Mapping the Literature on Asset Management: A Bibliometric Analysis

Renan Favarao da Silva[*], **Gilberto Francisco Martha de Souza**

Department of Mechatronics and Mechanical System Engineering, University of São Paulo, Av. Prof. Mello Morais, São Paulo, BRAZIL.

ABSTRACT

Asset management is a contemporary research area that coordinates activities to realize value from assets in organizations. Consolidated with the international ISO 55000 series, it has become an active field of infrastructure. In this context, this paper aims to map the literature on asset management through a bibliometric analysis. In order to have a comprehensive mapping, a bibliometric approach was conducted in three steps: data collection, data processing and extraction of results. The analysis processes focused on publication trends, key research areas, main sources of publication, contributing authors and countries and its collaboration as main topics of bibliometric. A total of 2,449 documents related to asset management was collected according to the search protocol. Publication trends identified a rapid growth over the past 15 years on asset management and a concentration of documents in five research areas: Financial and business, Infrastructure, Maintenance, Optimization and Management. The source of publications and contributing authors were both identified not only by the greatest number of documents on the field but their relevance by citation index. Lastly, the USA, England, Canada, Australia and China were found to be the most publishing countries and strong international collaborators on asset management. Thus, these findings are expected to contribute to researchers around the world as bibliometric mapping is an interesting approach to provide a detailed overview of a scientific field and insights for further research.

Keywords: Asset management, ISO 55000, Literature mapping, Bibliometric analysis, VOSviewer.

Correspondence
Renan Favarao da Silva
University of São Paulo, Dept. of Mechatronics and Mechanical System Engineering, Av. Prof. Mello Morais, 2231, São Paulo, SP, 05508-030, BRAZIL.
Email: renanfavarao@usp.br

INTRODUCTION

Since assets are part of an organization, potential or actual value are expected from them. For decades, managers have wondered whether physical assets needed to produce products and provide services have been managed effectively and efficiently.[1] In asset intensive infrastructure sectors (e.g. water, gas, electricity, oil, or transportation), effective management of physical assets plays an increasingly important role in the optimization of business performance.[2] As a consequence, asset management has become an active field of interest, especially with the publication of the international ISO 55000 series for asset management in 2014.

The ISO 55000 series is the first official international standard in the asset management discipline that has reached global consensus. According to it, asset management is defined as the coordinated activity of an organization to realize value from assets. It typically involves balancing costs, opportunities and risks against the desired performance of assets to achieve organizational objectives.[3] In other words, asset management is called to ensure that assets are used optimally and decision-making concerning them is aligned with the organizational needs.[2] Nevertheless, asset management is not an idea that came out of nowhere, but a result of decades of new thoughts that led to the current state, even going through moments of not being well defined.[4] The term asset management has been widely used up to now with fundamental differences in interpretation and usage, stemming from numerous academic and professional sources (e.g., maintenance, project management, financial markets and information technology).[2] As the ISO 55000 series for asset management is a new milestone for the discipline, a systematic analysis of this area of research is pertinent to the literature.

Despite a growing literature on asset management in recent years, to our knowledge, there are no available publications regarding the evolution and mapping of this scientific field. There are reviews on specific asset management topics such as optimization in decision-making in infrastructure,[5] multi-asset systems,[6] and metro transportation systems.[7] Analyzing the asset management discipline as a whole provides researchers and practitioners with an overview that is important for a broad understanding of the subject, for the development of research agendas

and the identification of approaches, solutions and areas of application. Accordingly, this gap motivated the conception of this research.

In this context, this paper aims to map the literature on asset management through a bibliometric analysis. Thus, it intends to answer the following questions about the state of the art in asset management: How have asset management publications evolved over the years? What are the key areas addressed in asset management? How are these areas conceptually represented? What are the main sources of publications and contributing authors? How is this production distributed across countries? And how is the social structure of collaboration between countries represented?

Applications of bibliometric methods have become present in several research areas for literature mapping and analysis.[8–15] An analysis of research parameters is useful and interesting to researchers around the world, especially for early-career in the field, as it is possible to get a quick overview of the present status and trends.[15] Not only can bibliometrics facilitate research retrospectives, but it can also help in the exploration of research hotspots objectively and quantitatively, which contribute to the progress and advancement of a certain research area in many different ways.[10] Since there is no systematic prior analysis on asset management, this paper is expected to contribute to the enhancement of this expanding field of research.

METHODOLOGY

The method used for mapping the literature was based on the bibliometric approach comprising three main steps: data collection, data processing and extraction of results. [15] Bibliometric analysis is the area of research that helps analyze current trends in the literature on a particular area and provides a general outline and general structure of the area of research.[13] The specifics of each of these three steps, however, were elaborated in alignment with the questions proposed for this work and are shown in Table 1.

