On Quality and Complexity: Non-conformance failures, management perspectives and learning outcomes on a highways megaproject

Abstract

Purpose – The construction industry continues to struggle to deliver a right first time culture, seeking a panacea for improvement whilst maintaining project milestones. Complex construction projects demand stringent programmes, however, (un)foreseen changes, political influences and human behaviours all have significant impacts on delivering schemes without error. Previous studies have questioned the ability of the construction industry to successfully learn from errors. A major barrier has been the sharing of sensitive data from failed outcomes. Hence, this paper investigates non-conformance on an existing scheme and suggests avenues for improvement.

Design/methodology/approach – A mixed-method approach was adopted whereby 1260 non-conformance reports (NCRs) from a highways megaproject were interrogated using root cause analysis techniques to uncover the most frequent and costly areas. This was followed by a survey to industry professionals within a tier 1 principal contractor to gain insight into their perceptions of non-conformance and rework on construction projects.

Findings – Using Pareto analysis, we find that materials management, workmanship (poor quality execution) and supervision issues are the most frequently occurring and costly root causes of non-conformance on a major highways scheme. Furthermore, we link corresponding viewpoints of two project professional groups to the findings posed, achieving a high degree of consensus for the areas requiring development. Lastly, we suggest avenues for improvement via lessons learnt. These include greater emphasis on quality culture via a strong leadership mandate, enhanced vetting of workforce competence and improving the way materials are managed by embracing technology to drive efficiency.

Originality/value – This paper interrogates a current highways scheme using a uniquely rich, sensitive dataset to determine how the construction sector may improve efforts to achieving right first time outcomes.

Keywords Construction, lessons learnt, mixed-methods, root-cause analysis, survey

Paper type Research paper

1. Introduction

Over the past few decades, non-conformance and rework has been a major topic of discussion within the quality management community and the wider construction consortium, burdening projects both large and small (e.g. Abdul-Rahman et al., 1996; Battikha, 2008; Mahamid, 2022). The costs of rectifying non-conformance can be high, affecting a firm's profit margin and its competitiveness in the marketplace (Abdul-Rahman, 1995).

Non-conformance and rework typically leads to time and cost overruns, with efforts expended during the final phases of projects as they strive for contract completion and handover to clients (Love, 2002; Forcada et al., 2014). Unfortunately, many defects are not identified throughout the construction phase but instead realised when "it's too late" (Bunni, 2003). In addition, quantifying the correct root causes and corresponding costs has proved very challenging due to commercial sensitivity and/or negative perceptions if data is made available (Buchanan et al., 2013). The construction sector has seen varying rework figures, some as high as 16.5% of project cost, requesting a need for change (Burati et al., 1992; Abdul-Rahman et al., 1996; Love and Edwards, 2004; Senaratne and Sexton, 2009; Forcada et al., 2014; Ye et al., 2015; Love et al., 2018; Love et al., 2019; Trach et al., 2021; Mahamid, 2022). High rework costs detrimentally affect company profits, relationships with clients, the government and taxpayers. Eliminating rework costs can allow funds to be spent more effectively on regeneration, reinvestment, and provide greater opportunities for tendering and work winning. The aforementioned literature concludes the construction industry has found right first time delivery a challenge, particularly within the highways and rail sectors. It appears that non-conformance and rework in some form is anticipated and accepted as a by-product on all schemes due to stringent programmes and cost constraints taking priority over quality. For example, in one study, defects within concrete works were expected (Koch and Schultz, 2019).

A way of learning from previous projects and ensuring mistakes are not repeated is by sharing knowledge from failures. Lessons learnt as a potential output of non-conformance and rework can generate corrective actions to prevent reoccurrence both in real-time and on future schemes. However, these are typically not being generated or digested sufficiently within construction companies to educate future schemes (Shokri-Ghasabeh and Chileshe, 2014). Many companies struggle to learn from failures on projects, absorb lessons centrally, catalogue and disseminate learning outcomes appropriately with a clear message. Williams (2008) calls for more sophisticated approaches to capture and disperse lessons learnt outcomes, however, others have highlighted the difficulties in determining and quantifying them (Crow, 2006). Love and Edwards (2004) put emphasis on specific cause and effect relationships that may exist, highlighting the difficulties and barriers to positively influence schemes. For areas demonstrating weak cause and effect relationships, this may result in greater challenges to identify true root causes on construction schemes. As such, more drastic methods such as deep dives, forensic investigations or firefighting techniques are required immediately.

There are papers that discuss root causes of non-conformance and associated costs on construction schemes (Love and Li, 2000; Josephson et al., 2002), however the general body of knowledge relating to lessons learnt has not often been connected to NCRs, so there appears to be a gap in the lessons learnt from non-conformance studies. In addition, detailed datasets are rare within the literature. Therefore, up-to-date, large-scale evidence is required to understand how the construction industry has developed in learning from non-conformance outcomes.

As such, this study aims to (i) identify the most prominent and costly areas of failure from 1260 non-conformance report (NCR) data entries, (ii) provide insights into the perceptions of quality execution within the construction industry using two distinct professional groups from a tier 1 organisation and (iii) generate meaningful lessons learnt that can positively influence the wider quality community in its efforts to achieving project delivery without error.

Therefore, our research questions are:

(1) What are the most significant areas of failure from non-conformance data?

(2) How do project professionals within a tier 1 principal contractor perceive non-conformance and rework inside and outside their organisation?

(3) What are the corresponding lessons learnt to help drive towards right first time delivery?

2. Research Method and Design

2. 1 Research Context and Project Description

The A14 Cambridge to Huntingdon Improvement scheme is a £1.5Bn megaproject upgrading 21 miles of highways infrastructure in Cambridge. The project was set up as a three-way joint venture led by the client, Highways England. Collectively, the project housed over 2,200 staff during the high points of construction.

To successfully promote collaboration on the scheme, the project was stripped of parent company logos and rebranded as the Integrated Delivery Team (IDT). In recent years, all parties have played their part in seeking right first time and delivery without error. Unfortunately, due to various uncertainties highlighted in the analysis, this has proved challenging.

To promote right first time within their organisation, a tier 1 contractor commissioned a research opportunity for a passionate senior quality professional to investigate non-conformance on the UK’s current largest highways scheme to explore avenues for continuous improvement.

2.2 Research Process

To study the project from different methodological perspectives, the research project has adopted a mixed-method approach, split into two phases as shown in Figure 1. Phase 1 entails the collection and analysis of 1260 non-conformance reports from the A14 scheme to target significant areas of concern that require urgent intervention and improvement. Phase 2 targets two distinct professional working groups within a tier 1 contractor via a Microsoft Forms online survey. Each party were posed with a series of questions specifically tailored to quality delivery, non-conformance and rework within construction to better understand thoughts and perceptions of how complex delivery projects are being managed (Table I). The table clarifies the question being investigated, rationale for why each question was selected, and the measurement metric to capture a response. Furthermore, the survey is complimented by key findings from the quantitative analysis (phase 1) to identify whether they match the participants understanding. By doing so, we backup quantitative findings with thoughts of those directly involved in the decision-making processes, thus providing additional insights and validation to phase 1. Upon clear identification of literature gaps and formulation of research questions, phase 1 could commence.

Non-conformance outcomes: 'The dataset'

As part of a project's governance, assurance and improvement model for quality, NCRs are seen as a requirement for capturing noncompliance within process or product delivery, but also to learn from and mitigate the risk of a future recurrence. Non-conformance often has a stigma of substandard performance and poor quality delivery, which is typically linked with a negative blame culture. As a result, this information is categorised as sensitive by project and commercial managers and placed in the archives with very little interrogation (Calantone and Vickery, 2010). On the contrary, we argue that non-conformance reporting should be used more positively and proactively to drive continuous improvement. Projects should regularly analyse real-time non-conformance against risk management profiling to identify potential recurrence, negative outcomes, and opportunities for learning. The research reported here benefits from a uniquely rich digital non-conformance dataset featuring 1260 NCRs between the period of December 2016 to January 2021.

