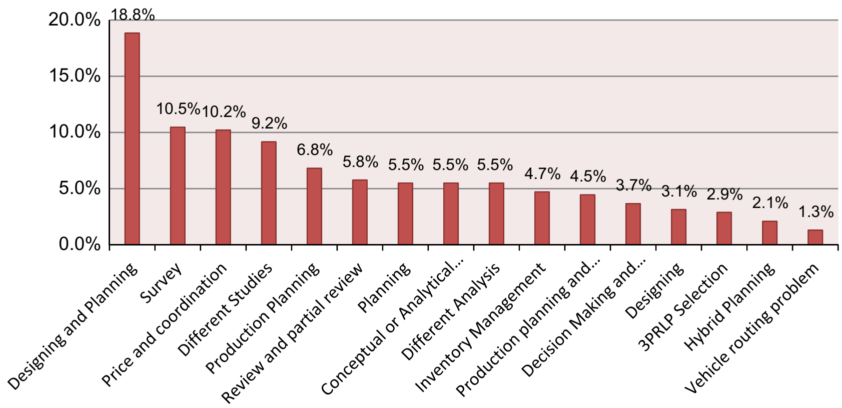

Fig. 5. The main problems of the research areas.

of product recovery activities using nonparametric χ^2 tests for homogeneity, Mann–Whitney *U*-tests and Friedman two-way ANOVA. Kapetanopoulou and Tagaras (2009) studied value recovery processes regarding 12 cases. The findings of the research included measurements of important quantifiable parameters of refurbishing and remanufacturing, such as the actual costs and prices expressed as fractions of the respective values for new products. Abraham (2011) surveyed strategic and operational factors of reverse logistics in apparel aftermarket in India in order to explore the benefits of collaboration and entrepreneurship. Quariguasi Frota Neto and Van Wassenhove (2013) studied take-back initiatives through 36 manufacturers (21 local and 15 international) in the market of personal computers in Brazil. Krikke, Hofenk, and Wang (2013) studied current return practices and contributed to our knowledge by developing and testing propositions on the drivers, volumes, and value of different returns along the life cycle, showing inefficiencies in current return practices that lead to value destruction, and comparing return practices in different regions and industries. They complemented and updated empirical data, as some references are over 10 years old and give handles to convert value destruction into value creation. Lai, Wu, and Wong (2013) was a survey on six broad aspects of practicing RL: Waste management, recycling, reuse, reprocessing, materials recovery, and design for RL. Ye, Zhao, Prahinski, and Li (2013) surveyed 209 manufacturers of the Pearl River Delta (PRD) in China. Their study investigates the effects of three institutional pressures on top managers' posture toward reverse logistics implementation: government, customer, and competitor pressures. The results reveal that in China institutional pressures have a statistically significant positive influence on top managers' posture toward reverse logistics implementation.

4.1.2. Surveys in closed-loop supply chain

Mollenkopf, Russo, and Frankel (2007) was a survey of containing four questions to analyze buyer behavior issues. They mentioned that most researchers examined distribution implications of product stock-outs rather than buyer behavior issues. Talbot, Lefebvre, and Lefebvre (2007) was a survey of 205 environmentally responsive small and medium enterprises (SMEs) operating in the fabricated metal products and electric/electronic products industries. Grant and Banomyong (2010) surveyed product recovery management (PRM) activities affected by strategic design and implementation of a closed-loop supply chain for fast-moving consumer goods through a case of a single-use camera. Martin, Guide, and Craighead (2010) investigated potential drivers of remake versus buy decisions for OEMs engaged in remanufacturing such as HP, Bosch, Black and Decker, GE, Xerox, Pitney-Bowes. The results suggest that specificity of operational assets, IP concerns, and frequency are primary drivers of in-house remanufacturing. Conversely, they could not find support for brand reputation, technological uncertainty, condition uncertainty, volume uncertainty, and product complexity as drivers of in-house remanufacturing. Sundin, Östlin, Rönnbäck, Lindahl, and Sandström (2008) through a survey, explained how three different remanufacturing companies manage to operate their remanufacturing of products used in product service systems (PSS) offerings. Olorunniwo and Li (2010) studied the impact of information sharing and collaboration on RL. They received 57 answered questionnaires and 38 undeliverable ones with the return rate being around 10 percent. In the survey of Subramoniam, Huisingh, and Chinnam (2010), the respondents were business unit managers/chief engineers from 18 companies in the United States and Europe. The authors believe that the framework in its current form provides valuable guidance for OEM suppliers to make strategic decisions for remanufactured products. These remanufacturing strategic decisions with a thorough consideration of carefully selected factors will help OEM companies to launch remanufactured products effectively and efficiently. Matsumoto and Umeda (2011) applied a survey to Japanese companies' motives and incentives (photocopiers, single-use cameras, auto parts, and ink and toner cartridges for printers) for remanufacturing. The interviews were conducted with 11 remanufacturers (four original equipment manufacturers and seven independent remanufacturers) in order to clarify their differences. Ramanathan (2011) surveyed the relationships between the performance of companies in handling product returns and customer loyalty affected by products risk characteristics.

4.1.3. Surveys in green

Zhu, Sarkis, and Lai (2008) surveyed power generating, chemical/petroleum, electrical/electronic, and automobile industries. Their findings provide insights into the capabilities of Chinese organizations on the adoption of Green Supply Chain Management (GSCM) practices in different industrial contexts and that these practices are not considered equitably across the four industries.

Zhu, Sarkis, Cordeiro, and Lai (2008) could manage to receive, test, and use in their study a total of 314 usable responses in Chinese manufacturing organizations. They found significant positive relationships between organizational learning mechanisms, organizational support, and the adoption of GSCM practices, after controlling for a number of other influences including regulations, marketing, supplier, cost pressures, industry levels of the relevant practice, and organizational size. Lu, Wu, and Kuo (2007), through a survey, presented an efficient Green Supply Chain (GSC) approach to enable managers to evaluate various projects and establish an environmentally benign product design. Bernon and Cullen (2007) was a survey to identify scale of returns in the UK retail sector, to explore and identify current management approaches related to RL, and to develop a suggested framework for managing returns. Thun and Müller (2010) was a survey of the empirical study of German companies from the automotive industry, i.e. original equipment manufacturers (OEMs) or automotive suppliers. Olugu, Wong, and Shaharoun (2011) surveyed 10 measures with 49 metrics and six measures with 23 metrics identified and developed for the forward and backward chains. Eltayeb, Zailani, and Ramayah (2011) constructed a structured questionnaire derived from literature employing a mail survey to collect responses from a group of 569 ISO 14001 certified firms in Malaysia with the response rate of 24%. They have explored that taking back products and packaging, business organizations can generate benefits to the environment, in the form of reduced waste and better resource utilization, in addition to economic benefits and cost reductions to the organizations.

