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An Overarching Review on Delay Analyses in Construction Projects

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Abstract: Numerous studies have been conducted by researchers on the delay analysis topic, which is one of the primary areas of scientific study due to the effects of delays on time and cost in construction projects. Following fruitful contributions made by the researchers, it is believed to be extremely important to summarize the existing studies in terms of being a road map for future studies and practitioners. In this context, not only does this study aim to detect the most significant authors, sources, organizations and countries contributing to the improvement of delay domain in the construction industry concerning delay analyses worldwide but also to provide the researchers with extensive insights concerning the prominent research themes, trends and gaps in the literature. Hence, 168 documents related to delay analyses from 1982 to 11 February 2021 were detected through the Scopus Database and the Web of Science Database, and scientometric analyses were conducted via VOSviewer software. By evaluating the related research, two main research areas were detected in this field, namely; improving the delay analysis methods and resolving the disputes before they occur. This study is believed to make theoretical and practical contributions in that it examines the delay analysis topic in all aspects such as prominent institutions, countries, authors and sources, synthesizes the data and highlights possible research domains, gaps and trends concerning the delay analysis topic in construction industry.

Keywords: delay analysis; scientometric analysis; construction; blockchain; smart contracts; critical chain project management

1. Introduction

Notwithstanding the undeniable contribution of the construction industry to the economy, dispute—which may conclude with cost and time overrun—is an inevitable part of the construction projects [1,2]. Delay is the main source of dispute and its proactive and timely resolution plays a core role in business success. However, most construction projects fail in resolving time-related disputes [3–5] and this interminable issue triggers the researchers' attention to concentrate on studies to overcome time-related disputes. As is seen in the literature, there has been steady and growing interest in the researches tackling the delay analysis contexts with different aspects. While some researchers have focused their attention on detecting the reasons for time-related disputes in order to prevent disputes during the course of the projects [6–8], other researchers have concentrated on detecting the strengths and weaknesses of the current delay analysis models [9,10], developing more robust models than the existing models [11,12] and identifying the most appropriate delay analysis methods for construction projects [13,14]. Although such attention is desirable for the sake of the construction industry, the accumulation of the volume of research in this field results in many challenges in terms of developing a holistic approach. Due to the density of studies, an overarching study is required. However, no holistic study concerning delay analysis domain in the construction industry has been conducted. Hence, this study aims to detect prominent researchers, sources, institutions

and countries as well as to guide researchers by highlighting the trend and any potential gaps in the literature. Studies related to delay analyses conducted between 1982 and 2021 (11 February) were searched through the Scopus Database and the Web of Science Database. To detect the most relevant documents, at the outset, the most cited articles concerning delay analysis issues were reviewed and thus the most common keywords were detected. After the relevant keywords were searched via Scopus Database and Web of Science Database, 168 related documents were obtained. Then, scientometric analyses which are 'Co-Item Analysis,' 'Citation Analysis' and 'Bibliographic Coupling Analysis' were conducted via VOSviewer software in order to detect the most concentrated research areas identifying the current trends and gaps in the literature along with the most relevant sources, organizations and countries concerning delay analysis subjects. As an endeavour to detect the gaps concerning the delay analysis field in the literature, this study broadly investigates the delay analyses including the intellectual core of existing studies which centres around the shared reasons of their occurrences. These studies are gathered around two main shared reasons, namely "improving the delay analysis methods" and "resolving the dispute before its arising." In addition to this, prominent institutions, countries, authors and sources contributing to the delay analysis field were detected in this research. Next, the bottlenecks and forerunner developments concerning existing delay analysis methods were closely examined in this study. Consequently, it is inferred from this study that conducting studies on overcoming the flaws of the existing delay analysis methods, developing a Building Information Modelling (BIM) based delay analysis, selecting the most appropriate delay analysis for projects, and integration of Critical Chain Project Management (CCPM), block chain and smart contract to the delay analysis domain are considered to be tremendously vital to improve the delay analysis domain in practice and literature. Therefore; this study is sincerely believed to illuminate the applications in the construction field and fine-tune the future research attempts concerning delay analysis.

2. Materials and Methods

This study adopted the science mapping method in order to detect the current trends and gaps in the literature as well as the most relevant sources, organizations, authors and countries concerning the delay analysis topic by analysing and visualizing large volumes of scientific documents. Science mapping, which is a generic process of domain analysis and visualization, targets to detect the intellectual structure of a scientific field [15]. The research methodology consists of three topics, namely 'Data Collection,' 'Selection of Science Mapping Tool' and 'Scientometric Techniques.'

2.1. Data Collection

Finding the gaps in the academic area and determining the research tendency is extremely important in terms of shedding light on new studies. Although numerous studies have been conducted concerning delay analyses, an all-encompassing study, which lights the way for future studies, to map the global research of the subject concerning delay analyses has not been conducted so far. In this study, the most concentrated research areas and the gaps in the literature concerning delay analysis methods in the construction industry will be examined via scientometric analysis. To achieve this objective, the methodology of this study is defined through the following steps.

2.2. Selection of Research Database

Many databases can be preferred for mapping bibliographic data such as Dimensions Database, Google Scholar, Web of Science and Scopus. Google Scholar can cause double citation counts and results in inadequate data for scientometric analysis [16]. Scopus, which is one of the most comprehensive databases, does not lead to double counting problems and includes a wider range of the latest publications than Web of Science [17–19]. Dimensions Database covers almost 97% of the Scopus database and it is a free scholarly database [20]. Considering all the circumstances, the Scopus Database and the Web of

Science Database were adopted to conduct the scientometric analysis concerning delay analyses in construction projects in order to include all the scientific papers in this study.

2.3. Detection of Keywords

In order to obtain scientific documents that are directly related to delay analyses in construction projects, the most related keywords were defined. Hence, the articles which were cited more than 50 times were listed [21–30] with the help of the Scopus Database and the Web of Science Database. When the related articles were elaborated, it was detected that either 'delay analysis' or 'delay claim' as keywords are common in the areas concerning title, abstracts and keywords of the articles. In addition to this, items such as 'project' and 'construction' are also common in all parts of the articles.

2.4. Detection of Relevant Documents

With respect to the Scopus Database, the following statement was typed on the "Advance Search" area: TITLE-ABS-KEY("delay analysis") or TITLE-ABS-KEY("delay claim") and ALL(construction) and ALL(project). When these keywords were searched via the search engine of Scopus Database, 242 documents published between 1982 and 2021 (11 February) were detected.

With respect to the Web of Science Database, the following statement was typed on the "Advance Search" area: "TI = ("delay analysis") or AB = ("delay analysis") or AK = ("delay analysis") or TI = ("delay claim") or AB = ("delay claim") or AK = ("delay claim") and AB = (project) and AB = (construction)" and Language: (English) and Document Types: (Article or Book or Proceedings Paper). Web of Science Categories were selected as Engineering Civil, Construction Building Technology, Engineering Multidisciplinary, Management, Law and Architecture to narrow the findings. When these keywords were searched via the search engine of the Web of Science Database, 120 documents published between 1982 and 2021 (11 February) were detected.

A total of 362 documents were reviewed manually and it was concluded that 70 documents were duplicated and 124 documents were detected as irrelevant. Therefore, a total of 168 documents were analysed in this research. It was also concluded that 63 relevant documents were obtained from the Web of Science Database and these were the same as the documents detected in Scopus.

A total of 124 studies that are not directly relevant to delay analysis domain in the construction industry are rather related to other aspects of delays. The studies pertaining to other industrial basis, cost, delay factors and so forth are categorized as tabulated in Table 1.

Table 1. Categorization of objectives of omitted documents obtained from Scopus Database and Web of Science Database.

