In search of Empirical Evidence for the Relationship Between Collaboration and Project Performance

Abstract:

Existing research suggests a positive relationship between the level of collaboration in projects and project performance in terms of cost, time and quality. However, empirical data to support this are scant and this paper responds to the calls for more empirical research on this specific relationship. In this paper, we conducted bivariate analysis on a dataset from 142 Norwegian projects which reported their cost, schedule and quality performance through the 10-10 benchmarking tool developed by the Construction Industry Institute (CII). We found a strong positive relationship between collaboration and project quality performance. Projects with good collaboration experienced fewer errors and deviations and more often delivered according to requirements and client expectations than projects with poor collaboration. We also propose an indicator that practitioners can apply to measure the collaboration quality in their projects.

1 Introduction

The McKinsey Global Institute (Barbosa et al., 2017) claims that USD1.6 trillion is wasted each year globally due to poor productivity in the construction industry and that in most countries construction is lagging behind other industries when it comes to productivity. The specific figures are open to debate, but in general, this productivity gap is widely recognized among researchers (Zhang et al., 2018, Fulford and Standing, 2014).

Among several areas to improve, it estimated that improved collaboration alone could improve construction productivity by 8-9% (Barbosa et al., 2017). The term *collaboration* has been defined by the Institute for Collaborative Working (ICW, 2017, p. 29): *"Collaboration is a commitment between two or more parties to create value by striving to achieve shared competitive goals and operational benefit through a spirit of mutual trust and openness*".

There is a general agreement that improved collaboration has a positive effect on performance in construction projects (Caniëls et al., 2019, Sarhan et al., 2017, Walker et al., 2017, Eriksson and Westerberg, 2011). The majority of existing studies are based on surveys with limited empirical support and more empirical research on the relationship between collaboration and project performance is needed (Bond-Barnard et al., 2018, Silva and Harper, 2018, Meng and

Gallagher, 2012). The purpose with this paper is to respond to this call for more empirical research as we used Dietrich et al. (2010)'s definition of collaboration quality and explored the relationship between collaboration quality and project performance in terms of cost, schedule and quality of the deliverables on a substantial dataset. We used these empirical data to test the proposition suggested by others, such as Eriksson and Westerberg (2011), that there is a positive relationship between collaboration and project performance.

Through bivariate analysis of a dataset of 142 Norwegian construction and infrastructure projects that utilize the 10-10 benchmarking system developed by the Construction Industry Institute (CII), we address the following research questions:

RQ: What is the relationship between collaboration quality in projects and project performance in terms of cost, schedule and quality?

The research objective of this paper is to establish an indicator to measure the collaboration quality in projects and use this indicator to investigate the relationship between collaboration quality and project performance. We contribute to the body of knowledge in a field where more empirical studies are needed (Bond-Barnard et al., 2018, Silva and Harper, 2018, Meng and Gallagher, 2012).

The structure of this paper is as follows. First, we present the theoretical background of the topic and present the research method. Next, we present the results and discuss their implications for theory and practice. This is followed by a conclusion where we summarize the paper and make recommendations for further research.

2 Theoretical background

The following section provides an overview of the state-of-the-art research on the relationship between collaboration and project performance. We identify a research gap calling for further empirical research on this topic. Finally, we discuss the theoretical foundation for building the collaboration quality construct that is used in this paper to analyze empirical data.

2.1 Relationship between collaboration and project performance

Collaboration generally has a positive effect on project performance (Bond-Barnard et al., 2018, Um and Kim, 2018, Cicmil and Marshall, 2005, Turner and Müller, 2003). It should lead to win-win situations for all parties (Bititci et al., 2007, Yeung et al., 2007) and the value of the relationship between customers and suppliers in supply chains is enhanced if there is a high degree of collaboration (Vaaland and Håkansson, 2003).

In **Table *2-1*** we present a summary of existing research that investigates the relationship between collaboration and project performance with regard to cost, time and quality, in other words, the performance measures within the traditional "iron triangle" of project efficiency constraints (Rezvani and Khosravi, 2018). In this table, a (+) symbol indicates where authors have found a correlation between collaboration and each of the three dimensions of the iron triangle, as opposed to a (-) symbol indicating that the authors studied this relation but found no correlation. A blank cell indicates that the authors did not study the relationship between collaboration and the specific dimension.

Table 2-1: Existing research on the relationship between collaboration and project performance in terms of cost, time and quality

Author	**Unit of analysis**	**Data collection method**	**Performance dimension**		
			Cost	**Schedule**	**Quality**
(Eriksson and Westerberg, 2011)	Factors affecting project performance	Conceptual framework based on literature	(+)	(+)	(+)
(Iyer and Jha, 2005)	Cost performance success factors	Survey, 112 practitioners in India	(+)		
(Chan et al., 2003)	Partnering benefits	Survey 78 respondents in Hong Kong	(+)	(+)	(+)
(Silva and Harper, 2018)	Correlation between team integration and performance (cost/time)	Survey 26 projects in the US	(+)	(-)	
(Ibrahim et al., 2018)	Difference in performance between IPD projects and non-IPD	Survey, 109 projects	(+)	(+)	(+)
(Franz et al., 2017)	Difference in performance between contract types	Survey, 204 projects in the US	(+)	(+)	(+)
(Suprapto et al., 2016)	Difference in performance between contract types	Survey, 119 practitioners from various in industries in the Netherlands	(+)	(+)	(+)
(Dietrich et al., 2010)	Collaboration antecedents and outcomes	Conceptual framework based on literature	(+)	(+)	(+)
(Cho and Ballard, 2011)	Difference in performance between IPD projects and nonIPD	49 construction projects	(+)	(+)	

(Asmar et al., 2013)	Difference in performance between IPD projects and nonIPD	Survey, 35 US construction projects	(-)	(+)	(+)
(Hanna, 2016)	Difference in performance between	Survey, 12 projects, 42 practitioners	(-)	(+)	(-)
	IPD projects and nonIPD				
(Bond-Barnard et al., 2018)	Link between collaboration and project success	Online survey, 151 respondents from various industries	(+)	(+)	(+)
Note:					
(+) authors suggest that there is a relationship with collaboration					
(-) authors suggest that there is no relationship with collaboration					
Blank cell: the author did not discuss the relationship with collaboration					

Eriksson and Westerberg (2011) proposed a conceptual framework with a positive relationship between collaboration level and project performance in terms of cost, time, and quality. In addition, they proposed a positive relationship between collaboration and success in terms of environmental impact, work environment and innovation. Similar findings were also reported by Dietrich et al. (2010), who through an extensive literature review of existing research found a relationship between collaboration quality and project success. Iyer and Jha (2005) conducted a survey of Indian construction projects where they identified coordination as the most significant factor that influenced project cost performance. Chan et al. (2003) conducted a survey of 78 practitioners working with partnering projects in Hong Kong and found that collaboration was positively related to all three sides of the iron triangle.

