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Article

Digitalization for sustainable maintenance services: A systematic literature review

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Digitalization for sustainable maintenance services: A systematic literature review



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ABSTRACT

Purpose: Maintenance services have evolved hugely from an inevitable part of production as a failure fixing activity to an essential strategic element to accomplish several business objectives including profit making. With the growing maintenance service industries, sustainability has remained a challenge and have garnered a great deal of attention over the last two decades. Maintenance services' impact on sustainability is a known concern and almost all sustainability dimensions are affected either positively or negatively. The purpose of this paper is to review and discuss the related literature on different maintenance services and their impact on sustainability.

Design/methodology/approach: This research aims to study these concepts (*maintenance services, sustainability impact and digitalization*) independently and in relation to each other through systematic literature review of high-quality articles, with a focus to understand the relation between maintenance and sustainability and depict the role of digitalization in achieving those sustainability goals.

Findings: This study presented the trend and publications related to maintenance services and its sustainability impact throughout 2009 to 2020. Publications related to maintenance services and corresponding sustainability impact were analyzed as a problem space and publications related to digitalization were analyzed as a solution space. Based on the analysis, a discussion on digitalization of maintenance service was conducted to highlight possible benefits and improvements towards various sustainability impacts.

Originality/value: Digitalization and digital technologies are evolving and advancing every day. It is still yet to be known, what role could digitalization play in the maintenance services' impact on sustainability. This paper contains a state of the art on publications and discussion related to the digitalization for sustainable maintenance services. It offers insights and information on the current body of knowledge to academics, researchers, practitioners, maintenance personnel, digital managers, development teams and stakeholders concerned with maintenance services.

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1. Introduction

Human needs and demands are the most important foundation of new and better advancements towards industrialization, technology development and service consumptions. These needs and demands keeps growing and with the always rising population growth, they grow exponentially. Then, the fulfilment of every need and demand leads to more production, more industries, more factories, more raw materials, more use of earth's natural resources and eventually more consumption, then again, more needs, more demands and this loop continues over and over again. This already has a significant effect on sustainability (Johnston et al., 2007) and many researches are being carried on addressing these issues. Maintenance services (Susto et al., 2015) is one area that is a significant part of the same ecosystem where *human needs and demands* and its fulfilment exists. Every product, asset or equipment is manufactured to fulfill a purpose and they all are expected to operate with full potential for a desired lifetime. Their operating conditions are always different even for same products. There are segments in time, when these products become less and less effective day by day and eventually stops to operate or fails to produce. This is called a downtime (Nittke, 2005) where the equipment is of no use at all, production stops or machine does not do what it is intended to do. The longer the downtime, the longer and bigger the loss. This is the value creator for maintenance where it can step-in and solve the problem and start the operations again. Some maintenance is performed after the breakdown or some before any failures; but maintenance is an inevitable need. From big industrial plants processing gold, silver, iron or steel to the plants processing waste water; huge car manufacturing factories to the medium sized factories making clothes; the small sweet confectionaries to household cooktops; every huge, big, medium or small industries, factories, machineries and equipment requires maintenance. Even the most sustainable known recycling centers require maintenance to their recycling machineries.

Maintenance can impact different sustainability dimensions. Machineries without maintenance for a longer period has a high probability to fail or become ineffective. This has impact on industry's profitability and on workers' health and safety. In contrast, a well-maintained asset can have higher availability and utilization (Arputharaj, 2015) and operate with best efficiency. The longer the asset is alive the lesser burden it is to the environment. These are just some common understandings and there is a lot more to research and find. So, maintenance service business is huge and covers all parts of the globe. We still are unaware of what and how large its impact is on sustainability development, or how can we maximize its impact, or can we even do that?

Technology is advancing every day and it has significant advances on maintenance services. The evolution of maintenance (Jain, Bhatti, & Singh, 2014) from reactive to preventative and then to proactive is an example of developing technologies. Nowadays, many equipment and their components are capable to collect their operational data for a period and this could be analyzed, and many interesting revelations could be made from it. This is an era of digitalization and it transforms organizations to utilize digital technologies and data to improve the way things are done. Digitalization can empower maintenance services by making use of collected data and advance technologies to monitor the equipment health, diagnose faults, predict and troubleshoot failures well before it could happen and even optimize the performance (Johansson, Roth, & Reim, 2019).

Digitalization could be the most sustainable approach towards maintenance services, and this is yet to be understood.

This literature review studies maintenance services and different sustainability impacts from the problem space and digitalization aspects from the solution space. It tries to analyze different kind of maintenance types, different sustainability dimensions impacted by it and the benefits and challenges provided by the adoption of digitalization. Finally, it correlates maintenance services and its impact on sustainability and the role of digitalization in making sustainable maintenance services.

Section 2 discusses the systematic literature review approach adopted for this research and the essential steps involved in the process. Section 3 presents the result of the SLR along with the content analysis. Section 4 provides the discussion based on this review. Finally, Section 5 concludes this review.

2. Methodology

This literature study partially adopts systematic literature review (Kitchenham & Charters, 2007; Pai et al., 2004) study to identify relevant academic literatures highlighting the concepts within the research protocol. The research protocol here consists of a problem space constituting main concepts defined as maintenance services and sustainability impact; and a solution space defined by digitalization. The goal of the systematic literature review reflects on identifying well documented maintenance services studies discussing the impacts on different sustainability dimensions or addressing any digitalization approaches within. The main target was to understand the correlation between maintenance services, its digitalization aspects and its impact on sustainability.

2.1. Selection of databases and search terms

Considering the main goal of this systematic literature review (as mentioned above), it can be deduced that the key search terms applicable are "Maintenance service", "sustainability", "effect", "impact" and "digitalization"; and identifying well documented maintenance services articles is the main target. Maintenance services related articles are commonly found in scientific reference databases such as Web of Science, Scopus, SpringerLink and EBSCO etc. and hence these four scientific reference databases were selected for this bibliographic search. These key concepts from the research protocol composed the search string together with Boolean operators AND/OR. The exact search string used is ("*Maintenance service**") AND (((*"Sustainab*"*) AND ("*Effect*" OR "*Impact*")) OR ("*Digital*"*)). The searches were conducted in November 2020 by the first author and it resulted in 1908 papers.

2.2. Selection process

The initial search yielded a huge number of articles in terms of quantity. In order to find the most relevant and highly usable contents, the searched articles were further filtered in 4 different stages using unique exclusion and inclusion criteria as depicted in Fig. 1.

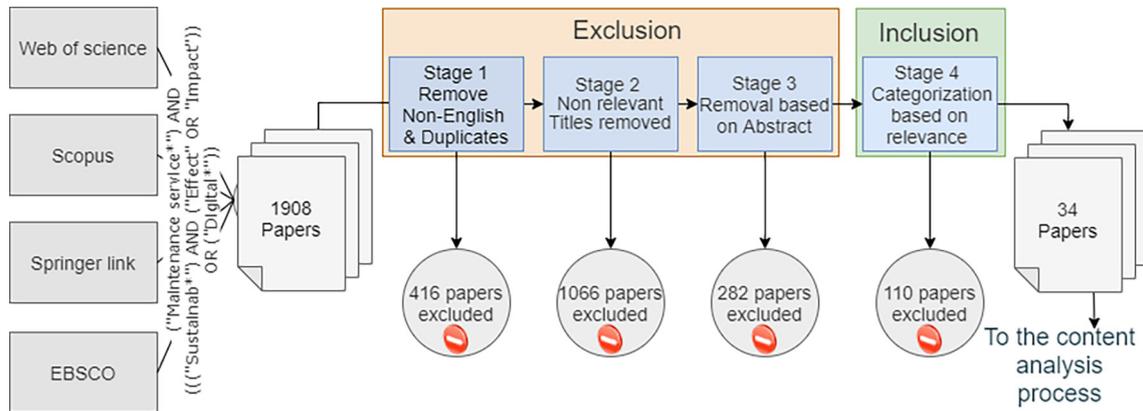


Fig. 1. Overview of selection process.