For data collection (1), all definitions used in this paper to search the database and export metadata records (1.1, 1.2 and 1.3) are shown in the data collection protocol in Table 2. This information makes it possible to search databases (1.4) for exporting metadata records (1.5) while contributing to search transparency and repeatability.

As can be seen in Table 2, asset management was the main keyword for the data collection since it is the central subject of this mapping. Its search string was written to cover both singular and plural variations. Moreover, the data collection protocol did not consider combinations of other terms with asset management for broader data collection.

Table 1: Bibliometric literature mapping method.

Step	Description
1	Data collection
1.1	Define the keyword(s) for the mapping scope
1.2	Define the database(s) for the search and search type
1.3	Define the filter(s) of interests (document types, timespan, etc.)
1.4	Search the keyword(s) in the databases
1.5	Export all metadata records of selected documents of the database(s)
2	Data processing
2.1	Gather all metadata records of the different database(s)
2.2	Remove duplicated metadata records
2.3	Standardize the writing of keywords from metadata records
3	Results extraction
3.1	Identify the publication trends
3.2	Identify the key areas in the mapping scope
3.3	Identify the main sources of publication
3.4	Identify the main contributing authors
3.5	Identify the main countries and collaborations

Table 2: Protocol for data collection.

Topic	Definition
Keywords	Asset management
Search string	"asset* management"
Database	Web of Science core collection
Search type	Topic (searches title, abstract, author keywords and keywords plus)
Document type filter	Articles, reviews and editorial materials, including those in early access
Period filter (timespan)	Every year until 2019
Date search	28-jan-20
Exported records file formats	Plain text and Tab-delimited

Web of Science Core Collection was defined as the database for data collection. This database is well-suited to evidence synthesis in the form of systematic reviews, as it meets all necessary performance requirements such as controlled vocabulary, Boolean queries, appropriate search string length, bulk download among other points.[16] In addition, it contains 74.8 million total records in over 21,100 peer-reviewed, high-quality scholarly journals published worldwide in over 250 disciplines. It also incorporates the Citation Reports tool that allows measuring and comparing citation impact for any group of work through original citation index such as citations per year, total times cited, average times cited and the *h*-index.[17] Regarding the type of search in the database, it was defined in the data collection protocol a topic search that encompasses the fields search title, abstract, author keywords and keywords plus. Articles, reviews and editorial materials, including the documents in early access, were prioritized in

the type of documents in the data collection protocol due to the relevance of these documents and the rigor of the review process. Lastly, every year until 2019 was considered in the data collection.

Data processing (2) includes the activities of grouping records from databases, structuring, cleaning, removing duplicate records (e.g., similar records extracted from more than source) and standardizing (e.g., setting defaults for similar keywords of different documents) as provided in steps 2.1, 2.2 and 2.3 of the mapping method (Table 1).

For results extraction (3), the analysis processes were defined according to the main points of each sub-step (3.1 to 3.5). These topics of analysis are commonly used in bibliometric studies of different research areas[9–13,15] and contribute to a broad process of mapping and discussion of the literature. Further details of the analysis processes for each topic are shown in Table 3.

As support, Microsoft Excel (Office 2016) was used to import the "tab-delimited" records to perform descriptive analyses, Citation Reports tool from Web of Science platform was used to access citation impact analysis (e.g., total times cited,

average times cited, *h*-index, among other information) and VOSviewer (version 1.6.11) was used to import the "plain text" records to create a non-descriptive analysis using bibliometric networks.

Finally, it is noteworthy that the software VOSviewer is also commonly used for bibliometric mapping.[8,9,11–13,15] Moreover, it is freely available to the bibliometric research community and it is based on the visualization of similarities (VOS) mapping technique which provides a distance-based map approach.[18] Among the options for the non-descriptive analysis, VOSviewer was selected due to the quality of graphical representations and to the consideration of distance as a strength of the relation between the data. In addition, these points contribute to the ease of interpretation.

RESULTS AND DISCUSSION

According to the protocol for data collection (Table 2), the search was performed in the Web of Science Core Collection database on 28 January 2020. A total of 2,449 documents, including articles, reviews and editorial materials, made up the data set for the data processing and the results extraction. Although these results can be divided into descriptive (e.g. publication trends, the main sources of publication and contributing authors, main keywords, etc.) and non-descriptive (e.g. key areas on asset management, the collaboration between countries, etc.), their presentation and discussion took place according to the five topics of the analysis presented in the following subsections.

Publication Trends

All 2,449 documents were distributed over time to highlight trends in publishing on the asset management discipline over the years. As can be seen in Figure 1, scientific production on asset management has grown rapidly over the past 15 years.

