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Review

Delay Causes and Emerging Digital Tools: A Novel Model of Delay Analysis, Including Integrated Project Delivery and PMBOK

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Abstract: Delay is one of the main challenges of construction projects, and there is still much to overcome in order to reach near zero delay in all construction projects. This project aims to conduct a systematic critical review including a bibliography analysis on delay literature in construction. The main questions consider what has been learnt from a decade investigating delay causes and effects in the construction literature and what factors have been missed in the literature. This paper also presents a new and challenging question regarding how digital tools and associated technologies may prevent any delay in construction projects, which can change the research direction from delay investigations to identifying prevention factors. The paper identifies the delay dataset, including 493 papers investigating delay in construction, and establishes a specific dataset of papers focusing on delay effects and causes (DEC), including 94 selected papers covering different factors examined in over 29 countries such as Iran, India, Turkey, Bangladesh, Saudi Arabia, the United Arab Emirates (UAE), Cambodia, Oman, Malaysia, Taiwan, China, Vietnam, the US, the UK, and Egypt. In addition, the paper identifies 30 critical factors with the frequency of occurrences over three times in the DEC dataset and computes their medians of ranking. This paper also discusses digital tools and methods that can be used for delay analysis and preventions, including MS Project, Oracle Primavera P6, and Open Plan by Deltek. The paper discusses the project schedule delay analysis from project management methodology perspectives. It also discusses the current method's limitations and future directions, which are based on the identification of the deficiency areas. In total, four overlooked factors are identified and suggested, including faulty data analysis, unmatched structure of the research questionnaires with new knowledge and standards [e.g., Project Management Body of Knowledge (PMBOK)], overlooked effects of digital technologies [e.g., Digital twin, Navisworks, Building Information Model (BIM), Geographic Information System (GIS), and Integrated Project Delivery (IPD)], and ignored job-site technologies. In addition, the paper presents the DEC model for future studies, including four main key factors. These factors are resources (e.g., project budgets, labour, material, equipment, and digital tool), project context, stakeholders performance (e.g., owner/client, consultant/designer, contractor, vendor/supplier), and external factors (e.g., ground condition, site location, regulation, natural disaster), which may significantly affect delay prevention and should be concurrently considered in the future delay investigations, since they may be required for designing an effective mitigation strategy when these proof points are identified. This would significantly help to utilise digital systems to prevent time overruns in different construction contexts.

Keywords: delay; time overruns; cost overruns; scheduling; PMBOK construction extension; PMI scheduling standards; Microsoft projects; primavera; BIM; GIS; risk analysis; IPD

1. Introduction

Disruptive technologies have been increasingly introduced to construction businesses in recent years, even though the industry continues to lag behind all other industries in its adoption of technology. However, there is not enough awareness of the current and best practices in project time management. The applications of these technologies for delay monitoring have not been fully examined regarding, for example, how intelligent or smart contracts can reduce disputes and delays in projects. While there is an urgent need to identify the application of new digital technologies and tools for preventing delay in a project, most papers still try to identify delay analysis techniques using the traditional approaches [1], such as conducting a survey including common factors determined many years ago [2,3]. This paper aims to review the literature over the past decade and develop directions for future studies in delay investigations in construction projects. The main objectives of the paper are: to identify the delay effects and causes (DEC) dataset; to identify key critical factors causing delay in construction projects in the previous decade; to identify dominant methods used in the delay literature; to review the current digital technology capacity for preventing delay; and to identify deficiency areas, present a conceptual DEC model, and map the future directions. These objectives are important to project management scholars to base their future investigations on a comprehensive critical analysis of a one-decade endeavour of delay investigations in different countries.

Project managers are able to plan the construction sequence, monitor the status of project activities, and update the project progress to identify the project delays by using project controls software systems, particularly software that is professionally developed for project time and cost management. Specifically, project scheduling software systems are able to manage changes to the schedule baseline to accomplish the planned project completion data. However, site logs in construction projects or periodical progress reports (e.g., daily or weekly) are required to capture the status of the project as an input into the project scheduling software. Applications or platforms developed for project time management are instrumental tools for evaluating the project deviation from the planned baseline. Project scheduling software can be used to compare the actual project progress compared to the planned baseline. The actual start and finish dates for project activities form the basis for actual progress calculations and document the as-built schedule information. Project scheduling software monitors the progress of all the project's activities with the order of the critical path, the near-critical path, and the non-critical path activities to evaluate the impact of delay on project schedule. If critical path activities slip, they immediately cause project delay. The components of a project schedule can be monitored by a variety of techniques such as float dissipation or erosion of float, missed start and finish dates, actual duration analysis, and earned value management using a project controls software system. Project scheduling software predominantly uses the critical path method (CPM) for its scheduling practice. Its use is often the focus of contract claims due to project time impacts and delays to the contract completion date. Schedule progress is measured against the contract planned dates. The baseline is an important reference in all scheduling software if contract and progress delay disputes arise between stakeholders involved in projects. A baseline is a complete copy of a project plan that we can compare to the current schedule to evaluate progress in all scheduling software. As a project progresses, certain types of project data are likely to change. When a project is in progress and data changes, the original baseline created for the project may not accurately measure performance against the current project. Empirical evidence suggests that, during these events, the project schedule needs to be re-baselined to reflect the revised plan to achieve the estimated completion date. Likewise, creating a new baseline may not yield accurate results for measuring performance, because some data change during the life of the project, which should be measured against the original project data [4].

The key terms and concepts used in the delay literature are briefly presented in Table 1. The definitions of these terms are significant, since they create alignment in thinking of specific delay causes, tools, and standards in the construction field. Some of the terms are interdisciplinary and are borrowed from different contexts such as Building Information Modeling (BIM), Integrated Project Delivery (IPD), and Geographic Information Systems (GIS). Table 2 shows several examples of delay in different contexts and countries. Delay may significantly affect project cost and may raise disputes, arbitration, litigation, and abandonment.

Table 1. Key terms and definitions that may be used in the delay literature.

Term/ Concept	Definition
Delay/Time Overruns	The difference between estimated and actual completion time [5], also known as time overrun [6] or extended time [7], mainly due to contractor, owner, or joint of all stakeholders tasks and actions [8].
Cost Overruns	The difference between estimated and actual cost results in increasing the total project cost, also known as budget overrun, due to unforeseen costs or underestimation of task's actual cost [9].
Scheduling	A control structure based on planning and dispatching [10].
PMBOK	Project Management Body of Knowledge (PMBOK) guide, including principals and knowledge required for project management [11].
Construction Extension	Focuses on construction projects by providing supplemental knowledge about project health, safety, security, and environmental management and project financial management and good practices.
PMI Scheduling Standards	Project Management Institute (PMI) refers to good practice methods for scheduling. Good practices are based on a general agreement on appropriate use of skills, tools, and techniques for enhancing the success chances of different projects.
Microsoft (MS) Projects	A tool for project planning and control [12].
Primavera	A tool for scheduling and project risk analysis [13].
Building Information Model (BIM)	Both Building Information Modelling (BIM) and Geographic Information Systems (GIS) [14] are analytical and visualisation systems. BIM is used for designing and sharing collaboratively generated rich data [15].
Geographic Information System (GIS)	Both Building Information Modelling (BIM) and Geographic Information Systems (GIS) [14] are analytical and visualisation systems. GIS is used for map processing, database visualisation, and spatial analysis and can be integrated with other systems [16,17].
Risk Analysis	Analysis of adverse events at different stages, including planning and programming, to enrich decisions [18].
Integrated Project Delivery (IPD)	Integrated Project Delivery (IPD) intends to increase the success of a project by addressing waste and inefficiency issues and adversarial relations in construction [19].

Table 2. Delay in different contexts, including the percentages of the delay reported in the literature.

Delay cases reported in the literature	Evidence of delay in percentage
UK: (1) 2017; construction projects in general [20]; (2) 1993-1994; government construction projects [21]; (3) 2001; government construction projects [22]	(1) About 30% of projects were delayed [20]; (2) the average time overrun was 23.2% [21]; (3) 70% of projects were delayed [22].
109 senior leaders of public and private organisations from across the globe, 26% from public bodies such as government agencies with the remainder represented by private enterprises [23]	(1) Just 25% of construction projects came within 10% of their original deadlines [23]
Philippines: 2010–2017; public–private partnership (PPP) projects	92.8% of projects were delayed [24].
Malaysia: (1) 2005; government contract projects [25]; (2) 2010–2014; Kuala Lumpur Airport Terminal 2 [26]	(1) 17.3% were delayed for over 3 months. [25]; (2) caused extra USD $2 billion to the final costs [26].
Oman: 2010–2013; A major public organisation	62% within their schedule [27].
Africa: (1) 2009–2012; Rwanda; public [28]; (2) 2000–2011; Ghana; roads [29]; (3) 1999–2005; Benin [30]; (4) 1970– 1998; Ghana; groundwater construction [30]	(1) 65.7% of projects were delayed [28]; (2) 70% were delayed for average of 17 months [29]; (3) 22% of projects were delayed for more than 2 years [30]; (4) 70% of projects were delayed [30].
India: 2012; central sector infrastructure projects	Approximately 57% of projects were delayed [31].
UAE: 1995–2005; construction projects in general	50% of projects were delayed [32].
Saudi Arabia: (1) 2004; private and public projects [6]; (2) construction of water and sewage works [33]	(1) 70% of projects were delayed from 10% to 30% of estimated time [6]; (2) time overrun decreased from 59% in 1994 [33] to 40% in 2004 [34].
Iran: (1) projects for government [35]; (2) Khuzestan steel company [36]	(1) The percentage of delay in 2001, 2002 and 2003 were respectively 30%, 74.5% and 75%. [35]; (2) the project duration is approximately 150% of project estimated duration [36].
US: (1) general projects of US and England [37]; (2) 2001; highway projects [38]	(1) Projects were respectively delayed for 2.5 weeks and approximately a month [37]; (2) the time overrun of projects was 25% of their contract duration [38].
Kuwait: 1990–2000; private residential housing projects [39]	56% of projects were delayed, approximately 54% were delayed for four months or more, and 30% were delayed for more than six months [39].
Nigeria: (1) 1991–1996; housing projects [40]; (2) 2000; most projects in Lagos city [41]	(1) 70% were delayed and caused 51.51% cost overrun [40]; (2) time overrun was in average 51% of the predicted duration [41].
Jordan: 1990–1997; public construction projects [42]	81.5% of projects were delayed [42].
Hong Kong: (1) 1990–1993; government projects [43]; (2) 1990–1993; private sector projects	(1) Only 40% within schedule [43]; (2) only 23% within schedule [43].
Western Canada: civil, institutional, high rise apartment building, and petrochemical	Several cases of 24 projects were delayed more than 100% of contract duration [44].
Indonesia	38% of projects were delayed [37].
Projects of 20 nations (Europe, North America, and other); during last 70 years; rail, fixed link (bridges and tunnels), and road	Time and cost overruns were, on average, 70% and 28%, respectively [45,46].
Rich democracies (Denmark, Germany, Japan, South Korea, Netherlands, Norway, Spain, Sweden, UK, and US); during last three decades; infrastructure projects	Average schedule overrun of projects was 42.7% [47].

This paper first systematically identifies articles investigating delay and time overrun in construction and then conducts a content analysis to review relevant articles in detail and provide a comprehensive understanding of the current literature. Finally, it identifies the gap in the literature and suggests future studies.

2. Review Method

Based on the initial review of the current practices in the literature, a set of strings was developed to select the final search criteria. The search string was selected as "delay overrun" or "time overrun" and "construction industry" or "construction project" and applied on the Scopus database, which resulted in 493 records using the search criteria, as shown in Appendix A.

The search was limited to articles investigating causes and effects in the past ten years, from 2009 to 2018. Therefore, "cause" and "effect" were also included in the search criteria. Applying the criteria resulted in developing the delay effects/causes (DEC) database in construction with 94 records using the search criteria shown in Appendix A. Different tools and techniques including VOS Viewer and clustering algorithms were used for visualisation and conducting the present systematic review.