4.1.4. Surveys in sustainability

Pagell and Wu (2009) was an interview-based survey to locate a common theme based on distribution of practices identified earlier in managerial literature. They used 10 case studies of exemplar firms to build a coherent and testable model of the elements necessary to create a sustainable supply chain. The analysis suggests that the practices that lead to a more sustainable supply chain are equal parts best practices in traditional supply chain management and new behaviors, some of which run counter to existing accepted "best" practice. Seuring and Müller (2008b) developed a Delphi study to address the question of which major issues/problems experts report regarding sustainable supply chain management. It also aims at identifying which specific issues should be addressed in sustainable supply chain management.

Studies in various subjects can extend research into areas called "**different studies**". This category contains conceptual and qualitative analyses in various subjects such conceptual modeling, study the relationships between network factors, value chain, product lifecycle management (PLM), sustainability issues, study on capabilities for product recovery, etc. Details of these studies are presented in the main classifications as follows:

4.1.5. Different studies in reverse logistics

Kumar and Putnam (2008) studied closing the loop of the supply chain. The objective of their paper was to identify the primary forces for three industry sectors (automotive, consumer appliances, and electronic) to close the supply chain loop in the product lifecycle. Jayaraman (2007) studied redefining the value chain strategy of CLSC. He mentioned that a redefined value chain should be part of the overall business strategy for manufacturers or retailers who handle product returns. Kumar and Craig (2007) studied Dell's closed-loop supply chain. They also considered SWOT (strengths, weaknesses, opportunities, and threats) analysis of Dell's company. Pagell, Wu, and Murthy (2007) studied four generic recycling options and their implications. The options include recycling with or without disassembly in combination with outsourcing recycling or active participation in recycling processes. The article presents and discusses the various recycling options available to managers, as well as the strategic implications of each of these choices. Jun, Kiritsis, and Xirouchakis (2007) studied product lifecycle management. They categorized and analyzed the product lifecycle through three main phases: Beginning of life (BOL), including design and production; middle of life (MOL), including logistics (distribution), use, service, and maintenance; and end of life (EOL), including reverse logistics (collecting), remanufacturing (disassembly, refurbishment, reassembly, etc.), reuse, recycling, and disposal. Subramoniam, Huisingh, and Chinnam (2009) studied strategic planning factors for automotive aftermarket remanufacturing through a review of the available literature in the fields of remanufacturing and reverse logistics. They presented some interesting propositions tested through a case study. Jayaraman et al. (2008) studied effects of RFID in reverse channel activities while analyzing two major consumer electronics companies. The paper tried to identify the reverse logistics supply-chain channels and the problems that companies face when they handle product returns along these channels. Then, they presented the critical role that information technology and collaboration can play to mitigate many of the problems and deficiencies. Wu and Cheng (2007) studied key factors of reverse logistics. It was an attempt to explore the key factors of reverse logistics of Chinese book publishing and the preferred solutions to current problems. Hsu et al. (2009) studied the business activities of distribution centers. They evaluated the business process of RL by studying business activities of distribution centers. They tried to develop a practical model that examines interactions and information exchanges between various components of the reverse logistics process. Rubio, Miranda, Chamorro, and Valero (2009) studied (case) implementability of RL and proposed a new packaging system that recovered through a reverse logistics system generating economic and environmental advantages. González-Torre, Alvarez, Sarkis, and Adenso-Díaz (2010) studied barriers of Environmentally Oriented Reverse Logistics Practices (EORLP) focusing on the Spanish automotive sector. They tried to classify and evaluate barriers to EORLP. They also studied whether internal or external barriers constitute a greater impediment for organizations seeking to implement EORLP. Simpson (2010) studied recycling of low value and often-complex waste materials. The study investigated practices used by manufacturing firms to recycle their more heterogeneous secondary materials that arise through the RL channel and waste management practices (such as identification during production and subsequent segregation for removal or re-management). Miemczyk (2008) studied capabilities for product recovery. His research offered three main conclusions, which can be considered for both theory and practice within the domain of EOL product recovery. First was the identification of important capabilities for product recovery within an institutional context, which can be further categorized into "process specific" and "managing institutional environments", but these are interdependent. Second, it is achieved that normative pressure such as those presented by industry groups (e.g. trade associations) also influence the processes adopted. Finally, institutional forces represent not just pressures to carry out certain actions but also constraints on existing processes and systems (but perhaps opportunities for first movers). Hans, Hribernik, and Thoben (2010) studied product life cycle management. They introduced the concept of item-level PLM and investigated the requirements that item-level PLM systems must fulfill in order to support sustainability in reverse logistics processes in an appropriate manner. Halabi, Montoya-Torres, Pirachicán, and Mejía (2013) studied the negative impact on the environment. The paper is a research approach of RL practices in Colombian enterprises, with a particular focus on the plastic sector. Besides, some conceptual models were presented for the companies under study. Results of that study were discussed and some suggestions to decrease a negative impact on the environment are presented. Liu, Liu, Xing, Mei, and Zhang (2013) studied a tolerance grading allocation method. They presented a method of tolerance grading allocation for remanufactured parts based on uncertainty analysis of the remanufacturing assembly. Marwede, Berger, Schlummer, Mäurer, and Reller (2013) studied recycling of thin film chalcogenide photovoltaic. They developed feasible recycling paths for chalcogenide photovoltaic modules. The paths are derived from a review of proven recycling processes through analyzing the available literature and interviewing key experts in this field.