Based on a survey of US public transportation projects, Silva and Harper (2018) investigated correlations between how well-integrated teams were in projects and how well these projects performed with regard to cost and schedule. They found that project organizations that experience high levels of collaboration, in general, perform better with regard to cost performance, while there was no clear correlation with schedule performance. However, in their survey, only 26 projects had registered cost and schedule performance and the authors have encouraged other researchers to collect more project data and perform similar studies. Recently Bond-Barnard et al. (2018) published results from a survey where they found empirical evidence of a positive relationship between collaboration and project management success in terms of cost, time and quality.

Several studies compare how projects using different contract types perform with regard to cost, time and quality. Sullivan et al. (2017) provide a summary of 30 existing studies performed by researchers on projects using either design-build (DB), construction manager at risk (CMR) or design-bid-build (DBB) delivery methods. However, none of these 30 studies included projects that utilize high-order collaborative arrangements. Recently, some empirical studies have been published with a focus on the performance of higher-order collaborative delivery methods. For example, Ibrahim et al. (2018) analyzed 109 projects and found that projects that utilized Integrated Project Delivery (IPD) arrangements, in general, outperformed the remaining projects that used less collaborative procurement arrangements. Similar findings are reported by Asmar et al. (2013), who compared 12 IPD projects with 23 non-IPD projects in the US and found that there were no significant differences in cost performance between these projects but that there was a small difference in schedule growth. However, they found that IPD projects were superior in quality performance compared with the non-IPD projects. Regarding quality performance, Hanna (2016) came to a different conclusion and found no difference in quality performance between IPD and non-IPD projects. However, Hanna (2016) did find similar results to those of Asmar et al. (2013) regarding cost and schedule growth.

Furthermore, Franz et al. (2017) collected data from 204 projects and found generally positive correlations between collaboration and project performance in terms of cost, time and quality. They found some differences between various delivery methods but highlighted that choosing a collaborative contract arrangement did not automatically lead to improved performance. Similar conclusions were reached by Suprapto et al. (2016), who studied project performance based on survey responses from 119 practitioners in the Netherlands and compared how projects (mainly oil and gas) used various contract types performed. Their main finding was that relational attitude and level of teamwork are more important than which type of contract is used.

2.2 Research gap

According to von Danwitz (2018), there is a general need for project management research for more quantitative studies based on large datasets. The majority of empirical research on the relationship between collaboration and performance in construction projects is focused on comparing projects that use different procurement arrangements and contract types as shown in **Table *2-1***. The prevailing view on performance measurement is that more research is needed on collaborative organizations (Bititci et al., 2012). Eriksson and Westerberg (2011) encourage researchers to collect data from a large number of projects to test their proposition that there is a positive relationship between collaboration and project performance.

"The value of having this framework tested is potentially great as the project management literature has many indications that increased cooperation may be a good strategy for achieving project success, but empirical evidence delineating this in a more holistic way is lacking" (Eriksson and Westerberg, 2011, p. 206).

There is a need for more empirical research to investigate the relationship between collaboration and project performance (Bond-Barnard et al., 2018, Silva and Harper, 2018, Meng and Gallagher, 2012).

2.3 Collaboration quality

Based on a review of existing literature, we have proposed constructs that describe the quality of the collaboration in projects. We will use these constructs to study the correlation between collaboration quality and project performance, as presented in the method section in this paper. These constructs are Trust, communication, teamwork, and coordination. Supporting literature that provides a theoretical foundation for each construct is presented in **Table *2-2***. In section 3 of this paper, we connect these four constructs to our dataset containing questionnaires collected from projects.

Table 2-2: Summary of elements describing collaboration quality

Collaboration element	Supporting literature
C1 - Trust	(Walker and Lloyd-Walker, 2016) (Chan et al., 2004) (von Danwitz, 2018) (Bond-Barnard et al., 2018) (Pinto et al., 2009) (Kadefors, 2004) (Haaskjold et al., 2019) (Nevstad et al., 2018) (Suprapto et al., 2015) (Ling et al., 2013) (Yeung et al., 2007) (Dietrich et al., 2010)

C2 - Communication	(Walker and Lloyd-Walker, 2016) (Dietrich et al., 2010) (Chan et al., 2004) (Badi and Pryke, 2015) (Aliakbarlou et al., 2018) (Simatupang and Sridharan, 2005) (Nevstad et al., 2018) (Suprapto et al., 2015) (Yap et al., 2017) (Hoegl and Gemuenden, 2001) (Yeung et al., 2007)
C3 – Teamwork	(Aliakbarlou et al., 2018) (Caniëls et al., 2019) (Suprapto et al., 2016) (Walker and Lloyd-Walker, 2016) (Hoegl and Gemuenden, 2001) (von Danwitz, 2018) (Ling et al., 2013)
C4 – Coordination	(Walker and Lloyd-Walker, 2016) (Dietrich et al., 2010) (Chan et al., 2004) (von Danwitz, 2018) (Hoegl and Gemuenden, 2001) (Ling et al., 2013) (Dietrich et al., 2010)

Several authors such as (Bond-Barnard et al., 2018, Pinto et al., 2009, Kadefors, 2004) have found a positive relationship between trust and collaboration in projects. Trust is defined by (Rousseau et al., 1998, p. 395) as follows: "Trust is a psychological state comprising the intention to accept vulnerability based upon positive expectations of the intentions or behavior of another". Furthermore, trust can have different forms. Calculative trust follows rational choices (Rousseau et al., 1998) and can be tangible in terms of for example certificates (Kadefors, 2004). Relational trust is less tangible and develops over time based on previous behavior (Rousseau et al., 1998) while institutional trust describes how necessary circumstances for trust are created through for example legal systems (Rousseau et al., 1998).

An openness that encourages the sharing of both bad and good news is positively associated with trust (Suprapto et al., 2015, McAllister, 1995). Having effective mechanisms to resolve issues is one of several factors that contributes to trust (Manu et al., 2015). Other elements of trust include role clarity (Henderson et al., 2016, Buvik and Rolfsen, 2015) and empowering team members and contractors with sufficient authority (Schoorman et al., 2007).