2.3. Exclusion criteria

First three stages within the selection process (as shown in Fig. 1) depicts exclusive stages. The exclusion criteria adopted within this research is based on:

- Research published in language other than English
- Duplicates within the search space
- Syntactically non-key concept inclusive paper titles
- Non-key concepts inclusive paper abstract, introduction and conclusion

Firstly, articles in any other language other than English and all duplicates were excluded in stage 1, which removed 416 papers including 268 non-English and 148 duplicate papers. Further in stage 2, titles were screened, reviewed and those titles which didn't contain any one of the key concepts, were excluded.

At stage 3, abstract, keywords and whenever necessary introduction and conclusion of the remaining 426 paper were screened. Based on the readings, the maintenance service papers were categorized usable and non-usable within this research context. All those maintenance services papers which contained types of maintenance studies, digitalization cases or addressed any impact or effect on sustainability were tagged usable and rest as non-usable. Solely based on these syntactic analyses; and strictly not reading the full text, 282 papers were removed. The result of the entire exclusion stages excluded 1764 papers limiting the remaining number of articles to 144 for the final stage filtration.

2.4. Type of study and inclusion criteria

Final stage in the selection process represents inclusive stage and relies on types of studies and inclusion criteria. The nature of the contribution of the article and the research method used within was screened and mapped to the categorized study types as shown in Table 1. Individually the article theme was further understood and mapped with the inclusion criteria. The inclusion criteria adopted in this research are:

Table 1
Types of study (Pires et al., 2015).

S1 What is the nature of contribution of article?	S2 What is the research method used?
S1.1 - The proposition of a framework	S2.1 - An experimental research?
S1.2 - Research about the state of the art	S2.2 - A case study?
S1.3 - A definition of a method or methodology	S2.3 - A literature review?
S1.4 - Futuristic ideas	S2.4 - Mixed Methods (combination of above)?
S1.5 - Other types of contribution	S2.5 - Other type of research?

- Q1: Does the article establish relation between maintenance services and Sustainability impacts?
- Q2: Does the article establish relation between maintenance services and Digitalization cases?
- Q1 + Q2: Does the article establish relation between maintenance services and both sustainability impacts and Digitalization cases?
- Q3: Does the article establish relation between maintenance services and other multiple key concepts other than sustainability and digitalization?

144 papers were still significantly a large number for an extensive full review for stage 4. However, abstract, introduction and conclusions were read and in almost half of the cases, full text was read and assessed for the study types and inclusion criteria. The articles that didn't fulfill any one of the inclusion criteria (Q1, Q2, Q1 + Q2, Q3) were tagged non-usable. The articles mapped as "Other" study types in terms of contribution (S1.5) and method (S2.4) were also tagged non-usable. Further, among those usable papers, inaccessible papers and papers containing hypothetical cases were also tagged non-usable. As a result, 34 high quality papers were revealed, and was selected for the final content analysis.

2.5. Convergence criteria for content analysis

Grading the selected articles for review tells how closely it is connected to any specific key concepts and helps to identify and categorize articles for further specific content analysis. The convergence criteria defined within the context of this literature research and its corresponding points used to score each paper are listed in Table 2. The selected 34 article were further scored using the defined criteria. Finally, the contents from the scored articles were analyzed and reviewed. The list of selected papers with marked type of studies, inclusion criteria, brief contextual description and convergence grading are listed in Appendix E.

3. Results and analysis

As an outcome of the search and selection process, 34 (out of 1908) high quality papers were selected for this literature review. The selected papers

Table 2
Convergence criteria and corresponding points.

Criteria	Points
C1 - Keywords maintenance services and sustainability impact were identified	0.5
C2 - Keywords maintenance services and digitalization cases were identified	0.5
C3 - Keywords other than maintenance services, sustainability and digitalization were introduced	0.5
C4 - Comparison of various maintenance studies made in the form of Literature review	0.5
C5 - Futuristic or digital solutions of maintenance services for improving sustainability proposed	0.5
Max	2.5

were from 31 different proceedings across four scientific databases, as shown in Table 3. The publishing dates for these selected articles ranged from 2009 to early 2020, including most of the selected papers from year 2014 (18% of all selected) and least from year 2012 i.e. zero papers. Fig. 2 shows the yearly - quantitative distribution of the selected papers.

During the stage 4 of the selection process, all the papers were categorized based on the study type categorization listed in Table 1. The mapping was performed to identify the nature of contribution of the articles and the methodology used within the research. The 'Type of study' mapping of the selected articles is shown in Fig. 3. The method mapping depicted that, among all the selected articles, 32% adopted case study and equally another 32% adopted literature review as the research method. The contribution mapping showed majority (38%) of the papers contributed towards state of the art and approximately 24% each contributed to present futuristic ideas and proposing a framework.

Besides 'Type of study' categorization, stage 4 mapped all the papers according to the inclusion criteria (concept) presented in Section 2.4. The concept mapping mostly describes how relevant each article is w.r.t to the

key concepts adopted in this research. The concept mapping of the selected articles is shown in Fig. 4. The analysis shows most (41%) of the selected articles establishes relationship between maintenance services and sustainability impacts followed by 26% establishing relationship between maintenance services and digitalization study. The unique 18% establishes relation between maintenance studies and both sustainability impact and digitalization concepts. Only 15% of the entire selected articles deals with something other than sustainability and digitalization. This 15% mostly studies different types of maintenance services and ideas focused to specific application areas.

As part of systematic mapping, all selected articles were scored based on convergence criteria presented in Table 2. Five different convergence criteria were presented each with 0.5 points. Articles fulfilling to all five criteria receives 2.5 (max) points. The least each article can receive was zero points and such articles were already excluded from the final selection. Thus, 0.5 points is the minimal in this case of final selected articles, as they meet at least one criterion. This grading helps in classifying the selected articles in terms of its degree of relevance for this review. The scores for each

Table 3
Scientific references databases used and their associated proceedings.

Databases	Publications
Web of Science	Journal of Facilities Management
Scopus	Procedia Manufacturing
Springer	Journal of Quality in Maintenance Engineering
EBSCO	Facilities
	International Journal of Lean Six Sigma
	Advances in Environmental Biology
	Intelligence and Lecture Notes in Bioinformatics)
	Journal of Cleaner Production
	Sustainability (Switzerland)
	IFAC-PapersOnLine
	Systems Management, IEEE IESM 2015
	International Journal of Industrial and Systems Engineering
	Environmental Performance Evaluation
	Journal of Manufacturing Technology Management
	Integrated Maintenance Planning in Manufacturing Systems
	Complex System Maintenance Handbook
	International Journal of System Assurance Engineering and Management
	Engineering Asset Lifecycle Management
	Integrated Maintenance Planning in Manufacturing Systems
	Neural Computing and Applications
	Knowledge-Based and Intelligent Information and Engineering Systems
	Procedia CIRP
	Building Maintenance Processes and Practices
	E-maintenance
	European Journal of Operational Research
	International Journal of Computer Integrated Manufacturing
	CIRP Annals - Manufacturing Technology
	International Journal of Procurement Management
	IFAC-PapersOnLine
	23rd International Conference for Production Research, ICPR 2015
	Industrial Marketing Management

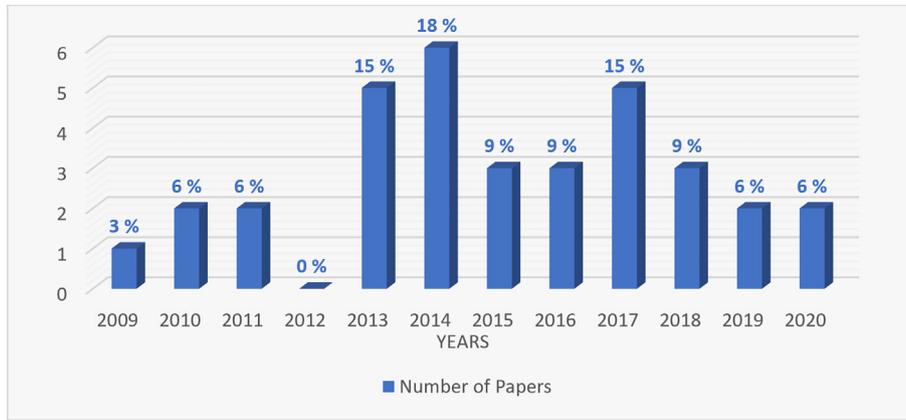


Fig. 2. Distribution of selected paper quantity vs years.