Objectives of Delay Analysis	Number
Other Industry Basis	71
Delay factors	11
Cost	9
The topics of proceedings	6
Scheduling	5
Delay claims	3
Delay prevention	7
Project Documentation	3
Change order	1
Progress monitoring	1
Legal risks	2
Exploring critical conflict issues	1
Excusable delays	1
Shared risks	1
Bidding	1
Productivity	1
Total	124

A flow diagram comprising the identification, screening, eligibility and inclusion of documents is depicted below (Figure 1) as per PRISMA Flow Diagram.
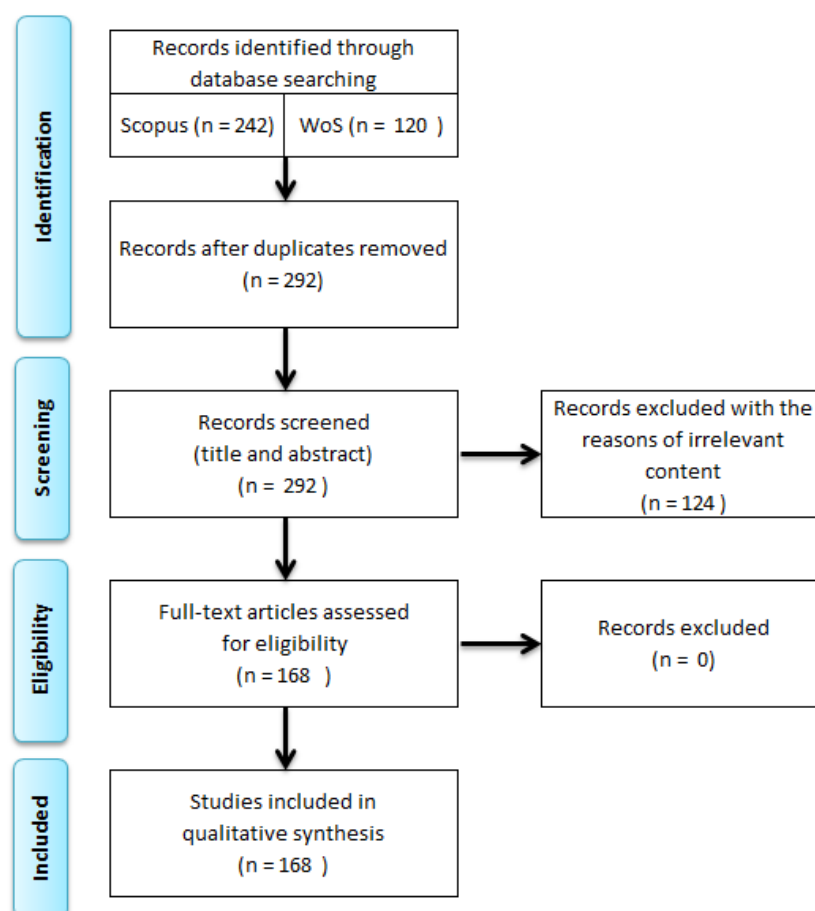

Figure 1. Flow diagram of identification, screening and inclusion of studies.

2.5. Selection of Science Mapping Tool

In order to examine any scientific field, an appropriate science mapping tool is to be adopted. Although there are many tools such as VOSviewer, Gephi, CiteSpace, Sci2 and HistCite, the tools which are VOSviewer, Gephi and CiteSpace are the most prominent [31]. Gephi is a free open-source visualization and exploration software for graphs and networks [32]. CiteSpace, which was developed as a tool for visualising and analysing trends and patterns in the literature, is also a free science mapping tool [33]. VOSviewer, which is one of the most recommended mapping and visualization tools that can illustrate data in a great visualized form [19,34], has special features concerning text-mining [35]. After an in-depth elaboration of the concerned software, it was concluded that VOSviewer satisfies the requirements of this study; therefore, the scientific papers obtained through searching with the concerning keywords in the Scopus Database and the Web of Science Database were analysed via VOSviewer software.

2.6. Scientometric Techniques

With the help of this quantitative analysis, the current trends towards the delay analysis topic in the construction industry, the gaps in the literature, potential research areas, and the most relevant countries, sources, organizations and authors, were revealed via VOSviewer software in this study. To achieve this, as a scientometric technique, 'Mappings Based on Text Data' and 'Bibliographic Data' analyses were conducted. Concerning the text data, the 'Co-Item Analysis' was accomplished to detect the most repeated words under the title, keywords and abstracts in the documents. For bibliographic data, 'Citation'

and 'Bibliographic Coupling' analyses were conducted. For citation analysis, the most cited authors, sources and organizations along with the number of publications were detected. For bibliographic coupling analysis, the countries publishing the largest number of documents related to delay analysis were investigated. A summary of scientometric techniques are depicted in Figure 2 below.
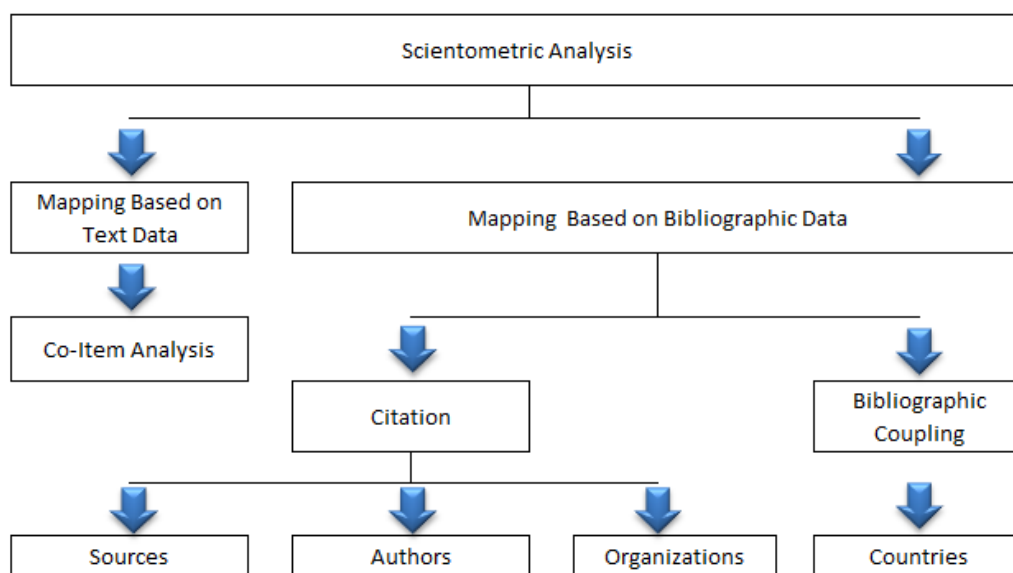

Figure 2. Summary of scientometric techniques.

3. Results

3.1. Density of Publications Concerning Delay Analysis

The earliest research concerning delay analysis is 'Management, Scheduling and Delay Claims', conducted by Leary Christopher P. in 1982. Between 1982 and 2021 (11 February), 168 documents published in total related to delay analyses in the construction industry are illustrated in Figure 3 below.

