Green Logistics for Heavy Equipment: a bibliometric analysis

S. Ferraro*, F. De Carlo*, A. Cantini*, L. Leoni*

** Department of Industrial Engineering (DIEF), University of Florence, Viale Morgagni, 40 59100 – Florence – Italy (saverio.ferraro@unifi.it, filippo.decarlo@unifi.it, alessandra.cantini@unifi.it, leoanrdo.leoni@unifi.it)*

Abstract: In recent years, the concept of sustainability has become increasingly important, driven by a greater awareness of the economic, environmental, and social context. At the same time, the design of efficient logistics systems has extended the boundaries and relationships between organisations, suppliers, and customers. On one hand, activities related to logistics processes positively stimulate economic development, while on the other hand they negatively impact the environmental context. From these two principles, the term green logistics was devised with the aim of reducing environmental externalities. Sustainable logistics is widely studied for conventional and consumer products, but less diffused for large industrial assets and equipment. These products are mostly of an engineer to order nature and require ad hoc logistics. In this paper, a bibliometric analysis is described, conducted to highlight using quantitative analysis the most important issues, trends, and challenges in the field of sustainable logistics and its management for large-scale and heavy products. Specifically, search results of heavy equipment logistics and sustainable heavy equipment logistics are compared using a classification tool. It emerged that logistics sustainability for heavy equipment is not widespread and that emerging topics such as machine learning algorithms and Industry 4.0 technologies can be opportunities for sustainable development. The results of this research may be of interest to logistics managers, logistics providers, and researchers for the identification of literature gaps and innovative opportunities.

Keywords: Green Logistics, Sustainability, Engineer To Order, Bibliometric Analysis, Heavy Equipment

I. INTRODUCTION

Large products cover their use in different sectors including agriculture, forestry, manufacturing [1], and especially construction [2]. Large machinery is required for activities related to the distribution of products [1], transportation of people [3], production, storage, and distribution of energy [4], [5]. Large products usually identify all those bulky items with a weight in the order of hundreds of kg and volumetric dimensions in the order of hundreds of m^3 [6]. These products are considered engineer to order (ETO) or make to order (MTO) and have complex bills of material, high degrees of customization, and large modular elements [7]. This leads to technical complications, dealing with non-standard components and products with low volumes and high variability. Specifically, products with large dimensions require large spaces and assets for their handling [7], leading to logistic activities of procurement, internal handling, storage, and delivery which are economically expensive [6], potentially risky [8], and with high environmental impact [2].

Despite the characteristics of large ETO and MTO products and their well-defined application areas, the scientific literature does not address the optimization of logistics activities within their Supply Chain [1]. Furthermore, as far as the authors know, there is little exploration of sustainable logistics for the heavy equipment supply chain. Sustainable logistics, also known as Green Logistics, is the topic that considers all logistic activities such as inbound logistics, internal logistics, and outbound logistics aiming at reducing environmental externalities [9]. Inbound logistics relate to the activities of a company's incoming flows such as procurement while outbound logistics look at the activities of outgoing flows such as transportation. Internal logistics concern all handling activities within an organisation needed to support the production process such as handling and storage. For example, the increasing use of freight transport activities, mainly involved in inbound and outbound logistics, is responsible for a large quantity of carbon emissions [10]. When it comes to the transportation of large products, in addition to the high environmental impact due to the high load and long distances to be traveled, many problems arise regarding the safety of the product, people, and infrastructure elements, complicating the route planning phase [11]. To deal with this issue, the concept of sustainable logistics is gaining importance because of the impact logistics can have not only environmentally, but also economically and socially [9]. When looking at products of large sizes, few applications are found in the literature. For instance, McDoungall and Williamson [13] present logistics challenges of large mountain pipelines considering also environmental restrictions, while Jia and Wang [14] propose a logistic risk assessment of hydropower equipment based on a fault tree analysis that considers also the environmental risk.

Based on the aforementioned considerations, the objective of this research is to compare the literature efforts directed at heavy equipment logistics and heavy equipment sustainable logistics. To fulfil the objective an in-depth bibliometric analysis is carried out. As a reminder, the article is structured as follows: in section 2 the methodology of the research is described, while, in section 3, the results are presented by comparing the two

search queries in terms of publication years, journals, keywords, and research topics. Section 4 discusses the results to identify the main trends and challenges for sustainable heavy equipment logistics. Finally, in section 5, conclusions are drawn and future developments are proposed.