Table 3: Analysis for results extraction.

| Step	Topic	Analysis processes
3.1	Publication trends	Filtering "Publication year" from exported metadata record and plotting a graph of documents per year in Microsoft Excel
3.1	Publication trends	Filtering "Research area" and "Publication year" from exported metadata record and crossing them in Microsoft Excel
3.1	Publication trends	Applying overlay visualization to bibliometric networks of subsequent analyses (3.2 and 3.5) in VOSviewer
3.2	Key areas in the mapping scope	Mapping and analyzing the keyword co-occurrence using a network visualization in VOSviewer based on the bibliographic data from exported metadata records
3.3	Main sources of publication	Filtering "Research area" and "Source" from exported metadata records in Microsoft Excel and combining them to citation indicators of Citation Reports from Web of Science platform
3.4.	Contributing authors	Filtering the exported authors' record count from exported metadata record in Microsoft Excel and combining them to citation indicators of Citation Reports from Web of Science platform
3.5	Main countries of publication	Filtering the exported countries/regions' record count from exported metadata record in Microsoft Excel
3.5	Collaboration among countries	Mapping and analyzing the co-authorship by countries using a network visualization in VOSviewer based on the bibliographic data from exported metadata records
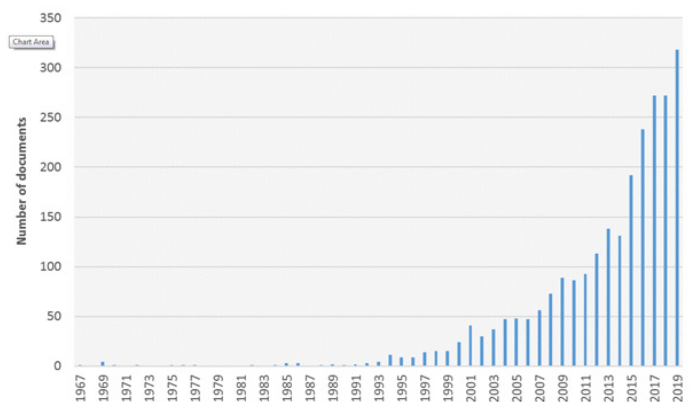
Figure 1: Number of documents published over the years on asset management.

The first documents mentioning asset management in the collected dataset date from the late 1960s.

The context of the term, however, was quite different from the context of most current documents as it can be seen in the distribution of the documents collected over the years by the research area in Table 4. Asset management was initially associated with Business economics research area until the late 1980s. In this period, research has used the term asset management to discuss how to manage investments mainly in the financial sector and some other applied areas as in Health

Table 4: Distribution of research areas over the years on asset management.

Period	Number of documents	Main research areas
2010 to 2019	1853	Engineering (51%), Business economics (23%), Water resources (11%) and Transportation (8%)
2000 to 2009	492	Engineering (52%), Business economics (20%), Transportation (14%) and Computer science (10%)
1990 to 1999	83	Engineering (37%), Business economics (20%), Environmental sciences ecology (16%), Water resources (16%) and Energy fuels (10%)
1980 to 1989	11	Business economics (45%), Health care sciences services (27%) and Engineering (11%)
Before 1980	10	Business economics (90%)

care sciences services. It is worth mentioning that the first studies related to asset management in the engineering area were presented in the 1980s.

In the 1990s, the growth of publications in asset management began which was driven by the use of the term beyond the financial and business economics areas, as it can be seen in Table 4. Engineering, Environmental sciences ecology, Water resources and Energy fuels were new research areas of the asset management publications. In these areas, the term asset management has come to be associated with planning and maintaining the condition and performance of the physical assets and infrastructure.

Environmental science ecology and Water resources have gained focus due to the privatization of the England water industry in the late 80s and the foundation of the Water Research Center. This has boosted applied asset management research to provide guidance and planning practices in the water industry and models for dealing with the deterioration of its physical assets. The same happened with the opening of the electric power industry in several countries which boosted research on electrical asset management in the engineering

area in similar topics. It was also in this decade, in 1994, that the Institute of Asset Management (IAM) was established, bringing together several companies interested in sharing experiences and best practices in physical asset management.

In the 2000s, the advance in scientific production on asset management was driven by the incorporation of the discipline in other areas such as civil engineering and transportation. Asset management applied to the construction industry has emphasized the assessment of decision support tools for infrastructure planning due to the challenges for maintenance, repair and renewal planning faced by asset owners and managers. Thus, these areas included applications aimed at infrastructure and transportation assets such as bridges, highways and pavements, and transport fleets.