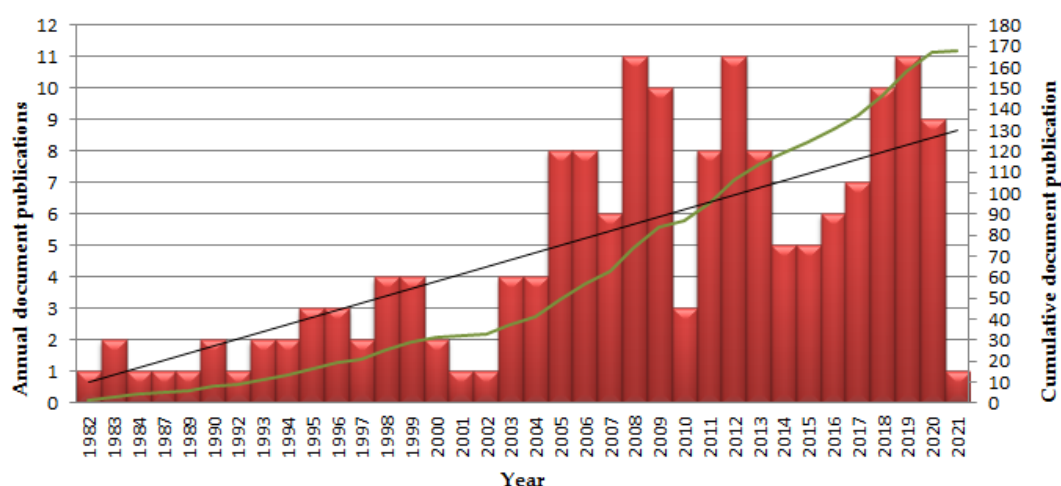**Figure 3.** Distribution of the indexed research published between 1982 and 11 February 2021.

While the numbers related to the cumulative line illustrated in green colour are represented on the right side, the amounts of annually published documents are shown on the left side of the graph. The black line represents the trend of the publications and the trend was computed as per linear regression. A linear regression analysis examines

the statistical relationship between two or more quantitative variables in order to forecast one from the other(s) [36]. By looking at the trend, it is explicitly inferred from the chart that the rate of publications concerning delay analyses in the construction industry has an accelerating trend by years. Publications were observed to skyrocket in 2005. While the average of annual publications concerning delay analyses in the construction industry was 2.2 until 2005, the average of yearly publications surged to almost 8 between 2005 and 2021. Bearing in mind that the study comprises the documents until 11 February 2021, 1 document published in 2021 does not represent the whole year. It is clear in Figure 3 that despite some interests for the studies concerning delay analysis topic until 2003, the trend has steadily accelerated since then, until 2020. Compared to the studies conducted in the 20th century, many more publications concerning delay analysis in the construction industry have been conducted in the 21st century. This is in line with the argument that delay analysis topic has become an increasingly needed research field, and growth in the number of publications is likely to continue in order to meet the needs in the industry and academia. A scientometric analysis is needed in order to gain insight into state-of-the-art developments by processing very large amounts of heterogeneous data, which has been growing rapidly; thus, this enables the researchers and practitioners to get better decisions on delay analysis.

3.2. Main Research Interests Concerning Delay Analysis

By mapping the term 'Co-Item' based on text data, the most repeated keywords were analysed via VOSviewer. According to the counting method, full counting was selected to identify occurrences of a term in all documents [37]. Afterwards, the minimum number of occurrences of a term was chosen as 20 in order to detect the most significant keywords and then the meaningful keywords were selected to identify the trend of delay analysis subjects in the construction industry. The most relevant repeated items in documents are illustrated in Figure 4 below.

The colours of the items represent the average years of the items as per the repetition in years. While the green ones identify the oldest items, the yellow stands for the newest items. The researchers who contributed to the documents coexisting with the items like 'cause', 'effect', 'impact' and 'factor' concentrated on resolving the dispute before it occurred [3,6,8,38–50]. Then, the documents spotting the items of 'concurrent delay' came into prominence. Because concurrent delay is a vital issue required to be solved by an appropriate delay analysis method, many researchers have focused on this subject [9–11,21,23,46,51–62]. When the item of 'case study' is elaborated with the associated documents, it can be concluded that the researchers conducting case studies mostly detected the strengths and weaknesses of the current delay analyses. The most cited articles in this manner [21,30] emphasize the critical drawbacks of the current delay analyses in the construction industry. The latest released documents containing the items such as 'approach', 'technique', 'model', 'delay analysis method', 'delay analysis technique' emphasized the pitfalls of the current delay analyses; therefore, they developed new delay analysis models [11,12,25,30,53,56,58,63–66]. In addition to this, integrations of delay analysis methods into the mediums of project management such as BIM came into prominence. Although many researchers have the joint agreement that BIM based delay analysis tools reduce the number of disputes resulting from delay issues in construction projects [67–71], few studies endeavoured to develop a framework examining the integration of delay analysis into BIM tools [72–75] to develop a BIM based delay analysis tool [76] and BIM based delay claim management tools [77]. Moreover, CCPM, as an innovative approach, was widely discussed in the literature and it is asserted to have great potential to remedy delay related issues of construction projects [78–81]. Furthermore, other approaches such as smart contracts and blockchain were brought to the agenda to maintain project tasks including delays [82]. In addition to mapping the occurrence of the terms, their magnitudes and subject areas are tabulated in Table 2 below.
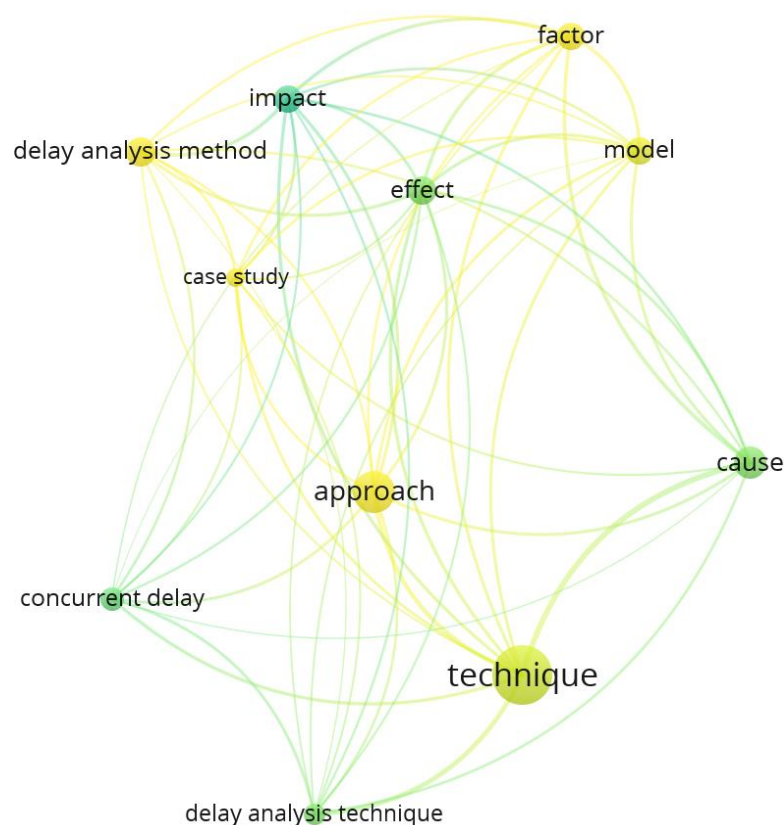
Figure 4. Mapping the items repeated in documents.

Table 2. Mapping the Items Repeated in Papers.

ID	Items	Subject of the Majority of Related Studies	Occurrences	Research Area	Rate
1	Technique	Techniques of delay analysis	126		
2	Approach	Developing delay analysis method	89		
3	Delay analysis method		63		
4	Model		59	Improving the delay analysis methods	0.66
5	Concurrent delay	Concurrent delay of owner and contractor	49		
6	Delay analysis technique	Techniques of delay analysis	45		
7	Case study	Strengths and weaknesses of delay analyses	39		
8	Cause	Reasons for delay in construction projects	68		
9	Factor	Reasons for delay in construction projects	59	Resolving the dispute before its arising	0.34
10	Effect	Effects of delaying events	61		
11	Impact		59		

Synthesizing the most cited articles identifies the trends and future directions of the subject concerning delay analysis. This also sheds light on the gaps that need to be improved and new research areas in line with the current needs concerning delay analysis. As depicted in Table 2, study areas can be categorized under two sections, which are improving the delay analysis techniques and resolving the dispute before it occurs. These

issues are the most relevant topics which constitute the current trends and gaps in the literature.