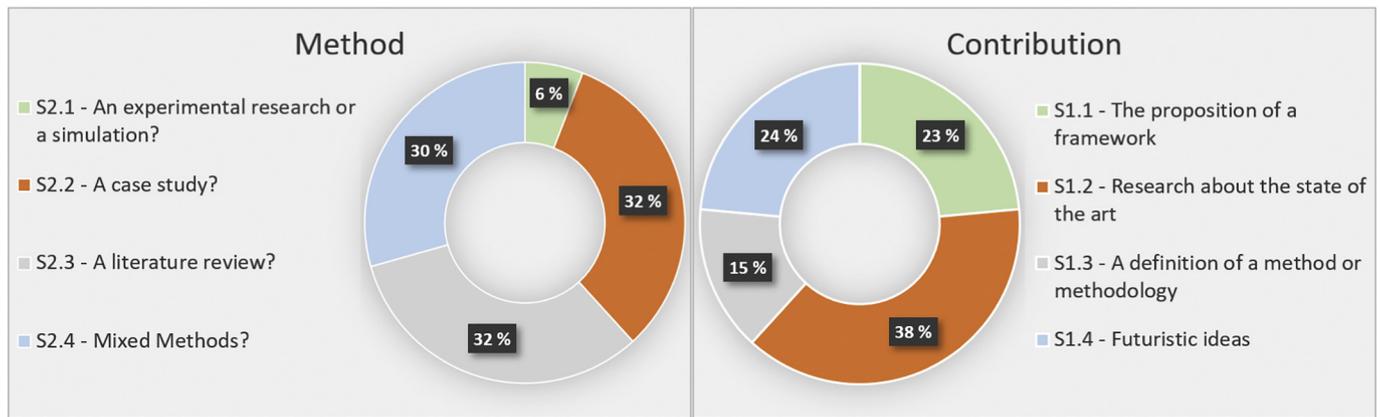


Fig. 3. Type of studies – Method and contributions based on the selected papers.

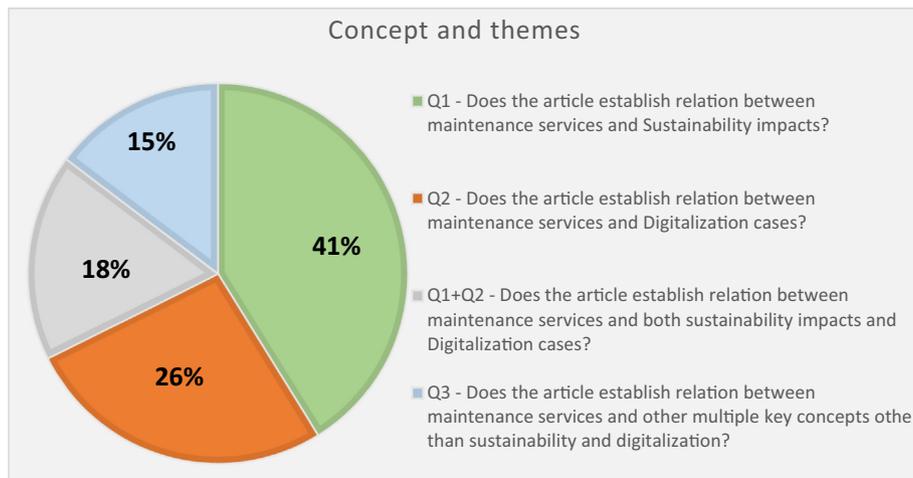


Fig. 4. Concept and themes – based on the selected papers.

paper can be seen in Appendix E and the score - quantitative distribution of the selected papers is shown in Fig. 5. Among all the selected papers, the grading distribution shows that only 6% seemed highly relevant with 29% moderately relevant and 26% relevant enough to discuss just one key concept.

ISIC classification of United Nations has categorized 21 different application area categories (United Nations Industrial Development Organization, 2015) as shown in Appendix A. Each selected paper was mapped to one of those UN ISIC application categories based on the primary focus of the maintenance services exhibited within the paper's

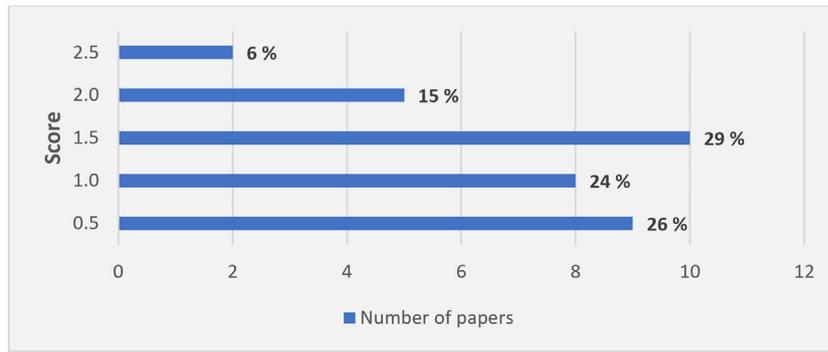


Fig. 5. Distribution of selected paper quantity vs convergence score.

application scope. The selected papers focused on various application areas ranging from mining to manufacturing, construction industries to real estates and financial activities to human health and social activities. This mapping revealed that ‘Manufacturing’ domain was the most popular application area as 35% of the selected articles primarily focused on it. Fig. 6. shows the quantification of articles categorized according to the ISIC classification of the UN.

The key concepts associated with this review are ‘maintenance services’, ‘sustainability impact’ and ‘digitalization’ within both problem and solution space. During the concept mapping, various other concepts existing in selected papers were enlisted and its frequency of occurrence as occurred in number of articles was recorded. All these existing concepts are represented together signaling the varying significance of each concepts within this review and depicted as co-occurrence map (Fig. 7) to identify the direction and depth of this review.

The co-occurrence map presented in Fig. 7 was obtained from the direct terminologies associated with key concepts in order to visualize the most essential direction for this review. This co-occurrence map clearly visualizes maintenance (main node) has two directional aspects of problem space. One is the maintenance types where its main categories (reactive, preventive, predictive and other) are displayed in the first level and the second level i.e. the deepest edges relate to their various sub types. The next direction is the sustainability dimensions and its only hierarchy level deals with the five different sustainability dimensions (economic, technological, social, environmental and governance) as shown in the map. The size of the bubble depicts its occurrence in number of selected articles, i.e. the larger the bubble, the more articles it has featured in and vice versa. The more frequent (big sized) ones such as various types of maintenance services and different sustainability dimensions (environmental, social, economic, technological etc.) are directly related to primary concepts and

are well discussed. Whereas, the lesser frequent ones (small sized) are related to the deeper discussions of those sub concepts and are superficially covered within the selected reviewed articles.

3.1. Maintenance service types

Maintenance service is explained variably in almost all of the selected articles. In general, maintenance service helps to retain values of assets; achieve desired performances; influence production quality and quantity; ensures reliability and safety; reduces production costs and improves customer satisfaction; and many more (Al-Turki et al., 2014a, 2014b; Chen, Zhang, & Wu, 2018; Chong et al., 2019; Jain et al., 2014; Roy et al., 2016; Starr et al., 2010). It can be understood that maintenance services intend to keep a product operating at its highest potential, throughout its lifetime. So, it mainly deals with either maintaining the asset or restoring them to its desired operating condition. Every product has different operational lifetime and thus requires different level of continuous maintenance. With some examples, Fig. 8 shows comparatively products with longer length of life requires higher level of continuous maintenance and vice versa (Roy et al., 2016).

