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Environmental impact of operations carried out in the context of distributed maintenance: a literature review

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Abstract **–** Operations related to distributed maintenance, like any other activity, have a considerable impact on the environment. This impact is not negligible and must be evaluated in order to have a global vision of the operations carried out within this framework. In order to highlight these environmental effects more clearly, it is necessary to determine indicators that will make it possible. A literature review should then be provided in order to collect as much information as possible concerning the environmental impact of this activity. With the aim of knowing in which direction this literature review will be oriented, it will be useful to identify the concrete aspects of distributed maintenance that represent a threat and have a significant impact on the environment, and to identify some parameters that will allow to carry out the analysis of their effects. The purpose of this paper is therefore to highlight the gaps in information in the literature and thus propose solution approaches, including adaptations in other domains such as maintenance and transports that could be well adapted in the context of distributed maintenance.

Keywords *– Distributed maintenance, Sustainable maintenance, Distributed sites, Sustainable transport, Environmental requirements, Pollution, Environmental indicators, Performance indicators.*

I. INTRODUCTION

Distributed maintenance is defined as an approach to implementing maintenance based on the analysis of activities and resources using a network approach [1]. It enables interventions to be carried out quickly and efficiently and takes advantage of an information system adapted to the needs and rigorous monitoring of operations. It also allows to reduce random shutdowns, control the supply chain, intelligently manage human and material resources and benefit from external expertise and flexibility [4]. However, recent environmental constraints are pushing to focus more on the issue of the environmental impact of the systems implemented. In fact, environmental impact assessment is defined as an interdisciplinary, multi-step procedure to ensure that environmental considerations are taken into account in decisions about projects that may have an impact on the environment [2]. In this case, this environmental impact assessment refers to the process of analyzing the effects of distributed maintenance operations on the environment and measuring the environmental acceptability [3] of this maintenance system. The question raised by this research topic and which will be addressed in this work is the following: which aspects of distributed maintenance represent a concrete threat to the environment and what are the most relevant indicators to better assess its environmental impact? In the continuation of this research work, it will be about to identify papers likely to enlighten further and to give elements of track for the resolution of this research issue. The methodological approach is presented in the second section. The third section presents the results of the literature review, including a brief summary of what is found in the documentation about the topic, as well as notable lacking in the literature that may constitute opportunities for future research. The last section concludes this literature review.

II. RESEARCH METHOD

A. Research databases

Several databases are available to the scientific community to search for relevant papers related to their work. In order to focus the scope of the results obtained and to circumscribe the level of relevance of the papers

found, Beluga (https://beluga.univ-grenoble-alpes.fr/discovery/search?vid=33UGRENOBLE_INST:UGrenoble&lang=fr) has been chosen because it enables to filter the results by title and abstract, the full text and other criteria. For this work, the search for papers is made in various databases available on Beluga such as IEEExplore, Science direct, Taylor and Francis, Web of science and 12 others.

B. *Defining and combining the relevant keywords*

The keywords allow to access more easily the scientific papers available in different databases. They are important words and expressions that describe and represent the content of these papers. In order to identify some interesting keywords, it is necessary to find those of the papers dealing with the subject: distributed maintenance on the one hand, and environmental impact assessment on the other hand. This will enable to evaluate the keywords while having a general vision of the studied subject. Thus, to ensure a preliminary search of papers, the two aspects stated above are considered while using variants, synonyms and other terms likely to help to circumscribe the research field. For more precision, these keywords are combined using the "AND" and "OR" operators. The links obtained are thus represented in Fig.1. (where each link represents the "AND" operator and each possible fork represents the "OR" operator) and a literal modeling of these logical relationships in Appendix 2. as used in the paper search:

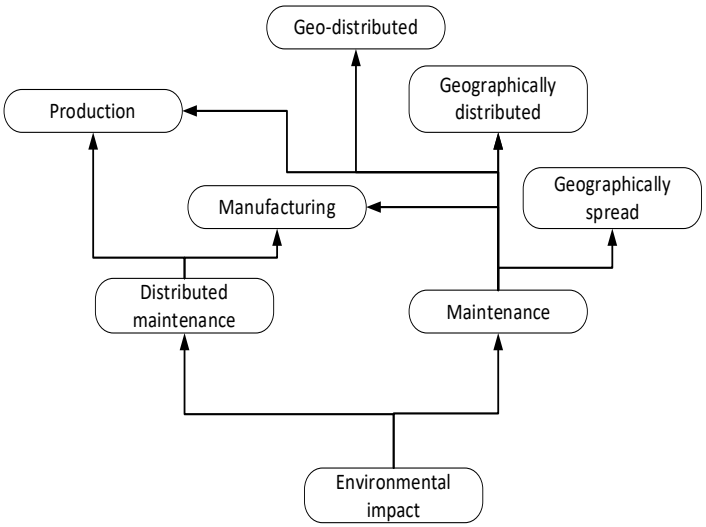

Fig.1. Definition of keywords for preliminary research

It is therefore a matter of highlighting the trivial keywords resulting from a preliminary analysis of the topic. First of all, the relationship between "distributed maintenance" and "production / manufacturing" helps to circumscribe the study framework. Indeed, the work is done in a context of distributed maintenance linked to the production activity, hence the necessity to restrict the study domain to this particular perimeter. Then, the relationship between "maintenance" and "geo-distributed / geographically distributed / geographically spread" enables to identify papers dealing with distributed maintenance without explicitly referring to it. Finally, the relationship between "environmental impact" and "maintenance / distributed maintenance" is used to extract papers dealing with the environmental impact of maintenance in general and distributed maintenance where feasible.

Once these combinations are obtained, the search for keywords used in the literature and directly connected to the study is involved. It should be noted that this preliminary paper search is exclusively aimed at determining relevant keywords. Thus, 29 papers are obtained on Beluga that contain at least one combination of the keywords in their titles, that are written in English and that were published between 1995 and 2022. At the end of this work, 82 keywords related to the two aspects treated are obtained. The keywords obtained are then represented in a mind mapping (see Appendix 1) to highlight the connections between these keywords identified in the documentation. In order to target the final keywords, those that will be retained should allow to establish a connection between distributed maintenance and the environmental impact study on the one hand, and those that deal with the definition of indicators to assess this impact on the other hand. A final list of keywords (Appendix 3.) is then obtained and their combination (Appendix 4.) with each other.

C. *Defining filters*

The definition of filters for this literature review aims at obtaining relevant papers in accordance with the subject treated. It is therefore a question of defining inclusion criteria that describe the selection characteristics of interesting papers, and exclusion criteria that refer to the elimination characteristics of papers that are not relevant to the study. Therefore, firstly consider all papers related to the topic that have

at least one combination of keywords either in their titles or in their abstracts, and were also published between 1995 and 2022. Then, eliminate the redundant ones, and finally focus on the papers that specifically deal with the environmental impact of the different aspects of distributed maintenance. The method can therefore be summarized in Fig. 2.:

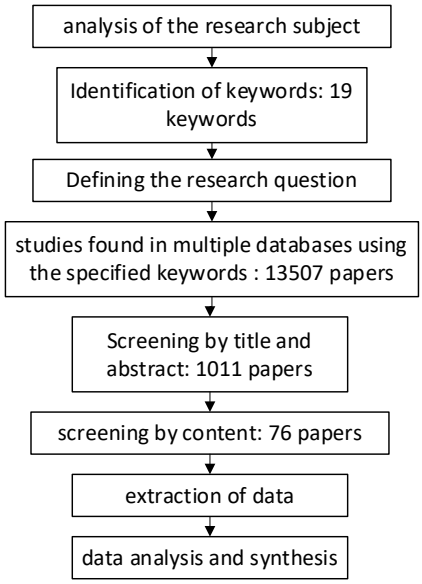

Fig. 2. Summarize of the research method

These steps enable to propose an assessment of the studies carried out and to take stock of the questions already asked. This approach is in line with the research objectives because it reduces the field of possibilities in order to extract as precisely as possible the information that could help.