Brought about by an integrated, collaborative goal to continuous improvement, the scheme adopted a stringent seven gate multi-level sign off NCR process that was agreed upon by all parties to ensure information was captured, analysed and closed out formally in accordance with client requirements (Figure 2). Three notable parties were responsible for completing each non-conformance report. The aforementioned IDT consisted of three principal contractors responsible for inputting accurate information within sections 1, 2, 3a, 4 and 5, an independent quality department consisting of quality professionals who verified the remedial works against set standards under section 6 and the client who would either challenge the information input in these sections and challenge under section 3 or accept closure of the defect under section 7. With such a rigorous process, the project provided a highly vetted dataset with detailed root causes, commentary and cost breakdowns.

As the creation of the database was to fulfil a project quality requirement, the data is considered secondary and independent which enhances the credibility, as the opportunity to directly influence it is limited (Calantone and Vickery, 2010). The potential for bias was considered in a number of ways. First, the dataset was cleaned and analysed via a random sampling approach (explained later). Second, the researcher triangulated different sources of evidence across the research process. Third, multiple layers of analysis were undertaken in terms of root cause, and across the research team, in order to promote multiple perspectives. To promote factually correct non-conformance information, the senior leadership team conveyed a clear message explaining that non-conformance data would be used for the purposes of continuous improvement rather than as a record of blame. Furthermore, mandating a strict, highly vetted non-conformance reporting process offered little opportunity for bias or inaccurate information which would later be challenged by others during the signoff process.

Phase 1 – Non-conformance data analysis

To ensure the data was managed efficiently and systematically, a protocol was devised and followed for the quantitative analysis (Figure 3).

Firstly, a data cleansing exercise was conducted to remove human error inputs such as grammatical mistakes, duplicated NCRs referenced within the dataset, and any rows missing via a numerical validation check. The authors encountered 24 cases whereby duplications of the same NCR had been raised or raised in error for training purposes. Furthermore, there were 31 cases whereby the non-conformance data entry was missing from the data export altogether. Both cases were classified as 'Example/Duplicate' and discounted from the analysis. Lastly, there were 12 NCRs that were incomplete or contained little information to accurately conclude the root cause of the problem. As such, these were categorised as 'Unclassified' and similarly discounted from the analysis.

Secondly, to remain impartial, a random sampling tool (https://www.randomizer.org/) was used to ensure NCRs were not chosen according to the researchers' preferences. The dataset was then split equally into seven whole number samples each consisting of 180 non-conformances prior to analysis. This also allowed the researchers to reflect after each sample as to whether a saturation point had been reached (Saunders et al., 2018). Fortunately, the research team had sufficient time to complete the analysis in full with the intention to maximize the impact of the research and provide more detailed statistics (Onwuegbuzie and Collins, 2007). The third and final task involved identifying a full list of root cause categories that could be generalized across sectors. By cross checking other literature against root causes identified by the project, e.g. the thirteen categories classified within Abdul-Rahman et al. (1996) and eight categories described within Josephson and Hammarlund (1999), twenty-five primary root causes were established at which point the dataset was ready for analysis.

Root cause analysis of NCR data

Root cause analysis (RCA) can be a powerful tool for uncovering the underlying causes of problems. It also enables appropriate remedial solutions to address and corrective action to prevent going forward. There are many forms of RCA that can be used for the purpose of problem-solving including Pareto, fishbone diagrams and scatter plot diagrams. However, the researchers opted for a highly effective, powerful technique commonly used in lean practices known as the ‘5 whys’ (Lindhard, 2014; Murugaiah et al., 2010). Taiichi Ohno, the father of Toyota’s Production System (TPS) considered the ‘5 whys’ his favourite tool as a method for problem solving. The process involves asking ‘why’ five times in succession until an actionable cause is reached to support problem solving (Ohno, 1988). To that end, each non-conformance within the dataset was challenged with the 5 why’s technique to assess the accuracy of root causes and corrective actions identified by the project. Pareto analysis has been considered a useful tool for identifying, prioritizing and addressing the factors that have the most impact on schemes (Cervone, 2009). Furthermore, frequency of causes presented by Pareto analysis implies useful defect classification was used (Kane, 2021). As such, Pareto analysis and visual management techniques were performed on the root cause classifications to understand the most prevalent and costly avenues of failure.

Phase 2 – Non-conformance and rework survey

On completion of the NCR data analysis, findings were formulated and transposed into a series of questions targeted to professionals within the construction sector. Specifically, two major working groups within a tier 1 contractor were targeted to participate in the survey. Group 1 consisted of sixty-seven member of the Contract Leaders (CL) community, who manage projects by making high level decisions relating to finances, programme, quality leadership and client engagement. They have an all-rounded understanding of their projects and are present from the start through to completion and handover. Group 2 consisted of ninety-five Quality Professionals (QP) from the quality and improvement community who have a detailed understanding of quality management and regulate the build onsite. They understand the challenges faced during construction and the detail surrounding quality performance. By comparing the two sets of result, we will gain further understanding of whether there is consensus of opinion between project leaders and the quality community.

To yield a fast, efficient response that could target many individuals, a digital online survey was deemed most appropriate to capture feedback. Specifically, a Microsoft Forms survey was constructed using the websites online proforma. Fourteen closed ended questions requesting a Yes/No response were constructed along with two multiple choice questions and one ranking question as per Table I. Questions were devised to focus on key areas of failure and lessons learnt outcomes from the data analysis findings whilst remaining relevant and relatable to the participant. On generation of the questions, the author begun with an internal assessment and pilot trial with five internal practitioners within the organisation. To ensure the questions remained relatable to both contract leaders and quality professionals, the pilot trial participants were a mix of two project managers, two quality professionals and a senior engineer. Feedback was provided by each pilot trial participant via email followed by a Microsoft Teams call at which point questions were tailored accordingly.

Ahead of dissemination to both working groups, an email statement explaining the context, purpose, intent and benefits of participation was formulated. Furthermore, to foster an open and honest forum for feedback, an anonymity clause was created briefing all participants that their feedback and personal data would remain strictly confidential. Lastly, a hyperlinked consent tab was constructed to navigate the participant to the survey upon agreement, thus satisfy consent requirements. Once complete, the survey was issued giving respondents 30 days to respond. Weekly reminder emails were sent to each group to re-emphasize the importance of engagement and increase the chance of participation.

To interpret and compare both groups survey responses, the numerical findings were exported from MS online portal into an Excel spreadsheet at which point the results were analysed and presented using descriptive statistics.

3. Results

3.1 NCR analysis results

On completion of the data analysis of 1260 NCRs, the data suggests the three most prominent areas of failure current on a highway's construction schemes are 'Materials Management' where either transportation, manufacture, storage or testing of a material had breached specification requirements in its lifecycle (240 NCRs; 19.5%), 'Workmanship/Poor quality execution' where quality processes and assurance had not been followed (181 NCRs; 14.7%) and Supervision where there had been either an insufficient or unqualified resource to oversee the works (137 NCRs; 11.1%). Combined, they account for 45.3% of the dataset alone. There are other fundamental areas in need of review and improvement including 'Setting out', 'Damage to permanent works' and 'Design' (Figure 4).

As materials management yielded the most nonconformities, a more granular analysis was conducted to pinpoint primary root cause types. Of these cases, by far the most frequently failing material was insitu concrete operations. Examples of non-compliant concrete were as a result of material deliveries failing to be delivered to site in accordance with the specification timeframes, pouring during inclement weather outside of specification, failing to test in accordance with specification and general mismanagement/storage of materials. Löfgren and Gylltoft (2001) comment that 'improvement of in-situ concrete construction is necessary', however two decades have passed and concrete non-conformance is still prevalent. The challenges of achieving the necessary compressive strength for insitu concrete has proved arduous and often unreliable (Magalhães et al., 2016).

Figure 5 represents the influence each activity had on the materials management elements of the scheme to draw attention to the most critical areas for improvement. The figure bubble size gives an indicator of the magnitude of the problem by cost. Similar trends were found by Love et al. (2018) which denotes concrete operations being one of the higher generators of NCRs, particularly from supply chain. This also suggests that the number of errors within concrete operations may be unavoidable unless stringent processes are implemented (e.g. pre-testing at batching facility prior to site delivery and/or real-time traffic forecasting for concrete deliveries to prevent unnecessary delays). The findings also indicated that although concrete was a more prevalent failing activity, storage and handling of project materials including precast elements was far more costly, yielding a total cost of £264,000. This was brought about by poor knowledge of how materials are to be correctly stored, careless behaviours causing damage during transportation and inadequate management of stockpiles leaving them exposed for prolonged periods of time rending the material noncompliant.