II. Methodology

A bibliometric analysis of two search queries is presented in this paper. The first query refers to the topic of heavy equipment logistics, while the second refers to the sustainable logistics of heavy equipment. The analysis aims to answer two research questions:

(1) How well are the two topics investigated in the literature and what are the main quantitative differences?

(2) What are the main trends and opportunities of the two topics and how can they be clustered?

Answering the research questions, two queries were identified, each one consisting of keywords that fall under the domains of product, operation, and sustainability (see Table I). The product domain identifies all the characteristics of large-scale attributes, the operation domain identifies logistics activities, and the sustainability domain identifies the environmental relevance.

TABLE I
KEYWORDS CLASSIFICATION

Product	Operation	Sustainability
large product, large scale product, big product, big size product, huge product, heavy product large item, large scale item, big item, big size item, huge item, heavy item large equipment, large scale equipment, big equipment, big size equipment, huge equipment, heavy equipment	logistics, transport*, inbound logistics, outbound logistics, movimentation, deliver*, handl*, storag*, warehous*	sustainabl*, environmental*, green

The first search query combines keywords from the first two columns to identify the topic of heavy machinery logistics. The second search query uses third-column keywords to add the topic of sustainability. Keyword composition was done using the OR operator for words under the same domain and the AND operator for combinations of words between different domains. The " operator is used in the search for words composed of two terms to identify the correct sequence of words. The * operator is used to include all words that share the same base.

The search was done within the Scopus database, filtering the results by subject area, excluding anonymous and not written in English articles (Table II). The selected subject areas are Engineering, Computer Science, and Environmental Science. For each search query, the partial results obtained by applying the inclusion criteria are shown in Table II. The last row of the table shows the final results used to compare heavy equipment logistics and heavy equipment sustainable logistics.

TABLE II
RESULTS OF INCLUSION CRITERIA

Inclusion Criteria	Query 1 results	Query 2 results
Keywords	1068	134
Subject Area	704	88
Anon	694	88
English	628	84

General information, journals, keywords, and trend topics were analysed on a quantitative level. The bibliometric analysis was conducted using a spreadsheet and the Bibliometrix package from RStudio.

III. Results

Regarding the first research question, the two queries return different results. The search related to heavy equipment logistics returns 628 articles. When the concept of sustainability is added, the papers decrease to 84.

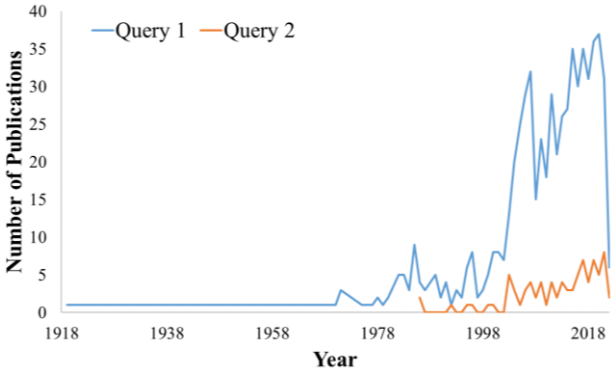

Fig. 1. Publication Year

As depicted in Fig. 1, the concept of heavy equipment logistics is well established, with the first paper published in 1919. This topic saw rapid growth in the first years of the 2000s and continued to grow in the following years. On contrary, the topic of sustainable heavy equipment logistics is more recent and the first paper dates to 1986. Even if sustainable logistics is an increasingly relevant topic, the search results do not show a growth similar to the first query.

From a subject area perspective, most of the articles belong to the category of Engineering, Computer Science, and Environmental Science. For the first query, the percentages are respectively 41%, 14%, and 9%, while for the second query 33%, 6%, and 22% (Fig. 2).

The high percentages are due to the search methodology and the use of inclusion criteria. It is worth mentioning that despite the application of filters, about 40% of the articles do not belong to the defined subject area.

