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A REVIEW OF THE RESEARCH ON REMANUFACTURING USING THE CITATION NETWORK ANALYSIS

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Abstract. *With an aim to better understand the past research on remanufacturing, this paper presents a literature review using the citation network analysis. Based on objective information (i.e., citations among journals and articles), a brief overview of the research on remanufacturing is provided. More specifically, two analyses are described: (1) centrality analysis of journals to identify the most influential journals in the field of remanufacturing and (2) cluster and content analysis of articles to recognize the research topics and communities of great attention in the field. It is expected that the results can provide researchers with an approximate idea of the journals and research topics that are important and promising.*
Keywords: Remanufacturing, Citation network analysis, Degree centrality, Modularity analysis, Cluster analysis, Content analysis

1. **Introduction.** As remanufacturing (i.e., the process of restoring used, discarded products to a like-new condition) has received increasing attention, the number of publications in the field of remanufacturing has increased significantly in past decades. According to Scopus (i.e., one of the largest databases of peer-reviewed literature [1]), more than 7,700 articles have been published in the area of remanufacturing since the 1960s, and the number of annual publications shows a significant increasing trend, as depicted in Figure 1.

With an aim to better understand the past research on remanufacturing, this paper presents a literature review that is based on the citation network analysis. Most literature reviews on remanufacturing have been conducted based on the authors' subjective analysis (e.g., [2-7]). For example, R. Kumar and P. Ramachandran classified the research topics of the research on revenue management in the remanufacturing field from a subjective perspective [2]. Unlike the other reviews, this paper presents a review based on objective information, i.e., citations among both journals and articles. The citation network analysis is a bibliometric method that has been widely used in many research fields including science, technology, the humanities, and the social sciences [8-10]. To the authors' best knowledge, this work is the first citation network analysis targeting the area of remanufacturing.

More specifically, this paper introduces the following two analyses, as shown in Figure 2. First, a centrality analysis of the journals is conducted to identify the influence of the journals in the field of remanufacturing. Next, a cluster and content analysis of the articles is performed to understand the research topics in the field.

The rest of the paper is organized as follows. Section 2 presents an overview of the research, describing the data collection and analysis. Section 3 presents the analysis results. Lastly, Section 4 concludes the paper, suggesting future research directions.

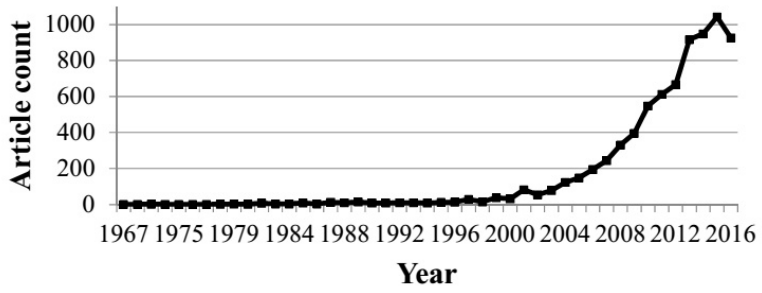

FIGURE 1. Publications in the field of remanufacturing (cumulative graph)