4.1.6. Different studies in closed-loop supply chain

Guide and Van Wassenhove (2009) studied strong business perspectives of CLSC. They observed complexities inherent in closing the loop for a supply chain. Atasu et al. (2008) studied the business economics of product reuse through an analytic research on the business economics of product reuse. However, it could be a critical review of analytic models in a closed-loop supply chain research. Östlin, Sundin, and Björkman (2008) studied seven different types of closed-loop relationships to gather cores. The aim of their research was to identify the kinds of relationships that exist between remanufacturers and customers/suppliers of cores, and how these relationships can be managed. Furthermore, they explored how the customer/supplier relationship perspective can support product take-back for remanufacturing with focus on the supply of cores. Visich et al. (2007) studied the effects of RFID in CLSC. They attempted enhancing value recovery with RFID and to implement an RFID enabled closed-loop system. De La Fuente, Ros, and Cardos (2008) studied re-thinking of the relationship among chain members. They proposed an integrated supply chain model regarding modeling constraints that included the strategic and operational alignments, system interoperability, information sharing and coordination of activities. The presented integrated model was validated in a company from the metal-mechanic sector. Kumar and Craig (2007) studied Dell's closed-loop supply chain. They also considered SWOT (strengths, weaknesses, opportunities, and threats) analysis of Dell's company. Pagell et al. (2007) studied four generic recycling options and their implications. Jun et al. (2007) studied product lifecycle management. They categorized and analyzed the product lifecycle through three main phases: Beginning of life (BOL), including design and production; middle of life (MOL), including logistics (distribution), use, service, and maintenance; and end of life (EOL), including reverse logistics (collecting), remanufacturing (disassembly, refurbishment, reassembly, etc.), reuse, recycling, and disposal. Quariguasi Frota Neto, Walther, Bloemhof-Ruwaard, Van Nunen, and Spengler (2007) studied environmental impact based on WEEE. They analyzed five items covered by the European Directive on WEEE, namely a TV set, a personal laptop, a refrigerator, a mobile phone, and a washing machine. They searched for "win–win" situations due to the adoption of traditional CLSC models, and tried to show one example of how to extend a CLSC formulation toward becoming a sustainable network. Pigosso et al. (2010) studied eco-design methods focused on 'end-of-life' strategies. Actually, it was an overview of eco-design methods through a proactive approach of environmental management, aimed to reduce total environmental impact of products. Guide and Li (2010) studied the potential for cannibalization and auction design. They used a novel research strategy by auctioning products donated by Robert Bosch Tools, NA, and Cisco Systems, Inc. to determine differences between consumers' willingness to pay (WTP) for new and remanufactured products and to help assess the extent of cannibalization of new product sales by remanufactured products. Kiritsis (2011) studied intelligent products and product data technologies. He introduced a new definition of the notion of an intelligent product inspired by what happens in nature with us as human beings and the way we develop intelligence and knowledge. Atasu and Boyaci (2010) studied the impact of legislation on CLSC. The aim of their article was to provide an overview of existing take-back legislation and its impact on closed-loop supply chains, determining the pressing research issues, and illustrating how operations research (OR), and management science (MS) methods and tools can be applied to examine these research issues. They provided their perspective on the effects of such legislation. Kiritsis, Nguyen, and Stark (2008) studied improving knowledge management. First, they introduced closed-loop PLM and then highlighted the benefits of optimized knowledge flow and use in BOL, MOL, and EOL.

4.1.7. Different studies in sustainability

Linton, Klassen, and Jayaraman (2007) studied current trends in sustainability. They provided a background to better understand current trends in this multidisciplinary field that intersect with operations management, and the research opportunities and challenges it presents. Beamon (2008) studied typical issues captured in sustainability. She took a wide perspective in her paper and discussed a range of issues typically captured in sustainability debates. de Brito and van der Laan (2010) studied opportunities and research agendas to integrate sustainability. They mentioned lack of holistic integration of sustainability with SCM. Badurdeen et al. (2009) studied new definitions for sustainable supply chain management (SSCM) based on total life-cycle. They extended the approach of 3R (reduce, reuse, and recycle) to 6R (adding recover, redesign, and remanufacture). Sharma et al. (2010) studied three major business strategies: The reduction of surplus supply of products, reduction of reverse supply, and internal marketing. Sarkis, Helms, and Hervani (2010) studied economic and environmental aspects of sustainability. They mentioned the lack of research in the relationship of social responsibility and RL. Utilizing practical examples from industry link reverse logistics practices with sustainability indicators, they tried to build a theory of reverse logistics for social responsibility.

Production planning is another huge research area, which tries to integrate manufacturing and remanufacturing planning. Some papers just assign planning of RL/CLSC and try to concentrate on tactical decision-making procedures. There are review and partial review papers, and they are discussed in the literature review section.

In the conceptual or analytical framework category, researchers try to establish a framework in various areas of RL/CLSC. Lambert, Riopel, and Abdul-Kader (2011) studied new research arising in the practical working environment. They proposed a decision conceptual framework including generic process mapping, decisions, economic aspects, and performance measures with a distinction in regard to strategic, tactical, and operational levels. Ordoobadi (2009) studied decision-making regarding outsourcing. Their proposed model had four phases: strategic, significance, economic, and decision. The model starts with a strategic analysis and either proceeds to the next phase or ends depending on the result of the analysis. If strategic analysis determines that activity is a core competency, then no further analysis is required, and that activity is performed in-house. Otherwise, the model proceeds to the second and third phases, namely significance and economic analysis. The results of the significance and economic analysis phases are then combined to determine a final course of action. Gobbi (2011) studied product residual value (PRV). This study provided a simple framework for designing the reverse chain on the basis of the evaluation of the PRV, depending on a series of factors exogenous to the reverse chain. They suggested that first-class recovery options (i.e. repair, refurbishment, remanufacturing) must be considered for returned products with high residual value and second-class recovery options (i.e. recycling and incineration) must be considered for returned products with low or no residual value. Morana and Seuring (2007) studied classification of products for EOL acquisition. Their proposed classification allows insight into what conditions are needed to apply for successful product acquisition. Defee, Esper, and Mollenkopf (2009) developed a conceptual framework incorporating reverse flows as a central element of corporate supply chain strategy, suggesting that closed-loop supply chains present an opportunity for competitive differentiation. Halldórsson, Kotzab, and Skjøtt-Larsen (2009) studied different strategies of sustainability focusing on integration. Marsillac (2008) studied relationships between green supply chains and the reverse logistics. Barker and Zabinsky (2008) studied classifying strategies based on various case studies of the literature and their research's case studies. They analyzed 13 case studies and abstracted key considerations common among all case studies. These considerations led to one of eight possible configurations. Then they classified an additional 24 case studies in the literature (De Brito et al., 2005), for a total of 37 case studies, to see if the same considerations were valid. Finally, they developed three new case studies, which represented three configurations within their framework. Wikner and Tang (2008) developed a conceptual framework for the concept of Customer Order Decoupling Point (CODP). They extended the conventional CODP framework for forward flow supply chains to cover also reverse material flows. Ciliberti, Pontrandolfo, and Scozzi (2008) developed a taxonomy of logistics social responsibility (LSR) practices. De La Fuente, Ros, and Ortiz (2010) developed a new enterprise modeling methodology called ERE-GIO, which suggested a definition of two phases of engineering (reverse and forward) and the conditions supplied in analysis of both current processes and those whose introduction is intended. Morana and Seuring (2011) aimed to outline an analytical framework for CLSC management, placing it within the political or societal environment, while linking it to related supply chain partners and single actor activities. The major contribution of their paper was the three level framework linking the societal, chain, and actor levels. Setaputra and Mukhopadhyay (2010) attempted to develop a research framework in the area of RL dividing it into six research categories. Xu et al. (2009) proposed a framework and methodology to model three principle information loops in wireless technology-enabled CLSC for product information tracking. Millet (2011) studied the framework of reverse logistics channel structures and proposed alternative structures with less environmental impact and higher economic benefits. Solvang and Hakam (2010) studied critical success factors of a logistics network. Actually, three critical success factors are explored and discussed in the paper. Choudhary and Seth (2011) studied Green Supply Chain Management integration. Shi, Li, Yang, Li, and Choi (2012) studied information integration of RL and tried to develop a framework. Mukherjee and Mondal (2009) studied the relationships among key issues pertaining to management of the remanufacturing process of an Indian photocopier remanufacturer to extract some meaningful insights relevant to managerial decision-making. Hazen (2011) studied improving RL functions. Toyasaki, Wakolbinger, and Kettinger (2013) studied the role of information systems in product recovery management.