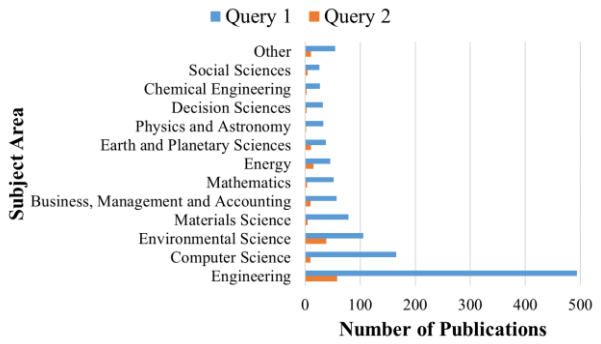

Fig. 2. Subject area

The two search queries were compared on the basis of the five major reference journals. As the number of publications per journal is not enough to assure scientific relevance and influence, also the number of citations per paper was reported.

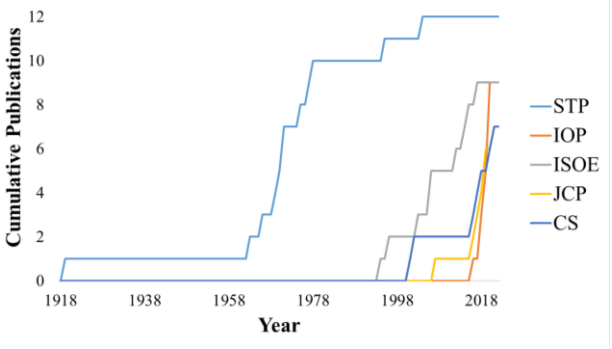

Fig. 3. Source Growth for heavy equipment logistics (Query 1)

Fig. 3 presents the cumulative publications over the time interval related to heavy equipment logistics. The journal in which the most papers have been published (12) is the SAE Technical Papers (STP) which saw an increase from around 1960. The journals IOP Conference Series: Materials Science and Engineering (IOP) and Proceedings of SPIE - The International Society for Optical Engineering (ISOE) follow with 9 papers each. Journal of Cleaner Production (JCP) and Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics) (CS) have 7 papers. It is worth mentioning that the journal with the highest growth in a single year is IOP with 4 articles in the year 2019.

From an impact point of view, the ranking of the five most relevant journals is not the same (see Table III). STP appears to be the journal with the lowest number of citations per publication (0.7). Whereas JCP (15.9) and ISOE (15.4) appear to be the most influential journals with the highest number of publications.

TABLE III
IMPACT LEVEL OF TOP FIVE JOURNALS FOR (QUERY 1)

Journal	Number of Publications	Number of Citations
STP	12	8
IOP	9	23
ISOE	9	139
JCP	7	111
CS	7	9

Regarding the research adding the concept of sustainability (Query 2), fig. 4 shows the top five journals for number of publications. The top journal is JCP with 7 articles followed by Proceedings of the Annual Offshore Technology Conference (OT) with 3 articles. This is followed by other journals with 2 publications including Applied Mechanics and Materials (M&M), Energies (E), and Environmental Science and Technology (ES&T).

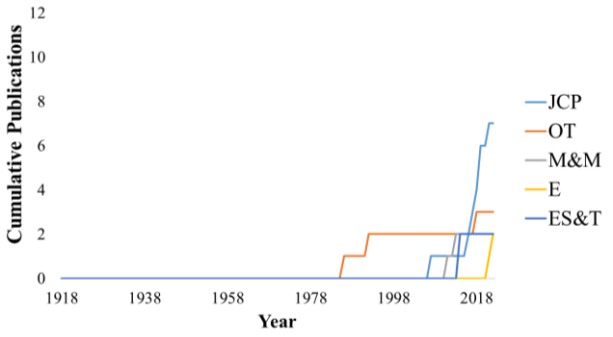

Fig. 4. Source Growth for heavy equipment sustainable logistics (Query 2)

Considering the impact level of the five journals, the results with the second query are different (Table IV). ES&T is the journal with the highest number of citations per publication (31), followed by JCP (15.9). The lowest value is assumed by M&M and E with currently no citations.

