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Forensic delay analysis as evidence of transaction costs in construction projects.

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2022

This file contains the corrections published in the corrigendum (<https://doi.org/10.1088/1755-1315/1101/5/052034>), followed by the full-text article.

Corrigendum: Forensic Delay Analysis as Evidence of Transaction Costs in Construction Projects (*IOP Conf. Ser.: Earth Environ. Sci.* 1101 052009)

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Description of corrigendum:

Page 1: the following text appears:

Construction projects are invariably and manifestly beset by delay [1]. A major consequence of this is costly and time-intensive disputes [5]. This article (or paper) examines disputes arising out of delay in construction projects, with a particular emphasis on viewing such disputes as a significant transaction cost.

In 1937 Coase introduced his theory of Transaction Cost Economics (TCE)[6], which was subsequently taken up and further developed by Williamson [7]. A number of observers have found this theory to be effective in accounting for inefficiencies in the construction sector. However, the practical application of some key aspects of TCE theory has proved contentious.

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Construction projects are invariably and manifestly beset by delay [1]. A major consequence of this is costly and time-intensive disputes [2, 3, 4]. This article (or paper) examines disputes arising out of delay in construction projects, with a particular emphasis on viewing such disputes as a significant transaction cost.

In 1937 Coase introduced his theory of Transaction Cost Economics (TCE) [5], which was subsequently taken up and further developed by Williamson [6]. A number of observers have found this theory to be effective in accounting for inefficiencies in the construction sector. However, the practical application of some key aspects of TCE theory has proved contentious.

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expenditure of effort which the management of transactional disputes ordinarily necessitates. First, a few background assumptions are outlined, drawing on relevant literature and comprising: (i) a review of distinctive characteristics of construction delay disputes and their typical management, and (ii) a brief summation of key elements of TCE theory. The adopted methodology outlines a case study approach to collection of data. Findings based on an analysis of the collected data include quantifying transaction costs across a range of typical contributors. Finally, having regard to the more encompassing body of work to which this paper contributes, consideration is given to how information technology within the construction sector might be more constructively deployed towards reducing or eradicating some of the transaction costs identified in the study, ultimately with a view to disposing of construction disputes more effectively or efficiently, or eliminating them altogether.

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It is instructive at this point to draw attention to Williamson's dichotomy used in reference to TCE approaches, namely: 'a governance branch and a measurement branch'[34]. Authors, including Reve and Levitt [35]; Winch [36] [37]; Walker and Wing [38]; Lai, [39]; Bridge and Tisdell [40]; and Bygballe, *et al.*, [41] have focused attention on the governance branch, following Eccles' initiative to apply TCE theory towards explaining 'boundaries' of construction companies and the organisation of their businesses and projects. Other writers have focused on applying the measurement branch of TCE theory to explain project performance and other phenomena, such as the behaviour of key stakeholders. For instance, Yates and Hardcastle [42] have focused on how bounded rationality and opportunistic behaviour might impact conflict and disputes in construction projects. Greenwood and Yates have adopted the same approach using evidence provided by a partnering case study [43]. Empirical studies by Li *et al.* [44] and You *et al.* [48] identified pre- and post-contract transaction costs, suggesting how these impacted the choice of project delivery systems and type of contract.

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This study is concerned with (i) identifying the processes and resources currently required for analysing delay disputes; (ii) categorising them using TCE 'language' and aligning them with components of transaction costs (as discussed above); and (iii) operationalising and measuring these costs by examining data collected from twelve project case studies. For ethical reasons cases have been anonymised and described by their function (i.e., Infrastructure Design; Panel Manufacturing Plant; Bridge Construction, etc.). The methodological approach is primarily archival and based upon analysis of the records of twelve case studies chosen from an initial sample of sixty projects. In common with many types of consultants, FDA activity records are kept for payroll, project accounting and client-billing purposes. These provided a rich source of data for identifying, categorising and quantifying the FDA processes and the resources required to sustain them. The selection of cases was based on four criteria. The first was that each involved a delay or delays upon which the parties were unable to reach agreement under the terms of the contract (hence escalated to a dispute). The second criterion was recency: the case studies were selected from the period between January 2015 and January 2021. Projects that started before this timeframe or were incomplete by the end of it were eliminated. The third criterion was representativeness: the case studies must, as far as possible, be reasonably representative of the range of projects dealt with. Finally, the fourth criterion, in order to secure the accessibility and consistency of collected data, was that the entire delay analysis process had been undertaken 'in-house' by a single FDA consultant. This is a significant filter, as projects are often completed by a network of analysts in different international locations. Based on the above criteria twelve projects were identified for further analysis. Daily record-keeping is a fundamental requirement for the FDA, as it is for most consultant organisations. The records from the twelve casestudy projects were reviewed to identify: (a) the type of task conducted by each consultant for each working day; (b) the reasons for conducting the tasks; (c) the product that was produced as a consequence of each task; and (d) the time spent on a particular task.