3.3. Top Research Sources Concerning Delay Analysis

The importance of analysing the academic documents in a scientific area has been emphasized by many studies [83]; thus the readers can reach the most suitable studies for their research domains. Hence, in this study, 'Citation Analysis' concerning the documents was conducted to indicate the significance of documents related to delay analysis. Therefore, the type of analysis was chosen as 'Citation' and the 'Unit of Analysis' was selected as 'Sources' in VOSviewer software. Then, the minimum number of documents of a source was selected as 1 and the minimum number of citations of a source was selected as 5 to figure out the most relevant sources. Of the 67 sources, 30 documents met the thresholds. Published Documents, Citations, Total Link Strength, Scopus Quartile and Web of Science Core Collection as per the sources are provided in Table 3 to spot the significant journals contributing to the delay analysis domain.

Table 3. Mapping the journals as per citations.

ID	Journals	Published Document	Citation	Total Link Strength	Scopus Quartile	Web of Science Core Collection
1	Journal of Construction Engineering and Management	22	705	208	Q1	Science Citation Index Expanded
2	International Journal of Project Management	5	159	70	Q1	Social Sciences Citation Index
3	Construction Management and Economics	6	205	63	Q1	Emerging Sources Citation Index
4	Buildings	4	31	55	Q1	Science Citation Index Expanded
5	Journal of Legal Affairs and Dispute Resolution in Engineering and Construction	8	18	47	Q3	Emerging Sources Citation Index
6	KSCE Journal of Civil Engineering	3	20	29	Q2	Science Citation Index Expanded
7	Canadian Journal of Civil Engineering	3	14	22	Q3	Science Citation Index Expanded
8	Journal of Civil Engineering and Management	1	8	16	Q1	Science Citation Index Expanded
9	Engineering, Construction and Architectural Management	3	30	13	Q1	Science Citation Index Expanded | Social Sciences Citation Index
10	International Journal of Construction Management	2	6	12	Q1	Emerging Sources Citation Index
11	Journal of Management in Engineering	2	29	10	Q1	Science Citation Index Expanded
12	Automation in Construction	2	53	8	Q1	Science Citation Index Expanded
13	Built Environment Project and Asset Management	1	9	4	Q3	Emerging Sources Citation Index
14	IEEE Transactions on Engineering Management	2	55	2	Q1	Science Citation Index Expanded | Social Sciences Citation Index
15	Journal of Cleaner Production	1	15	0	Q1	Science Citation Index Expanded
16	Civil Engineering	1	5	0	Q4	Science Citation Index Expanded

The tabulated journals are sorted as per their total link strength, which indicates the total strength of the links of the journals with other journals. Journal of Construction Engineering and Management is the top source that has published the most amounts of documents (22 documents). The top 4 journals contributing to the delay analysis domain in terms of their total link strength are; 'Journal of Construction Engineering and Management', 'International Journal of Project Management', 'Construction Management and Economics' and 'Buildings.'

3.4. Prominent Researchers

Researchers often collaborate with others to develop new ideas and to increase their efficiency [84]. Researchers who have contributions to shape the delay analysis domain in the literature are the precursors to new developments; therefore, this study aims to spot these authors by creating and visualizing the bibliometric network. Hence, in VOSviewer software, the type of analysis was chosen as 'Citation' and the 'Unit of Analysis' was selected as 'Authors.' In order to detect the most prominent researchers contributing to delay the analysis topic, the minimum number of documents of an author was selected as 3 and the minimum number of citations of an author was selected as 50. Of the 283 authors, 11 authors met the thresholds as illustrated in Figure 5. Concerning the 'Citation Analysis', Figure 5 indicates the magnitudes of the published documents as per the authors.
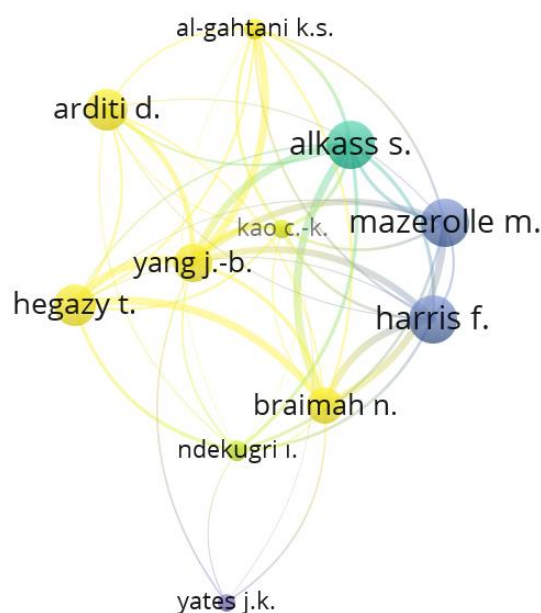
Figure 5. Magnitudes of the published documents as per the authors.

The colours represent the average years concerning the publications. While the authors highlighted in yellow stand for the authors who published more updated documents compared to the others, colours, namely green, blue and purple indicate the authors with relatively older contributions to the field of the delay analysis, respectively.

The number of the authors' studies on delay analysis and the number of citations are illustrated in Table 4 below.

In Table 4, the order of the authors was sorted as per the number of citations. As is seen in Table 4, while Yang j.-b. published the highest number of documents related to delay analysis by 14, Harris f., Mazerolle m., and Arditi d. published the biggest number of average citations.

Table 4. Documents and citations of authors.

ID	Author	Documents	Citations	Average Citations	Total Link Strength
1	Harris f.	3	133	44.33	51
2	Mazerolle m.	3	133	44.33	51
3	Arditi d.	3	115	38.33	31
4	Alkass s.	5	134	26.80	62
5	Hegazy t.	5	114	22.80	52
6	Kao c.-k.	3	51	17.00	40
7	Yates j.k.	3	50	16.67	9
8	Ndekugri ı.	4	59	14.75	33
9	Braimah n.	8	100	12.50	70
10	Al-gahtani k.s.	6	58	9.67	44
11	Yang j.-b.	14	107	7.64	91

3.5. Top Institutions

Bibliographic data were mapped to detect the most significant institutions contributing to the development of delay analysis context. After citation and organization were chosen as the type of analysis and unit of analysis respectively, the minimum number of documents of an organization was selected as 2 and the minimum number of citations of an organization was selected as 2 in order to detect the most relevant organizations concentrating on the delay analysis subject. Of the 260 organizations, 13 organizations met the thresholds as illustrated below.

While yellow colour indicates the organizations publishing more updated documents compared to the others, colours which are green and purple spot the organizations with relatively older contributions to the delay analysis domain respectively. In addition to mapping, document and citation numbers of each concerning organization are tabulated in Table 5 below.