Factoring cost as a fundamental driver of change, the results were further analysed into most costly areas. Interestingly, the frequency order does not directly relate to cost. Figure 6 represents the most-costly primary root cause categories using Pareto analysis. The three most costly root cause categories were: 'Workmanship/Poor quality execution' (£2,574,700), 'Supervision' (£697,050) and 'Materials Management' (£617,000) yielding a collective total of £3,888,750. Of the 181 workmanship issues, 79.4% were as a result of poor supply chain performance leaving 20.6% due to self-delivery. Similar patterns have been found by other researchers who conclude notable concerns with supply chain quality performance (Love et al., 2018). This is somewhat of an unsurprising statistic in the fact that principal contractors typically outsource the majority of works to specialist supply chain, therefore the likelihood of an internal error is reduced, pushing ownership onto the supplier.

To pinpoint which activities within a highways scheme are struggling with right first time, each non-conformance was further categorised into its corresponding activity type. As highways schemes are monitored against requirements set within the Specification for Highway Works (SHW), each NCR activity was mapped against the relevant series specification under highways standard MCHW, Volume 1 (2014). For example, if the activity involved drainage operations, the NCR would be categorised 'Series – 500 General (Drainage, services and ducts)'. Furthermore, there are many types of major reinforced concrete operations such as bridges, retaining walls, culverts etc. These were sub-categorised accordingly. Lastly, there were instances where the activity did not match any series within the specification. As such, four further categories were created for Archaeology, Materials Management, Plant Management and Process & Procedural.

Of the SHW series (including the additional four categories), the findings suggest that concrete operations on bridge constructions are the most significant area of failure, generating 180 NCRs for the project lifecycle at a cost of £584,500 (Figure 7). This is followed closely by drainage (136 NCRs; £786,600), earthworks (122 NCRs; £587,500) and general pavement (107 NCRs; £357,500) operations. A potential factor for the frequency of NCRs raised may be the magnitude of the works being completed. Typically, the above four series are significantly large packages of works on highways construction schemes which may offer greater opportunity for error. See Appendix I for detailed costs against SHW series.

3.2 Viewpoints from project professionals

The purpose of the survey was to identify whether two distinct working groups within a major contractor concurred with the findings from the NCR data analysis findings. Of the 162 employees within the two groups who were requested to participate in the study, 21 contract leaders and 38 quality professionals took part in the study and provided a response in full. This gives a response rate of 31.3% and 40% respectively.

Comparing responses from the two working groups, there are some noteworthy outcomes that warrant further discussion (Appendix II). It is apparent from question Q1 that the majority of both groups felt there were ongoing quality execution issues within the Tier 1 contractor. Furthermore, the extent of the problem extended to the roots of its supply chain (Q2). There is an overwhelming consensus that supply chain quality performance is of major concern and in desperate need of change. As the vast majority of works are outsourced to suppliers, it is far more likely that blame has been shifted onto the suppliers delivering the works. However, it is still the responsibility of the principal contractor to ensure supply chain are properly managed and routinely performance evaluated to meet contract requirements. Of the two sets of respondents, it was surprising to note that contract leaders indicate a more negative picture of internal quality within the organisation than the quality community. One explanation is that responses made by the quality participants adopt a more defensive position. Another potential reason could be that contract leaders are part of a consortium within the business that shares progress of different projects in monthly meetings. As such, their knowledge of collective project performance within the organisation is far more extensive than their quality counterparts. There may be quality performance issues within a particular sector that the quality team are simply unaware of.

To understand the impact of working without error, question Q5 was posed to understand whether right first time within construction is achievable (Get It Right Initiative, 2018). A pessimistic (and disheartening) statistic was uncovered whereby 85.7% of Contract Leaders and 86.8% of quality professionals believed completing construction schemes without error was an unattainable goal. This finding questions the existence of the required mental mindset needed for quality delivery within the profession.

On review of the NCR data, it was apparent that in many cases those determining remedial and corrective action solutions were not executing root cause analysis effectively to uncover the underlying cause. As such, many NCR solutions were incorrect, resulting in further occurrence throughout the project. We therefore asked both groups whether those managing and interacting with non-conformance issues were sufficiently trained in RCA techniques (Q6). Both groups were of a strong opinion that those engaging with NCRs are not sufficiently trained in Quality Management and to perform such techniques as Pareto, Fishbone, and the 5 why's. The findings suggest a requirement for team members involved with non-conformance to be sufficiently trained in the arts of RCA.

A less surprising finding is the prioritisation of cost and programme ahead of quality (Q10 and Q11). The industry has struggled with the notion that if we focus efforts on quality delivery throughout the lifecycle of a scheme, it will provide dividends when handover is reached. Simply chasing cost and critical paths are behaviours that need to be eradicated on projects. There is overwhelming consensus from the respondents that schemes value cost and programme more than quality delivery.

Similar trends have been observed with supply chain selection. It is unfortunate that projects still appear to select supply chains on price/cost quotations and not previous performance or the track record they hold (Q17). Decision-making solely on cost could be construed as risky and narrow minded. Evidence shows that longer term relationships lead to more consistent outcomes and better learning, but that monitoring, evaluation and support for suppliers is key to achieving those positive outcomes (Gosling et al., 2015, Gosling et al., 2019). With clear and concise metrics, supply chain can be measured against key performance indicators and supported throughout the project lifecycle. It will also allow projects to intervene at critical dips in performance. Note however that project teams must be wary of replacing suppliers without consideration of project knowledge, particularly for companies that outsource the majority of their works.

To understand where project professionals felt the most prevalent areas of failure stem, we asked them to choose the three most likely causes of non-conformance (Q13). Combined, both groups were of a shared opinion that workmanship brought about by poor quality execution, substandard supervision including engineering support and competence/training were the most significant areas of concern. This aligns with the NCR data analysis that yielded materials management, workmanship and supervision as the fundamental areas of failure. This aligns with a broader industry issue in positioning Suitably Qualified and Experienced Personnel (SQEP) in key delivery roles as specific skilled workers, engineers, surveyors and supervisors. As workmanship, supervision and competency link with SQEP, a resounding agreement from both working groups was seen (Q15).

4. Discussion, impact and implications

On the NCR data analysis findings, there are key outcomes that warrant further discussion and reflection. Firstly, quality execution (i.e. workmanship) is continually underperforming across construction. Greater emphasis on quality culture via a clear leadership mandate to instil consequence for sub-standard performance is vital. Without consequence and reward, there is lack of accountability to hold those responsible. Furthermore, process compliance is critical to ensuring consistent outcomes. Although new innovative digital QA methods are being introduced on projects, without clear direction and training to use, we are likely to revert back to paper methods or skip the process altogether. Stronger leadership direction to preach the benefits of embracing such methods are required (e.g. to improve efficiency of handover to clients and reduce administrative time consolidating QA records). Lastly, projects require accountability and consequence for not following processes set by their organisation. Greater investments in time and resource are required to shape quality related behaviours, similar to observed safety outcomes, e.g. Accident Frequency Rates (AFR). Lesson learnt (1).

Second, both the NCR analysis and survey conclude we are desperately struggling with SQEP resource in the construction industry. There are three areas for improvement that should be considered. Firstly, coaching and mentoring by senior members who are knowledgeable and can impart wisdom onto the younger, less experience members. This could form part of their Continuing Professional Development (CPD). Secondly, supply chain should be remeasured against performance and competency not price. Therefore, projects could implement a competency assessment matrix (CAM) for all individuals to satisfy competence against the requirements set for a particular role and should include supply chain as a vetting measure. Lesson Learnt (2).