Effective communication plays an important role in the collaborative relationship between clients and contractors (Aliakbarlou et al., 2018). It is important that all parties communicate and understand the project's objectives and goals (Yeung et al., 2007). Poor communication can lead to misunderstandings and conflicts (Lædre, 2009, Young, 2006). The quality of communication is often best when there is a balance between formal and informal communication (Turner and Müller, 2004). Geographical co-location often leads to better communication and higher collaboration levels among the parties (Walker and Lloyd-Walker, 2015). Another example is how the use of shared workspaces facilitates better communication between different professions on construction sites (Christensen, 2008).

Teamwork quality influences how well teams collaborate (Hoegl and Gemuenden, 2001). Parties that achieve a high order of collaboration often demonstrate strong elements of a no-blame culture, consensus when making decisions and a culture where the team members act for the best of the project instead of pursuing personal gains (Walker and Lloyd-Walker, 2015). Having team members with the right experience (Park and Lee, 2014, Patel et al., 2012) who are motivated by good leadership (Caniëls et al., 2019) contributes to a high-performing collaborative climate.

Coordination describes to what extent the parties have a common understanding of the goals and what activities need to be taken to achieve these (Dietrich et al., 2010). In order to collaborate, the parties must manage the interfaces between stakeholders effectively and ensure that resources are allocated where they are needed most (Chan et al., 2004). Having effective work processes to manage and coordinate activities and changes also contributes to improved collaboration (Simatupang and Sridharan, 2005).

Through a literature review, we have identified the need for more empirical research on the relationship between collaboration and project performance. Furthermore, we have presented the theoretical foundation for construct elements that describe collaboration quality. In the following section, we present the research method used as we analyzed a set of data from construction and infrastructure projects in Norway.

3 Data and methodology

Through deduction, we build constructs based on existing theory, analyze empirical data, and compare findings with previous research. The dataset contains quantitative empirical data collected from 142 Norwegian construction and infrastructure projects that utilize the 10-10 benchmarking tool. We conducted a bivariate analysis to explore relationships between collaboration quality and project performance. Typically we use bivariate analysis when we search for evidence that variation in one variable correlates with the variation in another variable (Bryman, 2016).

3.1 10-10 Benchmarking program of Norwegian construction projects

As a response to the negative trend in productivity in the Norwegian construction industry (Todsen, 2018) the Norwegian Building Authority (DiBK) initiated a study to identify measurement tools that industry actors could use to measure and benchmark their performance. The outcome of this study was a recommendation to implement the CII 10-10 benchmarking program in Norway (Langlo et al., 2017). The 10-10 Program was originally developed by the US-based Construction Industry Institute (CII) and is designed to evaluate project performance in the construction industry (Yun et al., 2016). Data from each project are recorded and companies receive benchmarking scores on their performance compared with other projects in the database. The categories for rating are based on CII's 30 years of research on best industry practice for 10 input factors and 10 outcomes, hence the name 10-10.

In Norway, several major construction owners and contractors have implemented the 10-10 Program in their project organizations and today data from 142 projects from 26 different companies have been registered in a common database for Norwegian projects. Companies participating in the 10-10 Program receive feedback on how they perform compared to a selection of comparable projects and use this as a tool for continuous improvement. Based on these measures, project organizations can evaluate how they are performing in order to adjust and improve their performance (Choong, 2014). In addition to providing a benchmarking tool for companies, one intention in establishing the 10-10 Program in Norway was to establish a database with a large volume of reliable project data that can be used for academic project management research (Langlo et al., 2017).

3.2 Suitability of 10-10 dataset to investigate research questions

The projects in the database can be grouped into three main characteristics which are: Road construction projects, power grid development projects, and building projects. The building projects typically include hospitals, schools, apartment buildings and other large buildings. With regards to the procurement method used for the 142 projects recorded in the database, the distribution was as follows: 50 of the projects used the design-bid-build method, 76 projects used design-build, 14 used parallel primes while 2 used Integrated Project Delivery models.

The authors have access to all data in the 10-10 database for Norwegian projects. Since 142 projects are registered in the database today and the fact that each of these contains in average 79 data points registered by project participants (in total 1,629 people), we consider this a substantial dataset. All these data are extracted from the CII 10-10 system and have subsequently been entered into the IBM SPSS software by the authors.

The dataset for each project consists of two main sections. The first section contains descriptive information which includes specific scope, cost, and schedule data for the project. Both planned and actual values are registered. The second section contains data collected through a questionnaire developed by CII based on their research on industry best practices (Yun et al., 2016). The full set of questionnaires can be downloaded from the 10-10 Program website (http://www.10-10program.org). Certified 10-10 benchmarking coordinators facilitate the data collection process in the companies to ensure the reliability of the data. These coordinators also provide guidance to respondents who have questions related to the interpretation of the questions. Numbers and values such as cost data, schedule data, etc., are entered into the database by the coordinator based on input from the project manager and/or project control personnel.
Furthermore, when a company's 10-10 coordinator submits the data to the database, the data is validated by CII in the United States as a final check of the dataset.

Respondents are chosen by the project manager and the company's certified 10-10 coordinator to ensure that relevant fields of expertise are covered. On average, each project in the dataset has 11.5 respondents filling in the questionnaire (total 1,629 respondents).

A schematic presentation of our research design is shown in **Figure *3-1***. The left side of the figure illustrates how we built a common construct for collaboration quality and this is further described in chapter 3.3 of this paper. The right side of **Figure *3-1*** shows how we measure project performance in terms of cost growth, schedule growth and quality of deliverables, something that is further described in section 3.4.