The results obtained can be classified into four categories (Table 1.). Each of them represents a particular aspect of the topic and is likely to contribute to the resolution of the research question. Indeed, distributed maintenance refers to maintenance interventions on geographically distributed production sites, so operators and spare parts are transported from the centralized maintenance workshop to the said sites. Therefore, assessing the environmental impact of distributed maintenance means analyzing the environmental effects of the maintenance operations on the one hand, and the transportation constraints (travel from the centralized maintenance workshop to the production sites) on the other hand. In order to be able to make a rigorous assessment, it is needed to materialize these impacts by measurable quantities: environmental impact indicators.

Table 1. Relevant articles found

section of the study	**N° of relevant results**	**References**
Distributed maintenance	9	[1], [4], [15] – [21]
Environmental impact assessment of maintenance operations	13	[3], [22] – [33]
Transportation-related environmental impact assessment	24	[5] – [9], [34] – [52]
Environmental impact indicators	30	[11] – [14], [53] – [78]

III. RESULTS OF CONTENT ANALYSIS

Distributed maintenance ensures the availability and reliability of industrial production equipment installed on several geographically distributed sites. In a more down-to-earth way, distributed maintenance is a type of maintenance whose added value is mobility (the use of transport vehicles for the mobility of workers and spare parts). Therefore, it is assumed that the study of the environmental impact of distributed maintenance could be done through a study of the impacts of maintenance activities on the one hand and the mobility function on the other. Following the above-mentioned information searches, the results obtained were subdivided into different categories. The study will therefore be based on each of them.

- *General information on distributed maintenance:*

The concept of distributed maintenance exploits the knowledge of maintenance and network organization [1]. Traditionally, the maintenance system has been designed with an internal vision. Today, the concepts of subcontracting, outsourcing and networking allow to approach the design of a maintenance system in a new and structured way: distributed maintenance [4]. The resulting system architecture includes a set of processes

(human, material and informational), internal or external to the production site, qualified to perform a set of processes. This maintenance system involves three main factors (Fig.3.): firstly, a centralized maintenance workshop constituting the very basis of maintenance operations, secondly, mobile maintenance workshops (transport vehicles) driven by a maintenance agent and carrying spare parts, and thirdly, geographically distributed production sites where maintenance operations are carried out.

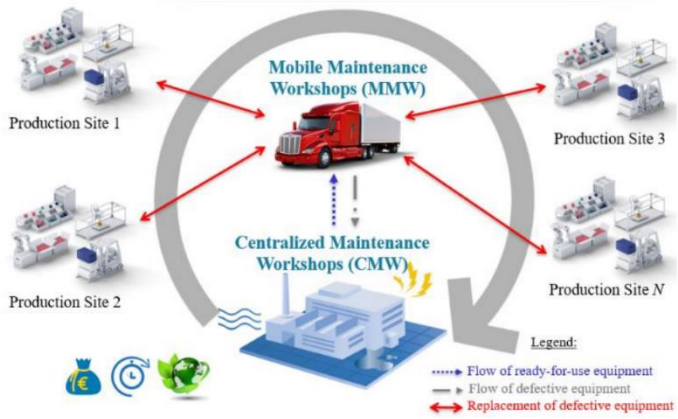

Fig. 3. Distributed maintenance context

The observation is the following: the structure of the distributed maintenance can be subdivided into two main activities which are the maintenance itself (carried out on the production sites for the replacement of defective parts and in the centralized maintenance workshop for more advanced interventions), and the transport (in particular to ensure the displacement of a maintenance worker, as well as the spare parts and the material needed). Based on this observation, it is therefore useful to look for papers dealing with the environmental impact of these two activities.