This growing interest has led to the development of several guidelines, reports and best practice cases in asset management, which subsequently resulted in efforts to standardize it.[2] The International Infrastructure Management Manual (IIMM) by National Asset Management Support (NAMS) was released in 2000 (constantly updated to its fifth edition in 2015) and the Publicly Available Specification 55 (PAS 55) by the IAM in collaboration of the British Standards Institution (BSI) in 2004 (currently, in the second edition of 2008). In 2009, using PAS 55 as a reference, BSI initiated the project to produce a formal International Standard through the International Organization for Standardization (ISO) with International collaboration. Development of the three standards was approved in 2010 and the three International Standards (ISO 55000, ISO 55001, ISO 55002) composed the ISO 55000 series for asset management in 2014.[1]

These publications contributed to consolidate the use of the term asset management primarily in the research area of Engineering (mainly civil, electrical electronic, industrial, environmental and mechanical) and related areas such as Water resources and Transportation from the 2000s as shown in Table 4. As a consequence, the Business economics area that originated the use of the term represents about one fifth of the publications on asset management in the last decades. Further analysis is performed by identifying and representing key areas of asset management literature through bibliometric networks in the following subsection.

Key Areas on Asset Management

The data collection identified 7,841 keywords in all metadata records and the topmost appeared keywords are exposed in Table 5. It can be seen that these most cited keywords are related to the previous predominant research areas as shown in Table 4. For example, Risk, Market and Investment are terms directly linked to the Business economics research area. Likewise, Maintenance, Infrastructure, Reliability, Network, Deterioration and Condition assessment are terms related to the areas of engineering research. Although this analysis

Table 5: Most appeared keywords.

Keyword	Occurrences	Keyword	Occurrences
Asset management	674	Impact	70
Model	198	Strategy	57
System	181	Decision-making	50
Management	148	Sustainability	50
Performance	147	Market	50
Maintenance	124	Network	48
Optimization	103	Deterioration	46
Risk	92	Design	45
Reliability	73	Investment	43
Framework	73	Power transformer	41
Infrastructure	70	Condition assessment	40

guides the topics most covered in asset management, it does not demonstrate how these issues are related to each other.

Thus, for mapping the key areas in asset management, it was used a keyword co-occurrence network approach through VOSviewer software. This is an approach widely used in bibliometric analysis of research fields.[9,13,15] Due to a large number of different keywords, the co-occurrence network was created considering the keywords that appeared in at least 1% of all collected documents. In other words, this is equivalent to a minimum occurrence in 25 of the 2,449 documents. 45 keywords have met this threshold and are represented in a co-occurrence network to compose the key areas on asset management in Figure 2.

These keywords when linked with each other based on their co-occurrence yield a network that highlights clusters of keywords around key areas on asset management. In the graphical visualization of a bibliometric network, the size of a
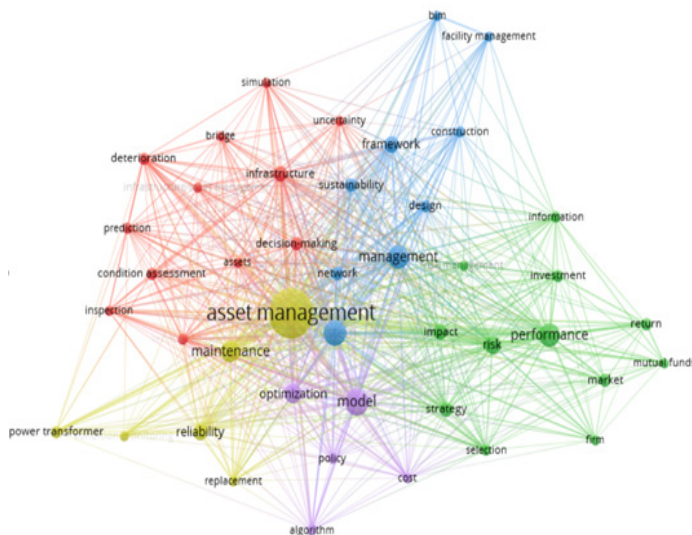

Figure 2: Keyword co-occurrence network on asset management.

circle denotes an item's relevance. Also, the placement of the circles and the use of colors highlight clusters and the distance between two nodes is inversely proportional to the number of co-occurrences between the keywords.[9]

As can be seen in Figure 2, VOSviewer has identified 5 different clusters of keywords in the co-occurrence network and each represents a key area on asset management. The keywords performance and risk are closer to the Financial and business area which conglomerates others as investment, return, mutual funds, market, strategy and impact. On the other hand, infrastructure, deterioration, condition assessment and decision-making are the main keywords of a second area related to Infrastructure area, which integrates other keywords as inspection, prediction, bridge, rehabilitation and infrastructure asset management. This area concentrates on research applied to the condition of infrastructure assets, mainly in the civil, transport and water areas.

The keyword maintenance is central to the third area on asset management which conglomerates other keywords such as reliability, replacement and condition-monitoring. This Maintenance area addresses maintenance management topics such as condition-based maintenance and reliability. Moreover, it is worth mentioning that power transformers are recurrent systems for the application of these approaches.