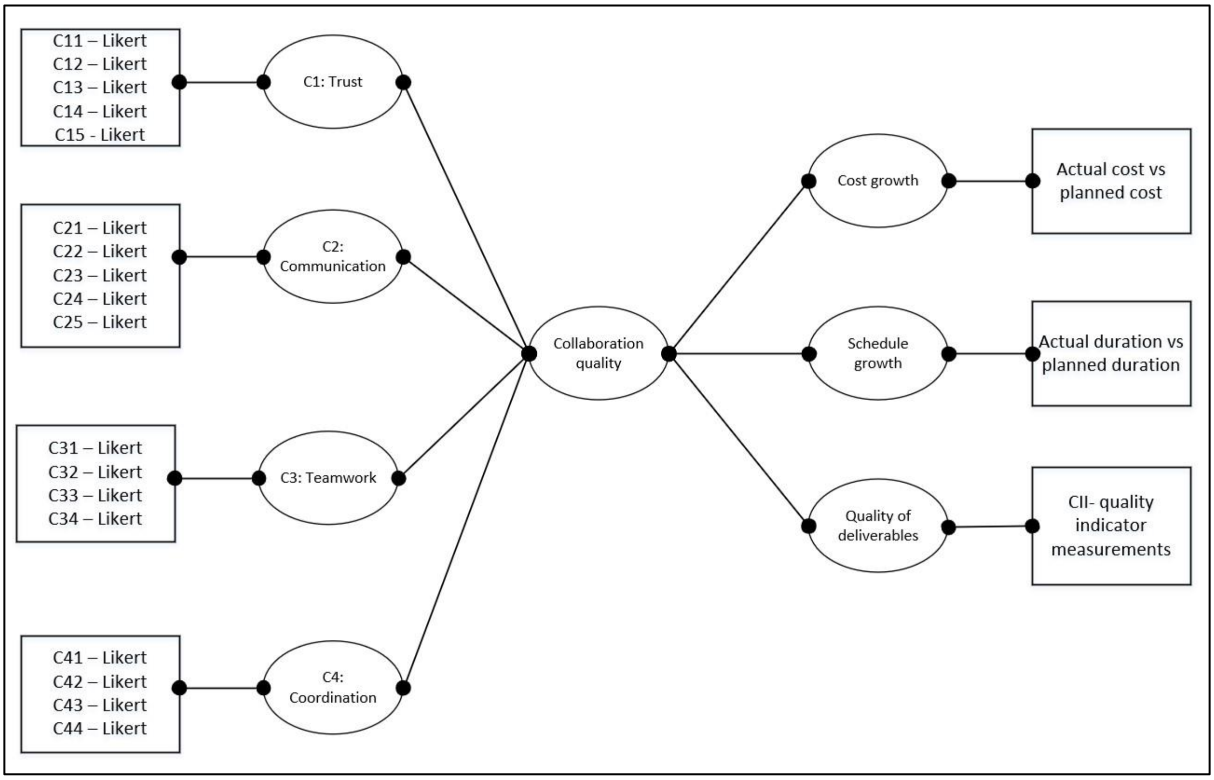

Figure 3-1: Research design schematic

3.3 Collaboration quality construct

Construct concepts must be soundly founded on theory and we must apply statistical tools to test that they are reliable and measure the same concept (Bryman, 2016). In this section, we provide the theoretical foundation for our constructs before we calculate the Cronbach's alpha to check the internal reliability of the constructs. In **Table *2-2*,** we presented a summary of elements that describe collaboration quality in projects. This summary was based on a literature review of existing research. Next, we searched the questions in the 10-10 dataset for questions that describe any of these elements and sorted these into the constructs. A complete list of which questions are associated with each question from the questionnaire is presented in **Table *3-1*** together with supporting literature providing the theoretical foundation for allocating the questions to the construct to ensure validity. All the questions in this table utilize the same Likert scale with five increments ranging from *strongly disagree* (1) to *strongly agree* (5).

Table 3-1: Building constructs for collaboration quality based on questions in the 10-10 questionnaire

Question from 10-10 questionnaire	Supporting literature
C1: Trust	

C11-Project leaders were open to hearing "bad news", and they wanted input from project team members	(Suprapto et al., 2015) (McAllister, 1995) (Chan et al., 2004) (Hoegl and Gemuenden, 2001)
C12 - When issues arose, there were effective mechanisms to ensure they were resolved	(Manu et al., 2015) (Dietrich et al., 2010) (Chan et al., 2004) (Ling et al., 2013) (Kvålshaugen and Sward, 2018)
C13-Project management team members were clear about their roles and how to work with others on the project	(Kalkman and de Waard, 2017) (Buvik and Rolfsen, 2015) (Dietrich et al., 2010) (Chan et al., 2004)
C14 - A high degree of trust, respect and transparency existed among companies working on this project	(Pinto et al., 2009) (Kadefors, 2004) (Walker and Lloyd-Walker, 2016) (Bond-Barnard et al., 2018) (Chan et al., 2004)
C15 - Project team members had the authority necessary to do their jobs	(Schoorman et al., 2007) (Park and Lee, 2014) (Kvålshaugen and Sward, 2018)
C2: Communication	
C21 - The project's objectives were appropriately communicated to the relevant project team members	(Yeung et al., 2007) (Walker and Lloyd-Walker, 2016) (Walker et al., 2017) (Badi and Pryke, 2015) (Hoegl and Gemuenden, 2001)
C22 – The project management team maintained open and effective communication	(Dietrich et al., 2010) (Walker et al., 2017) (Chan et al., 2004)
	(Hoegl and Gemuenden, 2001)
C23 - The owner level of involvement was appropriate	(Andersson, 2016) (Badi and Pryke, 2015) (Kvålshaugen and Sward, 2018)
C24 - Leaders effectively communicated business objectives, priorities and project goals	(Yeung et al., 2007) (Dietrich et al., 2010) (Ling et al., 2013)
C25 - Plan and progress including changes were communicated clearly and frequently among project stakeholders	(Simatupang and Sridharan, 2005) (Walker et al., 2017) (Ling et al., 2013)
C3: Teamwork	
C31 - People on this project worked effectively as a team	(Caniëls et al., 2019) (Suprapto et al., 2016) (Ling et al., 2013)
C32 - All of the necessary, relevant project team members were involved in the risk assessment process	(Walker and Lloyd-Walker, 2016) (Walker et al., 2017) (Tsiga et al., 2016)

C33 - The project team including project manager(s) had skills and experiences with similar projects / processes	(Patel et al., 2012) (Park and Lee, 2014)
C34 - Project leaders recognised and rewarded outstanding personnel and results	(Caniëls et al., 2019) (Maurer, 2010) (Kvålshaugen and Sward, 2018)
C4: Coordination	
C41 - The interfaces between project stakeholders were well managed	(Rahi et al., 2019) (Pinto, 2010) (PMI, 2017) (Jaafar and Yusof, 2019)
C42 - The project control system was effective in monitoring project progress in terms of cost, schedule and scope	(Yousefi et al., 2019) (PMI, 2017) (De Koning and Vanhoucke, 2016)
C43- A dedicated process was used to proactively manage change on this project	(Simatupang and Sridharan, 2005) (PMI, 2017) (Pinto, 2010)
C44- Resources were allocated according to project priorities	(Chan et al., 2004) (Patel et al., 2012) (PMI, 2017)

Furthermore, we consolidated the constructs C1-C4 into one combined construct called "Collaboration quality" as shown in **Table *3-2*** and **Figure *3-1***. This collective construct describes the overall collaboration quality in each project.