- *Environmental impact assessment of maintenance operations:*

There are many research works analyzing the impacts of a system (e.g., a process, a machine...) on the environment or treating the relationship between the environment and the company. However, few works deal with the relationship between maintenance and the environment, this relationship remains implicit in a context where the protection of the environment is a major issue [3].

An environmental impact study of distributed maintenance operations would therefore make it possible to take into consideration the negative and positive effects, to take into account the intentional and unintentional effects linked to the intervention procedures on the production sites and also to include the analysis of the causes of the observed effects. In order to be able to materialize this impact study in a concrete way, impact indicators will be used. However, measuring environmental performance presents many challenges: environmental impacts are complex and often difficult to quantify, there is no universally accepted approach to weighting different environmental impacts, and the availability and quality of environmental data is often poor. In addition to these obstacles, it will be essential to find indicators that can best characterize the impact of distributed maintenance activities.

- *Transportation-related environmental impact assessment:*

The mobility aspect represents the pillar of the distribution function in the context of distributed maintenance. Indeed, this maintenance is said to be distributed because the maintenance agents can intervene on several sites and also transport the spare parts as well as their working material. To carry out this task, it is necessary to use transport vehicles. Therefore, it is appropriate to study their environmental impact [5]. Transportation causes a multitude of environmental effects [6]. Given the diversity and complexity of the impacts, each has its own way of putting them into perspective. An indicator of the environmental impact of transport would thus aim to monitor the evolution of transport-induced air pollution over time and space, compare technological solutions, compare modes of transport, identify a particularly polluting element within the transport object under consideration, and assist regulation [7].

- *Environmental impact indicators:*

Environmental impact assessment requires the implementation of more or less innovative tools such as green accounts [8], eco-balance, green dashboard, environmental budgets, environmental external costs [9], and others. These tools enable to produce and communicate information on the environmental impacts

of human activities and on the measures taken to limit the depletion of natural resources. Among these tools, environmental audits and indicators are increasingly used. Environmental indicators are quantities [10], based on observable or calculable data (for example the carbon footprint), that reflect the environmental impacts of a given activity in a variety of ways [11]. They enable to evaluate the level of environmental performance and to identify possible areas for improvement.

There are several types of indicators [12]. Thus, selecting the most appropriate indicator remains a very difficult task. These indicators vary according to the system under study and the level of control, the number of action variables (simple or complex indicator), the position of the decision-making authority [12], etc. To judge that an indicator is good, it must cover many characteristics [13], in particular that the indicator is objective (independent of the interpretation of the manager or the measurement instrument), quantifiable faithful to the answers given (this characteristic is linked to the precision of the definition of the elements making up the indicator as well as the rigor of the information processing procedures), simple and understandable (the method of calculating the indicator must be understood and well assimilated by those who calculate the indicator), sensitive (sensitive to the phenomenon it is supposed to measure) [3]. Hence, the exploration of environmental impact indicators (Table 2.) for the evaluation of distributed maintenance could involve the prior study of its performance indicators in order to define the basis and framework of the environmental impact study that will follow.

Table 2. Classification of indicators in the context of distributed maintenance

Activity	**sub-activity**	**Indicator evaluation points**	**scope of evaluation**	**Example of indicators**
Distributed maintenance	Maintenance operations	Performance	cost, quality, energy, equipment availability, etc.	MTBF, MTTR, direct maintenance costs (labor, consumption of spare parts, etc.)
		Environmental impact	impact on air, water and soil through emissions, effluents, wastes	emissions of greenhouse gases (such as CO_2), ozone-depleting substances, total emissions to water, etc.
	Transport activities	global management	monitoring of operations: cost, vehicle traceability, fuel consumption	average time per trip, number of vehicles, average cost of operations, quality of service, etc.
		level of environmental pollution	atmospheric pollution, concentration of pollutants in soil and water	CO_2 emission, concentration of oil-derivatives, pesticides and salt in fresh water and soil, etc.