TABLE IV
IMPACT LEVEL OF TOP FIVE JOURNALS FOR (QUERY 2)

Journal	Number of Publications	Number of Citations
JCP	7	111
OT	3	1
M&M	2	0
E	2	0
ES&T	2	62

A. Keywords Analysis

Keywords analysis was conducted to identify the most commonly used terminology for heavy equipment logistics and trend topics. The analysis aimed to answer the first research question and highlight the differences in terms of keyword selection for the two topics. Methodologically, both the keywords used by the authors and those in the title and abstract of the papers were analysed using the Bibliometrix tool.

For the first search query, the keywords 'logistics' and 'heavy equipment' are in third and fifth position, respectively preceded by 'data mining' and 'maintenance' (Table V). Extending the analysis to article titles and abstracts, the term 'heavy equipment' is the most recurrent.

TABLE V
KEYWORDS OCCURRENCE FOR HEAVY EQUIPMENT LOGISTICS (QUERY 1)

Position	Keyword	Occurrence
1st	Data mining	14
2nd	Maintenance	9
3rd	Logistics	8
4th	Machine learning Optimization Simulation	6
5th	Heavy equipment Design Safety	5

Regarding the frequency of keywords, Fig. 7 shows the topic trends most frequently found in the abstracts. The graph shows the time interval of the keywords and their number. Specifically, the node position represents the year with the higher use of the keyword, and the node size is the number of citations. For example, the bigram 'heavy equipment' has the highest frequency within the abstracts and it counts 249 occurrences between 2005 and 2018, with the highest use during 2011.

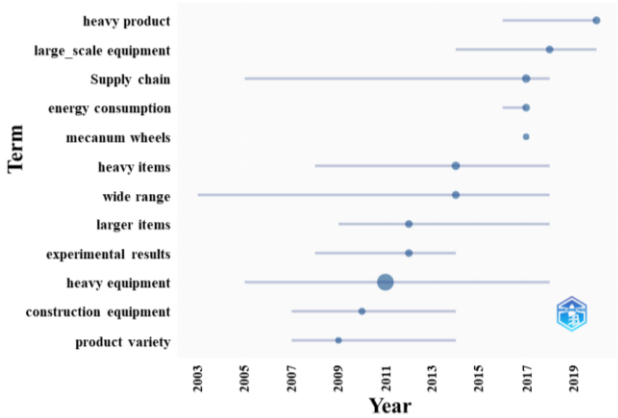

Fig. 7. Trend Topics for heavy equipment logistics (Query 1)

The graph shows the most recurrent couples with a minimum frequency of 15 occurrences to graphically show the most relevant abstract terms. It is interesting to highlight that the product size feature is often repeated within the abstracts, reaching high-frequency values, according to the size of the blue circles.

Instead, for the second search query, the results are different. The keyword 'sustainability' is one of the most frequently used, even if only with 2 occurrences (Table VI). Instead, the keywords 'logistics' and 'heavy equipment' are not recurrent. The term 'heavy equipment' is the most common if the analysis is extended to the abstract followed by terms relating to sustainability such as 'life cycle' and 'environmental impact'.

TABLE VI
KEYWORDS OCCURRENCE FOR HEAVY EQUIPMENT SUSTAINABLE LOGISTICS (QUERY 2)

Position	Keyword	Occurrence
1st	Sustainability Embodied energy Dams Distributed manufacturing Infrastructure Optimization Water storage	2
2nd	3D printing Agent-based simulation …	1

Fig. 8 shows the analysis of the trend topics most frequently found in the abstract with a word frequency at least of 7. Unlike the first query, even if the keyword 'heavy equipment' has the highest frequency, concepts related to sustainability are more relevant as, for example, 'environmental conditions', 'life cycle' and 'environmental impacts'.