The more questions that measure the same attribute, the greater the reliability of the data. However, when we use multiple indicator measures, such as several questions from a questionnaire, we need to make sure that these questions measure the same thing (Bryman, 2016). To validate that the various questions in a constructed measure the same attribute we must, in addition to building these on theory, check the internal reliability of the construct. A commonly used test is to calculate what is known as the "Cronbach's coefficient alpha" (Bryman, 2016). This is a coefficient developed by Cronbach (1951) to measure the internal consistency of a scale containing multiple items. The higher the value of the coefficient, the more reliable our constructs are. An often-cited source is Murphy and Davidshofer (2005), who suggested that values below 0.6 are unacceptable, 0.7 is low level, 0.8-0.9 is moderate to a high level, and above 0.9 is high level. Kaplan and Saccuzzo (2009) state that coefficients in the range between 0.7 and 0.8 are generally considered "good enough" for most research and that the more items included in a construct the more reliable it becomes. Bryman (2016) recommends 0.8 as a rule of thumb for an acceptable level. Although more than two decades old, it is interesting to read the work by Peterson (1994), who investigated alpha coefficients from 832 published studies and found that the mean value was 0.77. Furthermore, Peterson explored the alpha value for studies using various construct scales. For constructs based on more than three items and with Likert scales containing more than 4 scale items, the mean value was 0.78 (Peterson, 1994). Purely presenting Cronbach's alpha is not enough alone to verify that constructs measure the same attribute (Schmitt, 1996) and we must build the constructs on a solid theoretical foundation to ensure validity (Bryman, 2016) as shown in **Table *3-1***.

Using the IBM SPSS software, we calculated the Cronbach's alpha coefficient for our constructs and report these in **Table *3-2***. The Cronbach's alpha for the four constructs C1-C4 is in the range between 0.79 and 0.89. We also see from **Table *3-2*** that the Cronbach's alpha for the overall "collaboration quality" construct combining C1, C2, C3, and C4 is 0.93. We, therefore, argue that the questions from the questionnaire that have been associated with each construct have acceptable internal consistency, i.e., the various questions combined into a constructed measure the same attribute or concept.

In addition to the Cronbach's alpha being acceptable, we should investigate the factor loading to determines the minimum sample size needed to ensure statistical significance. A loading factor of 0.70 or higher means that a sample size of 60 is sufficient. For a sample size of 100, the factor loading should be above 0.55 (Hair et al., 2014). We see from **Table *3-2*** that our lowest factor loading is 0.73, i.e. acceptable for our sample size.

Furthermore, we should have composite reliability (CR) values of a minimum 0.70 (Bagozzi and Yi, 1988) and the values for the average variance extracted (AVE) should not be lower than 0.50 (Bagozzi and Yi, 1988, Fornell and Larcker, 1981). Our lowest CR value is 0.87 and the lowest AVE value is 0.60, i.e., acceptable.

Table 3-2: Reliability of constructs

Latent variable	**Observed variable (ref *Table 3-1*)**	**Factor loading □**	**Average variance extracted (AVE)**	**Composite reliability (CR)**	**Cronbach's □**
C1			**0.70**	**0.92**	**0.89**
	C11	0.79			
	C12	0.85			
	C13	0.85			
	C14	0.85			
	C15	0.84			
C2			**0.60**	**0.88**	**0.83**
	C21	0.77			
	C22	0.82			
	C23	0.73			

	C24	0.76			
	C25	0.81			
C3			**0.63**	**0.87**	**0.80**
	C31	0.84			
	C32	0.80			
	C33	0.76			
	C34	0.77			
C4			**0.62**	**0.87**	**0.79**
	C41	0.79			
	C42	0.76			
	C43	0.73			
	C44	0.86			
Collaboration			**0.82**	**0.95**	**0.93**
	C1	0.93			
	C2	0.90			
	C3	0.93			
	C4	0.87			

3.4 Performance in terms of cost, schedule and quality of deliverables

In this paper, we investigate how collaboration quality is related to project performance in terms of cost, time and quality. Above, we have described how we used the questionnaire from the 10-10 dataset to build reliable constructs measuring the collaboration quality in the projects. The following section describes how performance in terms of cost, time and quality is represented in the 10-10 dataset. Performance in terms of these dimensions is commonly known as the "iron triangle" (Rezvani and Khosravi, 2018). Most researchers today agree that iron triangle is too limited as a definition of project success (Müller and Jugdev, 2012). We agree, and broader definitions have for example been proposed by Pinto and Slevin (1988) as a supplement to the iron triangle to describe success. However, the dataset we investigate mainly contains performance metrics within the iron triangle of cost, time and quality. For this reason, we have chosen to narrow our study to these metrics.

In the dataset, both the planned cost and the actual cost were recorded for each project in monetary value. Based on this, a factor called cost growth is calculated. The cost growth factor is simply the actual cost compared with the planned cost. From the 142 projects included in the dataset, the cost growth factor was calculated for 104 of these. For the remaining cases, either planned cost or actual cost had not been registered sufficiently. Similarly, we can also calculate the scheduled growth for each project. The schedule growth factor is calculated by comparing the actual duration with the planned duration. From the 142 projects included in the dataset, the schedule growth factor was calculated for 125 of these. For the remaining cases, either planned duration or actual duration had not been registered sufficiently.

Quality is defined by PMI (2017) p. 718 as "the degree to which a set of inherent characteristics fulfills requirements", while Juran and Godfrey (1999) and Oakland (2012) remind us that quality is also associated with meeting customers' needs beyond purely conforming to specifications and requirements. The project should create value for the owner (Haddadi and Johansen, 2019). Based on the research of industry best practice, CII has developed a quality performance indicator that is measured with the 10-10 benchmarking tool. Based on the various data registered for each project, the quality performance indicator is calculated as a number ranging from 0 to100. This indicator cover several aspects related to quality best practices such as Amount of changes, errors, omissions and cost of quality (PMI, 2017), meeting functional and regulatory requirements (Arditi and Gunaydin, 1997), level of non-conformances and deviations (Yeung et al., 2013), conformity to expectations (Molenaar et al., 1999) and client satisfaction (Oakland, 2012, Juran and Godfrey, 1999).