Based on Figure 6 and Table 5, it is detected that the Concordia Institute for Information Systems Engineering, Concordia University contributed the most recent documents in the literature, and the Dept. of Civil Engineering, Univ. of Waterloo received the highest citations by 85.
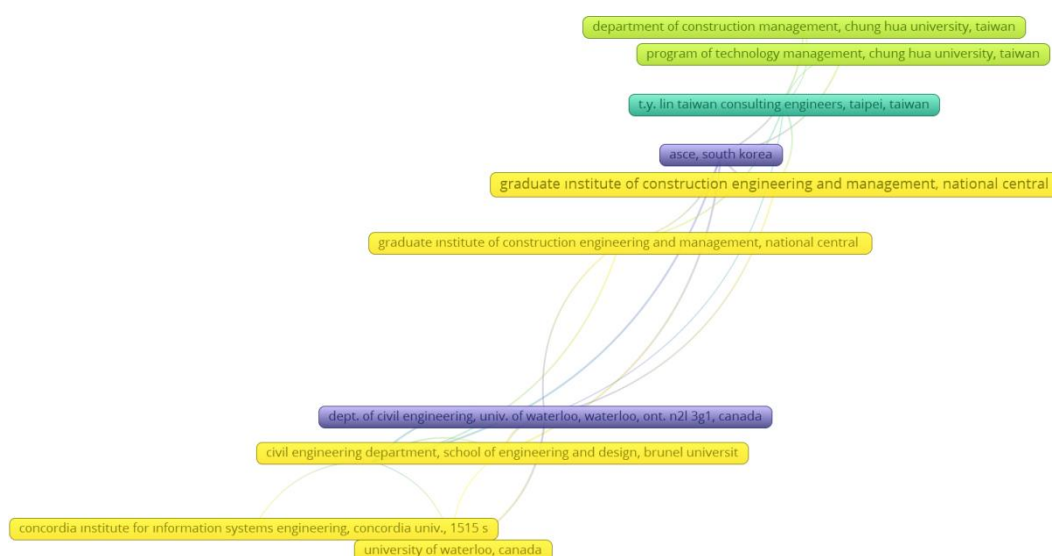

Figure 6. Mapping the organizations publishing documents related to delay analysis subject.

Table 5. Organizations publishing documents related to delay analysis subject.

ID	Organization	Documents	Citations	Total Link Strength
1	Dept. of Civil Engineering, Univ. of Waterloo, Waterloo, ont. n2l 3g1, Canada	2	85	15
2	ASCE, South Korea	2	59	15
3	Dept. of Civil and Environmental Engineering, Univ. of California, Berkeley, ca 94720, United States	2	41	12
4	Civil Engineering Department, School of Engineering and Design, Brunel University, Uxbridge, Middlesex, ub8 3ph, United Kingdom	2	27	10
5	T.Y. Lin Taiwan Consulting Engineers, Taipei, Taiwan	2	18	7
6	Graduate Institute of Construction Engineering and Management, National Central University, Taoyuan, Taiwan	2	11	8
7	Concordia Institute for Information Systems Engineering, Concordia Univ., 1515 Sainte-Catherine st. West, Montrial, qc h3g 2w1, Canada	2	4	1
8	Department of Construction Management, Chung Hua University, Taiwan	2	2	3
9	Graduate Institute of Construction Engineering and Management, National Central University, Taiwan	3	2	7
10	Program of Technology Management, Chung Hua University, Taiwan	2	2	3
11	Arcadis, United States	2	0	0
12	Department of Industrial Engineering, Najafabad Branch, Islamic Azad University, Najafabad, Iran	2	0	0
13	University of Waterloo, Canada	2	0	5

3.6. Influential Countries

'Bibliographic Coupling Analysis' with respect to the countries is limited by the condition that a minimum number of documents of a country is 5 in order to identify the most significant contributions. As a result of the limitation, of the 37 countries, 12 countries met the thresholds. Consequently, the magnitudes concerning documents, citations and average citation of each document as per countries are illustrated in Table 6 below.

Table 6. The magnitudes concerning document and citation as per countries.

ID	Country	Documents	Citations	Average Citation per Document	Total Link Strength
1	United States	42	647	15.40	232
2	United Kingdom	22	381	17.32	192
3	Canada	19	308	16.21	172
4	Taiwan	18	118	6.56	165
5	Australia	9	63	7.00	59
6	South Korea	9	143	15.89	57
7	Saudi Arabia	8	109	13.63	80
8	Egypt	7	18	2.57	35
9	Turkey	7	36	5.14	35
10	China	6	15	2.50	2
11	Iran	6	13	2.17	19
12	India	5	11	2.20	6

Followed by the UK with 22 and Canada with 19 documents, the US has firm research strength and influence in the area of delay analysis with 42 publications and 647 citations. Although the US published documents almost twice as much as the UK, on average, the documents published by the UK got the most citations by 17.32.

4. Discussion

In this research, overarching in-depth literature was conducted in the domain of delay analysis in the construction industry via scientometric analysis to develop a full picture of the delay analysis context and reveal the thematic gaps and future requirements. Figure 7 illustrates a summary of the findings derived from this study.
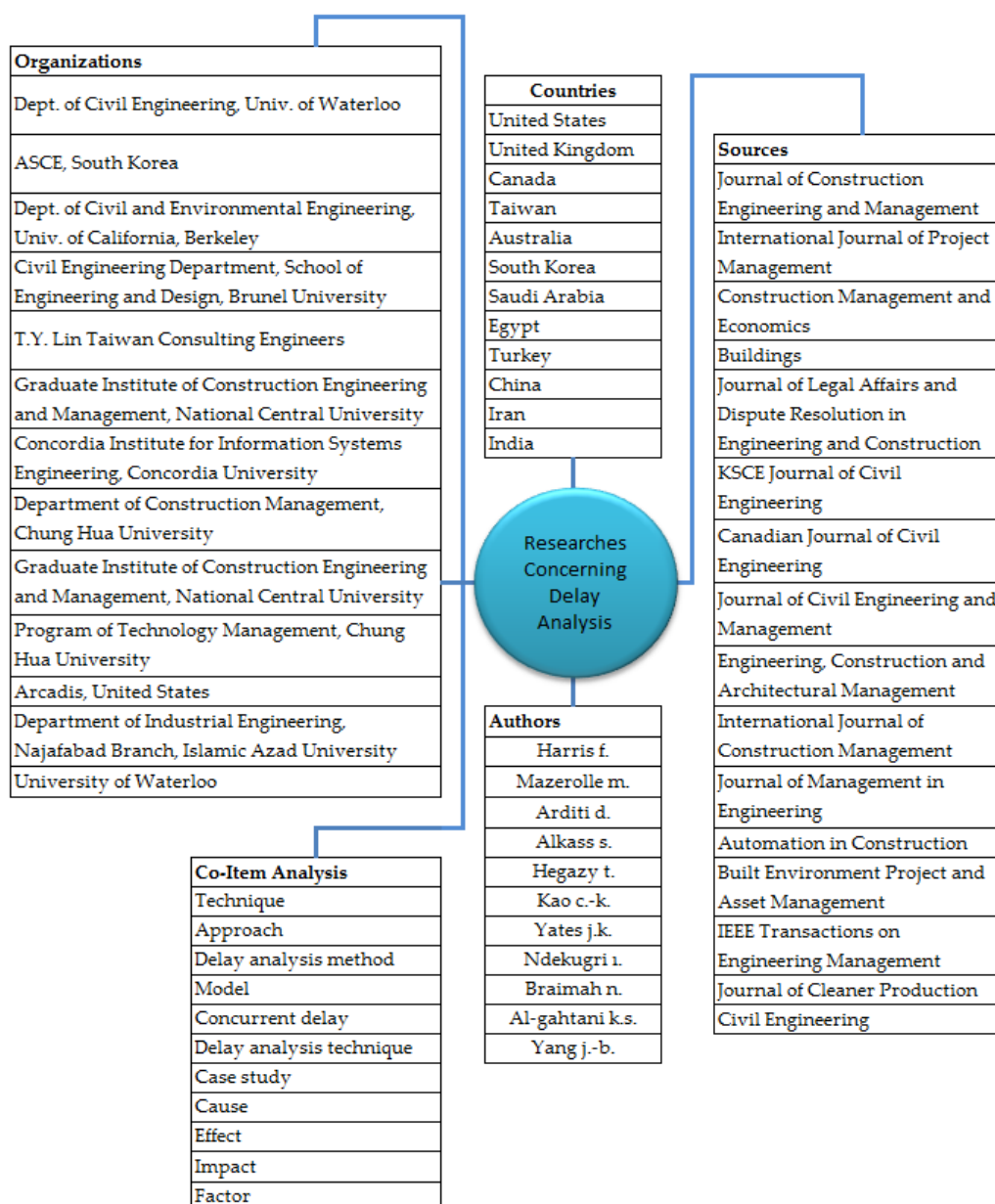
Organizations