The importance of quantifying maintenance drives managers to select and use relevant indicators to know the operating status of their department and to justify all past, current and future actions and expenditures [3]. Traditional definitions of maintenance focus on “good performance”. Of course, the notion of "good performance" can also include respect for the environment (operation without overconsumption of energy and materials, without air, soil and water pollution) but it is clear that “good performance” refers more to the availability of a machine and the environmental dimension remains implicit if not absent.

The outcome is that environmental performance remains a largely vague and ambiguous concept, and thus a source of subjective interpretations [14].

In view of all this, it seems obvious that there is a considerable gap to be filled. Indeed, this preliminary survey of research papers makes certain aspects obvious:

- The lack of information on maintenance indicators in the literature as well as the absence of works dealing with the environmental impact assessment of distributed maintenance;

- It does not provide a ready-made list of the steps to be taken to carry out an environmental impact assessment in this context, let alone indicators to assess it;

- There is a considerable need to integrate environmental constraints into distributed maintenance policies.

Considering all these shortcomings, it is advisable to think about the implementation of a study that could more or less contribute to fill these gaps.

IV. CONCLUSION

The need for this study is mainly based on the realization of a literature review on the evaluation of environmental impacts in a distributed maintenance context. The objective is to present a general view of what is currently found in the literature regarding the integration of environmental constraints in distributed maintenance activities. It was therefore possible to present the components of distributed maintenance as well as their interactions with each other, and thus highlight the real necessity of integrating environmental issues in the implementation of this maintenance system. It thus emerges a flagrant lack of information concerning the application of environmental strategies in maintenance policies in general, and a complete absence of information regarding this application in the context of distributed maintenance. It is within this framework that this work is situated, since the integration of the environmental dimension in distributed maintenance operations would allow the optimization of activities by taking into account environmental considerations. Given the above, the question arises as to what approaches can be adopted to best reduce the environmental impact of distributed maintenance operations, in order to provide a solid basis for environmental consequence management and improvement actions, and to promote the integration of the fundamental objectives of environmental protection and sustainable development.