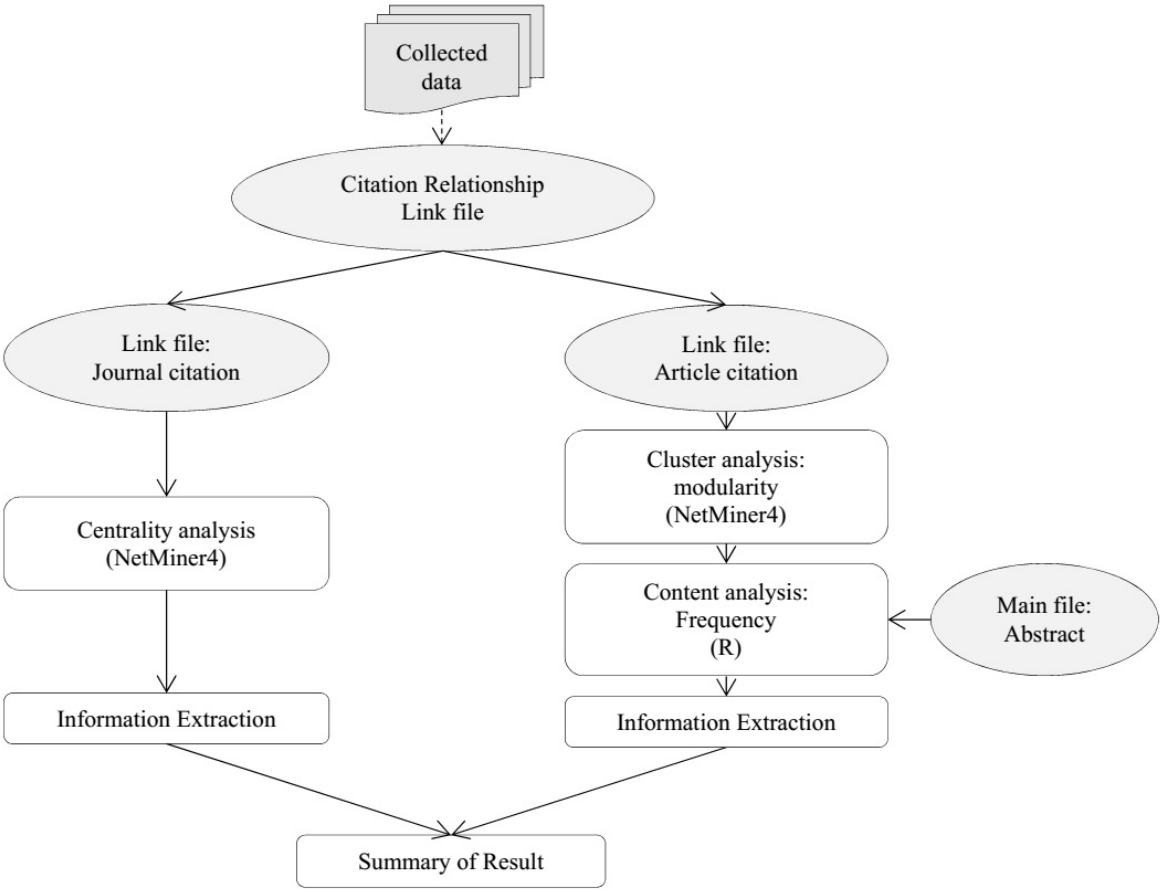

FIGURE 2. Publications in the field of remanufacturing

2. **Overview of the Research.** As shown in Figure 2, the citation network analysis in this paper consists of the following three parts: (1) data collection, (2) centrality analysis of journals, and (3) cluster and content analysis of articles. The network-analysis software package NetMiner4.0 and the statistical software R were used for the analyses.

2.1. **Data collection.** In this study, the bibliographic information of approximately 7,700 remanufacturing articles from 1967 to 2017 was used for the analysis. The data collection was conducted via Scopus (scopus.com). Considering whether the article title, keywords, or abstract include any of the six words, "remanufacture", "remanufacturing", "remanufactured", "refurbish", "refurbishing", and "refurbished", a total of 1,431 primary-source articles were first collected. Next, 6,301 articles that directly cite the primary sources were added, while the articles with 10 or fewer citations or without an abstract (approximately 400 articles) were removed from the analysis.

The information was stored in the following two types of Excel file: (1) a link file representing the citation relationships between the journals or between the articles, and (2) a main file including the article information. The link file defines two types of nodes (i.e., source and target), where the source and the target indicate a cited and a citing journal or article, respectively. (For instance, if Article X is cited in Article Y, X becomes a source and Y becomes a target.) A link between two nodes flows from the source to the target. The main file is the database of the article information. It stores the bibliographic information for the content analysis in the order of the article ID (assigned arbitrarily), author/s, article title, published year, journal, abstract, and keywords.

As shown in Figure 3, the citation network in this paper consists of nodes and links. Here, each node represents a journal or an article, and the link between two nodes represents the citation relationship between the nodes.

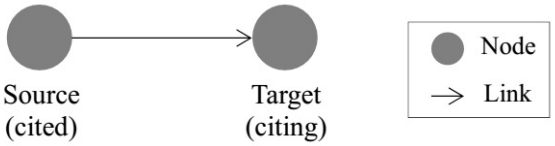

FIGURE 3. The network consists of nodes and links.

2.2. **Centrality analysis of journals.** It is commonly accepted that the more times that a journal is cited, the greater the influence of that journal in the research field. To identify the journals that are greatly influential in the remanufacturing field, this study conducted a centrality analysis of the journals.