3. Bibliography Analysis

This section reports the results of a quantitative analysis focusing on bibliographic attributes, including co-citations for identifying interconnections of the delay literature within selected articles and their corresponding citations. The systematic analysis alleviates bias during search, article selection, and bibliography analysis. The employed bibliometric method assists in identifying similarities and possible patterns of inquiry based on citation records and cited references [48,49].

Figure 1 shows the result of co-authorship analysis using the full counting method. The minimum number of papers of an author was considered as one, thus 1179 authors and co-authors of 493 selected articles were included and are visualised in Figure 1. Figure 2 shows the co-authorship network for all 259 co-authors using the full counting method based on the DEC dataset including 94 papers.

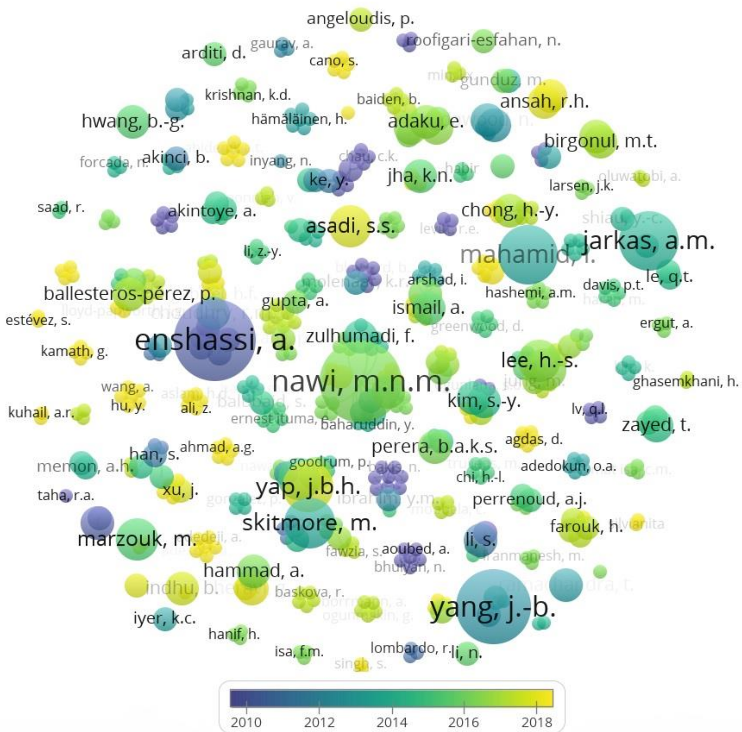

Figure 1. Visualisation of co-authorship network for all 1179 co-authors using the full counting method based on the first bibliographic dataset including 493 papers.

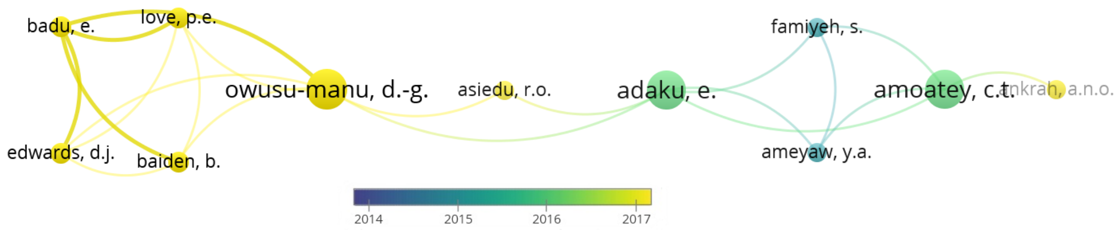

Figure 2. Visualisation of co-authorship network for all 259 co-authors using the full counting method based on the delay effects and causes (DEC) dataset including 94 papers.

For each of the 1179 authors, the total strength of the co-authorship links with all authors and co-authors were calculated, and the greatest link strength was considered for the visualisation of Figure 1. In addition, different numbers of papers from an author were selected for future investigation. The results show that, for the minimums of two, three, and four papers of an author, 138, 43, and 12 authors met the criteria. This shows that a limited number of authors continuously or frequently contribute to the delay literature, including Lee, H. S. [50–53], Park, M. [50–53], Yap, J. B. H. [54–58], Abdul-Rahman, H. [55,57,59,60], and Enshassi, A. [61–69]. This shows that, among a large set of scholars investigating delay in construction, only a limited number of authors are regularly co-authoring in the delay area. This is also limited in the DEC dataset where the criteria are applied and the focus of the literature is effect and cause.

Figure 3 shows the co-occurrence analytical map of keywords based on the first bibliographic dataset. For this visualisation a minimum number of 2 was selected for co-occurrence visualisation and a total of 713 keywords out of the sample of 2926 keywords are shown in Figure 3. The normalisation method of LinLog was used in VOS Viewer.

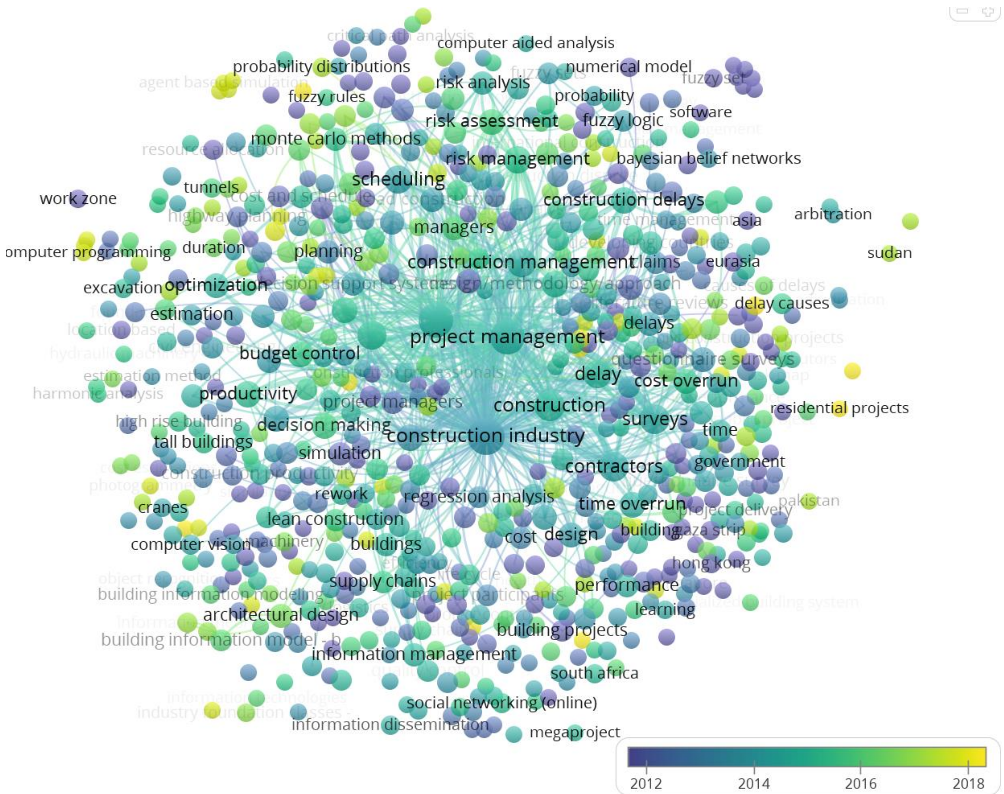

Figure 3. Co-occurrence analytical map of keywords created on the first bibliographic dataset. With the minimum number of co-occurrence of 2, a total of 713 keywords out of the sample of 2926 keywords are shown.

Figure 4 also shows the co-occurrence analytical map of keywords based on the first bibliographic dataset, but the minimum number of co-occurrence was selected as five to identify the most frequent concepts. Of the sample of 2926 keywords, 176 keywords are shown in Figure 4.

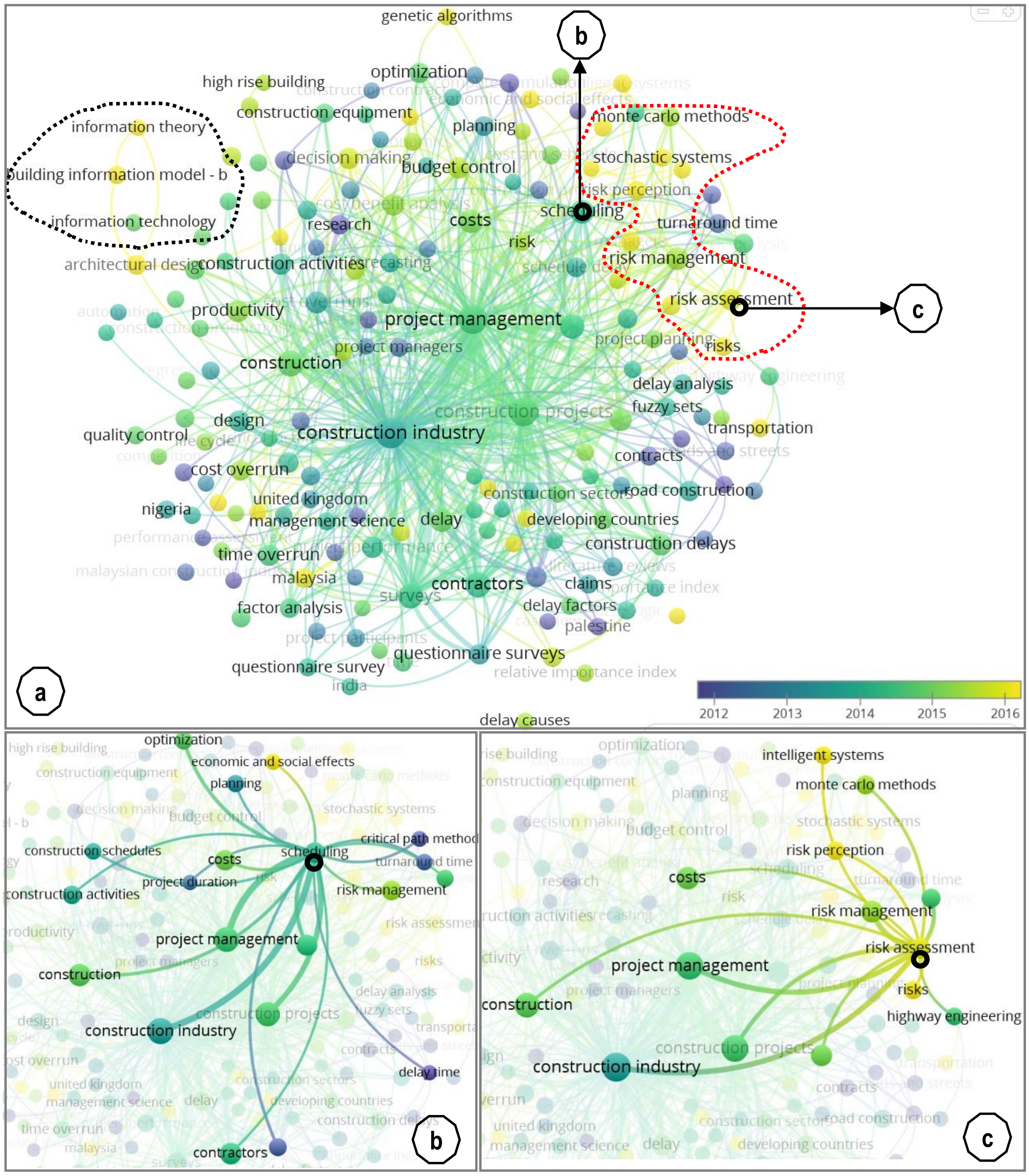

Figure 4. Co-occurrence analytical map of keywords created in the first dataset. With the minimum number of co-occurrence set as five, a total of 176 keywords out of the sample of 2926 keywords are shown. (**a**) All keywords co-occurrence network map; (**b**) scheduling co-occurrence network map; (**c**) risk assessment co-occurrence network map.