3.5 Criticism of the method

We have not designed the questions used in the dataset ourselves specifically to address the research questions of this paper, but instead reviewed an existing dataset and searched for relevant questions related to our research questions. With this pragmatic approach, we must be careful to avoid bias and ensure that the data we use from the 10-10 dataset is relevant for our specific research questions and soundly founded on existing theoretical frameworks. To compensate for this, we have performed an extensive literature review, presented in **Table *3-1***, to ensure that we have a solid theoretical foundation when we allocate questions to each construct. Furthermore, we have validated the internal reliability of these constructs by calculating Cronbach's alpha.

Companies that participate in the 10-10 program are proactive and seek continuous improvement in their projects. Since the dataset only contains data from such projects, one can argue that projects with less focus on continuous improvement and benchmarking will not be captured in the dataset, as they may not have been using the 10-10 benchmarking tool. Furthermore, we know that being measured does affect behavior (Spitzer, 2007) and one can, therefore, argue that there is a risk that participants may focus more on specific elements that they know will be measured through the 10-10 program than other elements not specifically measured. There is also a risk of respondent bias as many of the respondents to some extent are responsible or accountable for the project outcome. One can, therefore, argue that this may have influenced how respondents answer certain questions.

The data are collected in projects that are executed in Norway and one can, therefore, argue that some caution should be taken in generalizing findings outside this context. However, the questions in the questionnaire were developed by CII based on their comprehensive research on best practices (Yun et al., 2016) and we argue that this is an element that improves the generalisability of the findings.

4 Results and analysis

In this section, we report the results of our analysis. First, we provide a summary of the mean value and distribution for the various variables. Following this, we show detailed results from the bivariate analysis and report the Pearson's r correlations.

4.1 Descriptive summary

The main descriptive data from the analysis is shown in **Table *4-1*** and the frequency distribution of the data is presented in **Figure *4-1***. The projects experienced mean cost growth of 14% compared with the planned cost. Out of a total of 104 valid cases, 63 of these reported a cost-performance within +- 5% or better compared with the planned cost. The remaining 41 projects exceed the planned cost with more than 5%, and 16 of these exceeded the planned cost with more than 25%. The mean schedule growth factor was 13%. From 125 valid cases, 85 projects reported a schedule performance within +-5% of the planned duration or better. The other 40 projects exceed the planned duration with more than 5% where 23 of these exceeded the planned duration with more than 25%. These values for cost growth and schedule growth are similar to results published in a recent study of 418 projects where Chen et al. (2016) found that that 77% of the projects were completed on cost or below and that 68% finished on time, or ahead of time.

Table 4-1: Descriptive statistics

Variable	Scale	Mean value	Std. deviation	Valid cases
Cost growth	(Actual cost / planned cost) - 1	0.14	0.53	104
Schedule growth	(Actual duration / planned duration) - 1	0.13	0.51	125
Quality of deliverables	Indicator ranging from 0-100	70.4	9.9	142
Collaboration quality	Likert (1-5)	3.76	0.52	142

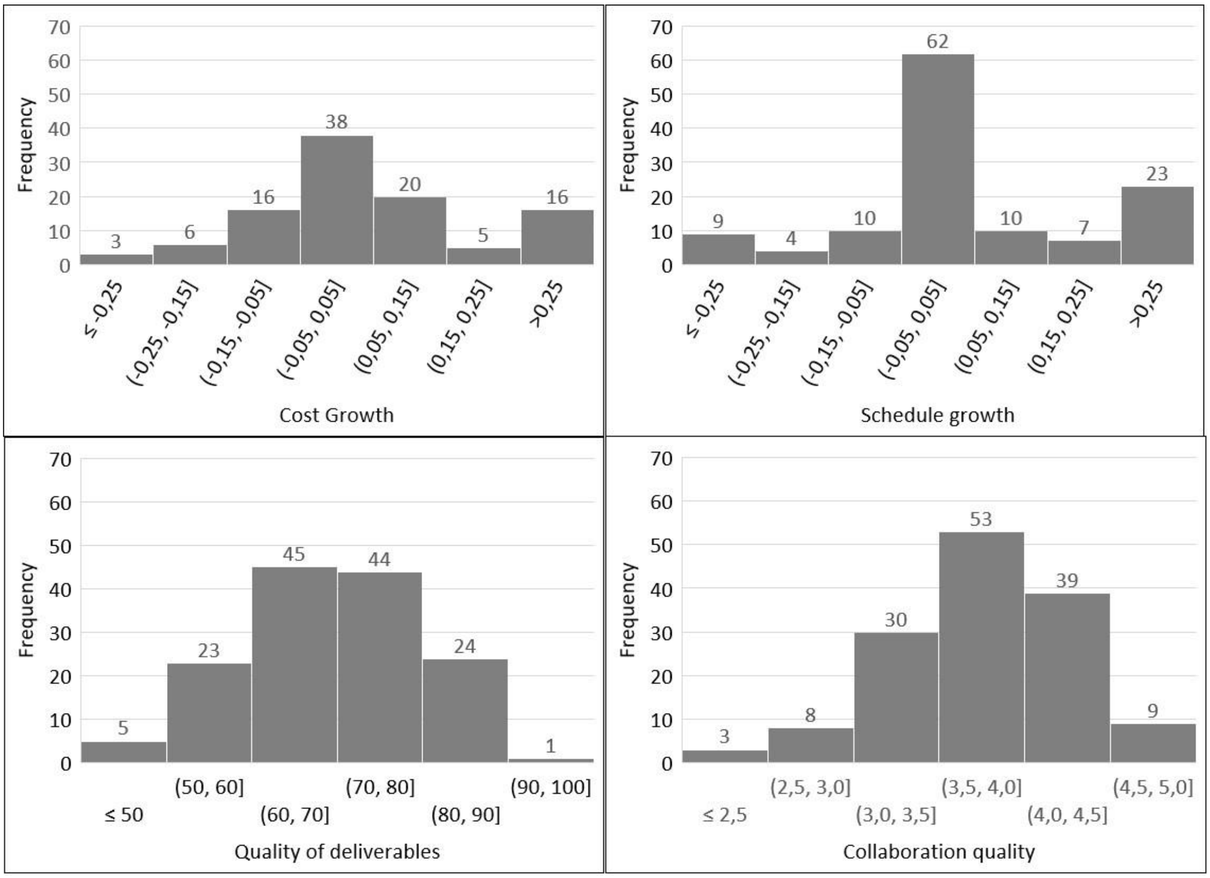

Figure 4-1: Frequency distribution of results. Cost growth (top left), schedule growth (top right), quality of deliverables (bottom left) and collaboration quality (bottom right).