Centrality is a common measure in a network analysis that is used to identify the power and influence of a node [11]. The centrality of a node represents how central the location of a node in an entire network; that is, how important a node is [12]. Among the various centrality measures, this study used *degree centrality* that was proposed by Freeman and is used to measure the number of links that belong to a node in a network [13].

Depending on the direction of the link, two types of degree centrality are relevant here: in-degree and out-degree centralities. Since this study aims to identify those journals that are more frequently cited compared with the others, *out-degree centrality* is of interest.

At the same time, to confirm that the out-degree centrality significantly differs by journal (i.e., certain journals are more frequently cited than others), the *network degree centralization index* was computed using Equation (1). If the index value is greater than 1, it represents a large difference between the centrality values among the nodes.

$$\text{Network degree centralization index} = \frac{\sum_{\text{everynode}} (\text{max. centrality} - \text{node's centrality})}{\#\text{node} - 2}. \tag{1}$$

2.3. **Cluster and content analysis of articles.** In general, researchers cite other articles on similar research topics or methodologies. If the cluster analysis is performed according to the citations, articles sharing similar research topics or methodologies will be clustered into a group.

To identify the cluster structure of the collected articles, this study first conducted clustering using the modularity analysis. The modularity analysis configures a network such that the number of links in a cluster is greater than the numbers of links between the clusters. This analysis used the CNM (Clauset-Newman-Moore) algorithm that is known as a useful tool in the discovery of clear clusters that correspond to specific topics [14]. As one of the cohesion algorithms, it starts in a completely non-clustered situation and combines small clusters one by one to improve the modularity value. Here, the modularity

value is a quantitative measure of the clustering quality, and it ranges from 0 to 1 [15]. A higher modularity value means that more meaningful clusters have been derived.

After the cluster structure is derived, the next step is the examination of the keywords of each cluster to reveal the research topics and interests of the cluster that have been actively studied. For such a content analysis, the abstracts of the articles of each cluster were analyzed using the frequency analysis. The nouns in the abstracts were extracted, and the frequency values of these words were analyzed to extract the distinctive nouns that represent each cluster.

3. **Analysis Result.**

3.1. **Centrality analysis of journals.**

This study first conducted an out-degree centrality analysis of the journals on remanufacturing. NetMiner 4.0 (analyze > centrality > degree; main process setting: sum of weight) was used for the analysis. In this study, a total of 1,817 journals were analyzed, and Table 1 shows a part of the result, i.e., the top five journals based on the centrality value.

TABLE 1. Centrality analysis results: Top five journals and their ranks by article count

Rank	**Journal name**	**Centrality***	**Article count (rank)**
1	Management Science	1.15	21 (56)
2	International Journal of Production Economics	1.09	369 (2)
3	Production and Operations Management	1.07	83 (10)
4	European Journal of Operational Research	0.92	156 (4)
5	Journal of Cleaner Production	0.71	381 (1)

* Network degree centralization index: 1.15

A higher centrality value indicates that a journal is more frequently cited and its influence in the field of remanufacturing is stronger. According to the results, the journal *Management Science* is the most cited journal in the area of remanufacturing (including self-citations), followed in sequence by *International Journal of Production Economics*, *Production and Operations Management*, *European Journal of Operational Research*, and *Journal of Cleaner Production*.

This study also compared the journal ranks by centrality value with those by article count. The results showed that the two ranks are different. For instance, *Journal of Cleaner Production* has published the most articles on remanufacturing, whereas it was ranked fifth in terms of its centrality value. This implies that, in the remanufacturing field, a journal that has published many articles is not necessarily a journal that has been frequently cited.

3.2. **Cluster and content analysis of articles.**

The citation network analysis of the articles was conducted in the following two steps: modularity analysis for clustering and content analysis (i.e., frequency analysis of the abstracts) of each cluster. In this study, NetMiner4.0 (cohesion > community > modularity) and R were used for the clustering and frequency analyses, respectively.

In the analysis of the citation relationships of approximately 7,300 articles, a total of 42 clusters were formed. Next, the content analysis was performed for the top 12 clusters, which account for more than 90% of the total data, to identify the characteristics of each cluster. A frequency analysis of 6,580 articles was conducted, and the Appendix shows a portion of the results. Please note that the following general words were removed from the

analysis as they appear redundantly across the clusters: remanufacture, product, system, method, approach, analysis, result, paper, study, model, process, and problem.