Maintenance services has generally evolved through years and generations. Jain et al. (2014) describes a type-based evolution where maintenance services evolved from breakdown maintenance in pre-1960s progressing to planned preventive in mid-60s then condition-based in 70’s to reliability-centered in 80’s and eventually to productive maintenance in 90’s. Similarly, 60 different kinds of maintenance over the last 70 years have been mentioned and studied within the selected articles. This is an indication of a continuous and consistent progress in the development and evolution of maintenance services. Based on the nature of those maintenance types explained within the articles, it has been categorized into 3

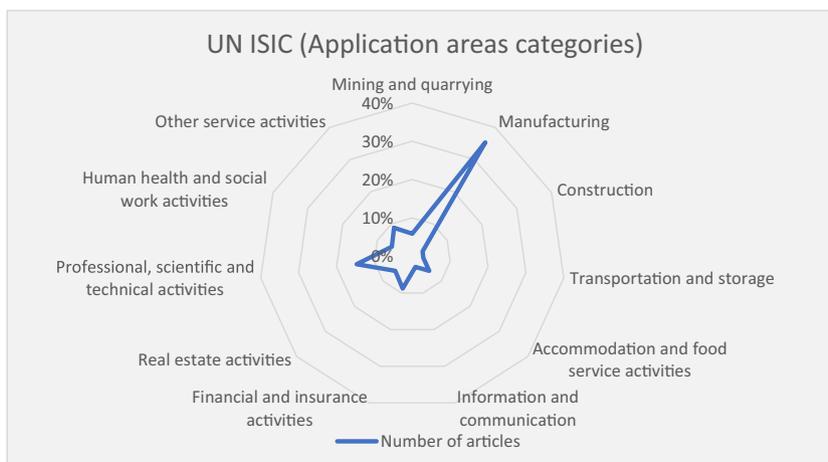


Fig. 6. Distribution of selected paper quantity vs UN ISIC classification.

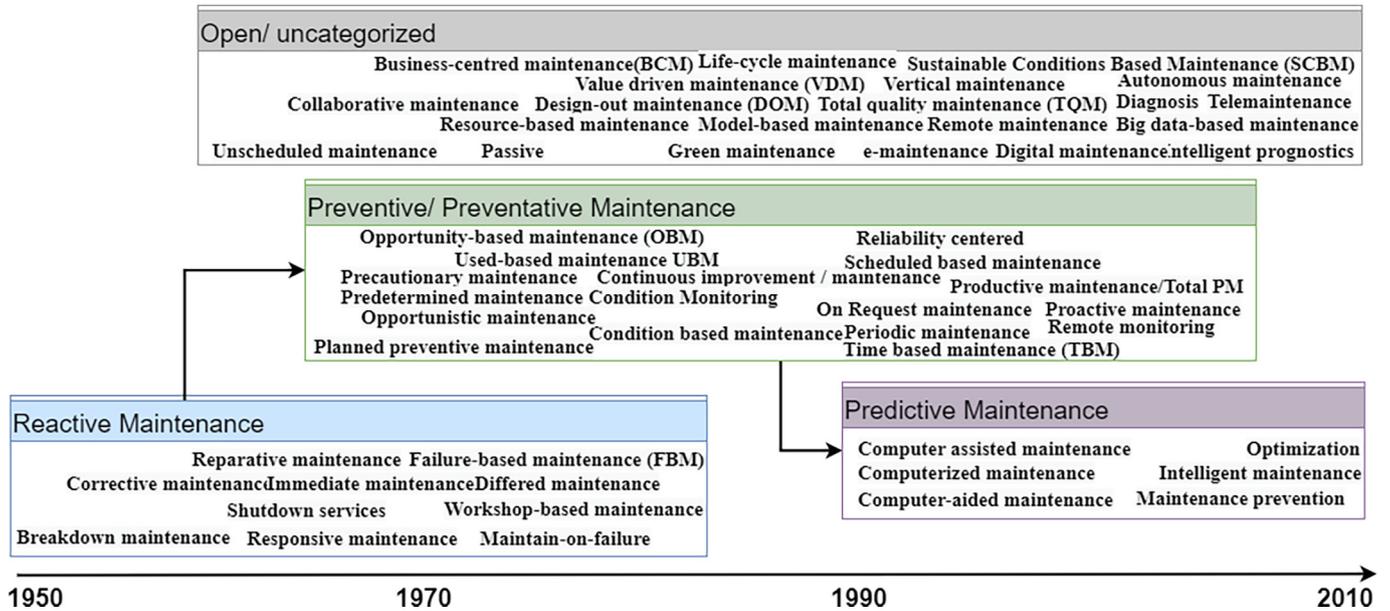


Fig. 9. Evolution of maintenance, (Jain et al., 2014). Maintenance types grouped (Appendix D) and time plotted according to the evolution explained within various selected articles.

Table 4 Maintenance services comparisons (Chen et al., 2018).

	Reactive	Preventive	Predictive
Types	Corrective-post-failure	Precautionary & scheduled	Precautionary & on-demand
Trigger mechanism	Reactive passively	Reactive actively	Perceptive actively
Service timing	Random	Periodic	Real-time
Downtime	Longest	Shorter	Proximity minimization
Maintenance node			
Key techniques	Fault repair	Key computational, overhaul and repair	Data collection & analysis, repair
Activities	Replacement, overhaul or repair of equipment after failure	Inspection, repair, or replacement of equipment on a regular basis; forecast or update regular plans based on design and experience	Repair or replacement of equipment on needs; monitor and collect condition data; seamless storage, large-scale computing; diagnose, predict life cycle and develop interventions

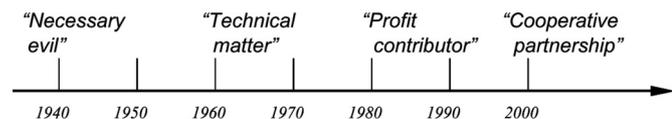


Fig. 10. Strategic evolution of maintenance functions (Pintelon & Parodi-herz, 2015).

availability and quality with limited resources and energy consumption. Sustainable maintenance in one aspect guarantees the compliance of processes and products, and reduces their industrial impacts on economy, society, and surrounding environment. In other aspect, it must be a sustainable business function and limit its own flows and impacts generated during all maintenance activities (U. Al-Turki et al., 2014a; Franciosi, Lambiase, & Miranda, 2017; Ighravwe & Oke, 2017; Franciosi et al., 2020). Various approaches establishing relationship

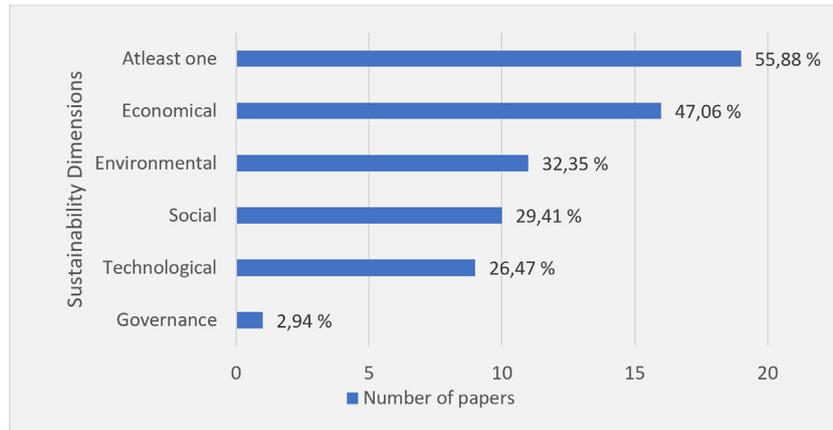


Fig. 11. Distribution of selected paper quantity vs sustainability dimensions.

between sustainability and maintenance, understanding of the impacts and ideas are discussed within many selected articles.

Economy is one of the major areas where maintenance impacts heavily. Even though, maintenance itself is an inevitable cost which adds to any organizations balance sheets, the cost of maintenance is not that expensive when considering the cost of not having it on right time. The downtime induced by the breakdown is way more and exponentially costlier (Iung & Levrat, 2014). Economic performance evaluation measures basically focus on traditional costs and revenues. There exist other hidden costs as well, which are revenue losses resulting from performance losses with respect to downtimes, low availability, non-quality and low product rates. Traditional evaluation measures do not consider hidden costs equally important as visible costs. Macchi et al. (2016) discusses this as one of the reasons behind the growing interest in economic performance evaluation alternatives. They also recommend calculating the indicators separating the hidden from the visible costs, including the resources spent in maintenance.