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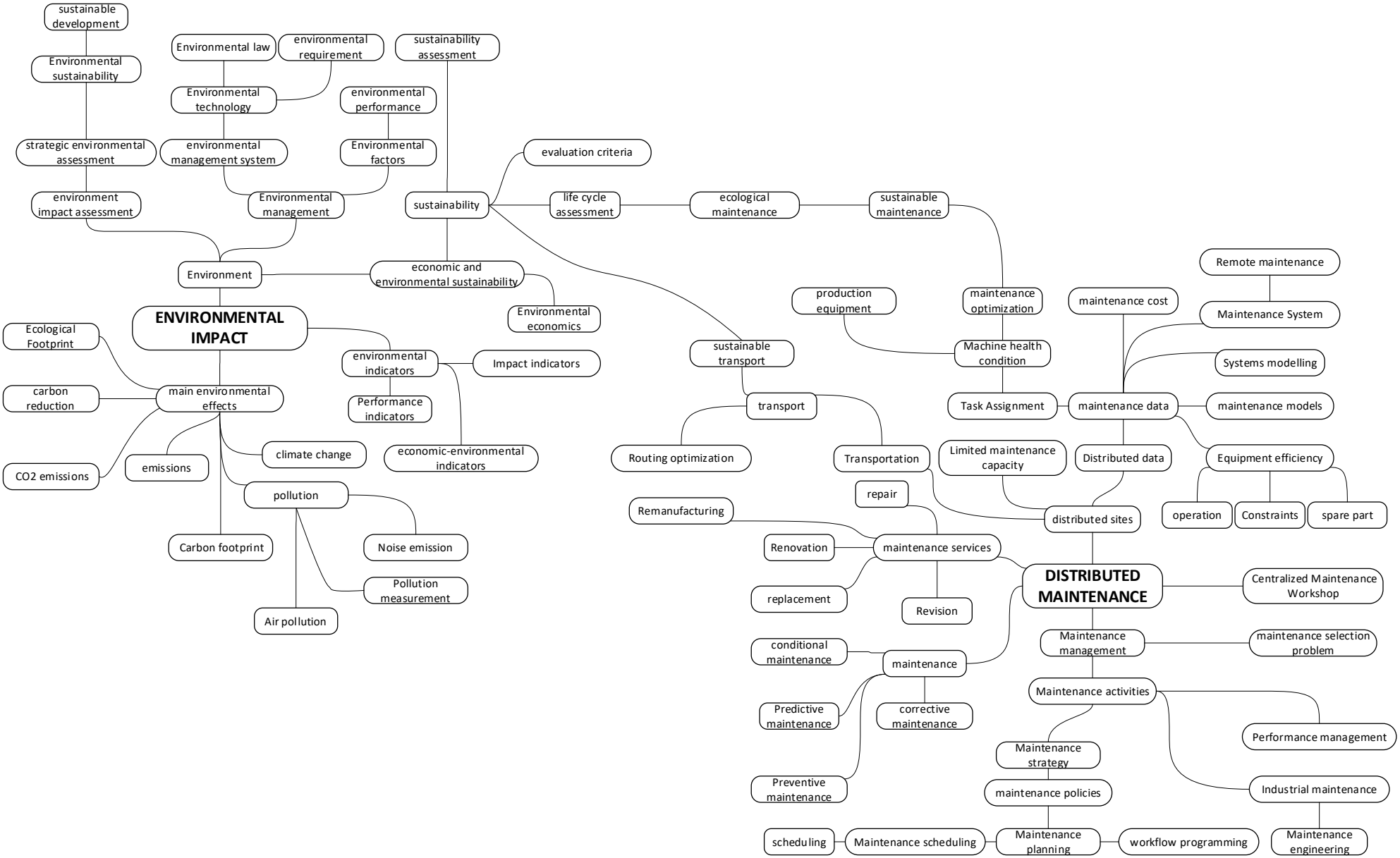
Appendix 1. Mind-Mapping to highlight keywords



Appendix 2. Preliminary combination of keywords

Distributed maintenance	**Environmental impact**
(“distributed maintenance” OR maintenance AND (production OR manufacturing OR “geo-distributed” OR “geographically distributed” OR “geographically spread”)	“environmental impact” AND (maintenance OR “distributed maintenance”)

Appendix 3. List of keywords used in the study field

Distributed maintenance	**Environmental impact**	**Indicators**
“maintenance optimization”, “maintenance” “machine health condition”, “distributed maintenance” “transport”, “distributed sites”, “sustainable transport”, “life cycle assessment”, “ecological maintenance”, “sustainable maintenance”	“environmental impact”, “environment”, “sustainability”, “pollution”, “environmental requirement”, “environmental management system”	“indicators”, “environmental indicators”, “performance indicators”

Appendix 4. Combination of keywords

Distributed maintenance AND environmental impact	**Environmental impact AND indicators**
(“maintenance optimization” OR “maintenance” OR “machine health condition” OR “distributed maintenance” OR “transport” OR “distributed sites” OR “sustainable transport” OR “life cycle assessment” OR “ecological maintenance” OR “sustainable maintenance”) AND (“environmental impact” OR “environment” OR “sustainability” OR “environmental indicators” OR “performance indicators”, “pollution” OR “environmental requirement” OR “environmental management system”)	(“environmental impact” OR “environment” OR “sustainability” OR “pollution” OR “environmental requirement” OR “environmental management system”) AND (“indicators” OR “environmental indicators” OR “performance indicators”)