Different analyses should be demonstrated here. This special category is related to papers which analyzed a specific subject in RL/CLSC. They are more quantitative-based than the category of "different study". This category contains quantitative studies with mathematical or simulation analyses in different subjects such as study on relationships between reduce, reuse, and disposal in the Japanese car market, analysis of long-term behavior of CLSC, study on green manufacturing/remanufacturing design, analysis on development of carpet industries, analysis of transportation costs and mode, study on product collection network strategy, estimating the remaining life, analysis of environmental legislation, analysis of profitability of reverse logistic, analysis of 3 variables influencing RL, forecasting return, forecasting analyses, and bullwhip measuring. Kumar and Yamaoka (2007) analyzed the relationships between reduce, reuse, and disposal in the Japanese car market. Georgiadis and Besiou (2008) analyzed the long-term behavior of the CLSC. They presented the development of a system dynamic model for a single producer, single product closed-loop supply chain with recycling activities applied to a real-world application. It can be used to understand the long-term system behavior under various environmental issues that lead to "ecological motivation". They developed a model which can further be used as a methodological tool for the conduct of sensitivity analyses on issues such as the firms' compliance to regulatory measures and green consumerism. Chung and Wee (2008) analyzed green manufacturing/remanufacturing design. Biehl et al. (2007) analyzed the development of reverse logistics in carpet industries. Kara et al. (2007) analyzed transportation modes and costs. Hanafi, Kara, and Kaebernick (2008) analyzed product-collection network strategies. Mazhar, Kara, and Kaebernick (2007) analyzed estimating the remaining life of products. Georgiadis and Besiou (2010) analyzed environmental legislation effects. Tan and Kumar (2008) analyzed the profitability of RL. Shankar et al. (2008) analyzed three variables influencing RL (enablers, results, and inhibitors of RL). Hu and Bidanda (2009) analyzed a decision support system (DSS) on product lifecycle management. Komoto et al. (2011) introduced three indicators (costs, environmental impacts, and delivery performance) of performance evaluation of simulation results in CLSC. Carrasco-Gallego and Ponce-Cueto (2009) analyzed forecasting return. Pati et al. (2010), Das and Dutta (2013), and Chatfield and Pritchard (2013) analyzed bullwhip measuring and effects. Sloan (2007) analyzed decision making on choosing a new device or a reprocessed device. Hernández, Poler, Mula, and Lario (2011) analyzed and proposed a collaborative decision-making model. Chung, Okudan, and Wysk (2011) analyzed robust product modular structure through the life cycle.

Inventory management studies, by investigating optimal order quantities and other inventory related decisions regarding remanufacturing effects and return products, play a major role in the operational level of the supply chain. Some researchers concentrate on production planning and inventory control decisions simultaneously. This integration elevates the productivity of operational decisions in CLSC and in RL.

Another category is assigned to decision-making and performance evaluation studies, as illustrated in detail here. Pochampally, Gupta, and Govindan (2009) defined metrics for performance evaluation of a RL/CLSC. They also proposed a Quality Function Deployment (QFD) and Linear Physical Programming (LPP)-based mathematical model to measure the performance of a RL/CLSC. Gehin, Zwolinski, and Brissaud (2008) studied product design regarding EOL and developed tools to help product designers in the identification of appropriate EOL strategies in the early design phase. Wadhwa, Madaan, and Chan (2009) proposed a fuzzy-logic-based MCDM methodology to consider the knowledge of experts (evaluators or sortation specialists) in the selection of the most appropriate alternative(s) for product reprocessing with respect to existing criteria (they compared five criteria). Yoshida (2008) studying risk analysis and decision-making area, proposed a generalized model where uncertainty is expressed by fuzzy and interval numbers. Tuzkaya and Gülsün (2008) proposed an integrated Analytic Network Process (ANP)-fuzzy technique for the evaluation of potential collection center locations. Mondragon, Lalwani, and Mondragon (2011) discussed measures for CLSCs of both forward and backward directions for shorter life cycle products. Nukala and Gupta (2007) developed a fuzzy mathematical programming approach that utilizes Analytic Hierarchy Process (AHP), Taguchi loss functions, and fuzzy programming techniques to weigh suppliers qualitatively as well as determine order quantities under uncertainty. Schmidt and Schwegler (2008) studied fulfilling ecological or sustainability responsibility and eco-efficiency performance evaluation. Olugu and Wong (2012) developed an expert fuzzy rule-based system for CLSC performance evaluation in the automotive industry. Barker and Zabinsky (2011) developed eight configurations of RL network utilizing an AHP approach. Shevtshenko and Wang (2009) studied the development of robust intelligent decision support systems. Krikke (2010) studied decision making in recovery by comparing opportunistic short-term decision-making. Ji (2008) studied complaint management (CM) in CLSC.

Some researchers concentrate on the strategic stage of RL/CLSC by considering network design problems (location decision variables). There are studies, which regard the valuable problem of a third party reverse logistic provider selection and vehicle routing problems decisions. The final category, called "hybrid planning", focuses on the planning stage including more specific points. These are interesting papers in terms of integrating different stages of decision-making. Frota Neto, Bloemhof-Ruwaard, Van Nunen, and Van Heck (2008) considered planning and production problems. Su (2009) regarded planning and pricing problems. Tonanont, Yimsiri, Jitpitaklert, and Rogers (2008) studied planning and performance evaluation with Data Envelopment Analysis (DEA) data. Sasikumar and Haq (2011) considered planning and third party reverse logistics provider selection problems. Amaro and Barbosa-Póvoa (2008) and Kumar and Chan (2011) studied integration of planning and scheduling problems. Tsai and Hung (2009) worked on planning and purchasing quantity problems. Abdallah, Diabat, and Simchi-Levi (2012) researched planning, production planning, and inventory management problems simultaneously.

4.2. Considering uncertainties

In terms of quantitative and some qualitative analyses, researchers may consider the parameters of their study as deterministic, as their precise values are known, or regard some uncertainties of real situations compatible with current markets. Different approaches are utilized by the authors to cope with data uncertainties like various stochastic approaches (considering probability distributions, chance constraints, and two-stage stochastic approaches, known as recourse problems), fuzzy logic (considering fuzzy type one and type two approaches), interval programming approaches (regarding interval values for the uncertain parameters), chaos theory, and combination of the mentioned approaches. Besides this, scenario generation approaches can be exploited separately or through solving procedures of different nondeterministic approaches. The illustration of different approaches in deterministic and nondeterministic studies is presented in Fig. 6. Appendix 4 is constructed to review different papers on this subject.

The complementary point of nondeterministic approaches is analyzing different parameters chosen as nondeterministic. This consideration reveals the importance of different data in RL and CLSC networks. The details of this analysis are depicted in Fig. 7a.