Figure 4 shows that risk management has become more important in recent years. This also shows that the recent publications may tend to offer suggestions to monitor and prevent delay. In addition, it shows that using questionnaire surveys is the traditional method of delay analysis. Figure 5 also shows the key concepts used in the DEC database (with questionnaire surveys being a dominant method from 2014) and that risk management has become a focus in literature more recently.

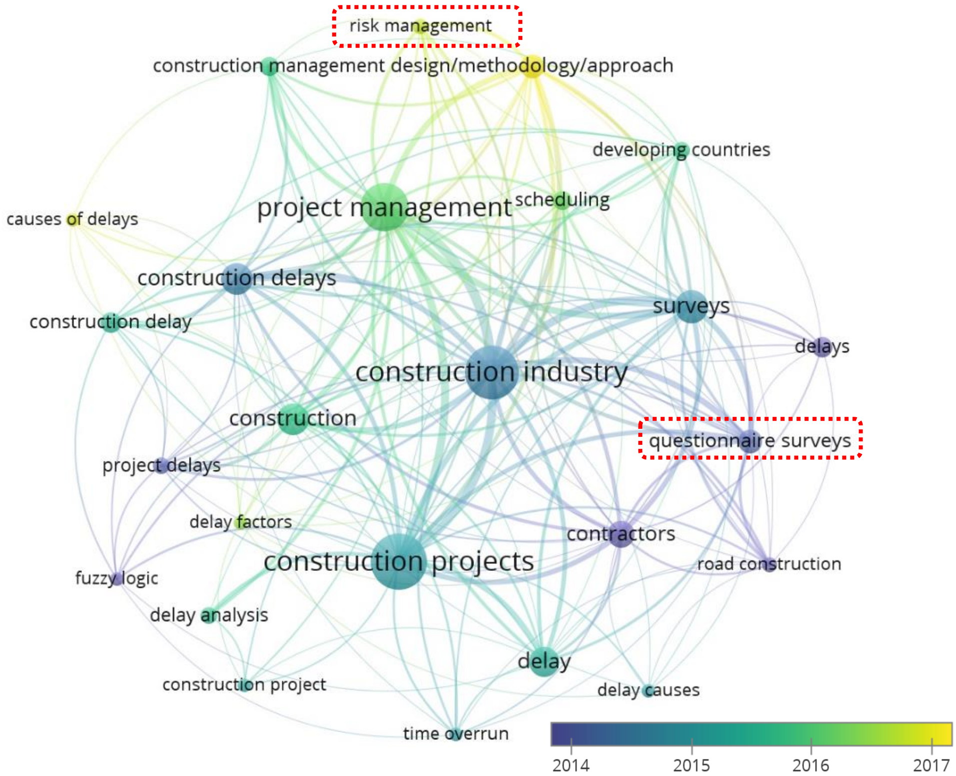

Figure 5. Co-occurrence analytical map of keywords created on the first dataset. With the minimum number of co-occurrence set as five, a total of 25 keywords out of the sample of 550 keywords are shown.

4. Content Analysis and Data Mining

This section critically reviews the content of the DEC dataset by investigating topics, keywords, and themes. First, the entire DEC dataset was grouped into five main clusters with each cluster against three criteria (the gap identification criteria). Figure 6 shows that there were three clusters within the DEC dataset based on the word similarity of the articles, which were separately analysed using thematic analysis techniques. Based on the results and the similarity of the words, the papers were assigned into five clusters. The DEC dataset could also be classified based on these findings. A careful content analysis showed that there were at least three different types of findings within the DEC dataset: (i) the first group of papers investigating causes of delay [70], effects of delay [71], mitigation strategies, and/or all causes and effects with appropriate mitigation strategies [72,73]; (ii) the second group investigating the effect of one special factor on delay [74]; (iii) the third group proposing and evaluating methods and/or models for identifying, ranking, and estimating delays [75].

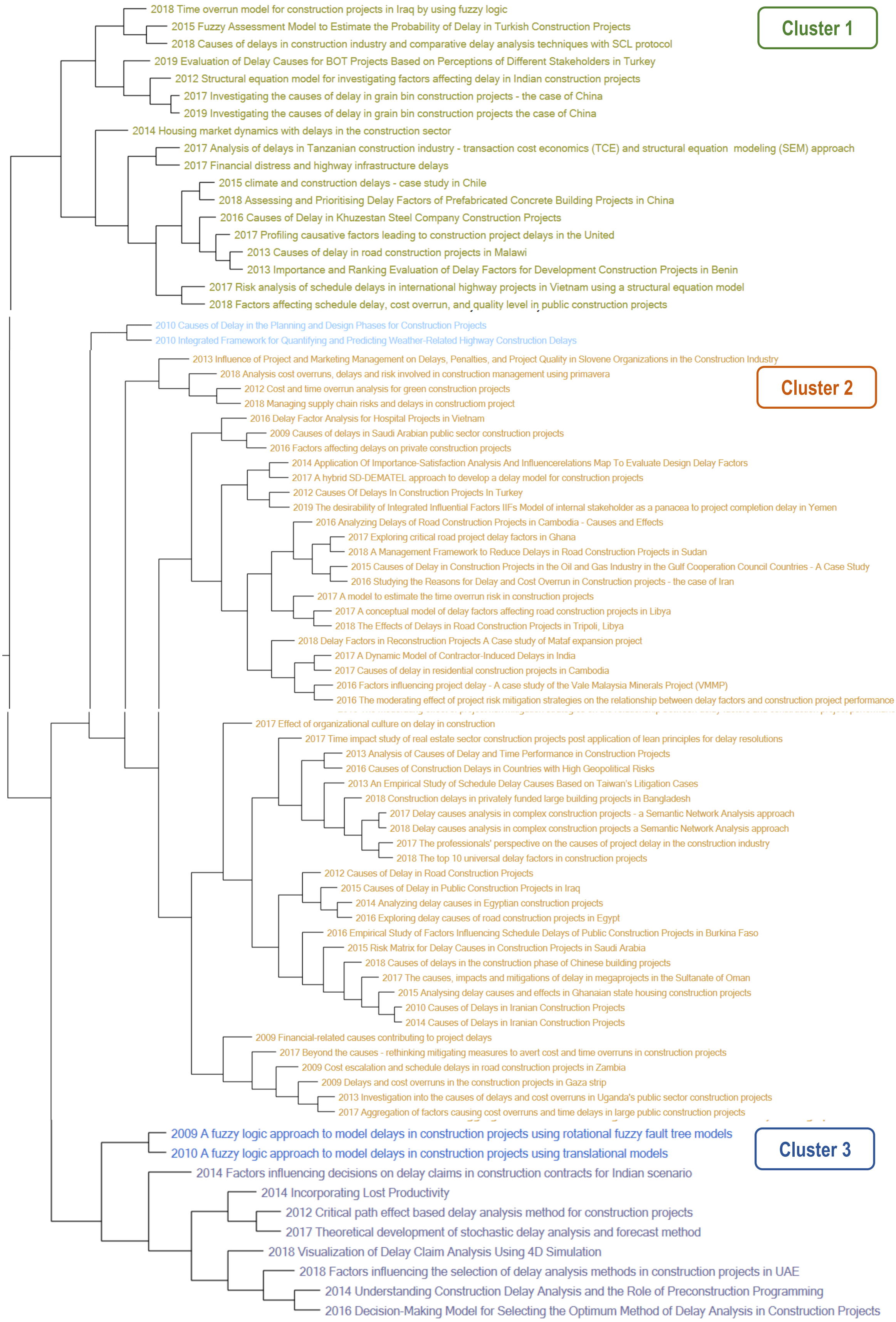

Figure 6. Five branches of papers in the DEC, including three clusters of the main relevant articles for the content analysis.

5. Current Practices in Delay and Time Overrun Investigations

We first investigated the publications in the past three years to identify the current practices in this field. Tables 3–5 show that most of them used questionnaires and focused on developing countries, and Figure 7 shows word clouds created for different sources based on stemmed words.

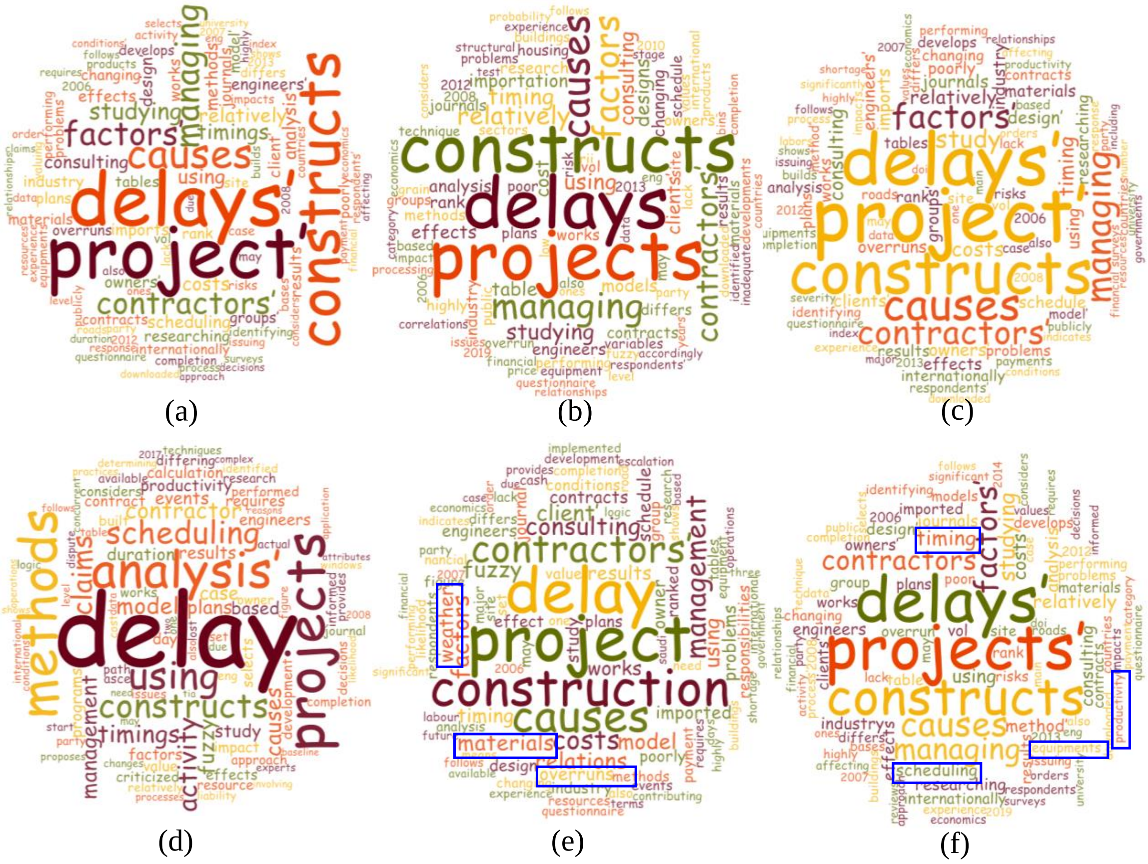

Figure 7. Word cloud created for different sources based on stemmed words. (**a**) All DEC dataset; (**b**) cluster 1; (**c**) cluster 2; (**d**) cluster 3; (**e**) published papers from 2009 to 2011; (**f**) published papers from 2016 to 2018.

Table 3. Summary of selected articles of cluster 1 of delay investigations from 2015 to 2018.

Focus of the Study, Location, and Sector	Method; Sample Size and Participants	Number of Examined Delay Factors and List of the Selected Factors Identified
Prioritize delay factors [76], China, prefabricated concrete building	Questionnaire; 30; academics, clients, contractors, and government.	24, inexperienced workforce, shortage of structural connections for prefabricated components, poor communication among participants, and low productivity.
Comparative delay analysis techniques with the Society of Construction Law's (SCL) protocol [72], Iran	Questionnaire; 175; clients, consultants, and contractors	78, client-related causes, labour and equipment causes, contractor-related causes, material-related causes, design-related causes, external causes, and consultant-related causes.