Thirdly, the way in which we manage materials on projects need re-evaluating. There are cases that fall into the competency/training category (e.g. a storeman not knowing the correct procedure to store a specific material) but there are many cases where alternative methods could drastically improve material compliance and efficiency. Specifically, how we efficiently manage concrete operations from plant manufacturer to on site pours. The data suggests a disjointed process is causing much of our concrete operations to become non-compliant due to many factors. For example: late deliveries causing materials to be out of specification, incorrectly specified materials provided, and lack of testing conducted. Hence, more advanced methods of recording, testing and delivering materials throughout projects are needed. A possible solution could be the embrace of technology to create digital batching and tracking system processes that can be accessed by all. The benefit of this is that engineers can verify the data ahead of site delivery to confirm specification and testing requirements have been pre-achieved, which will save time and reduce waste. Furthermore, during the delivery of materials, a possible solution is a live vehicle tracking system via GPS to help engineers assess the impact between pours and make appropriate decisions to resolve. At present, information is not sufficiently translated between parties causing non-conformance. To eradicate altogether, the consideration to omit insitu works and opt for precast alternatives should be high priority. Lesson learnt (3).

The impact of this research paper is threefold. Firstly, it provides three primary focus avenues for construction business leaders to improvement in the form of lessons learnt. Secondly, it gives opinions from project professionals within a major contracting organisation of quality within construction for top management to digest. Thirdly, it brings to light the ongoing struggle to achieving right first time within the highways sector.

The implications of this study call for quality system improvements with more robust NCR processes that have sophisticated detailed root cause analysis techniques, impact analysis and risk profiling of cost and likelihood that can generate meaningful solutions to influence improvement. Furthermore, the creation of lessons learnt from NCR analysis requires processing via a company hub that has the capability to cross-pollinate different sectors as required. At a broader level, the construction industry must rethink how to manage quality processes and the people that use them. Greater leadership direction along with technological advancements and supportive behavioural management training in a nurturing environment could play a vital part in eradicating human error.

5. Conclusion

The study explores the current impact of right first time quality execution through the empirical investigation of 1260 non-conformance reports provided by a highways megaproject in the UK. Using a mixed method approach of data analysis and survey responses, we aimed to firstly identify the most prominent areas of failure from 1260 non-conformance reports (NCR) data entries. The findings indicate that the most frequent failure areas were caused by sub-standard management of materials including their handling, distribution and testing, poor quality execution brought about by inadequate adherence to quality assurance processes and substandard site supervision whereby there was lack of resource or competence breach. Second, to provide insights from two distinct professional groups of the findings posed. We conclude that the industry is struggling with adequate resource in key project delivery roles with many being insufficiently trained to perform RCA problem solving techniques. Third and finally, generate meaningful lessons learnt that can help the wider quality community in its efforts to achieving delivery without error. The paper finds that greater leadership direction for the quality profession is needed. By providing a clearer purpose and vision, accountability and consequence for those involved in the process, it may address behaviours. Furthermore, we conclude the need for a competency assessment matrix against set criteria to address the issue of unsuitably qualified personnel in key delivery roles. Lastly, a specific request to overhaul the way we manage materials, particularly with concrete operations. The embrace of new, innovate technologies by all is a must to help drive efficiency and eradicate human error.

Sadly, the quality profession is not moving at the progressive pace that its counterpart, safety is. With this research, leaders can be approached with empirical evidence for change in the quality sphere.

Given the specific context in which the research was undertaken, the generalizability of the findings is a limitation of the work. The data used in this study is from a highways project, therefore, this exercise should be replicated in different sectors to identify any other prominent failure points. A further limitation is that the survey was conducted within the context of one principal contractor with a mixed range of knowledge/expertise across many sectors. Further research could consider delving into the noted lessons learnt streams identified within this paper. In particular, the need to explore and investigate these in the context of other projects, organisations and sectors.

References

Abdul-Rahman, H. (1995). "The cost of non-conformance during a highway project: a case study", *Construction Management and Economics, 13(1), 23-32.*

Abdul-Rahman, H., Thompson, P. A., & Whyte, I. L. (1996). "Capturing the cost of non-conformance on construction sites: An application of the quality cost matrix", *International Journal of Quality & Reliability Management, 13(1), 48-60.*

Buchanan, D., Boddy, D., & McCalman, J. (2013). "Getting in, getting on, getting out, and getting back". *In Doing Research in Organizations (RLE: Organizations) (pp. 63-77). Routledge.*

Battikha, M. G. (2008). "Reasoning mechanism for construction non-conformance root-cause analysis". *Journal of construction Engineering and Management, 134(4), 280-288.*

Bunni, N. G. (2003). "Risk and insurance in construction". *Routledge.*

Burati Jr, J. L., Farrington, J. J., & Ledbetter, W. B. (1992). "Causes of quality deviations in design and construction". *Journal of construction engineering and management, 118(1), 34-49.*

Calantone, R. J., & Vickery, S. K. (2010). "Introduction to the special topic forum: Using archival and secondary data sources in supply chain management research". *Journal of Supply Chain Management, 46(4), 3.*

Cervone, H. F. (2009). "Applied digital library project management: Using Pugh matrix analysis in complex decision-making situations". *OCLC Systems & Services: International digital library perspectives, 25(4), 228-232.*

Crow, L. H. (2006). "Useful metrics for managing failure mode corrective action". *In RAMS'06. Annual Reliability and Maintainability Symposium, 2006. (pp. 247-252).*

Forcada, N., Rusiñol, G., MacArulla, M., & Love, P. E. (2014). "Rework in highway projects". *Journal of Civil Engineering and Management, 20(4), 445-465.*

Get it Right Initiative. (2018). "A guide to improving value by reducing design error", Available at: https://getitright.uk.com/live/files/reports/5-giri-design-guide-improving-value-by-reducing-design-error-nov-2018-918.pdf, (accessed 11 January, 2023).

Gosling, J., Abouarghoub, W., Naim, M., & Moone, B. (2019). "Constructing supplier learning curves to evaluate relational gain in engineering projects". *Computers & Industrial Engineering, 131, 502-514.*

Gosling, J., Naim, M., Towill, D., Abouarghoub, W., & Moone, B. (2015). "Supplier development initiatives and their impact on the consistency of project performance". *Construction management and economics, 33(5-6), 390-403.*

Josephson, P. E., & Hammarlund, Y. (1999). "The causes and costs of defects in construction: A study of seven building projects". *Automation in construction, 8(6), 681-687.*

Josephson, P. E., Larsson, B., & Li, H. (2002). "Illustrative benchmarking rework and rework costs in Swedish construction industry". *Journal of management in engineering, 18(2), 76-83.*

Kane, V. E. (2021). "Useful paths for identifying Lean Six Sigma improvement opportunities". *International Journal of Quality & Reliability Management.*

Koch, C., & Schultz, C. S. (2019). "The production of defects in construction–an agency dissonance". *Construction management and economics, 37(9), 499-512.*

Lindhard, S. (2014). "Applying the 5 WHYs to identify root causes to non-completions in on-site construction". *In Proceedings of the 7th World Conference on Mass Customization, Personalization, and Co-Creation (MCPC 2014), Aalborg, Denmark, February 4th-7th, 2014 (pp. 51-61). Springer, Cham.*

Löfgren, I., & Gylltoft, K. (2001). "In-situ Concrete Building-important aspects of industrialised construction". *Nordic Concrete Research, 26(1), 61-81.*

Love, P. E. (2002). “Influence of project type and procurement method on rework costs in building construction projects”. *Journal of construction engineering and management, 128(1), 18-29.*

Love, P. E., & Edwards, D. J. (2004). “Determinants of rework in building construction projects”. *Engineering, Construction and Architectural Management, 11(4), 259-274.*

Love, P. E., & Li, H. (2000). “Quantifying the causes and costs of rework in construction”. *Construction Management & Economics, 18(4), 479-490.*

Love, P. E., Teo, P., & Morrison, J. (2018). “Revisiting quality failure costs in construction”. *Journal of construction engineering and management, 144(2), 05017020.*

Love, P.E.D., Smith, J., Ackermann, F. and Irani, Z. 2019. “Making sense of rework and its unintended consequence in projects: The emergence of uncomfortable knowledge”. *International Journal of Project Management 37(3), pp. 501–516.*

Magalhães, F. C., de Vasconcellos Real, M., & da Silva Filho, L. C. P. (2016). “The problem of non-compliant concrete and its influence on the reliability of reinforced concrete columns”. *Materials and structures, 49(4), 1485-1497.*

Mahamid, I. (2022). “Impact of rework on material waste in building construction projects”. *International Journal of Construction Management, 22(8), 1500-1507.*