As clarified in Fig. 7a, demands and return amounts are the most considerable nondeterministic parameters. In some cases, authors consider two or more nondeterministic parameters simultaneously. Other parameters regarded as nondeterministic can be different rates (Chatfield & Pritchard, 2013; Georgiadis & Athanasiou, 2010; Kawa & Golinska, 2010; Nativi & Lee, 2012; Shankar et al., 2008), delivery time (Pishvaee & Torabi, 2010), lead-time (Lieckens & Vandaele, 2007), transportation time (Krishnamurthy, Khorrami, & Schoenwald, 2008), waste generation (Fonseca, García-Sánchez, Ortega-Mier, & Saldanha-da-Gama, 2010), environmental issues (Wang & Hsu, 2010a; Wang & Hsu, 2010b), risk factors (Lundin, 2012), and different weights (Kannan, 2009; Nukala & Gupta, 2007; Pochampally & Gupta, 2008; Tuzkaya, Gülsün, & Önsel, 2011).

4.3. Analysis of modeling approaches

In terms of utilizing different approaches in modeling various problems of RL/CLSC, the integrity approach is used to construct general methods of modeling. Finally, based on various approaches of different studies, we divide the approaches into 13 categories: Conceptual and descriptive types of modeling (1), linear and mixed integer programming (MIP) (2), nonlinear programming methods (3), convex and concave programming (4), dynamic programming (5), queuing models (6), Markov decision process (7), graph theory (8), game theory (9), fuzzy logic (10), simulation modeling (11), multi-criteria decision making (MCDM) approaches (12), and other approaches (13) like artificial neural network (ANN) (Mazhar et al., 2007), piecewise interval programming (Zhang, Liu, & Tu, 2011), dynamic regression models (Carrasco-Gallego & Ponce-Cueto, 2009), statistical modeling (Pati et al., 2010), robust Bayesian belief networks with interval probabilities (Shevtshenko & Wang, 2009), engineering economics techniques (Krikke, 2010), combining input–output analysis and Laplace transforms (Bogataj & Grubbström, 2013), theory of production frontier (Lai et al., 2013), institutional theory (Ye et al., 2013), and novel neighborhood rough set approach (Bai & Sarkis, 2013).

It should be mentioned that such classifications can overlap each other, but attempts are made to find the aim of each paper in order to place it into a specific appropriate category. The references are arranged in different classifications in Appendix 5.

Interesting analyses of modeling approaches deal with the relations between problem classifications in RL/CLSC and modeling techniques. These connections give researchers some valuable points regarding finding major conventional approaches. Appendix 6 aims to depict these relations.

Reviewing results of Appendix 6, some interesting points of these important connections are seen. For instance, almost all pricing and coordination problems are set up by game theory approaches. Fuzzy logic is often utilized in decision-making problems, which usually consist of some weights in addition to designing and planning problems. Simulation techniques are also widely used in different problems. It should be mentioned that 43.5% of the correlated papers are regarded real data and 51.3% just generate appropriate instances. The others (5.2%) worked on the data of literature. Besides, based on Fig. 7b, exactly 30.5% of the correlated papers (81 out of 265 related papers) contain linear modeling and less than 7% (exactly 6.8%) deal with nonlinear programming. Further, based on Appendix 6, it can be distinguished that around 69.4% of the "design and planning" researches (50 out of 72) are founded by linear modeling. Therefore, we can roughly claim that the linear programming approach can be introduced as the dominating modeling approach for the design and planning problems of RL/CLSC.

4.4. Solution methodologies

Various approaches are used by researchers to solve mathematical problems in RL/CLSC. We have divided these solution methodologies into seven main categories. Some researchers try to solve problems with analytical or exact methods, which is complicated and limited in terms of solving large-scale problems. Some authors exploit general exact solvers like Lingo, GAMS, or CPLEX. Sample Average Approximation (SAA) techniques for solving stochastic optimization problems and other approximation methods are other types of solutions methodologies. For large-size problems, heuristic methods and meta-heuristic algorithms like Genetic Algorithm (GA), Simulated Annealing (SA), Tabu Search (TS), or Ant Colony (AC) are utilized by researchers. Simulation techniques and software are very powerful methodologies to consider uncertainties in real situations. Multi-criteria (or multi-objective) solution approaches like a goal programming approaches, AHP, ANP, and Technique for the Order of Prioritization by Similarity to Ideal Solution (TOPSIS) are used to solve appropriate problems. The frequencies of exploiting different solution methodologies are illustrated in Fig. 8. Appendix 7 presents the detailed analysis of papers in utilizing various types of solution methodologies.

An interesting analysis of solution techniques deals with relations between modeling techniques and solution methodologies. Definitely, there are reasonable interrelations between modeling approaches and appropriate solution techniques. Appendix 8 depicts these relations.

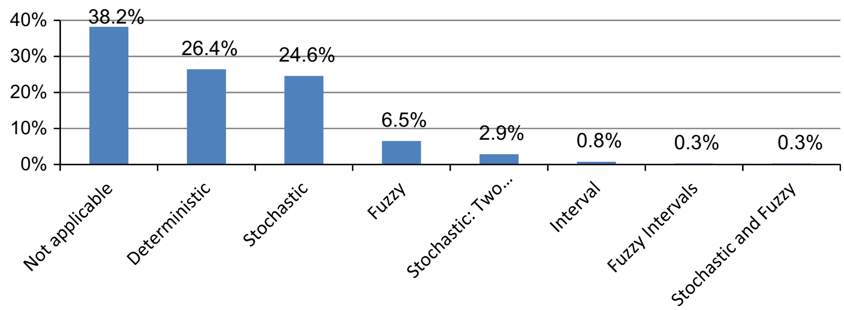

Fig. 6. Deterministic and nondeterministic approaches.

In Appendix 8, the number of papers in each cross-classifications cell are calculated and presented. Analyzing the results of Appendix 8 leads us to achieve valuable points of interrelations between modeling approaches and solution techniques. For instance, the main methods in game theory approaches are analytical and exact methods. For general linear and mixed-integer programming, different solution approaches are seen, which are utilized by the authors (the same situation is in nonlinear programming). Roughly speaking, simulation techniques, and meta-heuristic algorithms are used in different approaches of modeling by researchers.

4.5. Decision variables analysis

There is a substantial number of variables in the literature, generally divided into three main categories based on Chopra and Meindl (2010):

- RL/CLSC strategic decision variables: Designing decisions, like locations and capacities of facilities (configurations and structures), are made at this level. These are long-term decisions.
- RL/CLSC planning decision variables: Include decisions regarding which markets will be supplied from what locations (allocation level), and flow of supply chain network. These are mid-term decisions.
- RL/CLSC operational decision variables: Include allocating inventory or production to individual orders, setting a date by which the order is to be filled, and other short-term decisions.

As various types of decision variables are defined and researched by different authors, we review these decision variables in Appendix 9 and illustrate that portion of each category in Fig. 9.