From the top left and top right diagrams in **Figure *4-1*** we see the distribution for cost growth and schedule growth. We see that from those projects that finish above cost or behind schedule, many of them exceed the planned value with 25% or more. The fact that so many of the projects are found to the right in these two diagrams, away from the mean value, explains why the standard deviation is high compared with the mean value for cost growth and schedule growth in **Table *4-1***.

Moving on to the quality of deliverables, we see that on a scale from 0-100, the projects received a mean score of 70.4 for the measured indicator. From the bottom left diagram in **Figure *4-1*** we see that the distribution for this indicator follows a bell curve where few of the projects are to the far left or far right in the diagram. A similar distribution, although slightly skewed, is also found for the quality of collaboration indicator (bottom right diagram). On a Likert scale from 1 to 5, the mean score was 3.76 for this variable.

4.2 Bivariate analysis – Pearson's r correlation

A summary of Pearson's r correlations is shown in **Table *4-2***. The number between 0 and 1 indicates the strength of the relationship between the variables. A value close to 0 indicates a weak relationship, as opposed to values closer to 1, which indicates a strong relationship (Bryman, 2016). Various labeling systems exist to categorize the value of the correlation, i.e., the strength of the relationship. For example, Taylor (1990) argues that <0.35 indicates weak correlations while values between 0.36 and 0.67 have moderate strength. Higher values indicate strong correlations. A rule of thumb for medical research suggests the following: negligible (<0.30), low strength (0.30-0.50), moderate strength (0.50-0.70), high strength (0.70-0.90) and very high strength (>0.90) (Mukaka, 2012).

In addition to the strength of the relationship, we need to check if the relationships we found are statistically significant. I.e., to what extent can we expect that our findings apply to projects outside our sample size of 142 projects. According to Bryman (2016), statistical significance at <0.05 or lower is in general considered acceptable in social research. We can then argue that there is a five percent (or less) chance that we have identified a relationship in our dataset that is not representative of a larger population.

Table 4-2: Pearson's r correlations between performance and collaboration quality

Variable / Variable		Cost growth	Schedule growth	Quality of deliverables	Collaboration quality
Cost growth	Pearson Correlation	1			
	Sig. (2-tailed)				
	N	104			
Schedule growth	Pearson Correlation	-.002	1		
	Sig. (2-tailed)	.984			
	N	102	125		
Quality of deliverables	Pearson Correlation	-.147	-.086	1	
	Sig. (2-tailed)	.138	.341		
	N	104	125	142	
Collaboration quality	Pearson Correlation	-.088	-.081	.744**	1
	Sig. (2-tailed)	.372	.367	.000	
	N	104	125	142	142

Furthermore, we illustrate the findings in **Figure *4-2*** with scatter plots in the three first quadrants of the figure. Each dot in these scatter plots represents one project from the dataset. The horizontal axis shows the collaboration quality value for the project while the vertical axis indicates performance in terms of cost growth factor, schedule growth factor and quality of deliverables. Scatter plots are useful to examine bivariate relationships and variables grouped along a straight line indicate that there is a strong linear relationship or correlation (Hair et al., 2014). The fourth quadrant shows a schematic summary of the correlation between collaboration quality and each of the three sides of the iron triangle.