Table 3. *Cont.*

Focus of the Study, Location, and Sector	Method; Sample Size and Participants	Number of Examined Delay Factors and List of the Selected Factors Identified
Fuzzy assessment model to estimate the probability of delay [77], Turkey, public and private	Interviews questionnaire; 64; consultants, contractors employees, and designers	83, inexperienced contractor, poor project planning and scheduling, weak supervision and site management, changes in design, unreliable subcontractors, inexperienced labour, changes in orders, slowness in site delivery, late design documents approval, delay in payment, material delivery, weak communication and coordination between parties, and unqualified team.
Finance and delays [78], Ghana, highway project	Questionnaire; 78	Payment, project financing, cash flow, economic issues, project planning, and cost control.
Structural equation model for investigating factors affecting delay [79], India, public	Questionnaire; 77; clients, contractors and designers or architects	Delayed approval, design and scope changes, poor protocol and subcontractor changes, technical ability of head contractor, scheduling, labour productivity, weather conditions, proper planning and controlling of projects.
Time overrun model by using fuzzy logic [80], Iraq, private and government sectors	Questionnaire; 90, owners, consultants, supervising engineers and contractors	73, problems in funding (75%); poor site management (66%); weak project planning (58%). Owner: values of contract (70%); late decision-making (63%); contract duration (61%). Consultant: design delays and design mistakes (46%); improper design management (45%). External: topographic characteristics of site (41%).
Causes of delay [81], Malawi, road	Questionnaire; 45; clients, contractors and consultants	72, inadequate fuel, inadequate contractor cash-flow, inadequate foreign currency, payment, inadequate equipment, inadequate materials, inadequate technical workforce, and site mobilization slowness.
Prioritize delay factors [30], Benin, public projects: departmental hospital, school, administration office	Questionnaire; 175; contractor, owner, consultant and architect	35, financial difficulties, subcontractor's weak performance, material provision, drawing changes, scheduling by contractor, late inspections by the consultant, unavailability of equipment by contractor, and acceptance of improper design drawings.
Causes of delay [36], Khuzestan, Iran, steel company	Questionnaire; 35; owners, consultants and contractors	89, financial issues are the major delay factors, as well as drilling allowance, long administrative cycle to renew, and steady production of steel.
Risk analysis of schedule delays using a structural equation model [82], Vietnam, highway projects	Questionnaire; 246; project managers, supervisors, from contractors and owners	50, financial issues, policies and weakness of laws, competence of project management, financial ability and management of contractor, competence of design team, sub-contractor's selection and management, economical changes, and competence of supervision team.

Table 3. *Cont.*

Focus of the Study, Location, and Sector	Method; Sample Size and Participants	Number of Examined Delay Factors and List of the Selected Factors Identified
Delay causes for BOT Projects [70], Turkey, public–private partnership projects (PPP)	Workshop; 11; consultants, the private sector, and the public sector	Uncertainties and changes, regulation variation, budget shortage, changes in orders, changes in urban plan, changes in policy and regulations, lack of bidder, inadequate laws about usage of land, finance.
Climate and construction delays [83], Chile, bridge	Case study; 6; bridges	A method for risk managers to address climatic agents and required extra time to minimize adverse weather conditions and time delays.
Profiling causative factors leading to delays [84], UAE	Questionnaire; 208; clients, consultant and contractors	180, unreal duration imposed by clients, unfinished design, change orders, scheduling, weak project control, slow permission process from authorities, low labour productivity, delays in decisions, poor site management.
Analysis of delays using transaction cost economics (TCE) approach [85], Tanzania	Questionnaire; 400; clients, contractors and consultants using Structural Equation Modelling	36, finance shortage, weak planning, weak site management, unavailability of material, unpredicted site condition, delays in test approvals, preparation of drawings, communication between parties, skills shortage, availability of equipment.

Table 4. Summary of selected articles of cluster 2 of delay investigations from 2015 to 2018.

Focus of the Study, Location, and Sector	Method; Sample Size and Participants	Number of Factors Measured and Findings
Delay analysis [86], China, Beijing, Shanghai, Chongqing and Shenzhen, Design-bid-build projects	Questionnaire; 115; clients, consultants, and contractors	37, delayed payments, low bids, weak performance of subcontractors, and communication issues. Comparative analysis shows difficulty in claiming penalty and unreasonable upfront capital demanded by client.
Delays [87], Bangladesh, privately funded large building	Interviews; 70; stakeholders	Lack of experienced managers, lowest bidder, shortage of fund, scheduling, lack of skilled labour, site constraints, weak cost control, and contractor cash flow problem.
Delay Factors [88], Mataf, Mecca, Saudi Arabia, reconstruction project	Interviews; 14; project and construction managers and senior site engineers	Building material, rerouting electrical and mechanical utilities, safe access, conditions of site, taking down archaeological and antiquity elements, back-propping works, design changes, conflict between workforce.
Schedule delay [89], Denmark, public	Questionnaire; architects, surveyors	26, improper funding cost, mistakes or negligence in consultant material quality, and mistakes.
A framework to reduce delays [73], Sudan, road	Questionnaire; 100; people engaged in construction	66, using qualified and experienced managers, using suitable and enough tools and equipment, and suitable technical planning before starting the projects.
The effect of delays [71], Libya, Tripoli, road	Questionnaire; 256; stakeholders	Identified effects are time overrun, cost overrun, and blockage of economic and country development.

Table 4. *Cont.*

Focus of the Study, Location, and Sector	Method; Sample Size and Participants	Number of Factors Measured and Findings
The top 10 universal delay factors [90], Norway, hospitals, schools, hotels, etc.	Questionnaire; 202; clients, contractors and consultants	Weak scheduling, poor decision process, internal administrative procedures and bureaucracy, poor resources, weak parties' communication, slow inspection, changes, parties' lack of commitment and goals.
A model of delay factors [91], Libya, road	Questionnaire; 256; stakeholders	59, delays in utility services (such as power lines, water, etc.), project budget difficulties, short duration, delayed payments, and subsurface condition impacts conditions.
A dynamic model of contractor-induced delays [92], India, buildings, roads, bridges, railways, power plants, and industrial complex projects	Questionnaire; 100; Project managers, architects, engineers, designers, consultants, surveyors, contractors, and owners	Project financial difficulties, improper planning and scheduling, contractor's poor communication and coordination, conflict between parties and use of improper methods for construction, providing enough project finances and cash flow, proper planning and scheduling, using proper methods for construction, and considering the reworks in the schedule.
A hybrid System Dynamics-Decision Making Trial and Evaluation Laboratory (SD-DEMATEL) approach to develop a delay model [93], Iran	Questionnaire; 63; consultants, contractors, and clients	58, reworks, suspension of construction, delayed payment, poor project planning and scheduling, labour's low productivity, changes in orders, and construction mistakes, costs of implementation, acceleration in conduction of biding, and notification of contract and schedule pressure.
Time overrun risks [94], India, residential, industrial, and commercial	Questionnaire; 112; project managers	31, identified factors are manpower (21% of contribution), materials (18% of contribution), and scheduling and control related problems (18% of contribution).
Aggregation of factors causing cost overruns and time delays: trends and implications [95], large public projects	Analysis of a literature selection	Poor communication, late payment, weak controlling, delays in decisions, changes in order, reworks, weak labour and material planning, equipment shortage, project complexity, psychological positive interest, fraud, bad weather conditions, and ground conditions.
Beyond the causes: rethinking mitigating measures to avert cost and time overruns [96], Ghana, public	Check list; 7; quantity surveyors, architects, and engineers	9, financial limitation by government, weak supervision and project planning, change orders, insufficient allowance of contingency, weak administration of contract, qualifies team of project, poor coordination, risk related to cultural and political issues.
Causes of delay [97], Cambodia, residential	Questionnaire	31, materials shortage, unreal scheduling, late material delivery, labour shortage, project complexity, delayed payment, weak site management, delay by subcontractor, and accidents because of weak site safety.
Organisational culture in delay [74], US and India	Questionnaire; 84; contractors	6, Indian: market culture, large delay due to contractors. US: clan culture, less delay due to owners.

Table 4. *Cont.*

Focus of the Study, Location, and Sector	Method; Sample Size and Participants	Number of Factors Measured and Findings
Exploring critical delay factors [29], Ghana, road	Questionnaires; 123; stakeholders and site staff	Delayed payment, inexperienced contractor, scope changes, delayed furnish and site delivery to the contractor, and inflexible funding.
The causes, impacts and mitigations of delay [98], Oman, Sultanate, megaprojects	Questionnaire; 53; clients, consultants, and contractors	75, low bid, main contractor's financial condition, delays in making decisions by client, and weak planning by the main contractor. Effects are extra cost and time overrun. Mitigation: experienced contractors and consultant, proper planning, and suitable supervision.
The professionals' perspectives on the causes of project delay [99], UK, all sectors	Interviews; 41; seniors of developers, consultants, clients, and contractors	32, insufficient planning, poor information flow and communication, poor decisions, ineffective management, poor control, financial problems, unclear scopes, design problems, inappropriate risks transfer, lack of knowledge and competence, health and safety restrictions, poor resources and logistics management
Analyzing delay causes and effects [100], Ghana, state housing	Questionnaire; 31; architects, surveyors, engineers, managers, land economists	Delayed payment to contractor or supplier, inflation and price fluctuation, price growth in materials, insufficient funds of sponsors or clients, changes in orders, and weak financial or capital market. Identified effects are cost overrun, time overrun, litigation, discontinuity by client, and arbitration.
Causes of delay [27], Gulf cooperation council countries (Oman), oil and gas industry	Questionnaire; 59; clients, contractors, and consultants	44, weak supervision, contractor's insufficient planning and scheduling, delay in delivery of materials, poor communication among project parties, and weak interaction with vendors. Suggested to validate findings.
Causes of delay [101], Iraq, public	Questionnaire; 134; clients, contractors, and consultants	65, safety measures, laws and bureaucracy variations by government, holidays, lowest bidder weak performance, changes in design by owner and consultants, delayed payments by the owner, problems with local community, inexperienced owner in construction and economic and local and global conditions.
Risk matrix for delay Causes [102], Saudi Arabia	Questionnaire; 51; consultants	35, lower bid, changes in material, management of contract, contract duration, fluctuations in materials' price, changes in design, weak planning, pressure of inflation.
Analyzing delays: causes and effects [103], Cambodia, road	Questionnaire; 153; contractor and consultant	64, working during rainy season, flooding, effect on people's land, lowest bidder selection, repeated breakdowns of equipment, weak site arrangement.