Environment is equally compromised all the way from manufacturing a product to its use and then maintaining it for further use and finally to scrap it and dump or recycle. In every step, environment and economy is hugely impacted. Maintenance intends to have a positive impact on environment by ensuring the re- operability of maintained equipment, however the maintenance approach itself in many cases are contributing to the negative environmental impact (Franciosi et al., 2017) and needs reconsiderations to minimize those negative impacts. Subjected to maintenance, energy consumptions, emissions and global warming potentials are the key drivers impacting the environment whereas total resource depletion, acidification, eutrophication, ozone depletion, resource consumption, waste generation and pollution etc. also contributes to some extent (Macchi et al., 2016). Al-Turki et al. (2014a) introduces a concept of closed loop product life cycle system as shown in Fig. 12, which illustrates the use of 6Rs featuring maintenance services. Environment provides the raw materials and energy for manufacturing and the maintenance services facilitates in recovering, recycling, redesigning, reducing, remanufacturing and reusing of the earth's natural resources and eventually is returned in the form of waste and emissions, back to environment/earth after the retirement.

With the growing number of failures, breakdowns and maintenance burdening the environment, there has been a demand for sustainable maintenance strategies. Various authors have brought up deployment of concepts such as lean maintenance and green maintenance (Abdul Lateef & Abdul-Aziz, 2015; Iung & Levrat, 2014; Kazemi, 2013) services to support circular economy paradigms through the vision of life-cycle maintenance. Kazemi (2013) proposes a green maintenance model which aims to evaluate the overall maintenance cost incurred by the maintenance decisions and focused on three factors, maintenance performance, environmental impacts and budget of maintenance. Iung and Levrat (2014) have brought up a concept of maintenance-centered circular manufacturing and explains that, through the vision of lifecycle management, the role of maintenance

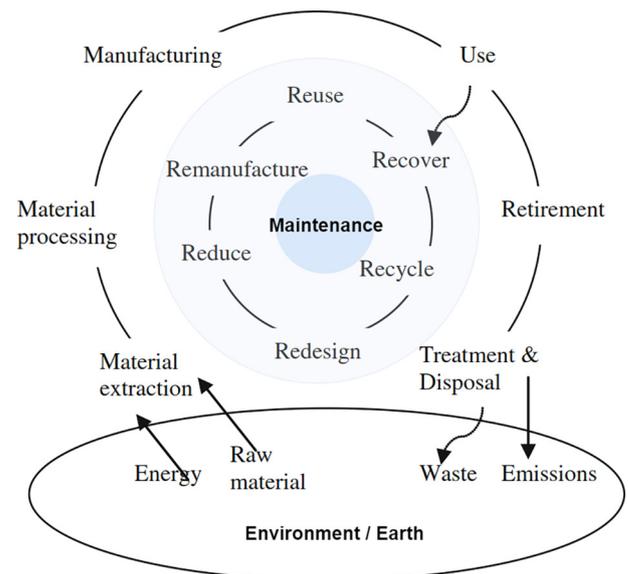


Fig. 12. Closed loop product life cycle system (Al-Turki et al., 2014a).

has changed and defends a profit vision for the maintenance by improving different sustainability impacts.

Health and safety are very important aspects of the society. People's health and safety is always at stake throughout the manufacturing process, product lifecycle and maintenance; this impacts the social dimension. Maintenance equally contribute to positive and negative impacts on health and safety dimensions as well-maintained equipment ensures a safe and healthy environment whereas non-maintained assets or structures triggers serious health problems and accidents (Al-Turki et al., 2014a). Jasiulewicz-Kaczmarek and Drozyner (2013b) highlights that with the advancement in the maintenance service types, the rate of incident has dramatically reduced as shown in Fig. 13. It shows, during the earlier time, when maintenance was vastly reactive, considered wastage of time and was rarely part of any production plan; faults and errors occurred randomly resulting to accidents and lost time injuries. Incident rate was very high and directly proportional to the number of failures. With the introduction of preventive maintenance, safety awareness was created by providing safety procedures, instructions, trainings, and guidelines. This helped in reducing the incidents rate drastically. Later, with predictive maintenance, upcoming faults and failures are predicted early enough and most failures never occurs. This developed a safe behavior and a safety culture minimizing the unsafe incidents to almost zero. This depicts a positive sustainability

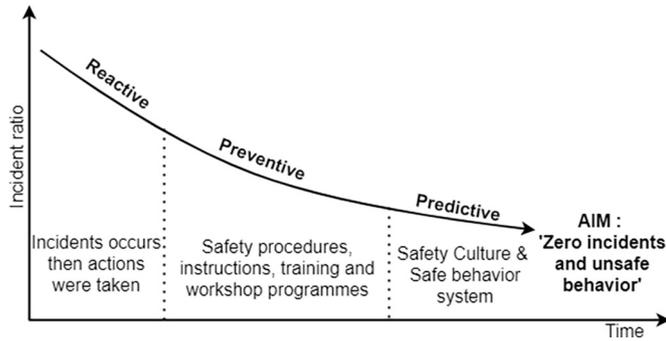


Fig. 13. The decline in incident ratio with time evolution of maintenance services (Jasiulewicz-Kaczmarek & Drozyner, 2013a).

impact of maintenance services which signifies a positive technological change driving a positive social impact.

Understanding the impact of maintenance services on sustainability is challenging. Franciosi et al. (2020) has reviewed various maintenance services and tried to create a conceptual framework for identifying the impacts on sustainability as shown in Fig. 14. This framework is a 3-planed model dealing with 3 sustainability dimensions, social, environmental, and economic. The X-axis deals with the reference systems or the type of impacts; Y-axis depicts the impacted sustainability dimensions; and the Z-axis indicates impacting maintenance processes. It has 3 columns; first column indicates the sustainability indicators directly affected by the maintenance process. The second and third column depicts indicators related to target system and target system output respectively; and are same for each maintenance process. These indicators are indirectly affected by the efficiency and inefficiency of maintenance process. Even though, it is impossible to directly identify which maintenance process can cause an indirect impact on those indicators, all effects are reported in column two and three. Each sustainability category intersects with the different maintenance system and this content of each intersection represents a *cube of knowledge* and they further includes several impact indicators. These *cube of knowledge* with indicators can be accessed from the study presented in (Franciosi et al., 2020). Based on the process, the intersection is known, and the corresponding *cube of knowledge* is accessed, and impact is identified.

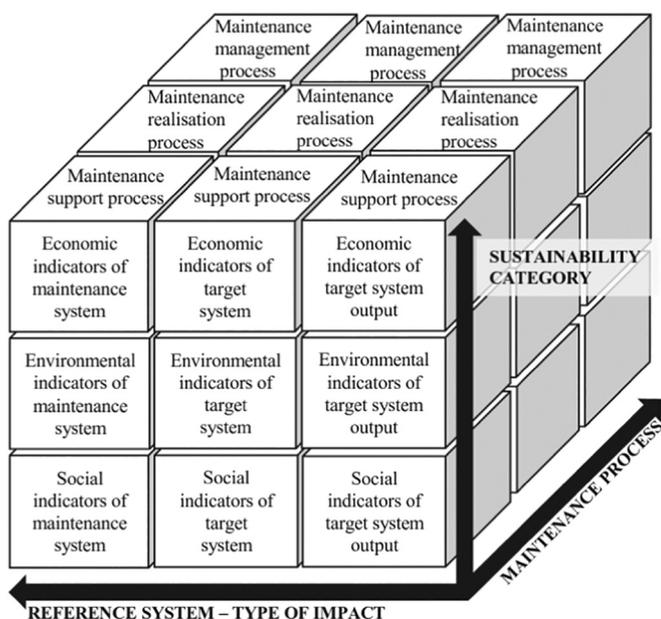


Fig. 14. The cube of knowledge identifying the impacts on sustainability. (Franciosi et al., 2020).