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Table 1. Case studies (CS).

CS	Project Type	Service	Location	Client	Contract	Forum
1	Mixed use development	Independent delay report	Asia	Contr.	FIDIC	Arb.
2	Shopping centre	Independent delay report	UK	Eng.	JCT	Adj.
3	Infrastructure (tunnelling)	Independent delay report	UK	Contr.	NEC	Adj.
4	Railway services	Independent delay report	UK	Eng.	NEC	CAP
5	Bridge construction	Independent delay report	Africa	Con.	FIDIC	DAB
6	Panel manufacturing plant	Delay analysis report	UK	Suppl.	NEC	Neg.
7	Infrastructure design	Delay analysis report	UK	Design.	NEC	Neg.
8	Infrastructure construction	Independent delay report	UK	Contr.	Bespoke	Adj.
9	Infrastructure design	Delay analysis report	UK	Design.	NEC	Neg.
10	Data centre	Independent delay report	UK	Contr.	JCT	Adj.
11	Food packaging plant	Independent delay report	UK	Contr.	JCT	Adj.
12	Office building	Independent delay report	UK	Contr.	JCT	Adj.

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...Undifferentiated activities (or 'Others') where in a record it was difficult to allocate time to a single category, e.g., where records related to time spent overall on all of them, it was assumed that the relative proportion of time could be allocated to Categories 1-3 pro-rata to

the predominant patterns from data that could be differentiated. Analysis of the records from each of the twelve case studies produced the following results.

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... Undifferentiated activities (or 'Others') where it was difficult to allocate time to a single category (e.g. where the records indicate that the time was spent on more than one category of activities). In those instances, it was assumed that the relative proportion of time could be allocated to Categories 1-3 pro-rata to the predominant patterns from data that could be differentiated. An analysis of the records from each of the twelve case studies produced the following results.

Table 2 is incorrect and should be:

Table 2. Summary of production hours.

Categories	Preliminary Tasks	Delay	Causation	Others	Total	Total less Others
Production hours Case 1	84	725	561	418	1788	1370
Production hours Case 2	24	231	39	252	546	294
Production hours Case 3	44	179	238	20	481	461
Production hours Case 4	101	1975	37	571	2684	2113
Production hours Case 5	58	374	175	381	988	607
Production hours Case 6	52	374	35	17	378	461
Production hours Case 7	27	1518	823	1588	3956	2368
Production hours Case 8	211	144	6	623	984	361
Production hours Case 9	74	641	730	624	2069	1445
Production hours Case 10	58	594	47	70	769	699
Production hours Case 11	15	773	44	1101	1933	832
Production hours Case 12	16	413	30	319	778	459
Production hours (all cases)	764	7941	2765	5984	17354	11470

Page 7: the following text appears:

...Although the study was limited in terms of sample size, it is based on the kind of evidence that has hitherto been rare or non-existent. Not only does this provide empirical evidence to support the estimates but provides a relatively detailed indication of the categories of activities performed by FD analysts and quantifies the time spent on those tasks which can be used as an indicator of the cost of the service. Perhaps most importantly, the evidence indicates that there is a duplication of costs where the delay analysis is conducted originally by the commercial teams of the parties and again by independent consultants. It could be argued that the efforts of both teams are examples of construction project transaction costs and that these costs increase when the commercial team is unable to complete the task effectively and external FD analysts are contracted to complete the claims.