Optimization, model, policy, cost, algorithm integrates an Optimization area that concentrates the research on asset management that prioritizes models for maintenance policies optimization, and asset life cycle cost. Finally, a Management area conglomerates keywords as management, building information management (BIM), facility management, construction, framework and system. It mainly addresses discussions on asset management about frameworks for implementation and information management in projects, buildings and facilities.

Accordingly, four of the five identified key areas of asset management literature, Infrastructure, Maintenance, Optimization and Management, relate to the engineering research field, which corroborates the distribution of research areas on asset management in the last decade (Table 4). In general, the content of these areas covers technical approaches to improve the results of the organizations through asset management. There is a predominance of developing approaches for the maintenance stage of the asset life cycle, especially to monitor and assess the condition of the physical assets in order to implement optimized maintenance strategies in infrastructure industries.

In addition, trends in the main key areas were analyzed through the overlay visualization of the keywords co-occurrence network in VOSviewer as shown in Figure 3. The color patterns highlight the co-occurrence of the keywords in

data collected over the years. In general, these keywords co-occurrences with asset management have occurred on average after the 2010s which corroborates with previous results of the expansion of this research field in recent years.

It is noteworthy that the most recent publications associated with asset management are mainly in the management area evidenced by keywords such as BIM, facility management,

frameworks and sustainability. These topics associated with asset management have emerged on average after 2015 as well as some other specific topics of other areas such as power transformer and bridges. Therefore, this analysis was able to relate which topics are emerging in discussion around the research field.

Main Source of Publication

The knowledge regarding the publications' performance is particularly important since it serves as a guide for leading journals in a research area.[14] The data collection identified 1,006 sources of publications, concentrating about half of the production (1,226 docs.) in only 10% of these sources. It is also noteworthy that a quarter of all asset management literature collected (614 docs.) is concentrated in 22 journals (2.2% of the sources of publication). This shows that the scientific production in the field of research in asset management is very concentrated in a few journals.

In order to identify the most relevant publication sources, the 35 journals with the most publications on asset management had its citation impact index analyzed through Citation Reports in the Web of Science platform. These topmost publishing journals were ranked according to the relevance to the asset management field by the h-index of the journal's
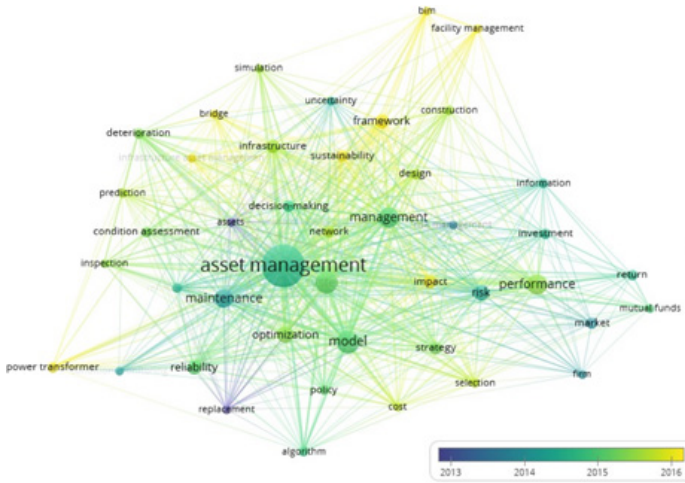

Figure 3: Keyword co-occurrence network on asset management over the years.

Table 6: Main publishing journals on asset management.

Source title	Number of docs.	h-index of the docs.	Average citations per item	Sum of times cited	h-index of the journal
Journal of Infrastructure Systems	43	13	9.5	410	59
IEEE Transactions on Power Delivery	27	13	17.0	459	163
Reliability Engineering and System Safety	28	11	13.3	374	119
Journal of Banking and Finance	16	11	55.6	891	135
Urban Water Journal	30	10	10.1	305	33
Water Science and Technology	29	10	8.9	259	124
IEEE Transactions on Dielectrics and Electrical Insulation	28	10	11.5	323	101
IEEE Transactions on Power Systems	17	10	22.3	380	221
Transportation Research Record	119	9	3.1	376	94
Automation in Construction	18	9	17.5	316	95
Expert Systems with Applications	12	9	23.0	276	162
Journal of Computing in Civil Engineering	19	8	13.4	255	64
International Journal of Electrical Power Energy Systems	14	8	18.2	256	100
Structure and Infrastructure Engineering	32	7	7.8	251	36
Journal of Performance of Constructed Facilities	20	7	6.8	137	41
Journal of Management in Engineering	15	7	7.4	112	55
Journal of Finance	13	7	19.4	253	264
IEEE Transactions on Smart Grid	12	7	16.5	199	121
Electric Power Systems Research	11	7	17.9	197	104
Built Environment Project and Asset Management	26	6	6.2	162	13

collected documents as shown in Table 6. Lastly, each journal had its *h*-index accessed by the SCImago platform.