3.3. Digitalization of maintenance services

Technology and maintenance impact each other equally. One of the key components responsible for the evolution of maintenance is the technological advancements in-order to provide most suitable maintenance services. On the other hand, the evolution of maintenance from reactive to proactive has forced a change in equipment or asset technologies so that they adopt and adept to newer, effective and efficient maintenance services (Jantunen et al., 2010). In overall, all sustainability dimensions are impacted by maintenance services in one way or other and Jain et al. (2014) suggests that in the present era of globalization and to compete globally, it is necessary for all industries to move towards modern developments in all aspects including maintenance. Digitalization is one of the best approaches to modernize maintenance and it allows emergence of advanced tools for making industries more competitive, effective, and sustainable in the field of maintenance.

Looking back into the evolution of maintenance, reactive ways dealt with fixing the raised faults then a routine-based maintenance was in place for preventing faults and then used new and advanced tools to predict failures before it could happen. This shows, new tools were developed and new ways of doing things have been adopted. This is already maintenance towards digitalization. Paschou et al. (2020) presented industrial cases of Rolls-Royce, General Electric and KONE and showed that effective and efficient smart services can be delivered through the application of digital technologies. They highlighted that, the adoption of advanced technologies such as machine learning, artificial intelligence, analytics, big data and cloud computing etc. empowers the traditional maintenance services and transforms them into smart, effective and efficient maintenance services; by increasing service delivery efficiency and enabling sophisticated and novel service offerings. Over the last 30 years, numerous maintenance services such as computerized (computer-aided/computer-assisted) maintenance (Jain et al., 2014; Rocha & Rodrigues, 2017); optimization (Goyal et al., 2017); intelligent maintenance (Turner et al., 2019); e-maintenance (Jantunen et al., 2010; Tan et al., 2014); tele-maintenance (Genquan et al., 2011); diagnostics and intelligent prognostics (Starr et al., 2010); remote monitoring (Chen et al., 2018); remote maintenance, digital maintenance, and big data-based maintenance (Roy et al., 2016) etc. emerged and has been the evolving face of digitalization in the field of maintenance. Five main functions viz. monitoring, diagnosis, prediction, troubleshooting and optimization in presence of real time data defines the digitalization of maintenance services (Chen et al., 2018) as depicted in Fig. 15. Continuous availability of real-time asset or equipment data is a key concern as it aids in real time (remote or on-site) monitoring of the equipment and its operating conditions; helps in diagnosing the behavior, preferences, patterns and failures based on the collected or available data; helps to predict future failures, together with the use of advanced approaches like machine learning and artificial intelligence etc.; helps in understanding the raised faults and its (remote or on-site) troubleshooting; and improves or optimizes asset and its operating performances based on the historical faults, troubleshooting and predictions analysis.

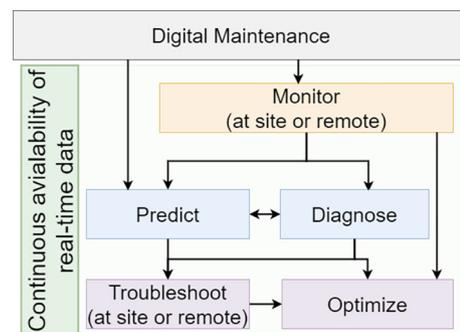


Fig. 15. Basic building blocks of modern digital maintenance, improvised from (Chen et al., 2018).

4. Discussion

Digitalization of maintenance services not just modernizes maintenance; they create significant benefits and influence maintenance services to create positive sustainable impacts on all sustainability dimensions. It is one of the best approaches to modernize maintenance and it allows emergence of advanced tools for making industries more competitive, effective, and sustainable in the field of maintenance. Digitalization motivates the use of equipment and process data, both real-time and historical. The extensive use of data and analysis is the key to modern maintenance involving various data-based digital technologies such as live monitoring; predicting failures early; diagnosing and troubleshooting faults and failures at site and even remotely; and optimizing asset performances, efficiency, accuracy and even productivity.

4.1. Benefits of digital maintenance

Digital maintenance enhances the development, improvement and use of new tools and technologies making them more effective. The use of vast historical and live data along with analytics capabilities has been the backbone of modern-day maintenance services. The maintenance functionalities such as monitoring, diagnosing, troubleshooting, predicting and optimization is an outcome of a positive technological impact and in return

these technological advances further impact the technological sustainability positively.

According to (Johansson et al., 2019), digital maintenance services are increasingly and positively affecting today's environment and society. As through digitalization of maintenance, using correct type of tools and technologies, only necessary, adequate, and correct type of maintenance can be utilized through real-time predictions and diagnosis. This minimizes waste and energy consumptions, saves time, and eventually helps in promoting a positive environmental impact. Along with the positive environmental awareness, digital maintenance contributes largely in reducing accidents by already predicting, troubleshooting, and preventing failures early and remotely. This creates safety culture; empowers safe behavior and assures a safe and healthy work environment. Hence, it ensures a positive implication of digital maintenance on environment and society.

Digitalization of maintenance services impacts economic sustainability hugely and positively. All the tools and use of data aids in carrying most of the maintenance functions remotely, e.g. remote monitoring, remote troubleshooting, live diagnosis, prediction based on artificial intelligence, and remote optimization etc. This significantly reduces huge portion of service delivery costs and reduces almost all unplanned maintenance. This eventually, leads to reduction in operation costs; reduction in onsite personal services; reduction in travel cost, travel time and carbon footprint; lesser delays, and shutdowns. This directly relates to efficient and effective maintenance practices with improved product performance, high

Table 5
Benefits of digitalization of maintenance services (enlisted from papers in primary study).

SD	Benefits of digitalization	
Economic	<p>Minimize downtime (Chen et al., 2018; Ighravwe & Oke, 2017)</p> <p>Replace onsite personal services with remote services (Paschou et al., 2020)</p> <p>Reduce service delivery costs (Chen et al., 2018; Paschou et al., 2020)</p> <p>Save time (Jain et al., 2014; Johansson et al., 2019)</p> <p>Improve maintenance efficiency and effectiveness (Arputharaj, 2015; Iung & Levrat, 2014; Roy et al., 2016)</p> <p>Improve product performance and availability (Franciosi et al., 2017; Franciosi et al., 2020)</p> <p>Strengthen competitiveness (Simões, Gomes, & Yasin, 2011)</p>	<p>Use of tools and data helps in detecting and preventing failures in advance; this saves time and money. Digitalization facilitates remote maintenance functions which relates to less service engineers on site, lowered cost to maintain, lowered travel cost and saved time.</p> <p>Up-to-date equipment process and data helps in monitoring; accurately diagnosing and troubleshooting; predicting and optimizing.</p> <p>The reduction in downtimes and well-maintained equipment means high availability and performance capability.</p> <p>Improved availability, performance provides a confidence of competitiveness.</p>
Environmental	<p>Technological advances and development of effective tools (Olanrewaju & Abdul-Aziz, 2015)</p> <p>Save time (Jain et al., 2014; Johansson et al., 2019)</p> <p>Reduce waste (Jasiulewicz-Kaczmarek & Drozyner, 2011; Pintelon & Parodi-herz, 2015)</p> <p>Minimizes carbon footprint (Iung & Levrat, 2014; Sénéchal, 2018)</p> <p>Reduce energy consumption (Iung & Levrat, 2014; Pires et al., 2015)</p> <p>Reduce environmental impact (Kazemi, 2013)</p> <p>Build sustainable business/production with profitable margins (Chen et al., 2018; Paschou et al., 2020)</p>	<p>By using correct type of tools and technologies, only necessary, adequate, and correct type of maintenance can be utilized through real-time predictions and diagnosis. This minimizes waste, reduces energy consumptions, saves time. Reduction in travel and use of digital tools minimizes carbon footprint.</p> <p>All these eventually helps in promoting a positive environmental impact and help in achieving maintenance goals effectively and efficiently. This builds sustainable businesses with profitable margins.</p>
Social	<p>Reduce accidents, assures safety and healthy work environment (Chen et al., 2018; Jain et al., 2014; Jasiulewicz-Kaczmarek & Drozyner, 2013b)</p> <p>Create safety culture and empowers safe behavior (Trocka-Leszczynska & Jablonska, 2013b, 2013a)</p> <p>Secure the transmission of data (Chowdhury & Akram, 2011; Paschou et al., 2020)</p> <p>Mitigate risks (Mangano & de Marco, 2014; Starr et al., 2010; Tan et al., 2014)</p>	<p>Digital maintenance contributes largely in reducing accidents by already predicting, troubleshooting, and preventing failures early and remotely. This creates safety culture; empowers safe behavior and assures a safe and healthy work environment. Confiding for safety mitigates risks. The new tools and technology also ensure data and communication security, which is a vital social need in present scenarios. This ensures a positive implication of digital maintenance on environment and society.</p>
Technological	<p>New technological advancements in effective maintenance tools (Olanrewaju & Abdul-Aziz, 2015)</p> <p>Replace onsite personal services with remote services (Paschou et al., 2020)</p> <p>Use of data and analytics (Paschou et al., 2020; Roy et al., 2016; Turner et al., 2019)</p> <p>Secure the transmission of data (Chowdhury & Akram, 2011; Paschou et al., 2020)</p>	<p>The use of vast historical and live data along with analytics capabilities has been the backbone of modern-day maintenance services. New and effective tools have emerged and facilitates the maintenance functionalities such as monitoring, diagnosing, troubleshooting, predicting and optimization. This is an outcome of a positive technological impact and in return these advancements promote secure and reliable transmission of data, effective and prompt maintenance services, reduced operating costs etc.</p>
Governance	<p>Encouraging safety culture and safe behavior (Trocka-Leszczynska & Jablonska, 2013a, 2013b)</p> <p>Helps in decision making (Chong et al., 2019; Iung & Levrat, 2014; Starr et al., 2010)</p> <p>Enabling better strategic planning (Al-Turki et al., 2014)</p>	<p>With digitalization, the maintenance service is reliable, safe, effective and keeps the plant operating to its maximum potential. It reduces downtime and increases availability and contributes to overall cost and profitability. This helps organization in decision making and strategic planning.</p>