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The authors would like to acknowledge the assistance of the Major Projects Association, UK for its continuing support throughout the study.

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The authors would like to acknowledge the assistance of the Major Projects Association, UK for its continuing support throughout the study. The findings presented in this paper are one aspect of a wider research investigating the potential of advances in information technology and the incorporation of contractual solutions to achieve more efficient and effective resolutions of fact-related construction delay disputes.

Forensic Delay Analysis as Evidence of Transaction Costs in Construction Projects

V A Atanasov^{1,2}, D J Greenwood³, H Ross⁴ and D E Sanchez⁵

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Abstract. Construction projects are characterised by supply chains with multiple contracts and significant transaction costs. An example of these costs is to be found in the management of project delays. The operationalisation and measurement of transaction costs, especially in the construction context, has hitherto proved difficult. The work reported here is concerned with defining and measuring the resources required for the management of contractual disputes relating to project delays. Its main argument is that concepts from transaction cost economics (TCE) theory (bounded rationality, uncertainty, information asymmetry, and opportunistic behaviour) present serious problems for transaction efficiency. This is exemplified in forensic analysis of construction project delays. Data from twelve case studies are analysed, to reveal that up to 90% of time spent on delay analysis was concerned with searching for and validating information which could, ostensibly, be automatically and reliably captured using digital technologies. This research forms part of a wider study that considers the implications of the identified inefficiencies and makes a case for the exploitation of advances in information technology on the more efficient resolution (or even avoidance) of contractual disputes. It concludes that there is a prima facie case for this, and therefore for the reduction in the transaction costs that relate to the management of construction project delays.

1. Introduction

Construction projects are invariably and manifestly beset by delay [1]. A major consequence of this is costly and time-intensive disputes [2, 3, 4]. This article (or paper) examines disputes arising out of delay in construction projects, with a particular emphasis on viewing such disputes as a significant transaction cost.

In 1937 Coase introduced his theory of Transaction Cost Economics (TCE) [5], which was subsequently taken up and further developed by Williamson [6]. A number of observers have found this theory to be effective in accounting for inefficiencies in the construction sector. However, the practical application of some key aspects of TCE theory has proved contentious.



This article centres around three key hypotheses: (1) that transactional disputes, and the ways in which they are managed, can be seen as an entirely avoidable transaction cost; (2) that – informed by TCE theory – such disputes suffer from informational shortcomings (or asymmetry), including a disequilibrium of information input by project stakeholders and (3) that, in the opinion of the authors of this paper, the drawbacks highlighted in (2) could be addressed by developing customised information tools that, albeit limited by what it is possible by today's technologies, could produce more robust information within the sector.

The empirical findings reported in this article originate from twelve project case studies which address hypothesis (1) (above) by seeking to define and quantify the expenditure of effort which the management of transactional disputes ordinarily necessitates. First, a few background assumptions are outlined, drawing on relevant literature and comprising (1) a review of distinctive characteristics of construction delay disputes and their typical management and (2) a brief summation of key elements of TCE theory. The adopted methodology outlines a case study approach to collection of data. Findings based on an analysis of the collected data include quantifying transaction costs across a range of typical contributors. Finally, having regard to the more encompassing body of work to which this paper contributes, consideration is given to how information technology within the construction sector might be more constructively deployed towards reducing or eradicating some of the transaction costs identified in the study, ultimately with a view to disposing of construction disputes more effectively and/or efficiently, or eliminating them altogether.

2. Literature Review

This part of the article sets out the findings of a literature review focusing on the two tasks mentioned above, namely: (1) reviewing distinctive characteristics of construction delay disputes and their typical management, and (2) briefly summarising key elements of TCE theory (extending to discussion of the practical application of those elements to key issues and difficulties prevalent in the construction sector).

2.1. Construction Delay Disputes

A report published in 2021, focusing on construction disputes in the global arena [7], estimates the cost of the average dispute as US\$54million, typically playing out over 13 months. The report does not separately itemise cost and duration attributable to delay-based claims, but the National Construction Contracts and Law Report [8], which examines the position in the UK, maintains that disputes centring on project delays were the most prevalent among UK-based construction industry players who had been involved in disputes.