As can be seen in Table 6, the number of documents published on asset management or the impact of the journal itself does not necessarily reflect the relevance of the topmost publishing journal in the ranking. As *h*-index reflects not just the number of documents or the number of citations, it provides an interesting complement to these metrics, since it discounts the disproportionate weight of highly cited papers or papers that have not yet been cited. Accordingly, a journal has an *h*-index of N, for example, if it has published N papers that have N or more citations each.[101]

It is worth mentioning that only two main sources of publication were not related to the areas of engineering research (Journal of Banking Finance and the Journal of Finance). Both journals are publications in the Business economics research area and are directly related to the Financial and business key area of the literature mapping (Figure 2). Consequently, the other main journals relate to other four key areas of asset management literature mapping (Infrastructure, Maintenance, Optimization and Management). However, since all these four key areas address different engineering topics, these remaining engineering journals relate to them to a greater or lesser extent, not just being directly limited to one of them.

Some sources of publications can be associated with one of these areas more directly such as journals that address infrastructure with the Infrastructure area (e.g., Journal of Infrastructure Systems and Structure and Infrastructure Engineering) or journals that address management topics with the Management area (e.g., Journal of Management in Engineering and Built Environment Project and Asset Management). On the other hand, key areas such as Maintenance or Optimization have cross-cutting topics that

can be associated with most of these main journals, depending on the focus of its articles.

Finally, it is emphasized that this identification of the main sources of publication on asset management corroborates the previous discussion about the consolidation of the term asset management primarily in the research area of engineering. Moreover, the central theme of most of these engineering journals is directly related to the technical areas incorporated throughout the evolution of the asset management discipline, such as water resources (e.g., Urban Water Journal and Water Science and Technology), electrical and electronic systems (e.g., IEEE Transactions on Power Delivery, IEEE Transactions on Dielectrics and Electrical Insulation, Electrical Insulation, IEEE Transactions on Power Systems, IEEE Transactions on Smart Grid and Electric Power Systems Research), infrastructure (e.g., Journal of Infrastructure Systems, Automation in Construction, Journal of Computing in Civil Engineering and Structure and Infrastructure Engineering), transportation (e.g., Transportation Research Record) and management (e.g., Journal of Management in Engineering and Built Environment Project and Asset Management).

Contributing Authors

Asset management is a field that has attracted many researchers over all these years. Among all collected documents (2,449), it was identified that 5,446 authors have contributed to it. Despite the large number, few authors have a significant number of documents in the area, as about 4,577 of the authors (about 91%) have only one published document. As main contributors, 90 authors are present in at least 5 documents while only 11 authors have a minimum of 10 documents related to asset management.

Table 7 presents further information related to the main contributing authors to asset management. These authors

Table 7: Main contributing authors on asset management.

Contributing author	Main research area	Main subarea	Number of docs.	*h*-index of the docs.	Sum of times cited
Marlow, D.	Engineering	Water resources	16	10	213
Burn, S.	Engineering	Water resources	8	8	147
Andrews, J.	Engineering	Transportation	17	7	154
Fotuhi-Firuzabad, M.	Engineering	Electrical electronic	11	7	235
Labi, S.	Engineering	Transportation	10	6	81
Sadiq, R.	Engineering	Infrastructure	8	6	211
Clemens, F.	Engineering	Water resources	19	5	76
Rowland, S. M.	Engineering	Electrical electronic	9	5	55
Love, P.	Engineering	Infrastructure	9	5	49
Hegazy, T.	Engineering	Infrastructure	8	5	47

were identified by listing the top 24 most publishing authors who account for about 10% of all data collected (253 docs.) and combining its citation index from Citation Reports in the Web of Science platform. Therefore, it was considered not just the greatest number of published documents but its relevance through the higher *h*-index of their published documents.

As can be seen in Table 7, these main contributing authors on asset management carry out research mainly in the engineering area. Since engineering is a wide area, these authors usually approach asset management under different areas of expertise. Fotuhi-Firuzabad, M. and Rowland, S. M. address research in the field of electrical and electronic engineering. While the first author focuses research on topics such as reliability and criticality for power transmission and distribution systems and equipment, the latter focuses on dielectrics and electrical insulation.

Marlow, D., Burn, S. and Clemens, F. collaborate with the water resources subarea on different topics, such as the management and condition assessment of water pipes and sewer systems. On the other hand, Andrews, J. and Labi, S. address asset management research for transportation systems such as modelling and condition-based maintenance for railway and highway and transportation assets.