availability, utilization, and throughput. Through digital approaches like e-maintenance, (Jantunen et al., 2010) mentions, companies understand that maintenance processes have higher return on investment, higher overall equipment effectiveness and more margins economically and technologically. All these leads to appropriate resource utilization and reduced costs, and hence positively impacts economic, environmental, social, and technological sustainability. Table 5 enlists various benefits of digitalization of maintenance services and is categorized according to different sustainability impacts.

4.2. Challenges

Despite having abundance of benefits, digitalization of maintenance services equally faces lots of challenges. Not all companies having adequate competencies to carry out a digital transformation of their maintenance services including the inability to understand effective implementation strategies and best practices is one of the major challenges. Sometimes, it is very difficult to see where the value can be created and to shift the focus from technology to strategic thinking. The most important of all is the missing right-mindset or transformation of traditional run-to-failure mindset to being able to see and connect maintenance services to the infrastructure that allows digitalization. As immediate lowering of operating costs is very challenging, and it does not attract all types of customers in a first place. With limited operational budgets there would be operational shortcomings and technological limitations. This leads to limited digital capabilities such as inability to automate maintenance tasks, no capability to optimize big data and limited remote monitoring etc. (Chowdhury & Akram, 2011). It is evident that digitalization of maintenance services does impact sustainability in many fronts, but to understand accurately what the impact is and how it is impacted is a huge challenge and requires in-depth and detailed research.

5. Conclusion

This review performed a bibliographic search in 4 scientific reference databases using a systematic literature review study. The objective was to find articles that would address different maintenance services, possible impact on sustainability and its digitalization aspects. Based on various inclusion and exclusion criteria, 34 articles were selected and 23 of them demonstrated correlation between maintenance services and one other concept. 6 other papers discussed relationship between maintenance services and both sustainability and digitalization. The remaining 5 papers studied the different concepts independently. The methodologies adopted by most of the selected articles were case study or literature review and almost half of them contributed by proposing a model or framework or provided futuristic ideas. Most of the maintenance services discussed within the selected articles were applicable to manufacturing, construction, and professional services industries. This suggests that significant number of researches has been conducted in this area and emphasizes the importance of this research.

The analysis shows that maintenance services is very important; it has been evolving and improving always, then, and now; and there exists a vast pool of available maintenance service types. The evolution has been driven by either different sustainability demands or the necessity to best utilize the asset or increase profitability and reduce loss. Service industries have risen and so the service economy. With this, advanced and professional maintenance services have been a vital way to gain sustainable competitive advantages for all customer enterprises. Now, maintenance services are not just a necessary activity to ensure reliability of technical structures or productivity of a company. It has a wider role to make a positive impact on society, environment, economy and technology; and digitalization is the approach to achieve this.

Digitalization transforms and empowers organizations to utilize digital technologies and data to improve the way things are done. In case of maintenance, it expands focus from one specific area to the entire process and facilitates benefits, cost savings and optimization of solutions globally. With digitalization, maintenance services have been improved to collect and analyze available data; and functions to monitor assets, predict and diagnose any faults, troubleshoot failures and optimize the asset or its operating performances. All of these can be achieved remotely or on site. It clearly provides an enormous amount of benefits to customers, providers and to the society and environment. Despite of its huge benefits, it is new; not competent enough and has difficulties in showing its adequate values. Also, industries still possess the traditional run-to-failure mindset and it is very difficult to abruptly transform it to a right one. No matter what the challenges are, or how vast they are, or how difficult it is to implement the digitalization of maintenance services; digitalization is the future and the right way towards sustainable, efficient, and effective maintenance.

One of the purposes of this literature study is to understand the current state and possible gaps in research related to maintenance services and its sustainability impacts. As an academic contribution, it provides a foundation of knowledge to researchers to understand various maintenance services, different sustainability dimensions and impacts. It helps in understanding the relation between maintenance and sustainability; and depict the role of digitalization in achieving various sustainability goals. It presents the current trend and publications related to maintenance services and its sustainability impact throughout 2009–2020. It also aids in identifying certain gaps in the literature on digital maintenance and provides valuable lessons learnt, possible benefits and improvements towards various sustainability impacts.

In addition, this literature paper provides a starting point for the author's doctoral study in the field of digital and sustainable maintenance services. It maps the research area and provides a holistic perception to build the further knowledge.

Declaration of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. ISIC classification of United Nations (Application areas categories)

	UN ISIC (Application areas categories)
A	Agriculture, forestry and fishing
B	Mining and quarrying
C	Manufacturing
D	Electricity, gas, steam and air conditioning supply
E	Water supply; sewerage, waste management and remediation activities
F	Construction
G	Wholesale and retail trade; repair of motor vehicles and motorcycles
H	Transportation and storage

(continued)

	UN ISIC (Application areas categories)
I	Accommodation and food service activities
J	Information and communication
K	Financial and insurance activities
L	Real estate activities
M	Professional, scientific and technical activities
N	Administrative and support service activities
O	Public administration and defence; compulsory social security
P	Education
Q	Human health and social work activities
R	Arts, entertainment and recreation
S	Other service activities
T	Activities of households as employers; undifferentiated goods- and services-producing activities of households for own use
U	Activities of extraterritorial organizations and bodies

Appendix B. List of inclusion criteria for the selection process (Theme of the article)

	Theme (Inclusion criteria)
Q1	Does the article establish relation between maintenance services and Sustainability impacts?
Q2	Does the article establish relation between maintenance services and Digitalization cases?
Q1 + Q2	Does the article establish relation between maintenance services and both sustainability impacts and Digitalization cases?
Q3	Does the article establish relation between maintenance services and other multiple key concepts other than sustainability and digitalization?