In Fig. 9, the number of papers that consider strategic, tactical, and operational decision variables are illustrated, complementing information in Appendix 9.

4.6. Period, product, and objective

The approaches considering different objectives, period, and product can be analyzed in various ways. Figs. 10–12 illustrate the trends in utilizing single/multi objective, single/multi period, and single/multi product approaches respectively. Based on Fig. 10, the number of papers which use single or multi objective approaches in different years of our study is found. The lack of multi objective approaches in recent publications can be clearly considered (87.6% for single-objective papers and 12.4% for multi-objective papers). Besides, Fig. 11 shows various and near trends (both around 50%) in single/multi period models. However, we can conclude a negative trend for single period researches recently in comparison with multi-period approaches. Fig. 12 proves the few researches in considering multi-part products (just 5.4%) and somehow multi-period approaches (just 29.3%) in comparison with single-period models (65.4%). It seems that computational difficulties of multi-product approach are a reason behind these results.

In order to analyze various types of objectives, Appendix 10 is developed to clarify the different objective functions used by researchers.

5. Discussion and future opportunities

In order to analyze the current gaps in the literature regarding various fields of RL and CLSC, this section discusses results of the review. Based on the consideration of this study, there are some research directions noticeable by researchers. Based on the classifications of Section 4, the findings of this study are categorized into six sub-sections.

5.1. Problem classification opportunities

An analysis of the current study reveals the existence of several opportunities for future research based on identified gaps in various investigated papers. These gaps are discussed in a detailed manner as follows:

5.1.1. Mutual interrelations

A major research opportunity is investigating the relationships between sustainability and green supply chain in RL and CLSC. From Fig. 4, it is evident that there are only few researches trying to work on green and sustainability subjects through an integrated RL/CLSC point of view. By this approach, a new definition of integration, which considers the sustainable and green issues in RL and CLSC, is proposed. Indeed, there should be some surveys, reviews, and case studies in investigating the effects of RL/CLSC in sustainable manufacturing and green production and vice versa (instead of trying to prove which one covers the other). The paper of Chaabane, Ramudhin, and Paquet (2012) is suggested as one of the sustainable-closed-loop supply chain studies. The complementary and necessary point for the mentioned integration is that when we identify green and sustainability, we mean studies that cover green or sustainability aspects of RL/CLSC. It means that the pure green (environmental issues such as CO_2 emissions) and/or sustainability (such as social issues) in the supply chain are not considered in our study. Therefore, this study reveals that such integrated studies between RL/CLSC with green/sustainability are a necessity and a gap in the literature. Furthermore, in terms of quantitative research, this integration can be undertaken by regarding common objective functions and decision variables.

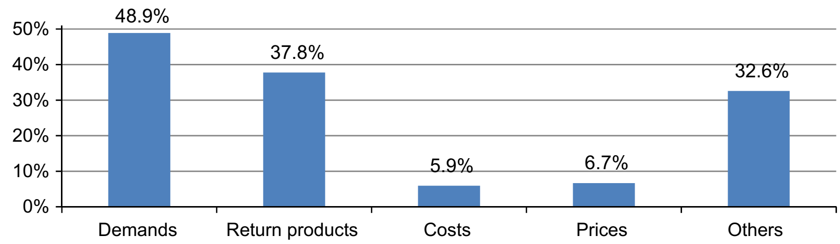

Fig. 7a. Various nondeterministic parameters.

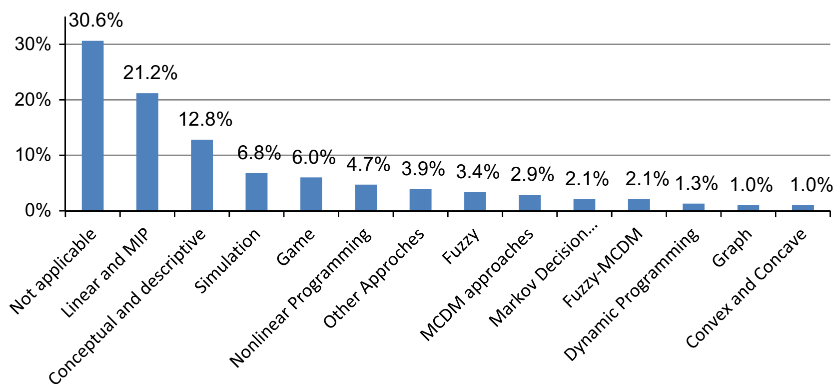

Fig. 7b. Various modeling approaches.

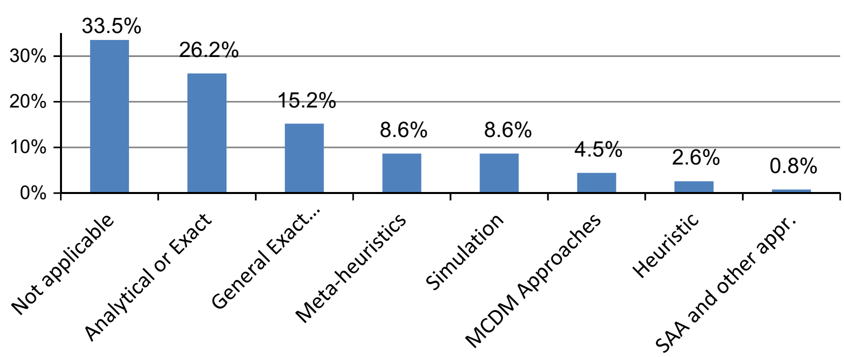

Fig. 8. Utilized solution methodologies.

5.1.2. Comprehensive view

Generally, research of various studies on different problems of RL and CLSC concentrate on a special subject from an independent point of view. For instance, we think of price and coordination problems as a completely separated study of network designing problems. Alternatively, no relation between 3PRLP selection investigations and pricing or planning level decisions of a network can be found. However, the cooperation between an OEM and its 3PRLPs explicitly affects pricing and determining network flow decisions. Finally, it is time to consider the impacts of various studies as illustrated in Fig. 5 in a comprehensive way but not as an individual subject of research (or direction of research). Kim, Goyal, and Kim (2013) and Amin and Zhang (2013) are two of the suggested papers in this direction.

To find a better view of interrelation study opportunities, related references and illustrations are presented in Section 4.1.