Love, P., Hegazy, T. and Sadiq, R. develop research in the civil infrastructure subarea, such as buildings and constructions, under different approaches. Love, P. discusses these issues mainly under information management through digital technologies as building information modeling (BIM). Hegazy, T. addresses other management topics about civil infrastructure assets such as finance and life cycle optimization. Lastly, Sadiq, R. works mainly with research that supports decision making in infrastructure asset management and addresses the management of public infrastructure assets considering aspects of sustainability.

Besides, half of all asset management documents from these main contributing authors were published in 12 of the 18 engineering journals listed in Table 6. This corroborates the result of the main sources of publication in asset management since these main contributing authors generally publish their work in those previously analyzed journals. The most preferred journals by these authors are Structure and Infrastructure Engineering (12 docs.), IEEE Transactions on Dielectrics and Electrical Insulation (7 docs.), Water Science and Technology (7 docs.) and Reliability Engineering and System Safety (6 docs.).

Countries and Collaboration

The span of the geographical area is an indication of the versatility and popularity of a research field which the more countries engaged, the more significant the research field is

around the world.[15] Among all collected documents (2,449), authors from 100 countries have contributed to the literature on asset management. It is also noteworthy that 28 countries have at least 20 documents published reiterating the global relevance of the research area. The topmost publishing contributing countries in data collected are the USA (679 docs.), England (328 docs.), Canada (186 docs.), Australia (182 docs.), China (139 docs.), Netherlands (102 docs.) Germany (100 docs.) and Italy (91 docs.).

Collaboration among countries is common in areas of globally relevant research. The collected data has shown that there is global collaboration in asset management as counting records by country is higher than the number of documents. There are documents, therefore, in which there is more than one country of origin among the authors. Figure 4 presents the collaboration network generated by country co-authorship network in VOSviewer composed of 35 countries that concentrate around 90% of all collected documents (2,214 docs.) and have met the thresholds of at least 15 documents per country.

As can be seen in Figure 4, the main collaborating countries are the USA, England, Australia, Canada, Italy, China and Germany as they have the largest number of links with different countries. The color patterns in VOSviewer bibliometric networks highlights a different cluster of collaboration. Thus, eastern countries such as South Korea, Japan, Thailand, Taiwan, Malaysia and Singapore collaborate mainly with each other and with regional exponents such as China and Australia. In general, the European countries in the network have many collaborations with each other. The presence and collaboration of South American countries are limited to Brazil and Chile. Both collaborate mostly with each other and with other Latin-speaking countries such as Spain and Portugal in addition to the main collaborating countries.

The collaboration trend was analyzed through the overlay visualization of the global collaboration network in VOSviewer as shown in Figure 5. The color patterns highlight
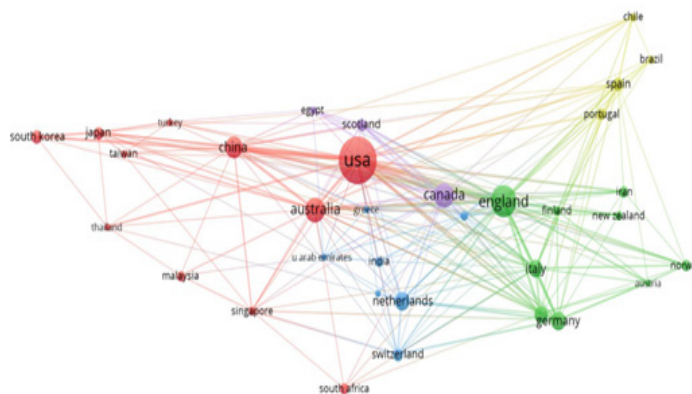

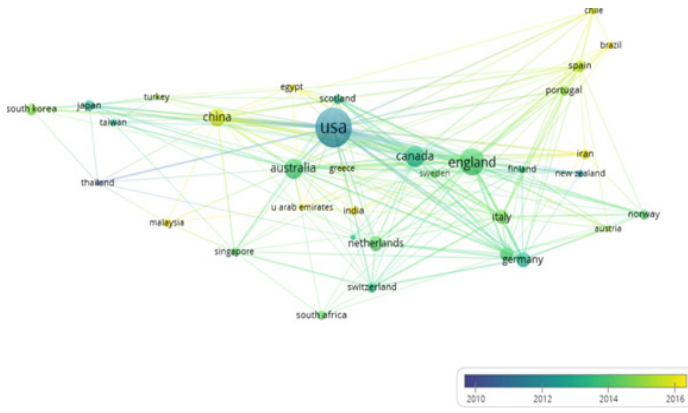**Figure 4:** Global collaboration network on asset management.

Figure 5: Global collaboration network on asset management over the years.

the collaboration over the years. In general, countries with the most recent collaborations are also those with few asset management publications. In other words, these are emerging countries that are collaborating with the most contributing countries.