Murugaiah, U., Benjamin, S. J., Marathamuthu, M. S., & Muthaiyah, S. (2010). “Scrap loss reduction using the 5-whys analysis”. *International Journal of Quality & Reliability Management, 27(5), 527-540.*

Ohno, T. (1988). “Toyota Production System: Beyond Large-Scale Production”. *CRC Press, Cambridge, Mass..*

Onwuegbuzie, A. J., & Collins, K. M. (2007). “A typology of mixed methods sampling designs in social science research”. *Qualitative Report, 12(2), 281-316.*

Saunders, B., Sim, J., Kingstone, T., Baker, S., Waterfield, J., Bartlam, B., ... & Jinks, C. (2018). “Saturation in qualitative research: exploring its conceptualization and operationalization”. *Quality & quantity, 52(4), 1893-1907.*

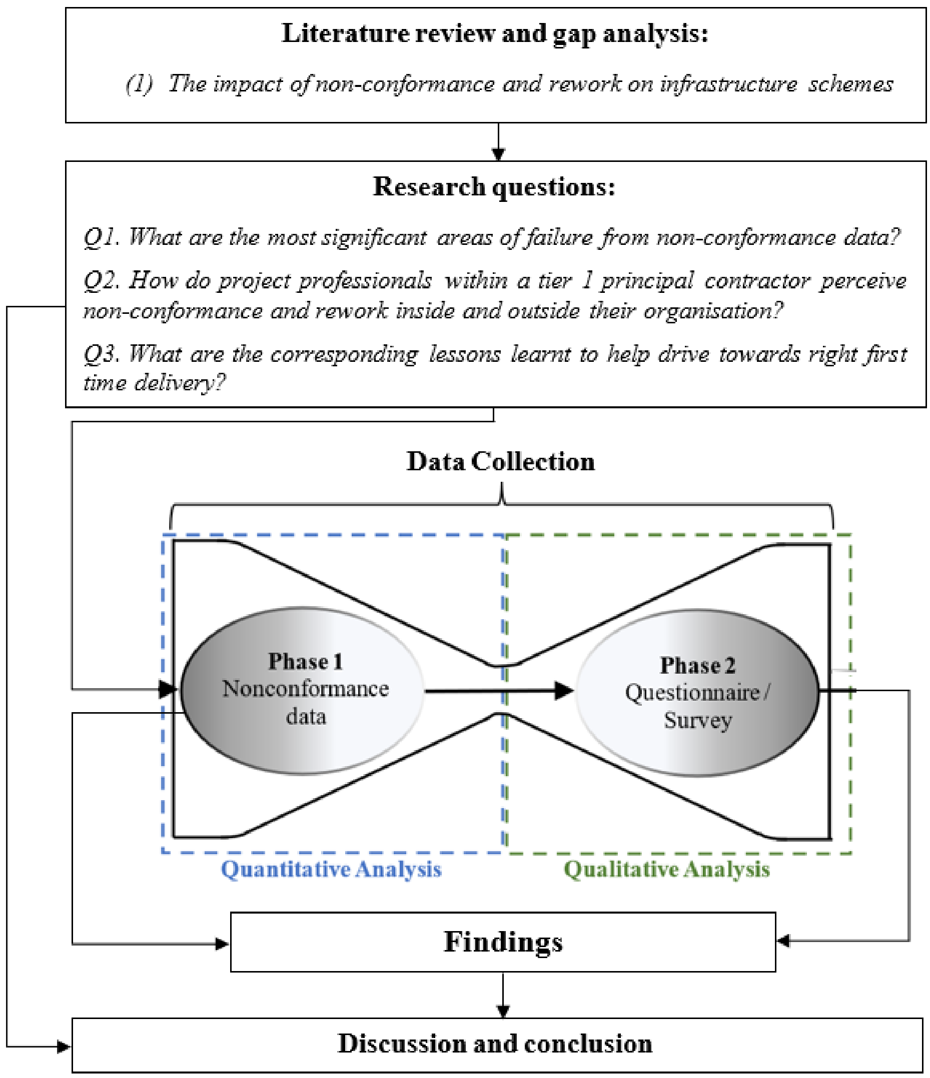
Senaratne, S., & Sexton, M. G. (2009). “Role of knowledge in managing construction project change”. *Engineering, Construction and Architectural Management, 16(2). 186-200.*

Shokri-Ghasabeh, M., & Chileshe, N. (2014). “Knowledge management: Barriers to capturing lessons learned from Australian construction contractors perspective”. *Construction Innovation, 14(1), 108-134.*

Trach, R., Lendo-Siwicka, M., Pawluk, K., & Połoński, M. (2021). “Analysis of direct rework costs in Ukrainian construction”. *Archives of Civil Engineering, 67(2), 397-411.*

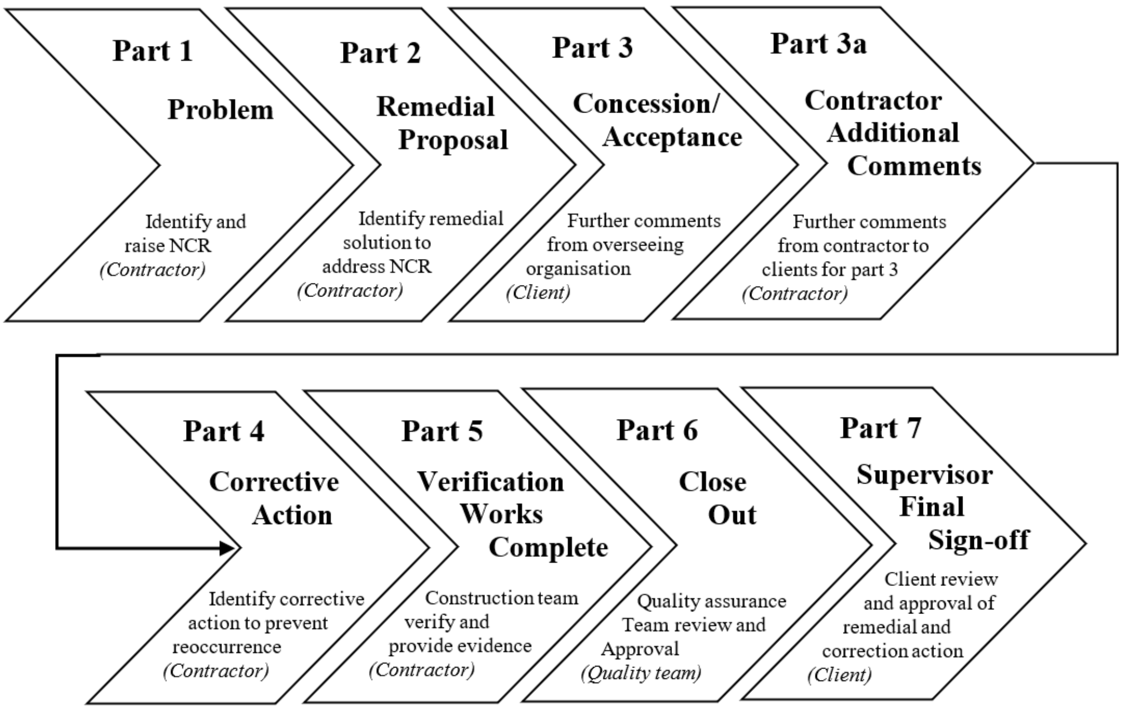
Williams, T. (2008). “How do organizations learn lessons from projects—And do they?”. *IEEE Transactions on engineering management, 55(2), 248-266.*

Ye, G., Jin, Z., Xia, B., & Skitmore, M. (2015). “Analyzing causes for reworks in construction projects in China”. *Journal of management in engineering, 31(6), 04014097.*



Literature review and gap analysis:
(1) The impact of non-conformance and rework on infrastructure schemes
Research questions:
Q1. What are the most significant areas of failure from non-conformance data?
Q2. How do project professionals within a tier 1 principal contractor perceive non-conformance and rework inside and outside their organisation?
Q3. What are the corresponding lessons learnt to help drive towards right first time delivery?
Data Collection
Phase 1
Nonconformance data
Phase 2
Questionnaire / Survey
Quantitative Analysis
Qualitative Analysis
Findings
Discussion and conclusion