2.2. Construction Project Delays and their Analysis

Pickavance points out that the expression 'delay' lends itself to a variety of interpretations [9]. This difficulty is amplified by the failure of most published standard form contracts to define this important term – and this can itself be a catalyst for disputes. Burr identifies 23 possible meanings, noting that per se the concept lacks 'intrinsic quality'. However, he concludes that delay in completion of the works can be regarded as an 'adverse effect upon completion' by the contractor of the entirety, or a defined section, of the works, as required by the contract [10]. Needless to say, all parties involved in construction projects can suffer delay-related losses. Leading publishers of standard form contracts use contractual devices such as liquidated damages (LDs) and extensions of time (EOTs) as a means of apportioning risk. But those mechanisms are usually of general application and may not assist in averting disputes. The Society of Construction Law [11] has sought to introduce procedures for parties to opt into and follow. However, delay-related disputes are inherently complex, and this can often be compounded by an absence of supporting information [12] and a tendency for differences between parties to escalate from claims into disputes [13]. This may precipitate disputes that require to be resolved by formal or informal processes [14].

Kumaraswamy [15] notes that the complexity and often high value of construction disputes have created a need for specialist consultants who practise the techniques of forensic delay analysis (FDA), coming from a background in dispute resolution and claims management. The merits and demerits of FDA techniques are explored in literature where the focus is on distinguishing between methods used for project programme/schedule analysis [11, 16, 17, 18, 19]. The quantification of project delays is usually reliant both on critical path analysis (CPA) and on the availability of validated programmes. In situations where the project records that are required to validate construction programmes are not readily available (as often happens) the CPA may turn out to be both speculative and subjective. FDA techniques may be deployed to facilitate case-building in preparation for dispute resolution processes such as adjudication, arbitration, expert determination, or litigation. In that context, FDA consultants may take on the role of independent experts. As Carmichael and Murray put it: the process calls for a 'vast number of documents to be reviewed and people to be interviewed'[20]. Alkass *et al.* have estimated that the process of gathering and organising information accounts for approximately 70% of the task of building a case and 30% of the time is spent on the analysis of the claim [21]. This claim lacks empirical substantiation, however. In the 2017 SCL Delay and Disruption Protocol [11] there is recognition that any FDA method adopted must be reliant upon the nature, extent and quality of both the programme information and records available. Essentially, what is being suggested here is that the management and resolution of construction disputes, facilitated by FDA, are a clear example of transaction costs. Perhaps inevitably, this engages TCE theory towards the goal of understanding how greater efficiencies can be achieved in construction projects.

In the next part of this paper there is a brief summary of the key literature on TCE theory, with an exploration of its practical application in the construction context.

2.3. *Transaction Cost Theory*

According to the theory's originator the 'costs of organizing transactions' arise from efforts 'to conduct negotiations leading up to a bargain, to draw up the contract, to undertake the inspection needed to make sure that the terms are being observed, and so on' [22]. Dahlman identified 'search and information costs, bargaining and decision costs, policing and enforcement costs' and added that 'fundamentally [these] reduce to... resource losses due to lack of information'[23]. Williamson recognises two factors that influence these costs as 'the characteristics of the human decision makers ... on the one hand and the objective properties of the market on the other'[24]. Eccles following Williamson, described two influential pairings of these factors as (1) bounded rationality and uncertainty/complexity and (2) opportunism and small numbers [25]. TCE theory has its critics; the most cited being Simon who claimed they have 'no empirical support' [26] and Ghoshal and Moran who regarded TCE as 'not only wrong but also dangerous ...' [27]. These criticisms have themselves been refuted; by Masten in the former case [28], and by Williamson, in the latter [29]. David and Han describe a 'significant variation in support for the theory's predictions'[30]. This debate has continued. Recent examples include Lacity and Khan who conclude that TCE theory only applies 'to specific contexts' [31]; Schermann *et al.* with evidence that both supports and negates TCE theory [32]; and Haaskjold *et al.* who argues a general association between collaboration and reduced transaction costs but support a more restricted context-specific view of TCE applicability [33].