Dept. of Civil Engineering, Univ. of Waterloo

ASCE, South Korea

Dept. of Civil and Environmental Engineering, Univ. of California, Berkeley

Civil Engineering Department, School of Engineering and Design, Brunel University

T.Y. Lin Taiwan Consulting Engineers

Graduate Institute of Construction Engineering and Management, National Central University

Concordia Institute for Information Systems Engineering, Concordia University

Department of Construction Management, Chung Hua University

Graduate Institute of Construction Engineering and Management, National Central University

Program of Technology Management, Chung Hua University

Arcadis, United States

Department of Industrial Engineering, Najafabad Branch, Islamic Azad University

University of Waterloo

Countries

United States
United Kingdom
Canada
Taiwan
Australia
South Korea
Saudi Arabia
Egypt
Turkey
China
Iran
India

Researches Concerning Delay Analysis

Sources

Journal of Construction Engineering and Management
International Journal of Project Management
Construction Management and Economics
Buildings
Journal of Legal Affairs and Dispute Resolution in Engineering and Construction
KSCE Journal of Civil Engineering
Canadian Journal of Civil Engineering
Journal of Civil Engineering and Management
Engineering, Construction and Architectural Management
International Journal of Construction Management
Journal of Management in Engineering
Automation in Construction
Built Environment Project and Asset Management
IEEE Transactions on Engineering Management
Journal of Cleaner Production
Civil Engineering

Authors

Harris f.
Mazerolle m.
Arditi d.
Alkass s.
Hegazy t.
Kao c.-k.
Yates j.k.
Ndekugri i.
Braimah n.
Al-gahtani k.s.
Yang j.-b.

Co-Item Analysis

Technique
Approach
Delay analysis method
Model
Concurrent delay
Delay analysis technique
Case study
Cause
Effect
Impact
Factor

Figure 7. Summary of the outcomes of the study.

When the conducted scientometric analyses were evaluated, it was detected that many countries have contributed to the development of delay analysis. Nearly 2 out of 3 publications related to delay analysis were released from the US, the UK, Taiwan and Canada. Although the delay analysis subject is global, it can be inferred from the study that

the delay analysis subject is more popular in developed countries. Sixty-seven sources have published delay analysis related documents, and the 'Journal of Construction Engineering and Management' constitutes the majority of the cited sources since it contains the earliest publications related to this subject. Additionally, when existing studies are examined, it can be concluded that researchers concentrated on 4 main themes such as the frameworks of existing delay analyses, the development of 4D-BIM based delay analysis models, the development of new models, and the selection of delay analysis models.

4.1. Frameworks of Existing Delay Analyses

Co-Item Analysis revealed that themes such as technique, approach, delay analysis method, model, concurrent delay, delay analysis technique, case, study, cause, effect, impact and factor took the attention of researchers for resolving the problems resulting from delays in construction projects. When the keywords were elaborated as per publication years, it seems that the research subject concerning improving the delay analysis techniques is a more current issue than resolving the dispute before its occurrence.

Due to the downsides of the existing delay analysis methods, their techniques and effectiveness were detected as the most frequently mentioned and widely discussed themes by the researchers [10,21,51,57,85–90]. Despite the numerous contributions made by the researchers, the delay issue remains one of the biggest concerns of the construction industry and most of the projects still suffer from dispute resolution in terms of time. Perera and Sutrisna [91] emphasize that "the outcomes produced by some methods are more reliable and relatively objective, but those by others are overwhelmingly subjective. However, none of these methods is considered perfect." It is clear that the techniques concerning delay analysis need to be improved; therefore, today, improving the delay analysis models is one of the most up to date subjects for the academicians.

One of the most striking problems concerning the existing delay analysis models identified by the researchers is ignoring the CPM during the computation of delay and designation of it to the responsible parties [92,93]. Additionally, actualized schedules may contradict with the planned schedule [94]; therefore, disregarding the actual site progress cannot give the accurate result for delay analyses [95,96]. Actual progress consideration for the time intervals is also vital to detect the fluctuations on the Critical Path (CP) during the execution of delay analysis [12,92,97]. Delays are not always successive on the CP, from time to time, delays resulting from owner and contractor can be concurrent; therefore, these delays should be detected and apportioned to the parties [10,52,57,61] in line with the float ownerships defined in the project contract [10,21,62,92,97–99]. Additionally, many of the delay analysis models compute the delays for only one side of the party at a time, and this requires extra computation along with associated time and cost. Not only the delayed activities but also time-shortened activities are to be considered during the execution of the delay analysis [53,92]. Also, the accuracies of delay analysis methods are questioned by practitioners and courts [92]. The most accepted delay analysis methods in the construction industry, such as Time Impact Analysis (TIA), But-For Analysis, Windows Analysis (WA) and their derivatives [90,92,95,100], entail an excessive number of requirements such as time, cost and experts [13,21,25,30,57,95,101,102]; therefore, the difficulties of their implementations make the practitioners suffer from their applications [67,90,103]. It can be derived from the existing studies that the most appropriate delay analysis models should consider the following attributes; CPM, actual sequence of work, concurrency, float ownership and fluctuations of critical paths. Research concerning the benchmarking of the existing delay analysis models to examine their strengths and weaknesses over these attributes can be conducted and improvement in the models can be sought.

Another flaw of the existing delay analyses—which also triggers the institutions to develop new models—is the inconsistent applications of the delay analysis models in the construction industry due to the lack of the procedures [88,104]. Institutions like the Association for the Advancement of Cost Engineering (AACE) and the Society of Construction Law (SCL) contributed to the development of the delay resolution process. In 2006, AACE

published AACE International Recommended Practice No. 52R-06 analysis [101]. This practice provides a guideline without establishing a standard and discusses the application of Time Impact Analysis in the construction industry. In 2007, AACE published AACE International Recommended Practice No. 29R-03 Forensic Schedule Analysis [105]. The purpose of this practice is to deliver a unifying reference concerning the technical principles and guidelines for CPM applications in the construction industry to conduct a forensic schedule analysis. Additionally, this practice discusses delay analysis methods, irrespective of whether delay analysis methods are acceptable or unacceptable to courts. AACE published 'AACE Recommended Practice for Forensic Schedule Analysis' in 2010 [106]. This practice refers to investigating the events by adopting the CPM or the other recognized scheduling methods in conjunction with the process concerning the delay resolution and other concerning legal issues. Following this, SCL published the 'Society of Construction Law Delay and Disruption Protocol' in 2017 in order to offer useful guidance for delay and disruption issues occurring in construction projects [95]. Although there are such recommended practices and protocols in order to maintain consistent applications of delay analyses in the construction industry, it is suggested that algorithms and software integration are to be developed for the most accepted delay analysis models. In the literature, most of the delay analysis methods are described via Gantt Charts; however, procedure and algorithms considering the relationships of activities are needed. Thus, the application of delay analysis in construction projects can be standardized and disputes arising from different applications can be avoided.

4.2. Development of 4D-BIM Based Delay Analysis Methods

Although delay analyses are mostly conducted in planning tools, due to the increasing demand for BIM in the construction industry [107], 4D-BIM software tends to replace planning software in the near future. There have been studies that endeavour to improve the process of delay analysis implementations in BIM. The applicability of the delay analysis in BIM has been discussed by researchers and it has been concluded that most of the problems encountered during the delay analysis can be overcome through the integration of BIM [67,108].