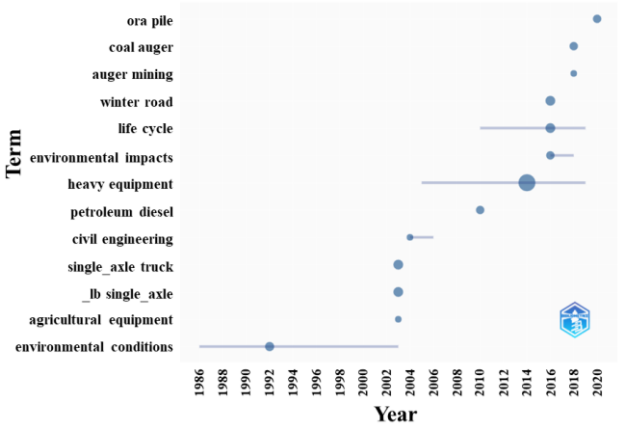

Fig. 8. Trend Topics for heavy equipment sustainable logistics (Query 2)

B. Topic Analysis

The analysis of interesting and emerging topics was done using a Thematic Map [15]. The chart groups topics into clusters, and places them along two axes. The x-axis represents the degree of relevance of the topic, while the y-axis represents the degree of development. The

Thematic Map chart divides the area into four quadrants. The upper right quadrant groups 'motor themes': well-developed topics relevant to the research area. The upper left quadrant contains the 'niche themes' that are very specific, but with few external relationships. The lower left quadrant contains 'emerging or disappearing themes' that are marginal and rarely developed. Finally, the lower right quadrant identifies 'basic themes' that are important to the research but are general in scope.

Trend analysis is done for both search queries using Bibliometrix software. The analysis takes into consideration only the keywords used by the authors, not those used in titles or abstract documents.

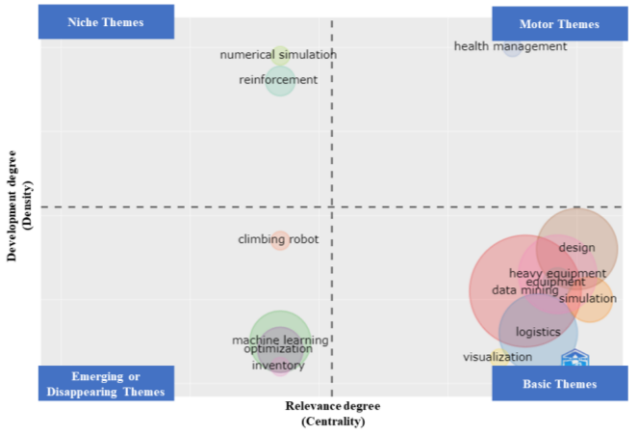

Fig. 9. Thematic Map for heavy equipment logistics (Query 1)

For the search query dealing with heavy equipment logistics, 14 clusters are identified (Fig. 9). Among the clusters, two aspects are of interest. The topics 'heavy equipment' and 'logistics' are considered basic themes, while 'machine learning' is an emerging theme. No sustainability concepts are included in this graph.

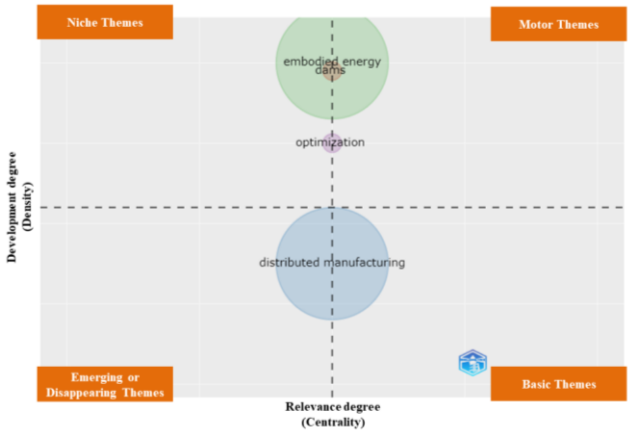

Fig. 10. Thematic Map for heavy equipment sustainable logistics (Query 2)

On the other hand, the search query that deals with sustainable logistics for heavy products identifies only 4 clusters not distributed by the degree of relevance (Fig. 10). The concept of sustainability is part of the cluster labeled as 'distributed manufacturing', so it is possible to state that, among the others, it is the least developed. Since it is a recent theme, we can also affirm that it is one of the emerging themes.

A summary of cluster analysis is given in Appendix A for the first query and in Appendix B for the second one (Table VII, Table VIII).

IV. Discussions

Considering the analysis of the two research topics, it is possible to highlight some issues.