2.4. *Construction Project Delays and their Analysis*

Williamson's refinement and redefinition of the original theories of Coase appeared to spark a keen interest amongst construction management researchers [34]. The authors undertook a systematic literature review of all academic articles and doctoral dissertations that describe or attempt to apply TCE theory related to the Construction Industry. Three academic search tools - Google Scholar, the database of the Association of Researchers in Construction Management (ARCOM), and that of the British Library (EthoS) - were used to determine the body of TCE work that has been published within the Construction Management field. In the 80 years since Coase first introduced the theory, no construction-related reference to TCE was found until Eccles' 1981 paper: suggesting the influence of

Williamson's more detailed publications from 1979 onwards. Of the 89 subsequent papers where authors had adopted a 'TCE-lens' to understanding the workings of the construction industry, there were four in the decade between 1981 and 1990; nine between 1991 and 2000; twenty-nine between 2001 and 2010; and between 2011 and 2020, a further forty-eight publications. This indicates a growing interest in the potential application of TCE to the Construction Industry, its organisations, and its projects.

It is instructive at this point to draw attention to Williamson's dichotomy used in reference to TCE approaches, namely: 'a governance branch and a measurement branch'[34]. Authors, including Reve and Levitt [35]; Winch [36]; Walker and Wing [38]; Lai [39]; Bridge and Tisdell [40]; and Bygballe, *et al.* [41] have focused their attention on the governance branch, following Eccles' initiative to apply TCE theory towards explaining 'boundaries' of construction companies and the organisation of their businesses and projects. Other writers have focused on applying the measurement branch of TCE theory to explain project performance and other phenomena, such as the behaviour of key stakeholders. For instance, Yates and Hardcastle [42] have focused on how bounded rationality and opportunistic behaviour might impact conflict and disputes in construction projects. Greenwood and Yates have adopted the same approach using evidence provided by a partnering case study [43]. Empirical studies by Li *et al.* [44] and You *et al.* [48] identified pre- and post-contract transaction costs, suggesting how these impacted the choice of project delivery systems and type of contract. However, the identified published articles (excepting those of the first author) have failed to operationalise and quantify the transaction costs that relate to the management of construction project delays.

The study reported in this paper occupies the measurement branch of TCE theory and the specific approach adopted is described in greater detail in the next part of the article (immediately below).

3. Research Methodology

This study is concerned with (1) identifying the processes and resources currently required for analysing delay disputes; (2) categorising them using TCE 'language' and aligning them with components of transaction costs (as discussed above) and (3) operationalising and measuring these costs by examining data collected from twelve project case studies. For ethical reasons cases have been anonymised and described by their function (e.g. Infrastructure Design; Panel Manufacturing Plant; Bridge Construction, etc.). The methodological approach is primarily archival and based upon analysis of the records of twelve case studies chosen from an initial sample of sixty projects. In common with many types of consultants, FDA activity records are kept for payroll, project accounting and client-billing purposes. These provided a rich source of data for identifying, categorising and quantifying the FDA processes and the resources required to sustain them. The selection of cases was based on four criteria. The first was that each involved a delay or delays upon which the parties were unable to reach agreement under the terms of the contract (hence escalated to a dispute). The second criterion was recency: the case studies were selected from the period between January 2015 and January 2021. Projects that started before this timeframe or were incomplete by the end of it were eliminated. The third criterion was representativeness: the case studies must, as far as possible, be reasonably representative of the range of projects dealt with. Finally, the fourth criterion, in order to secure the accessibility and consistency of collected data, was that the entire delay analysis process had been undertaken 'in-house' by a single FDA consultant. This is a significant filter, as projects are often completed by a network of analysts in different international locations. Based on the above criteria twelve projects were identified for further analysis. Daily record-keeping is a fundamental requirement for FD analysts, as it is for most consultant organisations. The records from the twelve case-study projects were reviewed to identify: (1) the type of task conducted by each consultant for each working day; (2) the reasons for conducting the tasks; (3) the product that was produced as a consequence of each task; and (4) the time spent on a particular task.