It is noteworthy that although England, Canada, Australia and the Netherlands are among the topmost publishing countries, their collaborations are recent. China's collaborations are even more recent. The USA, otherwise, is the main contributing countries and the oldest collaborators as the average years of their collaborations date back to 2010. Finally, Table 8 presents further information related to the numbers of the global collaboration network on asset management.

As can be seen in Table 8, data collected suggest a greater dependence on international collaboration for beginners in the area of asset management research, that is, those countries with fewer published documents.

Table 8: Main collaborating countries on asset management.

Country	Number of links	Collaboration documents	Total of documents	Percentage of collaboration
USA	48	211	679	31%
England	40	165	328	50%
Canada	34	96	186	52%
Australia	31	83	182	45%
Italy	28	83	91	92%
Germany	26	80	100	80%
China	24	101	139	73%
France	21	65	89	73%
Spain	20	45	59	76%
Netherlands	18	46	102	45%

CONCLUSION

This paper aimed to map the literature on asset management through a bibliometric analysis. To achieve this goal, the methodology was structured in three steps: data collection, data processing and results extraction. The database considered the Web of Science Core Collection and the analysis processes focused on publication trends, key research areas, main sources of publication, contributing authors and countries and its collaborations. A total of 2,449 documents among articles, reviews and editorial material, including the documents in early access, were selected for the results analysis processes.

Publication trends on asset management identified a rapid growth over the past 15 years. This increase was driven by the use of the term beyond the financial and business economics areas after the late 1980s. The term asset management has come to be associated with planning and maintaining the condition and performance of the physical assets and infrastructure from the 90s. In the 2000s, asset management research in this context has boosted even more as the first international guidance on asset management has emerged. In the 2010s, with the international standard ISO 55000 series released, asset management publications have consolidated primarily in the fields of engineering (e.g., infrastructure, water resources, electrical electronic systems and transportation). It is noteworthy that the term asset management for financial research is still used and business economics area corresponds to about one fifth of all documents collected on asset management.

Key areas on asset management were identified through a co-occurrence network of the main referenced keywords in the collected data using VOSviewer software. The network mapped five clusters of close keywords in the collected data which were analyzed and classified. Financial and business, Infrastructure, Maintenance, Optimization and Management were the main areas covered in the asset management literature.

Journal of Infrastructure Systems, IEEE Transactions on Power Delivery, Reliability Engineering and System Safety, Journal of Banking and Finance and Urban Water Journal, were the most relevant journals on asset management publications based on the ranking of topmost publishing journals by the *h*-index of the journal's collected documents. About 5500 authors contributed to the asset management research area according to the data collected. However, nearly 85% of authors had only one published document. Therefore, the main contributors were identified based on the number of documents published and its citation *h*-index. Marlow, D., Burn, S., Andrews, J., Fotuhi–Firuzabad, M., Labi, S., Sadiq,

R., Clemens, F., Love, P., Hegazy, T. and Rowland, S. were observed to be relevant authors in this field.

A total of 100 countries in the data collected have been published on asset management over the years. The topmost publishing countries with more than one hundred documents were the USA, England, Canada, Australia, China, Netherlands and Germany. Collaboration among countries was observed in the collected data and mapped through a co–citation network using VOSviewer software. As well, the collaboration trend was analyzed through the overlay visualization of the global collaboration network. In general, it was identified that the countries that published the most in this field of research were also the ones that most collaborate internationally. Moreover, it was observed that the most recent countries in this area tended to be more dependent on these collaborations.

Although this bibliometric analysis has selected an important and broad database as Web of Science Core Collection, documents indexed only in other databases may be omitted from the data collection. However, it is worth mentioning that the search protocol considered asset management without combining with other terms and accepting writing variations for a broader data collection. In addition, the search protocol also considered a wide period of more than 50 years of the publication on asset management discipline. Thereby, these measures tried to compensate for this potential limitation.

This paper contributes to the research field for several reasons. It provides a comprehensive overview of publication trends on asset management and it maps the key areas of this research field. Second, it can help asset management scholars and specialists to identify main sources of publication for relevant information. Furthermore, this research helps to identify the authors and countries with the most potential for asset management development and production. Finally, it also enables the visualization of countries' collaborations in the asset management field for partnership opportunities.

Accordingly, it is expected that the results of this paper will contribute to researchers around the world as a bibliometric analysis is an interesting approach for a detailed overview of a scientific field. Moreover, it is also expected to contribute to the justification of future research directions on asset management through gaps in the literature mapping. As an opportunity, the ISO 55000 series for asset management

is surprisingly suggested for future research. Although it represents a milestone for the discipline of asset management, this issue is not being widely addressed in the literature. The development of frameworks and tools for application in this standardized context is a gap identified in this mapping of the literature.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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