5.2. Opportunities for considering uncertainties

Analyses of the current study reveal that there are opportunities for future research based on the identified gaps in uncertainty issues. These gaps are discussed in a more detailed manner as follows:

5.2.1. Modification to current nondeterministic approaches

The findings of the current study from Fig. 6 and analyses of Section 4.2 lead to some modifications of the current definition of nondeterministic approaches. Previously, most researchers considered stochastic ways to deal with uncertainties. However, in recent years, three other main approaches have emerged as new, powerful, and acceptable approaches, influencing the interpretation of nondeterministic situations, namely: fuzzy logic, interval approaches, and chaos theory. Interval approaches and chaos theory are completely missing approaches in RL/CLSC by researchers. However, they can produce major achievements in dealing with uncertainties. In terms of fuzzy applications, researchers utilize fuzzy logic just to consider quantitative weights, multi objective decision making, or multi criteria analysis. Finally, the way of our thinking in nondeterministic approaches can be extended from stochastic approaches to other well-behaved approaches. Further steps for future research can be the integration between different nondeterministic approaches. Amin and Zhang (2013), Das and

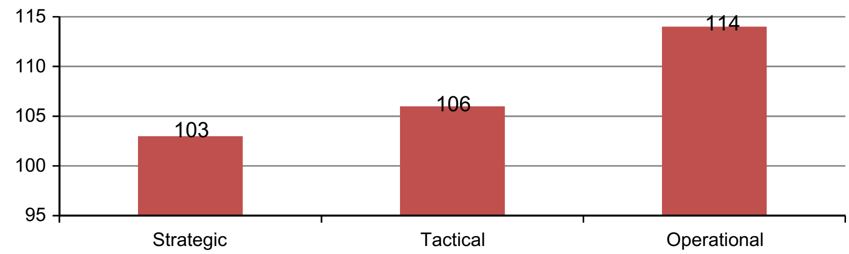

Fig. 9. Distribution of different decision variables defined and utilized by researchers in RL/CLSC.

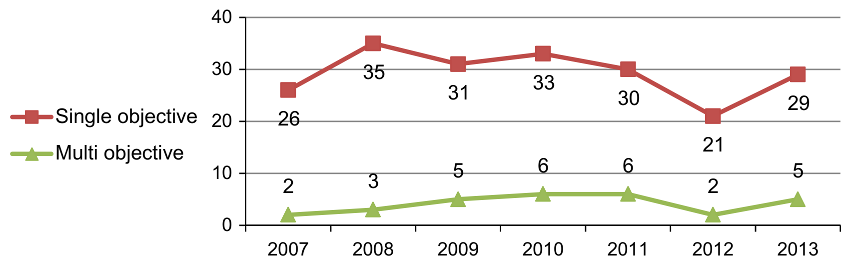

Fig. 10. Single and multiple objective analyses in different years.

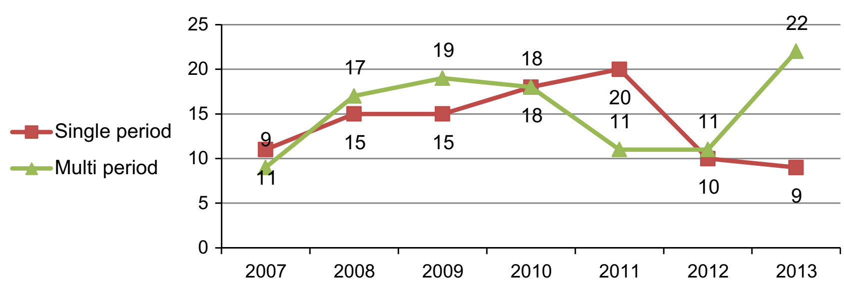

Fig. 11. Single and multiple period analyses in different years.

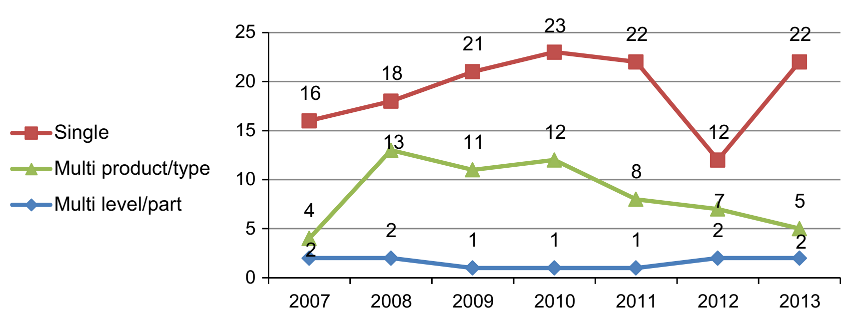

Fig. 12. Single and multiple product analyses in different years.

Dutta (2013), Hasani, Zegordi, and Nikbakhsh (2012) and Ramezani, Bashiri, and Tavakkoli-Moghaddam (2013) are suggested papers for readers in this direction.

5.2.2. Two-stage stochastic and robust optimization approaches

In terms of a stochastic way of handling uncertainties and reflecting real situations, analyses reveal that the researchers should consider two-stage stochastic approaches and robust optimization techniques as future directions of research, instead of regular stochastic programming. In addition, Fig. 6 illustrates the gaps of these near-to-reality techniques in RL/CLSC. Kara and Onut (2010), Piplani and Saraswat (2012), and Hasani et al. (2012) are suggested papers in this area.

5.2.3. Forecasting

The other missing subject in uncertainty issues is forecasting parameters approaches. Only a few papers (mostly conceptual) discussed and analyzed forecasting parameters especially for return products. This issue can be considered as a potential research area and may lead to the analysis of various topics such as the bullwhip effect in RL and CLSC. For instance, to construct a profitable reverse supply chain, the amounts of return will be critical. On the other hand, there is no guarantee about rate of return of products (also their demands) which will influence RL and CLSC. Meanwhile, if we do not have precise information of some parameters like return amounts, it will be difficult to construct a reliable and profitable RL/CLSC. Finally, studying the forecasting methods of various parameters like neural network and fuzzy approaches is a vital issue in RL/CLSC as future research. The suggested forecasting papers are those by Kumar and Yamaoka (2007), Hanafi et al. (2008), and Carrasco-Gallego and Ponce-Cueto (2009).

5.2.4. Uncertain parameters

Price, demand, and costs are important parameters that are regarded as uncertain in most related studies. However, these are not the only nondeterministic parameters, as there are other influential parameters. Some of them are mentioned here, such as used products' rate of return, production delays, quality of return products, time of receipt of return products, customer willingness to return used product, and various risks in RL and CLSC network (social, environmental, economic, political, and organizational risks). More analyses about risk issues can be found in Miller, 1992 and Zsidisin, Ellram, Carter, and Cavinato (2004).

More related references and detailed illustrations are presented in Section 4.2.

5.3. Opportunities in the analysis of modeling approaches

In modeling approaches, this study's analyses identified some gaps, which are clarified as follows:

5.3.1. Nonlinear programming and convex optimization

As real-world problems are always complex and complicated, problems cannot be modeled using simple linear programming approaches. There is a huge need to model some problems in nonlinear programming approaches (Luenberger, 2003). Indeed, based on the tractability of linear models in solving by various methodologies and complexities on nonlinear problems, researchers tried to develop and cope with different kinds of linear problems. In such situations, new advances in convex optimization in programming and solution methodologies open a new and useful paradigm for researchers for coping with current real problems. Complementary information about convex optimization tools and techniques in various fields can be found in Boyd and Vandenberghe (2004). Chung and Wee (2008), Qiaolun, Jianhua, and Tiegang (2008), Wang, Lai, and Shi (2011), and Sun, Wu, and Hu (2013) serve as suggested papers here.