4. Case Studies and Data Analysis

The table below provides a brief description of the case studies including project type, service, type of contract, location, the client, and dispute resolution forum.

Table 1. Case studies (CS).

CS	Project Type	Service	Location	Client	Contract	Forum
1	Mixed use development	Independent delay report	Asia	Contr.	FIDIC	Arb.
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11	Food packaging plant	Independent delay report	UK	Contr.	JCT	Adj.
12	Office building	Independent delay report	UK	Contr.	JCT	Adj.

Earlier work by the authors Atanasov *et al.* revealed that the FDA process can be divided into four broad categories (Cat.) of activities (or tasks) [49]. Preliminary tasks (Cat. 1) including a review of available records, meetings, or correspondence with clients to establish the aims and objectives of the FDA, and a basis for further requests for records. Delay analysis (Cat. 2) involving a review of available programmes to establish the accepted ‘baseline’ (as-planned) and updated programmes, their validation, and the creation of tables, schematics, and other charts to illustrate high level, mid-level, and detailed comparisons, and drafting the methodology and findings. It is a process where the start and completion dates of the programme activities are compared to the available as-built records which could be in the form of daily, weekly, fortnightly, or monthly reports. Causation analysis (Cat. 3) including a review of contemporaneous records to identify relevant issues, create chronologies to describe identified issues, produce tables, schematics, and other charts to illustrate findings and draft and edit relevant sections of the delay analysis reports. Undifferentiated activities (or ‘Others’) where it was difficult to allocate time to a single category (e.g. where the records indicate that the time was spent on more than one category of activities). In those instances, it was assumed that the relative proportion of time could be allocated to Categories 1-3 pro-rata to the predominant patterns from data that could be differentiated. An analysis of the records from each of the twelve case studies produced the following results.

Table 2. Summary of production hours.

Categories	Preliminary Tasks	Delay	Causation	Others	Total	Total less Others
Production hours Case 1	84	725	561	418	1788	1370
Production hours Case 2	24	231	39	252	546	294
Production hours Case 3	44	179	238	20	481	461
Production hours Case 4	101	1975	37	571	2684	2113
Production hours Case 5	58	374	175	381	988	607
Production hours Case 6	52	374	35	17	378	461
Production hours Case 7	27	1518	823	1588	3956	2368
Production hours Case 8	211	144	6	623	984	361
Production hours Case 9	74	641	730	624	2069	1445
Production hours Case 10	58	594	47	70	769	699
Production hours Case 11	15	773	44	1101	1933	832
Production hours Case 12	16	413	30	319	778	459
Production hours (all cases)	764	7941	2765	5984	17354	11470

Table 2 shows that the highest number of classifiable FDA hours (7941) were spent on quantification and analysis of the project Delay (69%) and Causation Analysis (24%). The quantification of delay consistently accounted for a significant percentage of the hours spent by the FD analysts. By contrast, in seven of the twelve case studies, the classifiable hours spent by the FD analysts on Causation Analysis were relatively insignificant (i.e. less than 10% of the classified hours). This indicates that the main aspect of the FDA consultancy service is the quantification of delay, including identification, validation and analysis of delays. In nine of the case studies a significant portion of the total hours (5984 hours) were difficult to classify with accuracy, though informal records suggest that these may be consistently attributable to the former two categories (generally, the description of the FDA activity only refers to Delay quantification and analysis and Causation analysis), it should be highlighted that this is an assumption made for the purpose of this research. However, the Delay category accounted for the highest total of hours.

In terms of the individual cases the information provided can be used to analyse the production hours. For example, in Case 1 the quantification and analysis of Delay accounted for around 53% of the classifiable hours (40% of the total). Although this activity accounted for around 40% of the total, it was not possible to identify the 'other' activities, due to the level of accuracy in the description provided in the time sheets. It may be that a significant part of the 418 'Others' hours was also spent on the quantification and analysis of Delay. The time spent on Causation Analysis (41%, or 31% of the total) was less than the time spent on identification, validation, and analysis of the accepted programmes.