Firstly, the concept of green logistics for heavy equipment is not very investigated and leaves a large space and opportunity for scientific research. In fact, from the analysis of general information, the search results of the first query are 7 times larger than the second query. For both queries, Keyword analysis shows that the term 'heavy equipment' does not fall within the keywords chosen by the authors of the papers, even though they are relevant within the articles and persistent over a broad time horizon. Furthermore, it is possible to state that the reference journal for the topic is the Journal of Cleaner Production. For the topic of sustainable large-scale logistics, JCP is not only the leading reference journal but has also a great impact in terms of citations.

From the topic analysis, the application of machine learning algorithms appears to be an emerging topic. Through this analysis, it is not possible to state with certainty for which activity they are applied. In any case, it is interesting to extend the research by applying these tools also to the logistic sustainability of large machinery for which only optimization models are shown. Finally, industry 4.0 technologies can be an opportunity for new innovative solutions aimed toward sustainable development. Although technologies such as Simulation and Big Data Analytics are considered basic themes for the logistics of large machinery, other technologies are now emerging (i.e., Robots) but not all of them are already established. Regarding sustainable logistics, there are even bigger opportunities for 4.0 technologies, since none of them is actually applied.

V. Conclusions and Future Developments

Nowadays, the concept of sustainable logistics is becoming increasingly relevant to reduce environmental externalities as much as possible. In this context, industrial products with unconventional weights and dimensions that involve difficult logistic tasks are not investigated enough. Within this article, the differences from a quantitative point of view between heavy equipment logistics and their sustainable applications were highlighted to identify gaps and research opportunities to be developed. To this end, a bibliometric analysis was conducted on two research questions to investigate (1) how well the two topics are studied in the literature and what the main differences are, (2) which are the main trends and opportunities, and how they can

be grouped. The main result obtained reveals the lack in the literature of articles related to the sustainable logistics of heavy equipment. Dealing with such products, both the difficulties of logistic operations and the high environmental impact of those, this topic is of great interest for the scientific value and its implications in the socio-economic context.

It is necessary to stress that this type of analysis is functional to a greater extent in qualitative and quantitative terms. Possible future developments can refine the bibliometric analysis by comparing in higher detail the trend topics over time. For example, it may be interesting to carry out a dynamic analysis of the thematic map to identify more clearly if some keywords shift between quadrants. Another development may be to extend the work through a bibliographic analysis of the articles. The extension may consider additional inclusion and exclusion criteria, and selection by reading the title, abstract, and the full text. Finally, it may be of interest to compare bibliometric and bibliographic results for sustainable logistics and the logistics of products that do not fall under the heavy equipment classification. This can highlight opportunities and applications that can be further explored and implemented, based on the constraints and characteristics of the products.

REFERENCES

[1] T. M. Simatupang and R. Sridharan, 'A critical analysis of supply chain issues in construction heavy equipment', *International Journal of Construction Management*, vol. 16, no. 4, pp. 326–338, 2016, doi: 10.1080/15623599.2016.1142250.

[2] J. M. C. Ongpeng, J. R. Dungca, K. B. Aviso, and R. R. Tan, 'Minimizing the carbon footprint of urban reconstruction projects', *Journal of Cleaner Production*, vol. 240, 2019, doi: 10.1016/j.jclepro.2019.118222.

[3] K. Ono, J. Tatsumi, and T. Nakao, 'Possible mass and long distance ferry transportation for health and humanitarian logistics at a disaster scene', 2017, vol. 25, pp. 1180–1197. doi: 10.1016/j.trpro.2017.05.137.

[4] K. D. Prashanth, P. Partlubair, and R. Dhanalakshmi, 'Evaluation and Ranking of Criteria Affecting the Supplier's Performance of a Heavy Industry by Fuzzy AHP Method', *Journal of Scientific and Industrial Research*, vol. 77, no. 5, pp. 268–270, 2018.

[5] J. Razack, I. Nazir-Khaleel, S. Rampersad, A. Zambrano, S. Chandarjeet, and S. Choon, 'Shorebase logistics for deepwater drilling operations in Trinidad, Guyana and Suriname', presented at the Society of Petroleum Engineers - SPE Trinidad and Tobago Section Energy Resources Conference 2018, 2018. doi: 10.2118/191230-ms.