An add-in tool, which is capable of conducting 'Impacted As-Planned' delay analysis model, was developed into BIM software (Revit 2017) by using the C programming language [76]. Vacanas et al. [109] proposed accommodating Unmanned Aerial Vehicle (UAV) technologies in infrastructure projects for delay and disruption analyses. In addition to this, some fruitful techniques and frameworks for the computation of delays via BIM software have been presented in the literature [72,73,75]. Marzouk et al. [72] proposed a methodology which visualizes and foresees claims to assist project parties in handling such claims in a proactive manner by combining the 5D BIM model with responsibility matrix of claims' causes. Essawy and Nassar [110] presented a model and software identifying the topological relationship of each building element type so as to generate construction sequence and its associated schedule. Marzouk et al. [74] proposed a model which illustrates how BIM-based claims can be analysed. Integration of delay analysis methods into 4D-BIM is observed to be useful for areas such as partnerships, negotiations, third party neutrals, referees, litigation process, claims metrics in relation to the use of 4D simulation, value of the claim and 4D simulation of delayed activities; therefore projects may gain efficiency with the use of BIM [111]. Additionally, major challenges occurring during the implementation of delay analyses, such as obtaining information and presenting the delay events, can be overcome through BIM implementations [112]. Based on the aforementioned studies, offering an information-intensive visualization, BIM is believed to be an ideal means to solve the problems encountered in delay analysis domain.

Although BIM provides visualization of delayed events, which is preferred by the stakeholders, undeniable challenges may also occur during the course of the delay analysis process via BIM software. Soltani et al. [113] conducted in-person interviews with construction law attorneys and forensic engineers and spotted these challenges as the high

cost of BIM implementation, time consumption, preference of conventional tools for the uncomplicated delays, complexity of BIM for judicial actors such as judges and expert witnesses, unawareness of judicial actors concerning BIM, insufficiency of BIM tools to develop trustworthy 3D models and potential of BIM to change the real story. Despite the expected effectiveness of BIM-based delay analysis, it is derived from the studies that there are some challenges encountered during the course of BIM adaptation in construction industry [114]; therefore, benefits of 4D-BIM based delay analysis tools in practice can be set forth by researchers in order to raise awareness for the construction actors.

4.3. Development of New Delay Analysis Methods

Because of the aforementioned flaws of the existing delay analyses, the development of an appropriate method always comes into prominence. Applications of the most accepted delay analysis methods such as TIA and WA in practice [95] are very demanding in terms of significant amounts of requirements such as time, cost and expertise [13,21,25,95,101]. In addition to this, the lack of procedures and algorithms of existing delay analyses reduce their usage and result in taxonomic confusion [115]. Thus, new approaches and models have been proposed to increase the efficiency of delay analyses [12,25,56,63–66,92,116–120]. Existing delay analysis methods are categorized as per Analysis Type (Effect and Cause or Cause and Effect), Critical Path Determined (Retrospectively or prospectively or contemporaneously) and Delay Impact Determined (Retrospectively or prospectively) by Society of Construction Law Delay and Disruption Protocol [95]. Therefore, delay analysis methods detected in the literature were classified accordingly in Table 7.

Despite the development of many delay analysis methods, the resolution of delay is still one of the most problematic issues to overcome in construction projects [53,121]. One of the most striking reasons for these difficulties is the constant change on the critical path of the project work schedule and the effect of the delayed activities on the completion date of the projects [22]. Especially, in large-scale construction projects, elaborating the facts of the delays and apportioning the delays to the responsible parties are very difficult and time-consuming processes [117]. It is vital to determine the amount of the delay along with its responsible parties in order to reduce the disagreements in the projects and to execute the projects as per the expectations of the stakeholders [52]. When the delay is not shared out to the responsible parties thoroughly, parties tend to seek their rights in the courthouse which is a very time and cost consuming process [30]. Since delay analysis is one of the most challenging and vital topics in the construction industry, research on this matter are very valuable to maintain the fragile structure of the construction industry.

On the whole, by looking at the trend derived from this study, a new delay analysis model that has procedures and algorithms and solves the drawbacks of the current delay analyses seems to be needed and it seems that, in the near future, researchers will tend to develop more effective delay analysis methods.

Table 7. Existing Delay Analysis Methods.

#	Delay Analysis	Attributes of Delay Analyses						
		Analysis Type		Delay Impact Determined		Critical Path Determined		
		Effect & Cause	Cause & Effect	Retrospectively	Prospectively	Retrospectively	Prospectively	Contemporaneously
1	Global Impact Analysis	√		√		√		
2	Net Impact Analysis	√		√		√		
3	Collapse Analysis	√		√		√		
4	Modified But-For (MBF) method	√		√		√		
5	As Planned But-For	√		√		√		
6	As-Planned vs As-Built	√		√				√
7	SDAF Method	√		√				√
8	Windows Analysis	√		√				√
9	Modified Windows Schedule	√		√				√
10	Daily Windows Delay Analysis	√		√				√
11	Total Float Management Technique	√		√				√
12	Windows Analysis with Multiple Baseline Updates	√		√				√
13	Delay Analysis Method Using Delay Section (DAMUDS)	√		√				√
14	Effect-Based Delay Analysis Method (EDAM)	√		√				√
15	Isolated Delay Type (IDT)	√		√				√
16	Isolated Collapsed But-For (ICBF)	√		√				√
17	Stochastic Delay Analysis and Forecast Method (SDAF)	√		√				√
18	Float Ownership, Logic Change, And Resource Allocation (FLORA)	√		√				√
19	Accumulated Delay Analysis Method (ADAM)	√		√				√
20	Impacted As Planned (IAP)		√		√		√	
21	Time Impact Analysis (TIA)		√		√		√	

4.4. Selection of the Delay Analysis Methods

Selection criteria and selection methods concerning delay analyses have been developed by researchers by detecting the advantages and disadvantages of the existing delay analyses and requirements of the construction projects.

As is derived from the literature, numerous fruitful studies have been conducted to define selection criteria concerning the delay analysis methods. Upon surveying the construction firms in the UK, Braimah and Ndekugri [122] examined the factors influencing the selection of delay analysis methods. Eighteen factors were defined and ranked according to their relative importance. Through utilizing a factor analysis technique, the researchers categorized the eighteen factors under 6 groups. Additionally, Arditi D. and Pattanakitchamroon T. [21] discussed 4 main factors affecting the selection of delay analysis methods. Furthermore, Adhikaril, Kim, and Lee [14] defined a method for the selection of the most appropriate delay analysis method through analytical hierarchy process (AHP) under the constant circumstances of availability of information, time of analysis, capabilities of methodologies, time and fund available for analysis and other factors. Perera & Sutrisna [91] defined the use of AHP for the delay analyses in construction projects. Furthermore, Perera et al. [13] developed a robust Decision-Making Model (DMM) to select an optimum delay analysis method through Simple Additive Weighting (SAW) Method. However, a delay analysis method alone might not fit the entire project types since the projects are unique [23]. Despite this, the current delay analysis selection methods and criteria cover only a few delay analysis methods with limited constancy of project characteristics and thus it seems that this study area can be expanded by increasing the number of project types and delay analysis methods in the selection process of the delay analysis models. Therefore, future studies for this matter will be very fruitful for the academy and practice.

4.5. Contributions of Critical Chain Project Management

Recently, the most widely accepted delay analysis methods such as WA, TIA and their derivatives are performed based on CPM. However, CPM helping the project leaders to manage the time in construction projects might fail in terms of cost and time overruns [1]. Compared to CPM, CCPM is asserted to have more superior benefits for scheduling tasks and is believed to be one of the leading and promising innovations for the work schedule by resolving problems that arise from multitasking in human resources [1].