5.3.2. Other approaches

Trying to model a problem through new innovative ways instead of regular modeling approaches can give researchers capabilities, advances, and benefits (also limitations) of various methods. There are some successful attempts in this field, mentioned in Section 4.3, but there are also huge opportunities in exploiting such areas. Some of these approaches can be pointed out as queuing models (Lieckens & Vandaele, 2007), graph-based models, Markov decision process (Ferguson, Fleischmann, & Souza, 2008), piecewise interval programming (Zhang, Liu et al., 2011), dynamic regression models (Carrasco-Gallego & Ponce-Cueto, 2009), statistical approaches (Pati et al., 2010), and interval mathematics (Hasani et al., 2012).

More related references and detailed illustrations are presented in Section 4.3.

5.4. Opportunities in solution methodologies

Analyses of the current study reveal some critical opportunities of future research based on current gaps in solution methodologies. These gaps are clarified as follows:

5.4.1. Exact solution methods vs. heuristics

There are different discussions between one who just believes in analytical or exact solution methods and one who believes in heuristics and meta-heuristics. Actually, in many cases different approaches could be effective to some extent. For instance, when there is a large complex problem, utilizing heuristic and meta-heuristic algorithms is unavoidable, while we do not know anything about the quality of solutions in these cases. On the other hand, analytical and exact methods beside general exact solvers are rarely applicable to real-sized instances of a problem or nonlinear problems, so there is still a huge gap between theoretical solution methodologies and successful practical methods. Perhaps approximation algorithms or hybrid algorithms can present another acceptable way to solve complex problems theoretically and practically. However, advances in exact and heuristic algorithms should be continued to achieve elevated methods. In this manner, case studies such as those by Wei, Zhao, and Sun (2013), Toyasaki et al. (2013), and Subramanian, Ferguson, and Toktay (2013) can help researchers to apply and to modify their theoretical methodologies in practical situations. The analyses of Fig. 8 illustrate that simulation studies, heuristic methods, and meta-heuristic algorithms are more applicable in practical situations in comparison with analytical or exact solutions.

5.4.2. Beyond the rules

Some interesting points can be found by analyzing Appendix 8, which is about hidden rules utilizing some specific methodologies for specific problems. For instance, solution methodologies of all game-based modeling, considered pricing and coordination decision variables, are analytical. Approximation methods are rarely used by researchers in any problem. On the other hand, simulation approaches are widely used in different problems, etc. Such hidden rules can be broken by researchers to clarify new achievements in solution methodologies for different problems. The researches of Hammond and Beullens (2007), Walther, Schmid, and Spengler (2008), Du and Evans (2008), Chouinard, D'Amours, and Aït-Kadi (2008), Feng, Zhang, and Tang (2013), and Minner and Kiesmüller (2012) can be mentioned here.

Related references and an illustration are presented in Section 4.4.

5.5. Opportunities in decision variables analysis

Decision variables are the main parts of different studies, with necessary opportunities for future research and they are clarified as follows:

5.5.1. Integration

The illustrations in Appendix 9 lead to new considerations on integrating operational decision variables with tactical and strategic ones. Although strategic decision variables (like designing and capacity) are successfully integrated with tactical decision variables (like flows of the network), operational decision variables (like production planning and inventory decisions) remain separated. Therefore, it seems that we need new approaches to integrate different decision variables of different decision levels of RL and CLSC. The idealistic points of this direction would be the integration of the decision variables of RL/CLSC networks in all three predefined decision levels. Recently published papers of Kim et al. (2013) and Souza (2013) can be suggested here.

5.5.2. New variables

Definitely, case studies and survey-based analyses (like questionnaires, interviews, and experts' brainstorming meetings) are noticed by researchers to update current decision variables and to introduce new decision variables based on new requirements. Some areas could be environmental decision variables (Georgiadis & Besiou, 2010 and Wang et al., 2011), quality-analysis decision variables (Hernández et al., 2011), and different transportation decision variables (Chaabane et al., 2012; Lundin, 2012, and Paksoy, Bektaş, & Özceylan, 2011).

Related references and an illustration are presented in Section 4.5.

5.6. Opportunities of single and multiple objective approaches

Analyses of the current study reveal some vital directions for future research based on current gaps in objective function analyses. These gaps are as follows:

5.6.1. Multi objective and new approaches

Multi objective decision making is still a gap in different studies when compared to single objective analyses. As real world problems are rarely single objective, it is necessary for researchers to pay more attention to multi objective functions instead of single objective ones. On the other hand, the approaches for dealing with multi objective problems and achieving the optimal solutions (like Pareto optimal solutions) need to be revised to produce more robust and applicable methods in analyzing multi objective or multi criteria problems. Recent papers of Özkır and Başlıgil (2013), Amin and Zhang (2013), and Wang, Lu, and Zhang (2013) are suggested here.

5.6.2. Green, sustainable and environmental issues

The most important extension in current objective functions is regarding green, sustainable, environmental, and resilience objectives. As discussed in relation to the effects of green and sustainable supply chain in RL and CLSC, it is expected that researchers regard appropriate environmental, social, and green-based objectives in their analyses, which can be a critical future avenue for all entities in the RL/CLSC network. The studies of Quariguasi Frota Neto et al. (2010), Paksoy, Özceylan, and Weber (2010), Gupta and Evans (2009), and Wang et al. (2013) can be mentioned as elite papers in this direction.

Related references and an illustration are presented in Section 4.6.

6. Conclusion

This paper tries to present a comprehensive literature review of recent and state-of-the-art papers in RL/CLSC regarding vast numbers of publications in different scientific journals in RL and CLSC issues. Totally, 382 published papers between January 2007 and March 2013 are selected, reviewed, categorized, and analyzed to find the future directions and opportunities of research in RL/CLSC. The gaps in literature are identified and completely discussed to clarify the future research opportunities for the authors.

Mutual interrelations and a comprehensive view in selecting different problems suggests several future directions in problem classifications and opportunities. Modification opportunities in nondeterministic approaches, utilizing two-stage stochastic and robust optimization approaches, considering forecasting methods, and regarding new uncertain parameters are identified as future opportunities in uncertain parameters. Nonlinear programming and convex optimization, and utilizing other modeling approaches are recommended as opportunities in modeling approaches. Balancing concerns between exact and heuristics solution methodologies and trying to break current hidden rules in solution tools are discussed in solution methodologies and its opportunities. The integration of different levels of decision-making and defining new decision variables are future opportunities for the decision variables category. Paying attention to multi objective problems, utilizing new approaches, and applying more green, sustainable, and environmental objectives can be the future directions in single and multiple objective problems.

Acknowledgement

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Appendix A. Supplementary material

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.ejor.2014.07.012.

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