[6] M. J. Hermoso-Orzáez, J. Cámara-Martínez, J. I. Rojas-Sola, and A. Gago-Calderon, 'Analytical and economic methodology for storage of large heavyweight equipment in industrial processes', *Economic Research-Ekonomska Istrazivanja*, vol. 33, no. 1, pp. 3258–3287, 2020, doi: 10.1080/1331677X.2019.1696692.

[7] I. Zennaro, S. Finco, D. Battini, and A. Persona, 'Big size highly customised product manufacturing systems: a literature review and future research agenda', *International Journal of Production Research*, vol. 57, no. 15–16, pp. 5362–5385, 2019, doi: 10.1080/00207543.2019.1582819.

[8] F. Pan and Q. Sun, 'A Traffic Control Strategy of the Heavy-duty AGVS in a Square Topology', 2019, pp. 263–268. doi: 10.1109/ICMA.2019.8816435.

[9] R. Dekker, J. Bloemhof, and I. Mallidis, 'Operations Research for green logistics - An overview of aspects, issues, contributions and challenges', *European Journal of Operational Research*, vol. 219, no. 3, pp. 671–679, 2012, doi: 10.1016/j.ejor.2011.11.010.

[10] I. V. Larina, A. N. Larin, O. Kiriliuk, and M. Ingaldi, 'Green logistics - Modern transportation process technology', *Production Engineering Archives*, vol. 27, no. 3, pp. 184–190, 2021, doi: 10.30657/pea.2021.27.24.

[11] R. Palšaitis and A. Petraška, 'Heavyweight and oversized cargo transportation risk management', *Transport and Telecommunication*, vol. 13, no. 1, pp. 51–56, 2012.

[12] M. Wang, K. Liu, T.-M. Choi, and X. Yue, 'Effects of Carbon Emission Taxes on Transportation Mode Selections and Social Welfare', *IEEE Transactions on Systems, Man, and Cybernetics: Systems*, vol. 45, no. 11, pp. 1413–1423, 2015, doi: 10.1109/TSMC.2015.2411577.

[13] M. McDougall and K. Williamson, 'Access and logistics challenges in mountain terrain pipeline projects', 2014, vol. 1. doi: 10.1115/IPC201433521.

[14] D. H. Jia and S. J. Wang, 'The logistics risk assessment studies of the large equipment of hydropower project based on three-dimensional structure', *Advanced Materials Research*, vol. 734–737, pp. 1647–1655, 2013, doi: 10.4028/www.scientific.net/AMR.734-737.1647.

[15] M. J. Cobo, A. G. López-Herrera, E. Herrera-Viedma, and F. Herrera, 'An approach for detecting, quantifying, and visualizing the evolution of a research field: A practical application to the Fuzzy Sets Theory field', *Journal of informetrics*, vol. 5, no. 1, pp. 146–166, 2011.

Appendix A. FIRST APPENDIX

TABLE VII
CLUSTERS FOR HEAVY EQUIPMENT LOGISTICS
(QUERY 1)

Clusters Label	Keyword	Occurrence
1. Data mining	Data mining	14
	Maintenance	9
	Fp-tree	4
	Fufp-tree	3
	Incremental mining	3
2. Logistics	Logistics	8
	Heuristics	3
	Integer programming	3
3. Machine learning	Machine learning	6
	Neural networks	3
4. Optimization	Optimization	6
5. Simulation	Simulation	6
6. Design	Design	5
	Flexibility	4
	Assembly	3
	Handling	3
7. Heavy equipment	Heavy equipment	5
	Safety	5
	Construction equipment	4
8. Equipment	Equipment	4
9. Reinforcement	Reinforcement	4
10. Climbing robot	Climbing robot	3
11. Health management	Heath management	3
12. Inventory	Inventory	3
13. Numerical simulation	Numerical simulation	3
14. Visualization	Visualization	3

Appendix B. SECOND APPENDIX

TABLE VIII
CLUSTERS FOR HEAVY EQUIPMENT SUSTAINABLE LOGISTICS
(QUERY 2)

Clusters Label	Keyword	Occurrence
1. Dams	Dams	2
2. Distributed manufacturing	Distributed manufacturing	2
	Sustainability	2
3. Embodied energy	Embodied energy	2
	Infrastructure	2
4. Optimization	Optimization	2