Goldratt developed the Theory of Constraints (TOC) to manage systems concerning repetitive production. In principle of TOC, each system has a constraint, and performance of the system can be improved by increasing the performance of the resource constrains. CCPM, which was also developed by Goldratt [123], is an extension of TOC. CCPM improves the work schedule by reducing the uncertainties and statistical fluctuations [124]. For this matter, theory of CCPM has been widely discussed to improve project performance [124–132]. Additionally, the topic concerning performance of CCPM was analysed to mitigate delays [78]. Moreover, the domains concerning supply chain and critical chain concepts in Engineer, Procurement and Construct (EPC) projects were integrated [133]. Furthermore, overarching studies concerning CCPM were also conducted [134,135] and it was concluded that CCPM offers a number of opportunities for further research on scheduling topic. Since schedule is one of the vital requirements for the delay analyses, CCPM is also to be considered for delay analysis domain by researchers as an innovative method of planning and project management.

4.6. Contributions of Blockchain and Smart Contract

Applications of delay analyses depend on the project schedules, which develop in line with rapid technological innovations; thus, in this study, scheduling related documents including the topics of "Blockchain" and "Smart Contract" were also reviewed and synthesized in order to detect the current trends and research gaps concerning the delay analysis domain.

Being one of the rapidly developing approaches to improve the construction management process, blockchain can successfully handle excessive numbers of challenges such as trust, information sharing and process automation, from which construction management suffers [136]. Applications of blockchain on the supply chain and schedule were comprehensively discussed in valuable studies [136–141]. Delay analysis domain is believed to be improved by developments in schedule in terms of blockchain.

A blockchain-enabled contract, which is also called smart contract, is a computer code that automates execution of all parts of an agreement without any need of human intervention [136]. During this execution, the blockchain platform enables to store all the data related executions of the agreement securely and transparently. The digital transformation through smart contracts is currently being developed to remedy chronical peculiarities in the construction projects such as low productivity, poor regulation, lack of trust, inadequate collaboration, inadequate information sharing, and poor payment practices [142]. Blockchain technology along with smart contracts enables security of data and record transactions sequentially based on a distributed structure without relying on central authority [143]. Dakhli et al. [82] addressed that smart contracts should be designed in a way that consider all possible variants related to a task, such as absenteeism of a worker resulting in a delay, which could assist project management team to identify delay causes properly. Thus, helping prevent any ambiguity during the execution of projects, blockchain-enabled contract involved in delay management is believed to be promising.

In addition to this, blockchain technology is deemed applicable to schedule management which is one of the ten project management knowledge areas defined by PMBOK [144]. Blockchain was identified as an effective concept to detect the current or potential barriers like schedule delays [139,141]; therefore, it is believed that any development in blockchain technology concerning delay management will reduce the burden of project management in construction industry. By looking at the current trend in the literature and practice, delay management is expected to be the part of smart contracts in the near future. It is claimed that further studies carried out on the subjects such as blockchain and smart contract will make significant contributions to delay management by integrating delay analysis techniques with today's forerunner technologies.

5. Conclusions

The concept of delay analysis has received rising global attention from institutes, researchers and practitioners due to its significance in the construction industry. Although many research efforts dealing with different aspects of delay analysis have been made, there has been no study summarizing the studies conducted so far and identifying new study areas related to this subject. Therefore, this study is extremely valuable for drawing a road map for the examiners who aim to work in this field. It is believed that the overarching outcome of this study is as much a significant guide for the researchers as it is for the practitioners.

In this study, the keywords concerning delay analysis subjects were detected and the documents published between 1982 and 2021 (11 February) were searched through the Scopus Database and the Web of Science Database. After an in-depth elaboration, the irrelevant studies were omitted, and thus, 168 documents were detected. Later, scientometric analyses, namely 'Co-Item Analysis', 'Citation Analysis' and 'Bibliographic Coupling Analysis' were conducted to determine the trends, gaps and most relevant authors, sources, organizations and countries in the literature concerning the delay analysis domain. Consequently, the main research domains, gaps and trends concerning delay analyses were released. The research topics were categorized under six main headings, namely; framework of existing delay analyses, development of 4D-BIM based delay analysis methods, development of new delay analysis methods, selection of the delay analysis methods, contributions of critical chain management and contributions of blockchain and smart contract. Under these research topics, the gaps, trends and future directions were emphasized.

5.1. Academic and Practical Contributions

The resolution of delay related dispute requires a mutual agreement in terms of defining the responsible parties and extension of time. However, identifying responsible parties for delays in construction projects is the most likely source of dispute. Although numerous studies concerning the delay resolution in the construction industry have been published over the past few decades, the construction industry still suffers from the construction delays [73]; therefore, gaps and trends are to be recognized by the researchers and practitioners in order to improve delay resolution process. This study is unique in several ways. This paper presents the first comprehensive scientometric study investigating research on delay analysis, which is believed to shed light on the delay analysis context, rather than focusing on a case or an application. In other words, this study is believed to be invaluable in terms of providing a demonstration of previous research efforts to guide future scientific attempts concerning delay analysis domain. In practical terms, this study can enable the practitioners to synthesize delay analysis studies that capture the state-of-the-art research in delay analysis in the construction industry. Furthermore, this study provides a benchmarking tool for the practitioners to assess the delays occurring in the construction projects and also enhances the readiness of practitioners for adopting delay analysis methods and associated technology. On the whole, not only does this study discuss the published documents in an overarching manner in a way that helps the readers to comprehend the delay analysis domain holistically but also make significant contributions by paving the way for their future studies in the light of gaps and trends detected.

5.2. Recommendations for Academy and Practice

Although many scientific studies have been conducted in different aspects of the delay analysis domain, projects still suffer from various delays. Concerning delay analysis methods, TIA, Windows Analysis and their derivatives are the most adopted methods by the practitioners and courts. However, there is no practice illuminating the application techniques of these methods. The delay analysis model mentioned in a construction contract may result in conflict between the contractual parties in terms of the application of the concerning delay analysis. Hence, it is recommended that standards and procedures of delay analysis methods are to be published for the sake of the construction industry. This is believed to improve the construction process and save time and cost by reducing the time-related disputes. In addition to this, many authors detected the defects such as lack of procedure, time consumption, cost consumption, manpower of expert consumption, ignoring the CPM, ignoring the actual site progress, ignoring the fluctuation on CP, ignoring the concurrent delays and considering only owner's delays for some of the existing delay analysis models; therefore, a new delay analysis method overcoming the defects of the existing delay analysis methods can be developed. Moreover, few researchers emphasized the importance of the delay analysis application in Building Information Modelling (BIM). Delay analysis methods are dependent on scheduling software; however, there is an upsurging trend towards using 4D-BIM software instead of scheduling software in the construction industry. So it is highly recommended that delay analysis models have to be transferred to 4D-BIM software. Furthermore, since delay analyses require project schedule, any improvement made in the schedule domain is believed to direct the subject of delay analysis in the near future. Therefore, topics such as CCPM, blockchain and smart contract, which are currently improving the schedule subject, are to be taken into consideration in the research concerning the delay analysis field.

5.3. Limitations of This Study

Notwithstanding the contributions of this study, it has limitations. Even though the Scopus Database and the Web of Science Database were selected in this study due to its strong coverage compared to the other databases, it is possible that some documents may be dismissed by the Scopus Database and the Web of Science Database. In addition to this, although VOSviewer, which is a software tool for constructing and visualizing bibliometric

networks, is one of the most preferable scientometric tools, additional analyses that are not supported by VOSviewer software can be conducted via other scientometric tools in order to reveal further outcomes concerning delay analysis domain.

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