Table 4. *Cont.*

Focus of the Study, Location, and Sector	Method; Sample Size and Participants	Number of Factors Measured and Findings
Causes of delays [104], countries with high geopolitical risks, power transmission lines, infrastructure (utilities) and roadway	Window delay analysis method (detailed review of 36 projects), interviews with 18 experts	Extreme weather, site blockage, corruption, war, labour's low productivity, custom clearance issues, changing in route of supply chains, materials stealing; natural dangers, late approvals, change orders, design mistakes, obscure work scope, cash flow, rental equipment inadequacy, delays in site ownership, inadequate owner's site utilities, changing in supply chains.
Delay factor analysis [105], Vietnam, hospital	Questionnaire; 197	35, financial difficulties, absence of responsibilities, changes in design, and inexperienced contractor.
Empirical study of factors influencing schedule delays [106], Burkina Faso, public	Questionnaire; 140; clients, contractors, and consultants	27, contractor's financial ability, owner's financial difficulties, availability of equipment by contractor, delayed payment for finished work, and weak performance of subcontractor.
Exploring delay causes [107], Egypt, road	Questionnaire; 186; consultants, contractors, and engineers	293, political situations, segmentation of the west bank and limited movements between areas, award project to lowest bid price, progress payment delay by owner, and shortage of equipment.
Factors affecting delays [108], Jordan, private	Questionnaire; 120; stakeholders	45, manpower shortage, late approvals, materials shortage, and relation between different subcontractors.
Delay factors [109], Malaysia, Perak, Vale minerals project	Interviews; 10; contractor and client staff	Weak communication, slowness of material delivery, wrong selection of contractor, low productivity, weak management, and equipment mobilization.
Delay and cost overrun [110], Iran	Questionnaire; 86	Regulation (31%), owners (27%), consultant (25%), and contractor (17%).
Risk and relationship between delay factors [111], Malaysia	Questionnaire; 212; stakeholders	Environmental issues, resource issues, and coordination issues. Suggests longitudinal study and specific infrastructure projects.
Causes of delays [112], Saudi Arabia, public	Questionnaire; 86; stakeholders	112, finance issues, non-payment for contractor claims, inexperienced contractor, weak scheduling, delay in decisions and approvals, lack of material and labours.
Cost escalation and schedule delays [113], Zambia, road	Questionnaire; 60; stakeholders	Finance difficulties, economic and payments problems, materials preparation, contract and drawing changes, inadequate staffing and equipment, weak supervision.
Delays and cost overruns [114], Gaza Strip	Questionnaire; 114; stakeholders	110, strikes and closures of border, shortages of materials in markets and in delivery to the site.
Financial-related causes contributing to project delays [115], Malaysia	Questionnaire and interviews; 110; stakeholders	Cash flow, inadequate financial resources, loan gaining difficulties, and inflation.
Causes of delay [116], Palestine, road	Questionnaire; 64; contractors and consultants	52, political situation, lowest bidder, payment and inadequate equipment; improper ground condition, inadequate controllers, unsuitable design, natural hazards.

Table 4. *Cont.*

Focus of the Study, Location, and Sector	Method; Sample Size and Participants	Number of Factors Measured and Findings
Causes of delays [117], Turkey	Questionnaire; 71; project managers and site managers	34, changes in design and material, delayed payments, problems in cash flow, contractor's problems in finance, and low labour productivity.
Cost and time overrun analysis [118], India, green construction projects	Questionnaire; 17; Leadership in Energy and Environmental Design (LEED) professionals and other green experts	34, risks associated with reduced site disturbance, innovative waste water technologies, renewable energy, waste management, indoor chemical and pollutant source control, and LEED™ accredited professional.
Schedule delay causes [119], Taiwan	Case study; 79 litigation cases	Change in orders and scopes, late handover of site, and weather.
Time performance [120], Santiago, Chile	Residential case study; 2	Planning, subcontract, materials, labour, design, execution, and weather.
Delays, penalties, and project quality [121], Slovenia	Phone interviews; 30; managers, questionnaire	Suggests connecting the function of marketing with project management, but it reports that marketing management does not minimize fines and delays.
Causes of delays and cost overruns [122], Uganda, public	Interview, case study; questionnaire; 247; stakeholders	Variations in work scope, delays in payments, weak control and monitoring, capital's high cost, political fluctuation, and insecurity.
Analyzing delay causes [123], Egypt	Questionnaire; 33; stakeholders	43, material, cost, and currency variations, financial, site condition, inexperienced consultants, financing, low productivity, incompetent workforce, and change orders.
Design [124], Taiwan, high-tech facility	Questionnaire; 36; engineers managers	21, decision making and budget constraints, design duration.
Causes of delays [35], Iran	Questionnaire; 84; stakeholders	28, financial issues, inappropriate planning, site and contract management, and poor communication

Table 5. Summary of selected articles of cluster 3 of delay investigations from 2015 to 2018.

Focus of the Study, Location, and Sector	Method; Sample Size and Participants	Number of Factors Measured and Findings
Productivity and delay analysis [125]	A new method and a case study	This article proposes a method that is a tool for calculating the schedule impacts that happen when there is a problem in lost productivity.
Critical path effect based delay analysis method [126]	Hypothetical case studies	Analysis effects of delays on the critical path that performs delay analysis accurately and uses a process-based analysis approach to solve simultaneous delays.
Factors influencing delay claims [127], India	Arbitration awards, court cases, and professionals	Improper design and owner's neglect, changes in orders, weather and site conditions, delayed delivery, economic conditions, and quantity growth.
Understanding construction delay analysis and the role of preconstruction programming [128], UK	In-depth interview; experienced construction planning engineers	Complexity, cost, and time. Emphasizes the importance of baseline programs for resolving delay claims.

Table 5. *Cont.*

Focus of the Study, Location, and Sector	Method; Sample Size and Participants	Number of Factors Measured and Findings
Factors influencing the selection of delay analysis method [129], UAE, a hotel, an international school complex, a highway, sewage treatment plant, and a residential tower	Interviews; 8; experts; limited to case studies in the period of 2007–2012	Client's attitude, experience of the delay analyst, reputation and neutrality of the delay analyst, project complexity, and cost and timing of performing the analysis. Time Impact analysis (TIA) and Impacted as Planned (IAP) are two commonly used Delay Analyzing Methods DAMs. The ethnographical approach is suggested, since it provides the opportunity to capture real and live states of knowledge on the selection and the use of DAMs.
Visualisation of delay claim analysis using 4D simulation [130]		This article shows that 4D simulation is a reliable method for analyzing delay claim.
Stochastic delay analysis and forecast method [131]	Shi's method	This article proposes the Stochastic Delay Analysis and Forecast (SDAF) method, which is an informative analytical method and predicts the effect of a single activity's delay with probability for overall project delay.
Decision-making model for selecting the optimum method of delay analysis [75], UAE, Dubai	Semi structured interviews and questionnaire; 74; contactors and consultants	This article proposes the Digital Multimeter (DMM) objective tool, which can reduce the potential for disputes and conflicts arising from delays in construction projects.

Key Factors Identified in the Delay Literature

Tables 5–7 show a comprehensive list of factors and the priority of each factor in Asian and African countries. This helps us to understand the importance of current factors in the literature. These two tables are also used for identifying the frequency and the median of each factor. Most of the articles extracted a number of delay factors from the literature. Next, they evaluated each factor or validated them in their context by conducting a survey, and they finally presented the top ranked factors. For example, Al-kharashi and Skitmore [112] identified 112 delay factors from literature. Then, they conducted a survey and presented the 30 important factors from the results. Al-kharashi and Skitmore [112] reported only ten factors out of 30 and reported them in the abstract of their paper. Thus, this paper reported the top ten factors reported by them. Among the DEC dataset, only 63 articles included the causes/main cause of delay. A total of 55 articles were investigated in a certain region or country, which are presented in Tables 5–7.

Table 6. Priority list of delay factors within DEC literature for Asian countries, mainly Middle Eastern.

Factors	**India**					**Bangladesh**	**Saudi Arabia**			**Iraq**		**Turkey**			**Iran**			**UAE**	**Oman**		**Jordan**	**Palestine**	
	18 [92]	**20** [94]	**26** [74]	**66** [79]	**76** [127]	**6** [87]	**7** [88]	**41** [102]	**54** [112]	**13** [80]	**38** [101]	**15** [70]	**40** [77]	**63** [117]	**19** [93]	**51** [110]	**44** [36]	**30** [84]	**37** [27]	**32** [98]	**49** [108]	**56** [114]	**62** [116]
Scheduling issues	+	3		2		5		+	+	7			2		4	1		4&5	3	4	4		
Payment delay								+	+	6	6			2	3								4
Design changes				1		1	1	+			5	+	4	1				8					
Manpower issues		1				6		+	+	7	10		8								1		
Financing difficulties	+	4										+		3		3	1						
Poor supervision						1&4			+	3			3			12		9	1				
Lack of materials		2					5						5						5		3	2	
Contractor cash flow						10			+	1				4		5	3			2			
Poor communication	+								+										6				
Owner cash flow						3			+														
Subcontractors					6								6				2		2		4		
Change orders					4							+	9		6			3					
Equipment issues		5														14							5
Natural risks		5		2												8							
Labour productivity				2				+						5	5			6					
Culture and politics			+																			1	1&2
Approval delays				1			4		+				7				4	6			2		
Resources shortage					3																1		
Economic conditions											9												
Lowest bidder						2		+												1			3
Design problems							1																
Delay in site delivery					1				+				10										
Late change issues					2													2					
Contract issues								+		2						4							
Security							2				1												
Inflationary issues								+								10							
Lack of protocol				1																			
Inaccurate pricing									+		4	+				6							
Cost control						9												10					
Estimation issues						7				5								1					

Note: design problems are a general factor that contain items such as errors in drawings and improper/inadequate design documents.

Table 7. Priority list of delay factors within DEC literature for selected Asian countries.

Factors	**Cambodia**		**Malaysia**			**Taiwan**		**Palestine**		**China**			**Vietnam**	
	24 [97]	**42** [103]	**50** [109]	**52** [111]	**57** [115]	**59** [132]	**67** [119]	**56** [114]	**62** [116]	**3** [76]	**5** [86]	**29** [133]	**31** [82]	**46** [105]
Scheduling issues	2				1									
Payment delay	7	10			2				4		1			
Design changes						2	2					5		
Manpower issues	4	9								1		4		
Financing difficulties					3&6						+			
Poor supervision	8	7	5										3	8
Lack of materials	3&1		2					2						
Contractor cash flow					4									
Poor communication			1	3						2	4	2		
Owner cash flow					5								1	
Subcontractors	9										3	3		
Change orders						1&4	1							
Equipment issues									5			1		
Natural risks		2		1			4							
Labour productivity		11	4							3				
Culture and politics								1	1&2					
Approval delays														
Resources shortage	6			2										
Economic conditions														7
Lowest bidder		4							3		2			
Design problems														
Delay in site delivery							3							
Late change issues														
Contract issues														
Security	10													
Inflationary issues					7									
Lack of protocol													2	
Inaccurate pricing														
Cost control														
Estimation issues														

Based on the information collected from Tables 6–8, the frequency and the median of each factor were calculated. Table 9 shows that the most frequent factors contributing to project delay are scheduling issues, payment delay, design changes, manpower issues, and financing difficulties.

Table 8. Priority list of delay factors within DEC literature for African and other countries.

Factors	**Sudan: 1 [73]**	**Libya; 17 [91]**	**Norway; 12 [90]**	**Tanzania; 22 [85]**	**Ghana**				**US**		**UK; 33 [99]**	**Chile [120]**	**Egypt**		**Burkina Faso; 47 [106]**	**Zambia; 55 [113]**	**Denmark; 8 [89]**	**Malawi; 69 [81]**	**Benin; 70 [30]**	**Uganda; 72 [122]**
					23 [96]	**27 [29]**	**36 [100]**	**28 [78]**	**26 [74]**	**61 [134]**			**48 [107]**	**73 [123]**						
Scheduling issues			+	2	2			+			1	1							6	
Payment delay		4				1	1	+					4	3	4	1		4		2
Design changes			+			3	5				10			9					5	1
Manpower issues	3,5			9	6							4		9		7		9		
Financing difficulties	1	2			1,4	5	5	+			6						1			4
Poor supervision	2			3	2						4					9				
Material issues				4								3		1		5		7	4	
Change orders			+		3						8	5					2		9	
Contractor's financial problems					9			+						7	1	2		2	1	
Poor communication	4		+	8	7						2					11				
Owner's financial problem				1			4	+						3	2	2			2	
Subcontractors											2				5				3	
Equipment issues				10									5		3	8		5	8	
Approval delays			+	6															7	
Natural risks				5						+		6								
Labour productivity														8						
Culture and politics					8				+											5
Resources shortage			+											5						
Economic conditions								+					2	2		4		3		
Lowest bidder													3							
Delay in site delivery						4														
Drawing issues			+	7												6				
Contract issues					5											3				
Security																				
Inflationary issues							2													
Lack of protocol			+		10															
Inaccurate pricing																				
Controlling											5									3
Estimation issues		3																		

Table 9. Summary of important factors including frequency and median.