Appendix C. List of different sustainability dimensions included in the selected articles

	Sustainability dimension
D1	Social
D2	Environmental
D3	Economical
D4	Technological
D5	Governance

Appendix D. List of different maintenance types included in the selected articles

Maintenance in studies			
M1	Reactive maintenance	M3	Predictive maintenance
M1.1	Breakdown maintenance	M3.1	Computerized maintenance
M1.2	Shutdown services	M3.2	Maintenance prevention
M1.3	Response maintenance	M3.3	Optimization
M1.4	Corrective maintenance	M3.4	Computer-aided maintenance
M1.5	Reparative maintenance	M3.5	Intelligent maintenance
M1.6	Remote troubleshooting	M3.6	Computer assisted maintenance
M1.7	Failure-based maintenance (FBM)		
M1.8	Differed maintenance		
M1.9	Immediate maintenance	M4	Other types of maintenance
M1.10	Maintain-on-failure	M4.1	e-maintenance
M1.11	Workshop-based maintenance	M4.2	Green maintenance
		M4.3	Diagnosis
M2	Preventive/Preventative maintenance	M4.5	Autonomous maintenance
M2.1	Planned preventive maintenance	M4.6	Passive
M2.2	Condition based maintenance	M4.7	Design-out maintenance (DOM)
M2.3	Reliability centered maintenance	M4.8	Value driven maintenance (VDM)
M2.4	Productive maintenance/Total PM	M4.9	Business-centred maintenance(BCM)
M2.5	Opportunistic maintenance	M4.10	Unscheduled maintenance
M2.6	Continuous improvement/maintenance	M4.11	Intelligent prognostics
M2.7	Scheduled based maintenance	M4.12	Collaborative maintenance
M2.8	Proactive maintenance	M4.13	Telemaintenance
M2.9	Periodic maintenance	M4.14	Total quality maintenance (TQM)
M2.10	Remote monitoring	M4.15	Resource-based maintenance
M2.11	Precautionary maintenance	M4.16	Model-based maintenance
M2.12	Opportunity-based maintenance (OBM)	M4.17	Remote maintenance
M2.13	Used-based maintenance UBM	M4.18	Digital maintenance

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(continued)

Maintenance in studies				
M2.14	Time based maintenance (TBM)		M4.19	Vertical maintenance
M2.15	Predetermined maintenance		M4.20	Big data-based maintenance
M2.16	On Request maintenance		M4.21	Sustainable Conditions-based (SCBM)
M2.17	Condition monitoring		M4.22	Life-cycle maintenance

Appendix E. Marking and scoring the articles for the selection, categorization and content analysis

Authors	Year	Application area (Appx. A)	Inclusion criteria			Sustainability dimensions (Appx. C)	Maintenance types (Appx. D)	Score (Table 2)	Ref. in text
			Theme (Q) (Appx. B)	Contribution (Table 1)	Method (Table 1)				
Chong et al. (2019)	2019	K	Q3	S1.4	S2.3	D1, D3, D4	M1.4, M2.1	1,5	x
Nyemba, Mashamba, and Mbohwa (2017)	2017	M	Q1	S1.4	S2.2	–	–	1	–
Rocha and Rodrigues (2017)	2017	L	Q1	S1.4	S2.3	D1, D2, D3	M1, M1.4, M2.1, M2.3, M2.5, M3, M3.1	2	x
Tan et al. (2014)	2014	L	Q1 + Q2	S1.2	S2.2	D1, D2, D3, D4	M1, M4.1	2	x
Jain et al. (2014)	2014	C	Q1 + Q2	S1.1	S2.3	D1, D3	M1, M1.1, M1.4, M2.1, M2.2, M2.3, M2.4, M2.6, M3, M3.1, M3.2	1,5	x
Kazemi (2013)	2013	S	Q1	S1.1	S2.4	D2, D4	M1.5, M2.1, M2.7, M4.2	1	x
Jasiulewicz-Kaczmarek and Droźnyer (2013a)	2013	Q	Q1	S1.2	S2.4	D1, D2, D3	M1, M2.1, M2.8	1	x
Franciosi et al. (2020)	2020	C	Q1	S1.1	S2.3	D1, D2, D3, D4	M4.2	2.0	x
Chen et al. (2018)	2018	C	Q1 + Q2	S1.3	S2.1	D2, D3, D4	M1, M1.6, M2, M2.10, M3, M3.3, M4.3	2.5	x
Franciosi et al. (2017)	2017	B	Q1	S1.1	S2.1	D3	M1.4, M2.1,	0.5	x
Fontana et al. (2016)	2016	I	Q1	S1.3	S2.2	D1, D2, D3	M1, M2	1	–
Macchi et al. (2016)	2016	M	Q1	S1.2	S2.2	D2, D3, D4	M1.4, M2, M2.2, M3	1	x
Jasiulewicz-Kaczmarek and Droźnyer (2013b)	2013	C	Q1	S1.3	S2.4	D2	M1.4, M2.3, M2.4, M4.2	1	–
Ighravwe and Oke (2017)	2017	C	Q1	S1.3	S2.2	D1, D2, D3, D4	–	1	x
Al-Turki et al. (2014a)	2014	Q	Q1	S1.2	S2.4	D1	M1, M2.8, M2.10, M3	0.5	x
Pintelon and Parodi-herz (2015)	2015	M	Q3	S1.2	S2.3	D3, D4	M1.1, M1.4, M1.7, M2.1, M2.2, M2.3, M2.4, M2.5, M2.6, M2.7, M2.8, M2.9, M2.10, M2.11, M2.12, M2.13, M2.14, M3.1, M3.3, M4.1, M4.6, M4.7, M4.8, M4.9	1.5	x
Jantunen et al. (2010)	2010	M	Q1	S1.4	S2.4	D3	M4.1, M2.3, M3,	0.5	x
Heikkilä et al. (2009)	2009	B	Q3	S1.4	S2.2	D3	–	0.5	–
Al-Turki et al. (2014b)	2014	C	Q2	S1.2	S2.4	–	M1.2, M1.4, M1.8, M1.9, M2.1, M2.2, M2.3, M2.4, M2.5, M2.6, M2.7, M2.8, M2.15, M2.16, M3, M3.3, M4.1, M4.5, M4.10	1.5	x
Goyal et al. (2017)	2017	C	Q2	S1.2	S2.4	D3, D4	M1.1, M2.1, M2.2, M3.3	1.5	x
Genquan et al. (2011)	2011	M	Q2	S1.1	S2.4	–	M3.4, M4.12, M4.13	0.5	x
Lung and Levrat (2014)	2014	C	Q1	S1.4	S2.4	D1, D2, D3	M4.2	0.5	x
Abdul Lateef and Abdul-Aziz (2015)	2015	I	Q1	S1.1	S2.2	–	–	0.5	x
Starr et al. (2010)	2010	K	Q2	S1.4	S2.3	–	M1.1, M1.10, M2.1, M2.2, M2.3, M2.4, M2.8, M2.10, M2.12, M2.14, M2.17, M3, M4.3, M4.14	1.5	x
Shafiee and Chukova (2013)	2013	K	Q2	S1.2	S2.3	–	M2.1	0.5	–
Shagluf et al. (2018)	2018	C	Q2	S1.4	S2.2	–	M1, M2.1,	1	–
Turner et al. (2019)	2019	F	Q2	S1.2	S2.3	D2	M2.2, M3.5, M4.1	1.5	x
Roy et al. (2016)	2016	C	Q2	S1.2	S2.2	D2, D3, D4	M1.11, M2.1, M2.3, M2.10, M2.12, M3.1, M3.4, M4.3, M4.5, M4.11, M4.15, M4.16, M4.17, M4.18, M4.19	2	x
Marttonen, Viskari, and Kärri (2013)	2013	S	Q3	S1.2	S2.4	D3	–	0.5	–
Simões et al. (2011)	2011	C	Q3	S1.1	S2.3	–	–	0.5	–
Sénéchal (2018)	2018	C	Q1 + Q2	S1.3	S2.2	D1, D2, D3	M2.2, M4.21	2	x
Pires et al. (2015)	2015	S	Q1 + Q2	S1.2	S2.3	D1, D2, D3, D4	M2.2, M2.4, M2.12, M4.1, M4.2, M4.5, M4.12, M4.22	2.5	x
Paschou et al. (2020)	2020	J	Q1 + Q2	S1.1	S2.3	D1, D2, D3, D4, D5	M2.2, M2.10, M3, MM3.3, M4.1	1.5	x
Mangano and de Marco (2014)	2014	H	Q2	S1.2	S2.2	D2	M1.1, M1.4, M1.7, M2.1, M2.2, M2.14	1.5	–

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