5. Findings and Discussion

Based on twelve cases, the resources required for managing time-related contractual disputes over project delays were measured. The findings indicate that up to 90% of FDA costs were expended in retrieving, validating, and processing project records for analysis where most of those hours were spent on validation of as built data. This figure is particularly high compared to less than 25% spent on the more contentious aspect, i.e. making an argument for causation. Where such records are

incomplete, inferences are needed that themselves require further efforts to justify, including the use of processes such as reconstruction of the data which are prone to errors and biases. Although the study was limited in terms of sample size, it is based on the kind of evidence that has hitherto been rare or non-existent. The identified published work does not present such evidence. Not only does this study provides empirical evidence to support the estimates but it also offers a relatively detailed indication of the categories of activities performed by FD analysts and quantifies the time spent on those tasks which can be used as an indicator of the cost of the service. Perhaps most importantly, the evidence indicates that there is a duplication of costs where the delay analysis is conducted originally by the commercial teams of the parties and again by independent consultants. It could be argued that the efforts of both teams are examples of construction project transaction costs and that these costs increase when the commercial team is unable to complete the task effectively and external FD analysts are contracted to complete the claims.

Recognising the conclusion of Haaskjold *et al.* that ‘conflicts can lead to significant transaction costs’, the study was set within the lens of TCE theory [33]. This approach was supported by the findings, in that (1) contractual disputes offer a striking example of unnecessary transaction costs; and (2) that, reflecting TCE theory, these costs are fuelled by the phenomenon of bounded information, requiring what Dahlman (1979) identifies as ‘search and information costs’ and ‘resource losses due to lack of information’ [23]. Furthermore, such situations provide scope for opportunistic behaviour and exploitation by individual agents in their unwillingness to share any information that does exist. From an academic perspective, this is a rare example of the operationalisation and measurement of transaction costs.

More important is the practical relevance of the work. Despite the current deficiencies, the information required for FDA could potentially be made available in accurate and verifiable formats. For example, there is a range of software products to support the management of time on projects and versions of these were available to all the key participants in the cases in question. All such products have a facility for the capture and archiving of evolving versions of the schedules they are used to produce. A more recent technological advance is that of Building Information Modelling (BIM). Authors from Gibbs *et al.* to Sanchez *et al.* have explored how BIM and related digital technologies could assist with FDA [50, 51]. Advances such as the introduction of 3D scanners [52], drones [53], sensors [54] present an opportunity for accurate contemporaneous collection and processing of construction project information. Furthermore, the application of emerging blockchain technology to the capture of progress information could eliminate the requirement for human agency [55]. Properly managed, this could remove the possibility of information asymmetry and its opportunistic exploitation by one agent or another. In this way, the utilisation of information technology is likely to improve the current efficiency of resolution (or avoidance) of contractual disputes by reducing (or even eliminating) the factual arguments relating to the actual progress of the construction works. In summary, transaction efficiency could be improved by automating the capture and management of the required information by minimising arguments over the sufficiency or accuracy of the records and, as a consequence, potential disputes regarding the parties’ liability for critical project delays.

6. Conclusions and Further Research

Despite these opportunities, the proportion of time FD analysts spend on delay analysis indicates serious current deficiencies in the capture, storage, retrieval, and processing of information by the representatives of the organisations in question. The findings indicate that reconstruction and validation of data is a time-consuming and resource-intensive process. This lack of adequate and credible information is a clear example of bounded rationality, which, as discussed earlier, is one of the main factors in the escalation of transaction costs. Bounded rationality provides scope for opportunistic behaviour, and this is exploited by individual agents in their unwillingness to share such information that does exist. Together these factors add further to the conflict and disputes in construction projects, and ultimately to their cost. The adoption of available technical solutions would, in the language of TCE, reduce bounded rationality and information asymmetry, by making relevant

information reliable, accessible and transparent and thereby reducing uncertainty and opportunistic behaviour. Exploration of the previously noted issue of the potential duplication of project costs related to quantification and substantiation of project delays (i.e., by both the project commercial team and later by FDA consultants) and an investigation of effective solutions (technical and contractual) to reduce transaction costs would also be a valuable line of enquiry.

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