Figure2



Part 1
Problem
Identify and raise NCR
(Contractor)
Part 2
Remedial Proposal
Identify remedial solution to address NCR
(Contractor)
Part 3
Concession/ Acceptance
Further comments from overseeing organisation
(Client)
Part 3a
Contractor Additional Comments
Further comments from contractor to clients for part 3
(Contractor)
Part 4
Corrective Action
Identify corrective action to prevent reoccurrence
(Contractor)
Part 5
Verification Works Complete
Construction team verify and provide evidence
(Contractor)
Part 6
Close Out
Quality assurance Team review and Approval
(Quality team)
Part 7
Supervisor Final Sign-off
Client review and approval of remedial and correction action
(Client)

Figure 3

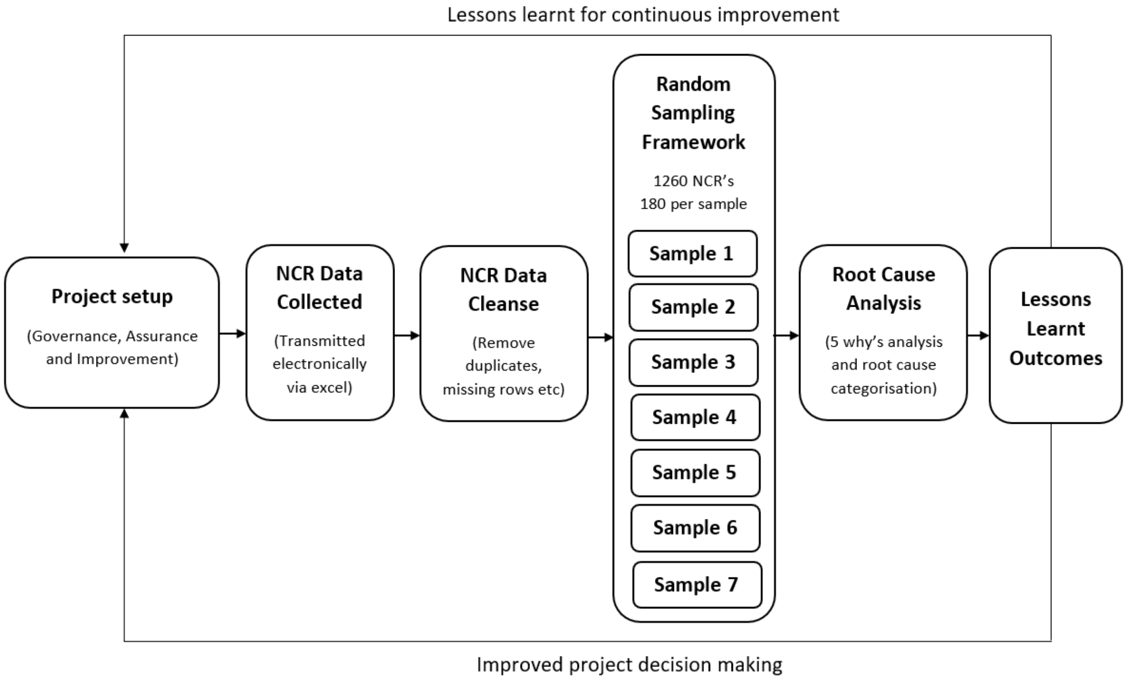
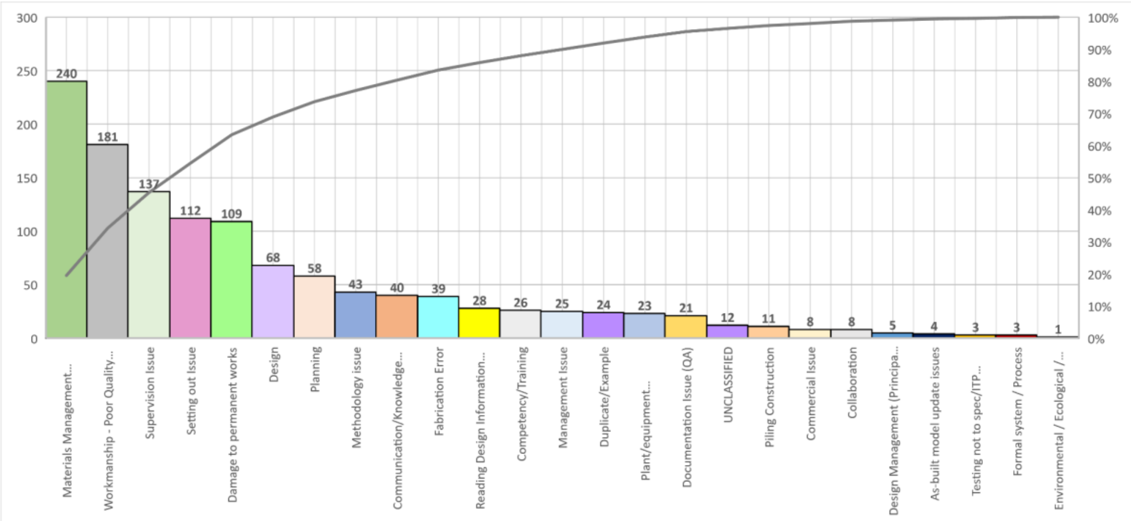

Lessons learnt for continuous improvement
Project setup
(Governance, Assurance and Improvement)
NCR Data Collected
(Transmitted electronically via excel)
NCR Data Cleanse
(Remove duplicates, missing rows etc)
Random Sampling Framework
1260 NCR's
180 per sample
Sample 1
Sample 2
Sample 3
Sample 4
Sample 5
Sample 6
Sample 7
Root Cause Analysis
(5 why's analysis and root cause categorisation)
Lessons Learnt Outcomes
Improved project decision making

Figure 4



300
250
200
150
100
50
0
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
240
181
137
112
109
68
58
43
40
39
28
26
25
24
23
21
12
11
8
8
5
4
3
3
1
Materials Management...
Workmanship - Poor Quality...
Supervision Issue
Setting out Issue
Damage to permanent works
Design
Planning
Methodology issue
Communication/Knowledge...
Fabrication Error
Reading Design Information...
Competency/Training
Management Issue
Duplicate/Example
Plant/equipment...
Documentation Issue (QA)
UNCLASSIFIED
Piling Construction
Commercial Issue
Collaboration
Design Management (Principa...
As-built model update issues
Testing not to spec/ITP...
Formal system / Process
Environmental / Ecological /...