Issue (Cause)	Description	Source (Article)	Reference	Frequency *	Median
Scheduling	Improper resource planning, inaccurate budgeting, procurement, unreal scheduling	81	1769	25	2
Payment delay	Delays in payment to labours/contractor	58	764	21	3.5
Design	Design and scope changes/lack of clarity (by owner, contractor, or architect)	77	1697	20	3.5
Manpower issues	Using unqualified personnel, lack of skilled workers/designers, poor qualification of the technical staff, staffing problems	70	990	20	6
Financing and cash flow	Cash flow problems, inflexible funding, insufficient contingency allowance, loan gaining problems, financial disputes, capital high costs, penalties	60	466	19	3.5
Supervision	Lack of experienced construction managers, poor supervisor	53	281	18	4
Material	Material change, late delivery, unavailability and lack of materials	76	1358	16	3
Change order	Design problems (by owner or others)	18	54	16	3
Contractor's financial problems	Cash flow/funding problems			15	4
Communication	Poor coordination, poor team working	59	357	15	2
Owner's financial problems	Cash flow/funding problems			12	3
Subcontractor	Unreliability, delays, being inexperienced	56	361	11	4
Equipment	Using inappropriate and inadequate tools and equipment, …	69	888	11	5
Approval	Approval delays in submission and inspection process of design, materials, completed work	67	366	11	5
Natural risks	Natural dangers (environmental related issues, extreme weather conditions, flooding, precipitation, temperature, soil temperature, and wind velocity)	33	77	10	5
Labour productivity	-	41	124	10	2
Culture and politics	Organisational culture, war, strikes and closures of border, political fluctuations, restricted movement between areas	55	510	8	6
Resources	Resources shortage, inadequacy/delays in human resources, material and equipment thefts	75	617	7	3
"Economic" conditions	Local or global economic, cost and currency variations, inadequate foreign currency to import materials and equipment	75	634	7	3.5
Lowest bid	Select lower bidder	15	30	7	2.5
Delay in site delivery	Late delivery/ handover of site	3	8	5	3.5
Drawing	Late/unfinished/changes issues of drawing	58	292	5	4
Contract management	Weak contract management, wrong duration of contract period, contract changes, contract values, old standards	31	71	5	3.5

Table 9. *Cont.*

Issue (Cause)	Description	Source (Article)	Reference	Frequency *	Median
Security	Weak site safety, health restriction, alternative safe access	25	85	4	2
Inflationary	Inflation pressure, lack of attention to inflation	2	7	4	7
Protocol	Lack of severe organisational protocol/policy directives/ strategies	14	54	4	2
Pricing	Wrong pricing and bidding, low performance of bidder, lack of bidder	59	423	4	5
Controlling	Improper monitoring and controlling/cost control	71	471	4	7
Estimation	Inaccurate time and cost estimation	71	442	4	4
Permits	Difficulties in obtaining work permits (drilling permits or tests)	38	161	4	4

Note: * frequency refers to the number of occurrences that the issue presented by researchers as an important cause of delay in the DEC dataset; the order of issues is based on the frequency values. Source refers to the number of papers mentioned in the selected issue; reference refers to the frequency of the selected issue within the DEC dataset; median refers to the value separating the higher half of the important factors presented as important in the DEC datasets by researchers.

Unique factors (with the frequency of three or less) are: "'Slow decision making process by owner" in Norway [90], UAE [84], and Oman [98]; "Changes in material types and specifications during construction" in Saudi Arabia [102], Turkey [117], and Zambia [113]; "Change/selection of subcontractors in the project" in India [79], Saudi Arabia [112], and Vietnam [105]; "Mobilization delay" in India [127], Malaysia [109], and Malawi [81]; "Site constraints (site blockage, impact of other's land)" in Bangladesh [87], Cambodia [103], and countries with high geopolitical risks [104]; "Impact of subsurface (underground) conditions" in Libya [91], Cambodia [103], and Egypt [123]; "Conflict between parties' in Iran [101], Turkey [70], and Egypt [107]; "Errors in construction" in Iran [93], Zambia [113], and Denmark [89]; "Fluctuation in price of materials" in Saudi Arabia [102] and Ghana [100]; "Conflict between labours" in Saudi Arabia [88] and Zambia [113]; "Labour strikes" in countries with high geopolitical risks [104] and Zambia [113]; "Using inappropriate construction methods" in India [92] and Iran [110]; "Insufficient/inaccurate document preparation" in Turkey [70] and Iran [110]; "Inaccurate first drafts/plan" in Iran [110] and Taiwan [132]; "Delay/weak interaction due to vendor" in India [127] and Oman [27]; "Unsuitable site location due to ignoring feasibility studies" in Iran [110] and Cambodia [103]; "Rework (by labours, consultant's workforce)" in Saudi Arabia [102] and Iran [93]; "Suspension of work (by the owner)" in Saudi Arabia [112] and Iran [93]; "Slow decision making by owner" in Saudi Arabia [112] and Iran [93]; "Owners' experience" in Saudi Arabia [112] and Cambodia [103]; "Consultant's experience (competence)" in Libya [91] and countries with high geopolitical risks [104]; "Contractor's experience" in Norway [90] and the UK [99]; "Project complexity" in Norway [90] and the UK [99]; "Wrong evaluation and selection procedure (wrong selection of contractor)" in Turkey [70] and Malaysia [109]; "Working during rainy season" in Cambodia [103]; "Changing in route of supply chains" in countries with high geopolitical risks [104]; "Weak management of contractor's schedule" in Oman [27]; "Long time between design and construction" in Saudi Arabia [102]; "Interference of the execution (by owner)" in Saudi Arabia [112]; "Delays in ownership" in countries with high geopolitical risks [104]; "Office issues" in Norway [90]; "User issues" in Norway [90]; "Official and non-official holidays" in Iran [101]; "Problems with local community" in Iran [101]; "Unpredicted quantity growth" in Turkey [70]; "Old cost lists' items" in Iran [110]; "slow steel production" in [36]; "Poor information (lack of knowledge)" in the UK [99]; "Unsuitable commercial decisions" in the UK [99]; "Unforeseen circumstances" in the UK [99]; "Corruption" in countries with high geopolitical risks [104]; "Custom clearance issues" in [104]; ”Inadequate fuel” in Malawi [81]; and “Delayed compensation paid to land owners” in Malawi [81].

6. Technology Applications for Time Control and Risk Management

Scheduling issues were identified as one of the most frequent factors causing delay in projects (refer to Table 9).

A good project schedule can serve as a key management tool for making decisions and predicting whether the project will finish on time and within budget. Regular updates to the project schedule are essential to record progress and identify potential problems.

There are various project scheduling software systems, such as Microsoft Project, Oracle Primavera P6, Open Plan Professional (OPP), FastTrack Schedule, ZOHO Projects, @risk, Workfront, eResource Scheduler, ConceptDraw Project, Resource Guru, Smartsheet, and many other software, packages, and platforms. Each of these project schedule software options has different strengths, but they offer the best options for a variety of management needs.

Project scheduling software has been developed to communicate what work needs to be performed, which resources of the organisation will perform the work, and the timeframes in which that work needs to be performed. The project scheduling software should reflect all the work associated with delivering the project on time. However, Microsoft Project, Oracle Primavera P6, and Open Plan by Deltek are the most practical, powerful, and common software in practice. Table 10 compares the strengths and the features of these three.

Table 10. Project delay analysis feature comparison between Microsoft (MS) Project, Primavera P6, and Open Plan by Deltek.

Delay Analysis Feature	MS Project	Oracle Primavera P6	Open Plan by Deltek
Updating and rescheduling for delay analysis	*** We can update the schedule project by updating individual task progress and then rescheduling all the uncompleted tasks to start after the status date. Auto schedule is also available.	***** We can update project progress by applying actual data to activities directly in a project or by using timesheet updates from the Progress Reporter module	**** We can update the schedule the project by updating individual task progress. Open plan can integrate with excel Comma Separated Values (CSV) files to import project status data provided the correct table structure is created within Open Plan.
Resource levelling and delay analysis	*** Resource levelling is only available at a single project level, and MS Project is not able to handle levelling when interdependency with another project exists.	**** To handle scheduling conflicts that may occur during levelling, we can add priorities that specify which project or activity is levelled first. This module is only available at Oracle Primavera software.	***** Ability to split, stretch, and re-profile activities for resource scheduling. Resources files are shared across projects assigned at the activity level and are levelling prioritise assigned at the activity level.

Table 10. *Cont.*

Delay Analysis Feature	MS Project	Oracle Primavera P6	Open Plan by Deltek
Risk and delay analysis	* MS Project only considers deterministic tasks duration, and it assumes the relationships among tasks are deterministic, thus uncertainty analysis is not available.	**** The integrated risk management feature identifies, categorizes, and prioritizes potential risks associated with specific work breakdown structure (WBS) elements and resources. Able to create risk control plans and assign a probability of occurrence and an organisational breakdown structure (OBS) element to risks.	*** Provides the ability to calculate three point estimates at the activity level, along with mean and standard deviations for early dates, late dates, and float. Risks are then able to be exported via spreadsheet risk views.
Earned value management (EVM) and delay analysis	*** Earned value analysis is available in MS Project; however, Oracle Primavera P6 can manage EVM.	***** Earned value can be defined at both WBS and activity levels. Able to compute performance percent complete and estimate to complete (ETC).	* Not available and needs to be integrated with Deltek Cobra.

****: The advantage of each software across the selected features.

In order to use scheduling software for project delay analysis, the following questions need to be asked before using scheduling software:

- What data need to be assembled as inputs to record the delay events for the update, and what methods will be used to collect the data?
- How often should projects be updated?
- Are resources local or offsite?
- Which project teams are resources participating in?
- Who on each team will be gathering the information used for the project update, and with what frequency are the data updated within the schedule?
- Who needs to see the results of the update, and when do they need to see them?
- What types of information need to be generated after each update to communicate progress before the next update?

The answers to these questions help determine how the project management office, the project managers, and the project planning function uses the module to update projects.

Careful details of events are developed in the project schedule to identify delays coupled with an accurate assessment of the source of the delay, thus the responsibility can be assigned.

Activity late finish date is one the main components of each scheduling software to calculate schedule delays. Activity late finish date is the latest possible point in time in which the schedule activity can be completed without violating schedule constraint or delaying the project end date (PMBOK). The late finish date is the point at which the schedule activity contains no float.

Progress curves are used as a basis for comparing the schedule baseline. When the project schedule, the work breakdown structure (WBS), or both are modified through integrated change control, the progress curves are revised to indicate the new progress curve information. Figure 8 shows the float analysis for identifying schedule delays as a basis of S-curve updates in project scheduling software.

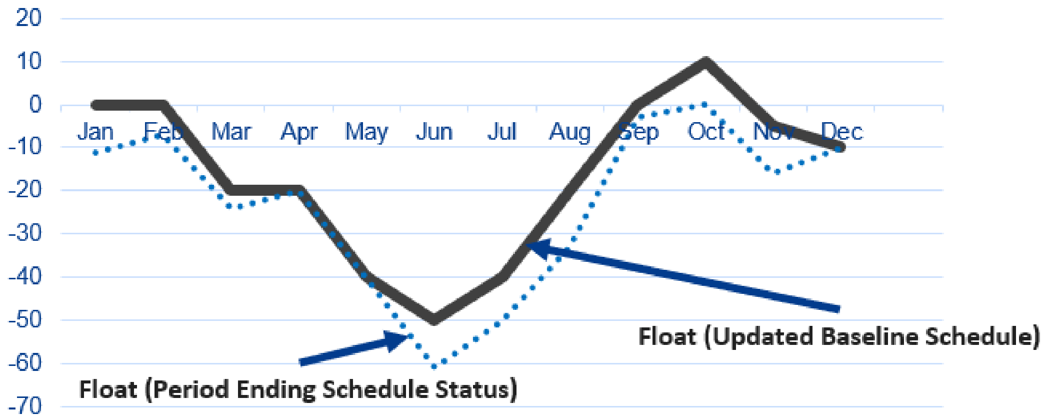

Figure 8. Float analysis and progress curves basis for schedule delays [adopted from Management Body of Knowledge (PMBOK)].