Most of the articles in the remanufacturing field include the terms "supply chain", "environment", and "sustain". Each cluster, however, also contains some words that reveal the distinctive characteristics of each of the clusters, and the Appendix shows the common words (highlighted) and the unique words (bold) for each cluster. Table 2 presents a summary of the characteristics of each cluster. For example, it is evident that the focus of Cluster G36, which forms the largest cluster, is money-related topic such as price, profit, retail, and market. The cluster mainly deals with the pricing issues in remanufacturing, such as the extent of the incentives that should be offered to the supplier of the products and the determination of the optimal retail price for the maximization of the remanufacturing profit. Cluster G41 addresses the inventory-management issues in product recovery, while G37 includes research on network algorithms that is for the purpose of optimizing various network problems (e.g., reverse-logistics network, closed-loop supply chain network, and recovery network).

Table 2. Main research topics in remanufacturing

	Cluster	**Research Topic**
1	G36	Cost and profit in market
2	G41	Inventory management in product recovery
3	G35	Design for disassembly
4	G39	Quality management
5	G40	Supply Chain Management (SCM) using dynamic modeling
6	G31	Green design
7	G32	Material energy efficiency
8	G34	Reverse-logistics process framework
9	G42	Creating value for closed-loop supply chains
10	G33	Sustainable management of electronic waste
11	G38	Product-service-system business model
12	G37	Optimization models for various network problems

These results help researchers in the identification of the kinds of research communities (according to the research topics) that exist in the remanufacturing field and the research topics that have been actively studied in the area.

4. **Conclusion.** With the aim of the attainment of an improved understanding of the research in the field of remanufacturing, this paper conducted two citation network analyses for journals and articles, respectively.

First, the centrality of the journals from a remanufacturing standpoint was examined by using the out-degree centrality analysis. In a comparison of the rank of the degree centrality with the rank of the number of publications, it was revealed that the number of articles does not necessarily represent the influence of a journal. Based on the citation relationships among the journals, the following journals were identified as the most influential journals in the field: *Management Science*, *International Journal of Production Economics*, *Production and Operations Management*, *European Journal of Operational Research*, and *Journal of Cleaner Production*.

Next, the cluster and content analysis was conducted for the remanufacturing articles. By performing the modularity analysis, a total of 42 clusters were formed, revealing that the top 12 clusters cover 90% of the articles. The frequency analysis of the article abstracts showed that following 12 research topics have received great attention in the field: cost and profit in market, logistics and inventory, design for disassembly, quality management,

capacity optimization, green design, material efficiency, reverse logistics, closed-loop supply chains, electronic-waste recycling, product-service system, and optimization through network.

This study helps researchers in the identification of the journals of importance and topics that have been actively researched in the remanufacturing area. One limitation of the study, however, is that the network analysis was conducted without a consideration of time. To better identify the research trends in the remanufacturing field, time must be included in future analyses.

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Appendix. Cluster and content analysis results for the top 12 clusters

	Clustering			**Top 10 Extracted Keywords**									
	Group ID	Article count	Cum. %	1	2	3	4	5	6	7	8	9	10
1	G36	2083	29%	supply chain	design	**price**	environment	development	decision	sustain	**optimize**	**profit**	**retail**
2	G41	1846	54%	supply chain	optimize	**logistic**	return	reverse	propose	**inventory**	network	demand	design
3	G35	641	63%	**disassemble**	design	environment	development	propose	recycle	optimize	present	sequence	base
4	G39	638	72%	supply chain	optimize	base	**manage**	perform	return	propose	development	design	**quality**
5	G40	224	75%	supply chain	**dynamic**	effect	perform	design	simulation	**optimize**	base	**capacity**	decision
6	G31	221	78%	environment	manage	sustain	supply chain	development	practice	**green**	industry	perform	waste
7	G32	219	81%	**material**	**energy**	environment	sustain	**efficiency**	technology	design	impact	resource	potential
8	G34	211	84%	sustain	environment	develop	manage	**logistic**	supply chain	**reverse**	practice	industry	design
9	G42	166	86%	supply chain	manage	sustain	return	network	decision	logistic	operation	develop	**close**
10	G33	124	88%	**waste**	**recycle**	manage	development	**electronic**	environment	inform	compute	country	generate
11	G38	107	89%	**service**	busy	development	value	design	provide	propose	base	manage	company
12	G37	100	90%	optimize	supply chain	propose	**network**	**algorithm**	decision	base	**logistic**	demand	design