Figure 5

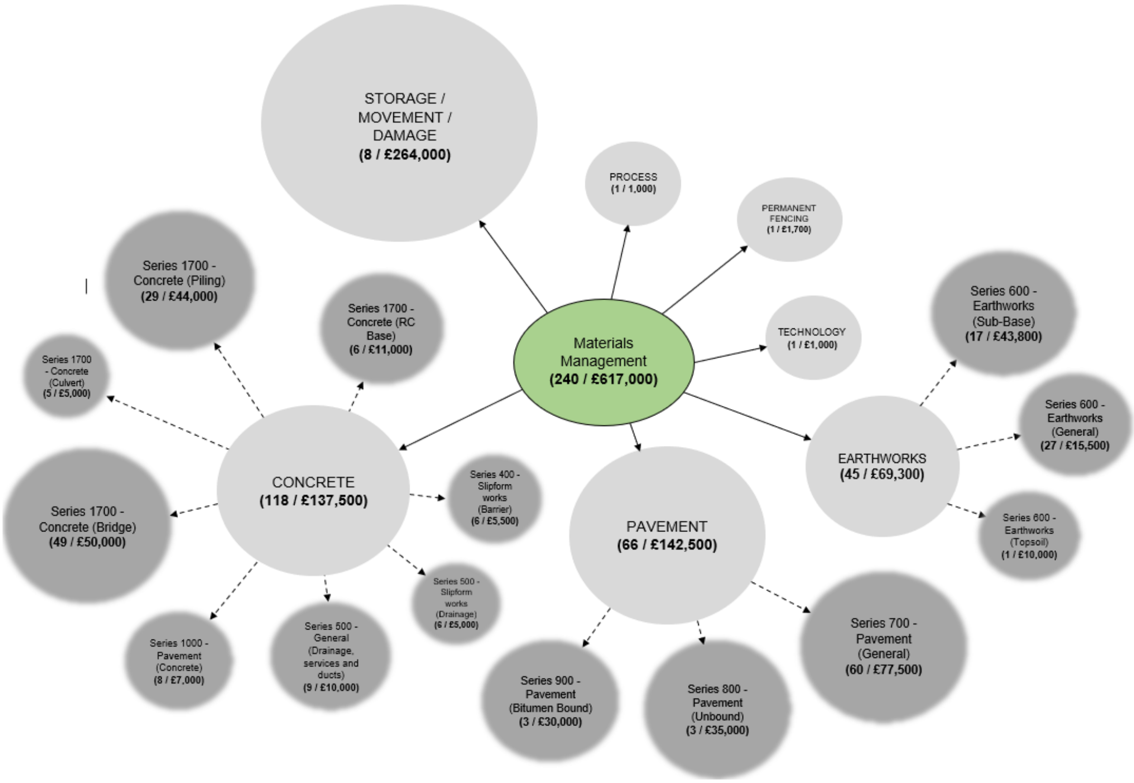
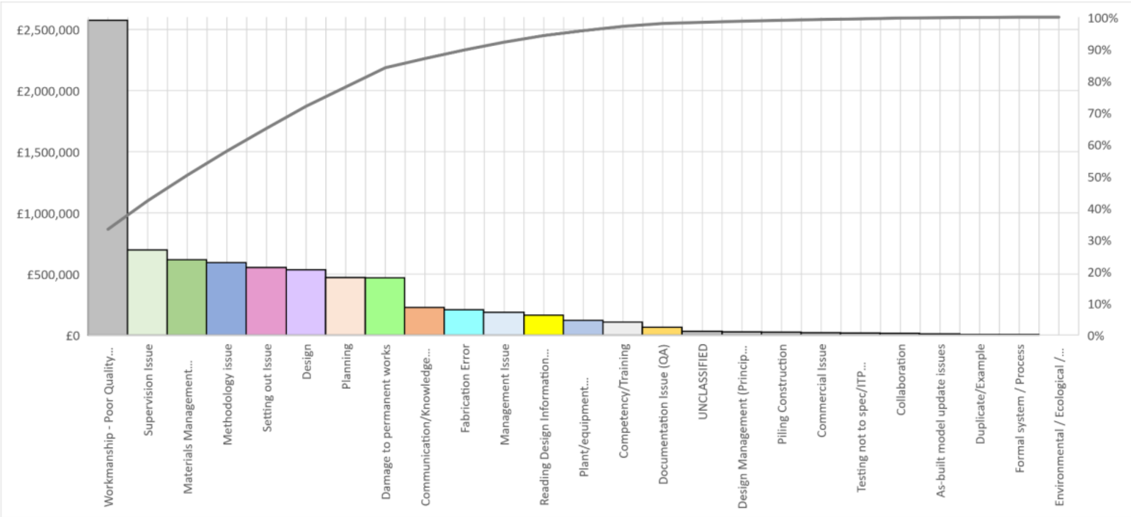

STORAGE / MOVEMENT / DAMAGE (8 / £264,000)
PROCESS (1 / 1,000)
PERMANENT FENCING (1 / £1,700)
TECHNOLOGY (1 / £1,000)
Materials Management (240 / £617,000)
Series 1700 - Concrete (Piling) (29 / £44,000)
Series 1700 - Concrete (RC Base) (6 / £11,000)
Series 1700 - Concrete (Culvert) (5 / £5,000)
CONCRETE (118 / £137,500)
Series 1700 - Concrete (Bridge) (49 / £50,000)
Series 400 - Slipform works (Barrier) (6 / £5,500)
Series 500 - Slipform works (Drainage) (6 / £5,000)
Series 1000 - Pavement (Concrete) (8 / £7,000)
Series 500 - General (Drainage, services and ducts) (9 / £10,000)
PAVEMENT (66 / £142,500)
Series 900 - Pavement (Bitumen Bound) (3 / £30,000)
Series 800 - Pavement (Unbound) (3 / £35,000)
Series 700 - Pavement (General) (60 / £77,500)
EARTHWORKS (45 / £69,300)
Series 600 - Earthworks (Sub-Base) (17 / £43,800)
Series 600 - Earthworks (General) (27 / £15,500)
Series 600 - Earthworks (Topsoil) (1 / £10,000)

Figure 6



£2,500,000
£2,000,000
£1,500,000
£1,000,000
£500,000
£0
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Workmanship - Poor Quality...
Supervision Issue
Materials Management...
Methodology issue
Setting out Issue
Design
Planning
Damage to permanent works
Communication/Knowledge...
Fabrication Error
Management Issue
Reading Design Information...
Plant/equipment...
Competency/Training
Documentation Issue (QA)
UNCLASSIFIED
Design Management (Princip...
Piling Construction
Commercial Issue
Testing not to spec/ITP...
Collaboration
As-built model update issues
Duplicate/Example
Formal system / Process
Environmental / Ecological /...

Figure 7

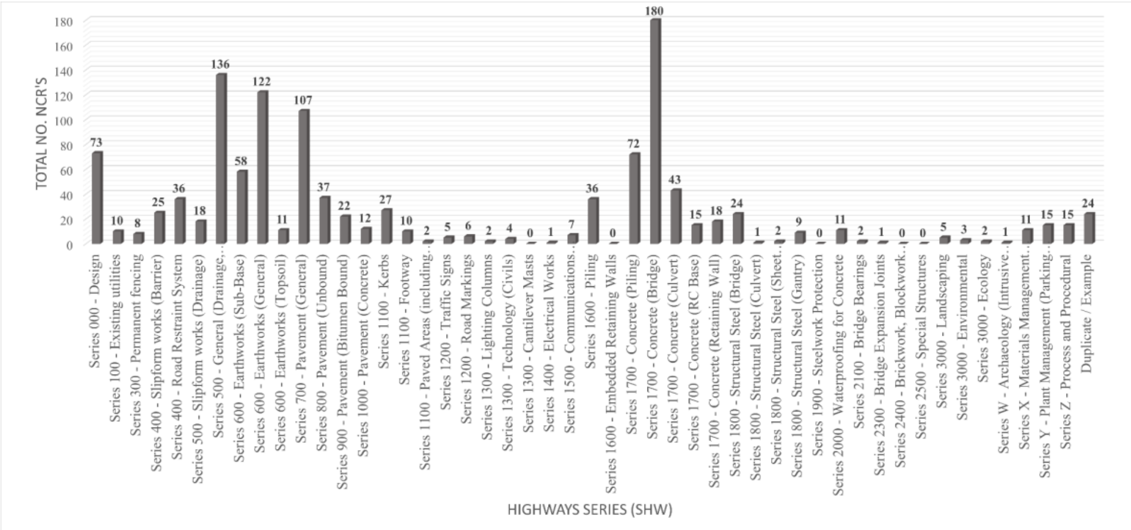

TOTAL NO. NCR'S
180
160
140
120
100
80
60
40
20
0
73
10
8
25
36
18
136
58
122
11
107
37
22
12
27
10
2
5
6
2
4
0
1
7
36
0
72
180
43
15
18
24
1
2
9
0
11
2
1
0
0
5
3
2
1
11
15
15
24
Series 000 - Design
Series 100 - Existing utilities
Series 300 - Permanent fencing
Series 400 - Slipform works (Barrier)
Series 400 - Road Restraint System
Series 500 - Slipform works (Drainage)
Series 500 - General (Drainage…
Series 600 - Earthworks (Sub-Base)
Series 600 - Earthworks (General)
Series 600 - Earthworks (Topsoil)
Series 700 - Pavement (General)
Series 800 - Pavement (Unbound)
Series 900 - Pavement (Bitumen Bound)
Series 1000 - Pavement (Concrete)
Series 1100 - Kerbs
Series 1100 - Footway
Series 1100 - Paved Areas (including…
Series 1200 - Traffic Signs
Series 1200 - Road Markings
Series 1300 - Lighting Columns
Series 1300 - Technology (Civils)
Series 1300 - Cantilever Masts
Series 1400 - Electrical Works
Series 1500 - Communications…
Series 1600 - Piling
Series 1600 - Embedded Retaining Walls
Series 1700 - Concrete (Piling)
Series 1700 - Concrete (Bridge)
Series 1700 - Concrete (Culvert)
Series 1700 - Concrete (RC Base)
Series 1700 - Concrete (Retaining Wall)
Series 1800 - Structural Steel (Bridge)
Series 1800 - Structural Steel (Culvert)
Series 1800 - Structural Steel (Sheet…
Series 1800 - Structural Steel (Gantry)
Series 1900 - Steelwork Protection
Series 2000 - Waterproofing for Concrete
Series 2100 - Bridge Bearings
Series 2300 - Bridge Expansion Joints
Series 2400 - Brickwork, Blockwork…
Series 2500 - Special Structures
Series 3000 - Landscaping
Series 3000 - Environmental
Series 3000 - Ecology
Series W - Archaeology (Intrusive…
Series X - Materials Management…
Series Y - Plant Management (Parking…
Series Z - Process and Procedural
Duplicate / Example
HIGHWAYS SERIES (SHW)

Table 1. Data requirements table used for construction survey.