Progress updates are used to calculate delays by using scheduling software. The network schedules are updated on a regular basis, and the agreed timings for updates are generally agreed upon within the special conditions of contract. For example, monthly updates based on the latest schedule baseline are common. Generally, the construction management team updates the schedule with a marking up of the changes from the previous month and provides these details for the project planning function to enter into the scheduling software (e.g., MS Project or Oracle Primavera P6). It is sent to the contractor's project controls team for review until the cut-off date. The project control manager checks and reviews the updated schedule with the project manager. Upon completion of the input work, time calculation and analysis are done within the review process as follows:

- Total float consuming status compared with the previous month schedule.
- Critical path schedule analysis.
- Based on the above analysis, if problem areas are found, these are identified and reported to the project manager. The project control manager implements suggested countermeasures in conjunction with the related managers and under the project managers' instruction. Once the project manager approves the counter measures, they are incorporated in the schedule. Close monitoring is made to meet the corrective action plan. Until a decision on the countermeasures is made, the schedule is not changed.
- The updated schedule is issued to each project management office (PMO), project control department, or project manager as an updated project control for their work and for the next monthly update.
- When compared with the initial estimate, the updated information may indicate some variances in the scheduling basis. On the other hand, along with the project progress, schedule deviations may be detected from the initial scenario caused by various factors.

6.1. Progress Measurement Method in Scheduling Software

The progress is calculated based on milestones, which are defined. Each work package is weighed; this physical weight factor is calculated according to supplier contract price. The assessment of planned progress between milestones is obtained by assuming linear progress development between milestones; see Equation (1):

$$\%\mathrm{Complete} = \frac{\sum_{i=1}^{n} \%\mathrm{complete} \times \mathrm{weight}_i}{\sum_{i=1}^{n} \mathrm{weight}_n} \quad (1)$$

Each activity weight is calculated based on an activity attribute, such as man-hours, material, or cost applied. For example, the length of time for earthwork is a function of the volume of soil cutting and filling in the specific area of the project site.

6.2. Primavera P6 and Delay Analysis

Schedule delay analysis is a method used to determine the extent of impact from potential delay to the agreed milestones. The schedule analysis method in Primavera P6 involves inserting additional activities indicating delays or changes into an updated schedule representing progress up to the point when a delay event occurs to determine the impact of those delay activities. Saving a project baseline plays a crucial role in delay analysis and is a fundamental step in Primavera P6 for schedule delay analysis. Figure 9 shows the baseline in the blue bar and the actual timeline in the yellow bar; as can be seen, a five-day delay in EC160 activity occurred.

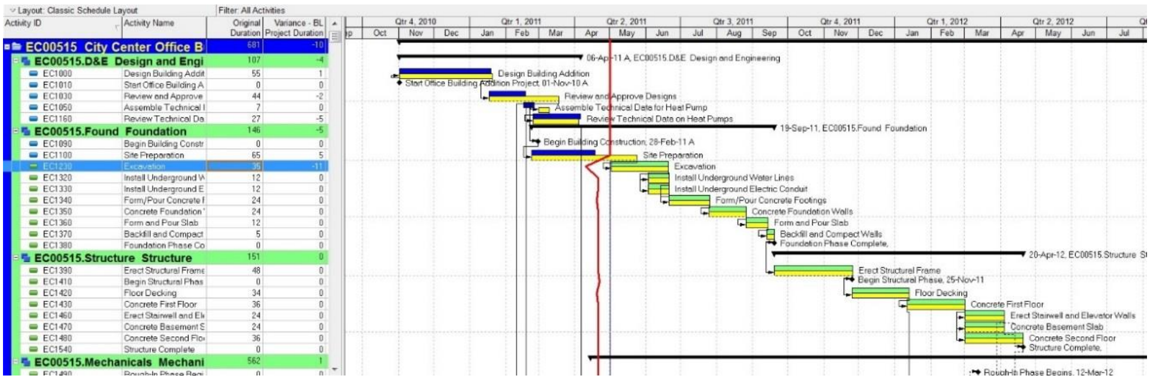

Figure 9. Baseline in blue bar and actual timeline in yellow bar.

Primavera P6 is powerful software to analyse project delays, schedule variances, schedule performance index, estimate to completion, and other aspects of earned value management. Figure 10 shows the earned value feature of the Primavera P6 and respective diagrams.

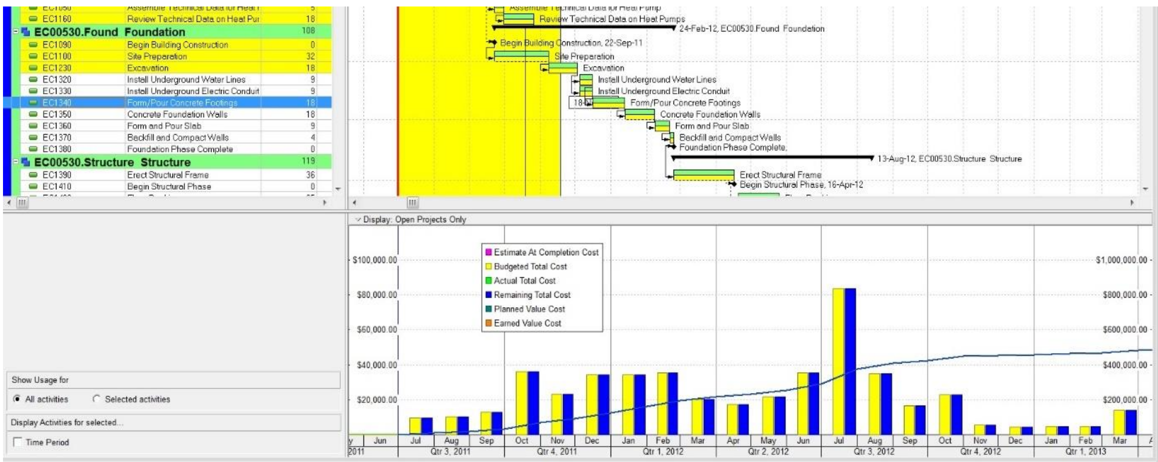

Figure 10. Earned value analysis using Primavera P6.

In Primavera P6 software, the Progress Spotlight feature is used to highlight the activities that should have started, progressed, or finished between the previous data date and the new data date in the Gantt Chart view. Figure 11 shows the Spotlight feature in Primavera P6 software for identifying the delayed activities.

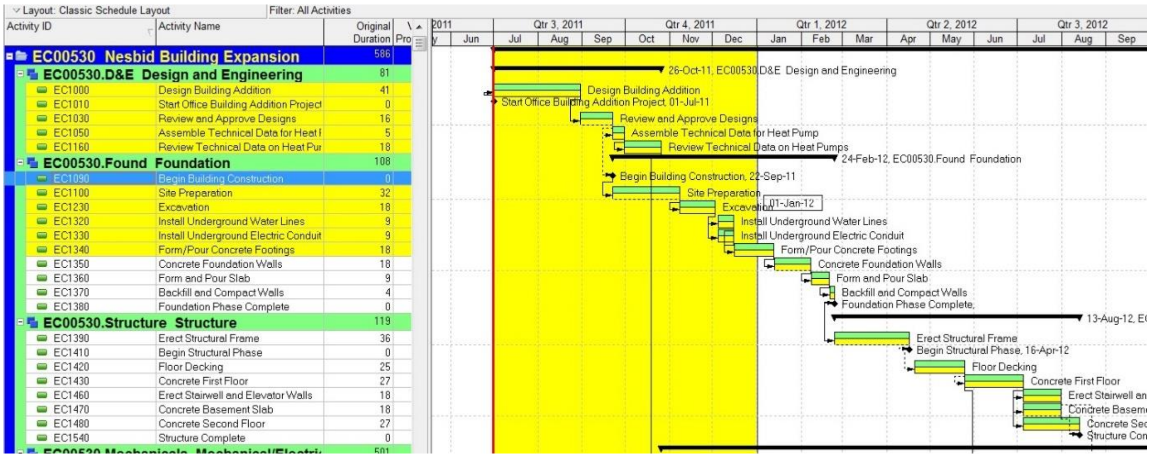

Figure 11. Primavera P6 Progress Spotlight.

7. Project Schedule Delay Analysis from Project Management Methodology Perspectives

7.1. Project Management Body of Knowledge (PMBOK)

Based on the guide to project management body of knowledge [135], project time management encompasses the processes required to manage the project in a timely manner. Project time management has six main processes: (1) plan schedule management; (2) define activities; (3) sequence activities; (4) estimate activity durations; (5) develop schedule; and (6) control schedule. Project Management Body of Knowledge (PBMOK) also emphasises that the schedule baseline is the pillar of delay analysis in projects. A schedule baseline is the approved project timeline upon which any actual dates and changes need to be compared with the schedule baseline for analysing the delays in the schedule model. Updating the project schedule requires maintaining the actual data for project time performance. Any change to the critical path within the schedule baseline leads to delay. In addition, project time management in construction projects needs to focus particularly on other subjects as well as resource definition, allocation and resource levelling, activities to capture contingency allowances, weightage definition, progress curves, monitoring and schedule control procedures, and conditions for owner acceptance approval [136].

7.2. Practice Standard for Scheduling

Practice Standard for Scheduling is a Project Management Institute's (PMI's) standard with the detailed focus on project time management processes, project scheduling models, and techniques. This practice standard expands on information contained in the PMBOK guide. The main goal of this standard is to develop schedule models that are appropriate and fit for purposes of projects. This practice standard introduces schedule model creation by selecting a scheduling approach and a scheduling tool. Based on this practice standard, project work breakdown structure and project-specific data are incorporated within the scheduling technique to develop a unique schedule model. Practice Standard for Scheduling has many hints and techniques for managing delays in the project schedule. For example, when the work on an activity is delayed, it is beneficial for the activity to be split into two or more activities at natural break points. In another example, lags and leads also play important roles in managing the impact of delays on the overall project schedule. In addition, assigning a finish date to the end milestone can help the project schedule to better manage delays and changes in the project master schedule [137].

7.3. Agile Practice Guide

Agile planning focuses on shorter build cycles and tangible results at frequent and incremental intervals. An important part of agile scheduling is using multiple iterations instead of shifting from one phase to another, which makes the scheduling more complex but more efficient. Scrum and Kanban are two main agile frameworks for planning. Both frameworks are used to break down the work into small and manageable pieces. For controlling the project schedule developed by agile approaches, Burndown charts are typically used. Burndown charts are the most applicable agile tracking and controlling mechanisms used by project teams. The main characteristic of a Burndown chart is tracking the remaining work overtime. Caution should be taken when using agile approach delays because rework is high. Agile planning is a suitable project planning technique for a short-term project such as a software development project but is not recommended for construction projects [135,138].

8. Discussion and the DEC conceptual model

This paper, unlike other reviews, identified critical common factors and developed the DEC conceptual model for future investigations. The present review contributes to the body of knowledge in two main ways: (i) it identifies the gaps and the deficiency areas in the DEC literature; and (ii) it develops a conceptual model that can be used to design a questionnaire for further investigations in different contexts. These contributions are discussed below and are presented in Table 8 and Figure 12, respectively.

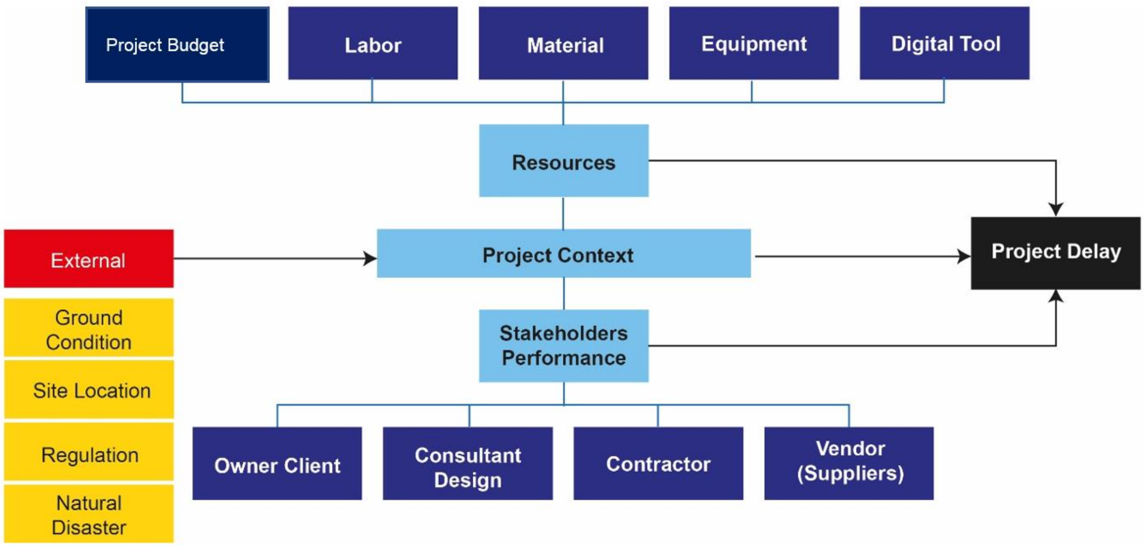

Figure 12. The DEC conceptual model including main constructs of resources, project context, and stakeholders.

Table 10 shows that four factors were overlooked in the DEC dataset. The data analysis and the interpretations are not always valid or reliable due to small samples of participants, low quality of data, unmatched structure of the research questionnaire with the current DEC literature or the case study context, overlooking the effects of technology adoption by all construction stakeholders, or ignoring jobsite upgraded equipment. The overlooked factor (OF) refers to the data and the lack of evaluating new technologies in delay analysis (Table 11). For example, OF1 is the quality of data collected from questionnaires, which cannot be generalised as a valid finding of critical factors of construction projects all over the world. In fact, a major part of the DEC dataset focuses on developing countries; still, some of them suggested more investigations to understand the project complexity at different strategic, operational, and project levels in these countries [84]. This small dataset cannot represent all key practitioners with a real understanding of delay causes and effects. Some studies recruited a limited number of respondents (less than 150), which cannot represent all projects of a country and suffers from lack of validation [27]. This leads to bias in the findings of some studies. In some cases, the survey participants were selected carefully, while some cases were supposed to be selected randomly, but in reality, their strategy of randomness was never clarified. Some of the studies used Analytic Hierarchy Process (AHP) or SD-DEMATEL [93] questionnaires to provide a consistency ratio to increase the reliability of the findings, but these studies suffer from a limited number of factors measured and a limited number of participants. The literature also suggests that comparison studies among developing countries [110] and longitudinal studies in delay analysis should be conducted to examine the relationships of factors and stakeholders in an extended period [111]. In addition, the future studies should focus on more specific types of construction projects, such as utility, highway construction, and dam construction projects, to find proper strategies to mitigate the effects of environmental issues [111].

Table 11. Future directions based on deficiencies of the current delay investigations.

Overlooked Factors (OF)	Examples	Suggestions for Future Directions (FD)
OF1: faulty data analysis and interpretations	• Mostly faulty surveys (questionnaires) due to size and participants	• FD1: mix methods using in-depth interviews and case studies; • FD2: investigate different projects such as PPP
OF2: unmatched structure of the research questionnaires with new knowledge and standards (e.g., PMBOK)	• Questionnaires are based on similar factors frequently asked	• FD3: a set of factors should be developed based on a new conceptual proven model.
OF3: overlooked effect of digital tools and technologies (e.g. Digital twin, Navisworks, BIM, GIS, and IPD)	• The DEC database does not appear to be linked to these digital technologies	• FD4: technology adoption [139] may affect projects duration and should be investigated in different contexts.
OF4: ignored job-site technologies and equipment,	• The DEC database does not analyse the effect of new job-site technologies	• FD5: the application of advanced job-site technologies such as advanced cranes, robotics, and 3D printing should be investigated.

Figure 12 shows the main constructions of the conceptual DEC model for analysing the causes and the effects of delay in construction projects. The key constructs are resources, project context, and stakeholders.

In contrast to traditional investigations, the DEC model suggests that future studies should carefully measure the effect of new "digital tools" and technologies in delay. Sepasgozar and Davis [140] discussed different technology types in construction, which can be further detailed and classified based on their application in time management. The effects of new digital tools and technologies on delay have not been evaluated in the literature. Some of the key digital technologies are listed as follows:

- Digital design communication tools: Digital Twin, Building Information Systems (BIM) including Revit, ArchiCAD, Navisworks, BIMx, BricsCAD, Archibus, Constructor, IntelliCAD, VisualARQ, Revizto; Geographic Information Systems (GIS) including QGIS, ArcGIS, and ArcMap [17]. The literature frequently reports that design mistakes, errors, changing orders and scopes, later approvals, and late technical decision makings were the main causes of delay in different contexts [95,99,104].
- Digital communication systems: cloud-based tools, emails, smart phones, and radio communication systems. Some studies report that the communication and the coordination between different parties were poor [27,95,96,99,109].

- Digital scheduling and planning tools: Microsoft Project, Oracle Primavera P6, FastTrack Schedule, ZOHO Projects, @risk, Workfront, eResource Scheduler, ConceptDraw Project, Resource Guru, Open Plan by Deltek, Smartsheet, and other software, packages, and platforms.
- Digital progress monitoring and job-site controlling tools: laser scanner [141], lidar [142–146], Internet of Things sensors, and photography camera [147].
- Digital contract management tools: intelligent or smart contracts. The literature shows that many projects suffer from weak administration of contracts [96].
- Digital devices to increase the productivity of heavy equipment: real-time locating systems, Global Positioning System (GPS), and radar.
- Digital production technologies: 3D printers [148].

New questionnaires can be designed based on the factors shown in Figure 12. Future studies also should identify the relationship between different causes and their effects on delay [79]. The visibility, the real-time monitoring, and the flexibility of the project using a wider range of digital technologies may mitigate the negative effects of resource and coordination issues. In case of using advanced and digital technologies, vendors have a significant role in successful technology adoption and implementation processes in the project [149–153], which can also mitigate the negative effects of productivity and coordination issues. Appropriate interaction between contractors and vendors (e.g., materials, equipment, or technology suppliers) during both design and construction phases affects delay [27]. Additional evidence is required to validate the results of surveys, which will be conducted in the future. Many delay cause factors can be explored using project evidence and digital data generated during the project, and the questionnaires used to collect participant views cannot be considered as accurate and should only be used as tools to explore delay causes and effects. However, the best way (as suggested by this paper) is to adopt a mixed method of big data generated during the project along with the questionnaire developed based on the factors presented in Figure 12.

9. Conclusions and an Agenda for Future

This paper aimed to identify the most relevant papers of delay causes and effects and to develop the DEC database for future critical analysis. The content of the DEC dataset was systematically analysed using bibliographic, cluster, and thematic analyses. This paper presented the DEC literature, including key findings of delay over the years. This study carefully conducted a systematic content analysis, resulting in four main overlooked factors and deficiency areas, which should be addressed in the future studies. The four factors are faulty data analysis and interpretations due to small samples of participants or low data reliability, unmatched structure of research questionnaires with the current policies or standards, overlooking the effects of technology adoption by construction stakeholders, and ignoring jobsite upgraded equipment. The key deficiencies were identified as faulty of data analysis and interpretations due to small sample of participants or low data reliability, unmatched structure of research questionnaires with the current policies or standards, overlooking the effects of technology adoption by construction stakeholders, and ignoring jobsite upgraded equipment. The overlooked factor refers to the data and the lack of evaluating new technologies in delay analysis. For example, OF1 refers to the quality of data collected from questionnaires, which cannot be generalised as a valid finding of critical factors of construction projects all over the world. In fact, a major part of the DEC dataset focuses on developing countries. This small dataset cannot represent all key practitioners with a real understanding of the delay causes and effects. Some studies recruited a limited number of respondents (less than 150), which cannot represent all projects of a country. This leads to bias in the findings of some studies. In some cases, the survey participants were selected carefully, and in some cases, they were supposed to be selected randomly, but in reality, it is not clear what their strategy of randomness was. Some studies used AHP questionnaires to provide a consistency ratio to increase the reliability of the findings, but these studies suffer from a limited number of factors measured and a limited number of participants.

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Appendix A

The search string was selected as "delay overrun" or "time overrun", and '"construction industry" or "construction project"' and was applied on the Scopus database using the following search criteria:

(TITLE-ABS-KEY (delay OR "time overrun") AND TITLE-ABS-KEY ("construction industry" OR "Construction project")) AND (LIMIT-TO (DOCTYPE , "ar") OR LIMIT-TO (DOCTYPE , "re")) AND (LIMIT-TO (LANGUAGE , "English")) AND (LIMIT-TO (SRCTYPE , "j")) AND (EXCLUDE (PUBYEAR , 2019)) AND (EXCLUDE (SUBJAREA , "MATE") OR EXCLUDE (SUBJAREA , "MATH") OR EXCLUDE (SUBJAREA , "ARTS") OR EXCLUDE (SUBJAREA , "CENG") OR EXCLUDE (SUBJAREA , "AGRI") OR EXCLUDE (SUBJAREA , "BIOC") OR EXCLUDE (SUBJAREA , "MEDI") OR EXCLUDE (SUBJAREA , "CHEM") OR EXCLUDE (SUBJAREA , "PHYS") OR EXCLUDE (SUBJAREA , "HEAL") OR EXCLUDE (SUBJAREA , "NURS") OR EXCLUDE (SUBJAREA , "PSYC") OR EXCLUDE (SUBJAREA , "Undefined")) AND (LIMIT-TO (PUBYEAR , 2018) OR LIMIT-TO (PUBYEAR , 2017) OR LIMIT-TO (PUBYEAR , 2016) OR LIMIT-TO (PUBYEAR , 2015) OR LIMIT-TO (PUBYEAR , 2014) OR LIMIT-TO (PUBYEAR , 2013) OR LIMIT-TO (PUBYEAR , 2012) OR LIMIT-TO (PUBYEAR , 2011) OR LIMIT-TO (PUBYEAR , 2010) OR LIMIT-TO (PUBYEAR , 2009)) AND (EXCLUDE (SUBJAREA , "ENVI") OR EXCLUDE (SUBJAREA , "ENER") OR EXCLUDE (SUBJAREA , "EART"))

The search limited to articles investigating causes and effects in the recent ten years from 2009 to 2018. Therefore, 'cause' and 'effect' also were included in the following search criteria:

(TITLE (delay OR "time overrun") AND TITLE-ABS-KEY ("construction industry" OR "Construction project") AND TITLE-ABS-KEY (cause OR effect)) AND (LIMIT-TO (DOCTYPE , "ar")) AND (LIMIT-TO (LANGUAGE , "English")) AND (LIMIT-TO (SRCTYPE , "j")) AND (LIMIT-TO (PUBYEAR , 2019) OR LIMIT-TO (PUBYEAR , 2018) OR LIMIT-TO (PUBYEAR , 2017) OR LIMIT-TO (PUBYEAR , 2016) OR LIMIT-TO (PUBYEAR , 2015) OR LIMIT-TO (PUBYEAR , 2014) OR LIMIT-TO (PUBYEAR , 2013) OR LIMIT-TO (PUBYEAR , 2012) OR LIMIT-TO (PUBYEAR , 2010) OR LIMIT-TO (PUBYEAR , 2009)) AND (LIMIT-TO (SUBJAREA , "ENGI") OR LIMIT-TO (SUBJAREA , "BUSI") OR LIMIT-TO (SUBJAREA , "DECI") OR LIMIT-TO (SUBJAREA , "ECON") OR LIMIT-TO (SUBJAREA , "SOCI") OR LIMIT-TO (SUBJAREA , "MULT"))

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