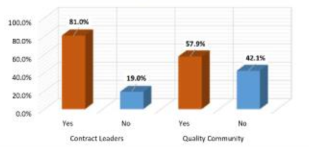
Investigative research questions	Rationale	Measurement metrics	Question reference
Is the company suffering with quality execution both in house and with its suppliers?	NCR data analysis concludes £1.8mil direct cost and £5.9mil indirect cost to correct on scheme insinuating a largescale quality related issue	Yes/No closed response	Q1 - 2
Is the company at risk of long-term profitability issues caused by nonconformance defects within the business?	A combined total of £7.7mil is a concerning figure. Other projects within the principal contractor may be reacting similarly.	Yes/No closed response	Q3
What do you believe the cost of nonconformance was on the highways scheme in question?	Knowledge of business and associated costs within the industry. Also, comparable past literature (Abdul-Rahman et al., 1996, Josephson et al., 2002, Love, 2002, Love et al., 2018)	Multiple choice question ranging of from zero to >1% (one answer only)	Q4
Is right-first-time achieveable? Is rework of some kind inevitable?	Professional knowledge of the industry and supportive findings of NCR quantitative analysis suggests no (Get It Right Initiative, 2018)	Yes/No closed response	Q5
Are those involved in NCR's sufficiently trained? Is the company struggling with suitably qualified personnel in key roles?	Quantitative analysis suggests poor RCA execution. Furthermore, it raises queries over competence of workforce (Mahamid, 2022)	Yes/No closed response	Q6 & Q15
Should contract arrangements be re-evaluated to apportion risk and costs? Does the company at times proceed at risk without approved designs?	71 nonconformance at a total cost of £558,100 are because of design related issues (Ye et al., 2015, Trach et al., 2021)	Yes/No closed response	Q7 - 8
What do projects see as priority from safety, programme, quality and cost? What do our clients think is priority?	Professional knowledge of the industry and supportive findings of NCR quantitative analysis suggests quality is last priority	Prioritisation question (priority rank first to last)	Q9 - 11
Do all parties understand the level of quality to be achieved?	Project experience of handover into operational maintenance suggests divide in level of quality to achieve. Data suggests difference of remedial action deemed acceptable.	Yes/No closed response	Q12
What do professionals perceive the most likely causes of nonconformance and rework in construction?	Various literature with many different root cause conclusions. Quantitative analysis poses the three most frequent via Pareto analysis.	Multiple choice answer (Select three most likely root	Q13

	(Abdul-Rahman et al., 1996, Josephson et al., 2002, Love, 2002, Love et al., 2018, Mahamid, 2022)	causes according to preference)	
Quantitative data findings yielded a total nonconformance cost of £7.7mil (Profit loss of 17%). Is this figure of concern?	Findings from quantitative data analysis and internal knowledge of company	Yes/No closed response	Q14
Should the company re-evaluate our approach to insitu concrete operations?	351 concrete related nonconformances discovered from the quantitative NCR analysis. Questions the process of quality execution with concrete operations	Yes/No closed response	Q16
Are there concerns the company selects supply chains primarily on price and not previous performance?	The majority of the nonconformances are supply chain driven (836 of 1260 NCRs were the responsibility of supply chain). Concerns relating to performance.	Yes/No closed response	Q17

COSTAIN Nonconformance and rework in construction - What have we learnt?

	Response rate	Interest Score
Contract Leaders	31.3%	8.2
Quality Community	40.0%	9.1

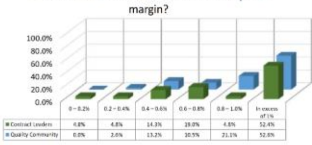
Q1: Do you see quality execution as a problem within Costain?



Q2: Do you see quality execution as a problem with our supply chain?

Q3: Are we at risk of post project completion latent defects causing long term profitability issues for the business?

Q4: What do you believe the cost of nonconformance rectification was of a 3% profit margin?



	0 – 0.2%	0.2 – 0.4%	0.4 – 0.6%	0.6 – 0.8%	0.8 – 1.0%	In excess of 1%
Contract Leaders	4.8%	4.8%	14.3%	19.0%	4.8%	52.4%
Quality Community	0.0%	2.6%	13.2%	10.5%	21.1%	52.6%

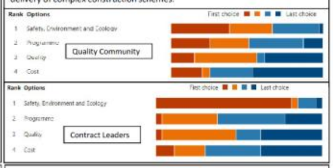
Q5: Is there an expectation that 'rework' in some form is inevitable and that 'right-first-time' from start to end of a scheme is unachievable?

Q6: Are our team members who manage NCR's sufficiently trained in RCA techniques?

Q7: Should our contractual arrangements with designers be re-evaluated to apportion cost as a result of design NCR's?

Q8: Do we at times progress at risk without approved design details as a result of design delay to stay on the critical path?

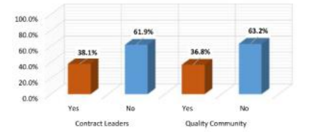
Q9: Rank SHE, Programme, Quality and Cost in priority order as you see it for delivery of complex construction schemes.



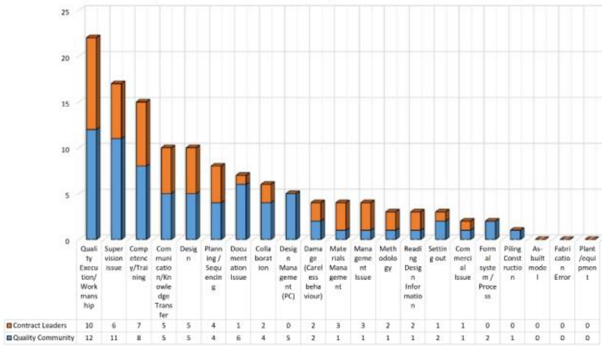
Q10: Do you believe cost and programme are treated as higher priority than quality delivery on our projects?

Q11: Do you think our clients value cost and programme over quality delivery on infrastructure schemes?

Q12: Do all parties on our project fully appreciate and understanding the level of quality to be achieved?

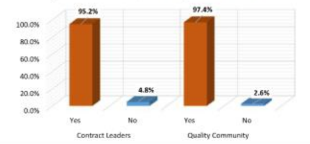


Q13: Which do you believe are the three most likely causes of nonconformance and rework?



	Quality Execution/ Workmanship	Supervision issue	Competency/Training	Communication/Knowledge Transfer	Design	Planning / Sequencing	Documentation Issue	Collaboration	Design Management (PC)	Damage (Careless behaviour)	Materials Management	Management Issue	Methodology	Reading Design Information	Setting out	Commercial Issue	Formal system / Process	Piling Construction	As-built model	Fabrication Error	Plant /equipment
Contract Leaders	10	6	7	5	5	4	1	2	0	2	3	3	2	2	1	1	0	0	0	0	0
Quality Community	12	11	8	5	5	4	6	4	5	2	1	1	1	1	2	1	2	1	0	0	0

Q14: Based on a 3% profit margin and a potential profit loss of 17%, Is this figure of concern?



Q15: We are struggling with SQEP resource (E.g engineers, supervisors). Do you agree with this statement?

Q16: Should we re-evaluate our approach to insitu concrete operations? (e.g. precast)

Q17: Are there concerns that typically we select supply chain primarily on price and not previous performance/track record?