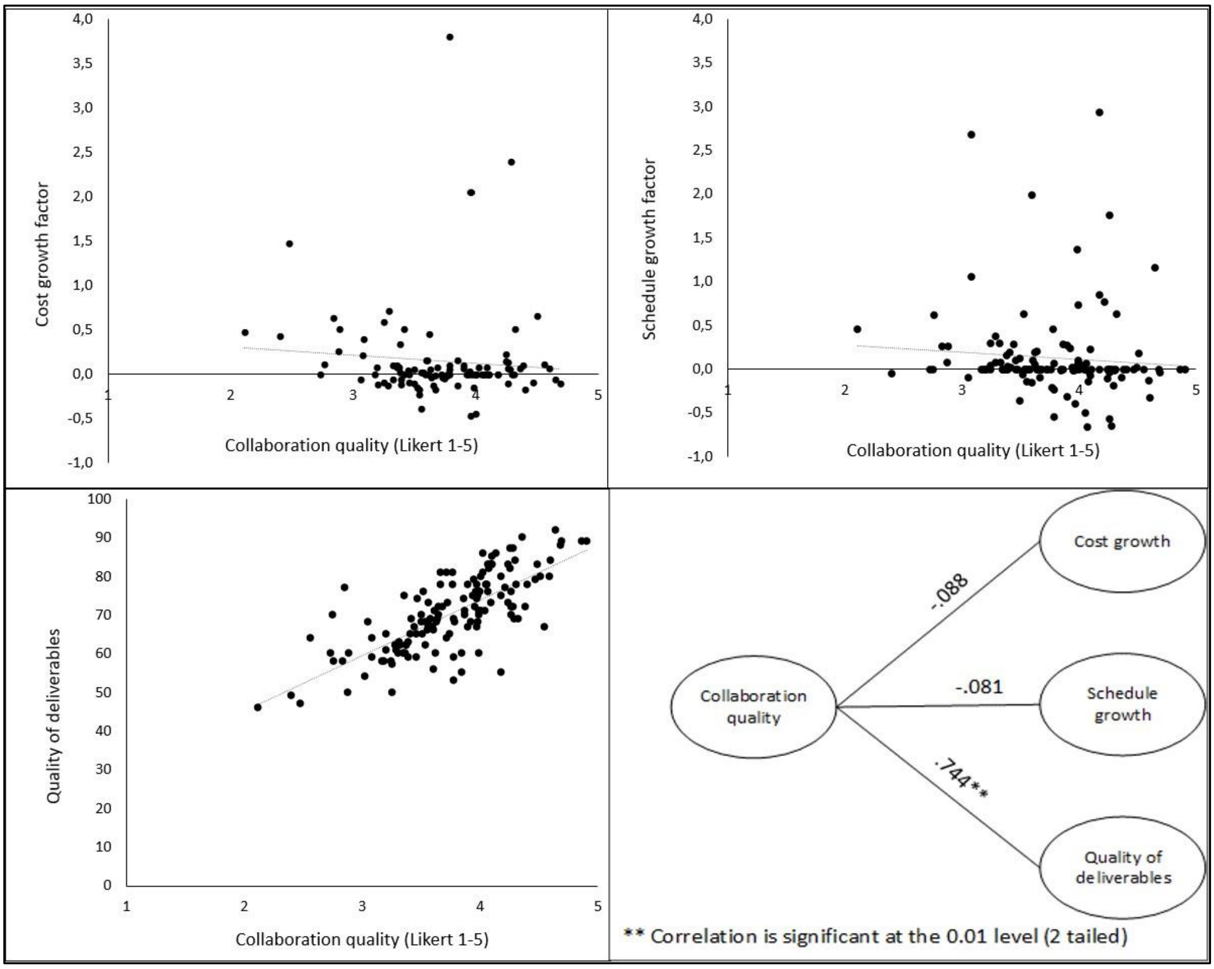

Figure 4-2: Correlation between collaboration quality and project performance

A common misuse of correlations is to interpret them as an explanation for cause and effect (Bryman, 2016). For example, our findings in **Table *4-2*** show a strong correlation between collaboration quality and the quality of the project deliverables. Although it is tempting to conclude that our findings show that improving collaboration will lead to improved quality of the deliverables, we cannot establish this cause and effect based on our findings. Our statistical analysis has purely identified that those projects that scored high on collaboration quality also, in general, scored high on the quality of their deliverables. We have to rely on existing research that investigates the specific cause and effect before making conclusions (Bryman, 2016).

4.2.1 Correlation between collaboration quality and cost growth

From ***Table 4-2*** we see that the value of the relationship found (-.088) is low and not statistically significant. Hence, we did not find evidence that suggests that projects that scored high on collaboration quality experience less cost growth than those that scored lower on collaboration quality. From the top left scatter plot in **Figure *4-2*** we see a few cases with very high-cost growth that may be considered outliers. To investigate the effect such potential outliers have on the results, we did a test where we removed these potential outliers from the dataset, but we found that this had very little impact on the results.

4.2.2 Correlation between collaboration quality and schedule growth

Moving on, we see from ***Table 4-2*** that we did not identify a relationship between collaboration quality and schedule growth either. The Pearson's r factor is -0.081 and it is not statistically significant. Our study, therefore, finds no evidence that there is a relationship between collaboration quality in a project and the scheduled growth in the project. We also have potential outliers related to schedule growth in the data set because a few of the cases have rather a high schedule growth values, as one can see in the top right scatter plot in **Figure *4-2***. To investigate the effect such potential outliers have on the results, we did a test where we removed these potential outliers from the dataset, but we found that this had very little impact on the results.

4.2.3 Correlation between collaboration quality and quality of deliverables

From ***Table 4-2*** we see that the relationship between collaboration quality and the quality of the deliverables is strong, with a value of 0.744. This relationship is also statistically significant at the 0.01 level. Projects that have received a high score for the collaboration quality construct have also received a high score for the quality level indicator of the project deliverables. From the bottom left scatter plot in **Figure *4-2***, we see that the variables follow a straight line. We, therefore, claim that we have found evidence suggesting a relationship between the quality of the collaboration in a project and the project performance in terms of quality.

5 Discussions and implications

In this section, we discuss the consequences of our findings and how they correspond with previous research in the field. Furthermore, we highlight contributions to the body of knowledge and practical implications from our research that practitioners may benefit from.

Most of the cited research in ***Table 2-1*** suggests that there is a relationship between collaboration quality in a project and the quality of the deliverables. Projects with a high level of collaboration are expected to experience fewer errors and deviations, more often meet requirements and more often have satisfied clients than projects with poor collaboration. Our research shows similar results as we find a clear correlation between collaboration quality in projects and how well these projects deliver in terms of the quality of the deliverables.

Consequently, our findings contribute to further validate existing research, as we have provided more empirical support in a field where several authors have highlighted the need for more empirical studies (Bond-Barnard et al., 2018, Silva and Harper, 2018, Meng and Gallagher, 2012). Our findings are similar to those of Eriksson and Westerberg (2011) and Bond-Barnard et al. (2018) who found a correlation between collaboration and quality performance. Participants in construction projects where there is a high level of trust are more likely to actively search for improvements and innovative solutions than in projects with less trust (Kadefors, 2004). Similarly, good communication and teamwork is important to ensure that all parties understand the goals for the projects and avoid misunderstandings (Li et al., 2015). If specifications and expectations are not clearly communicated, an opportunistic contractor may choose to reduce quality to increase profit or recoup costs for under-pricing (Liu et al., 2016). The best results are in general achieved when there is a balance between formal and informal communication (Turner and Müller, 2003). Trust, communication, teamwork and coordination are all important elements for collaboration (Haaskjold et al., 2019, Dietrich et al., 2010) and we found that projects that do well in these areas, in general, perform better in terms of quality of the project deliverables.

Our findings also raise a question related to how strong the relationship is between collaboration quality and project performance in terms of the remaining two sides of the iron triangle. Overrun on cost or time can often cause critical problems for project managers (Yousefi et al., 2019). With the exception of (Silva and Harper, 2018, Asmar et al., 2016, Asmar et al., 2013) the literature in ***Table 2-1*** suggests that projects with good collaboration in general also perform better in terms of both cost and schedule. Improved collaboration is one of several cures recommended by Zidane and Andersen (2018) as a remedy to reduce project delays. We found only weak correlations between collaboration and project performance in terms of cost and schedule. None of these were statistically significant. We do not argue that collaboration is bad for cost and schedule performance, but rather point out that for the projects we studied we found no clear correlations either way. There may be several reasons for this. The first obvious reason that needs to be discussed is the quality of our data itself. From the distribution in ***Figure 4-1*** we see that many of the projects reported a cost or schedule performance within +-5% of the planned value. We, therefore, excluded these from the dataset to explore how this affected the correlations. We found still no significant correlation with the cost growth of schedule growth even if we removed all projects that performed on cost and time from the dataset. Asmar et al. (2013) found similar results to us in their study. They found a correlation between collaboration and quality, but not with cost or schedule.

Another possible reason for the lack of correlation between collaboration quality and performance in terms of cost and schedule is that there may be several independent factors that affect cost and schedule performance that does not necessarily correlate with collaboration. There are many different factors affecting project success (Fortune and White, 2006). One example of a factor that may affect project cost and time performance is how well the scope of work was defined (Iyer and Jha, 2005). Projects may experience growth in scope as a result of new requirements from the client. This will lead to cost growth and schedule growth as the project will cost more and take longer to complete. However, the quality of the deliverables will not suffer if the scope work increases and the duration and budget are increased to accommodate the increased work scope.

The main contribution to theory is that we have provided empirical analyses based on a high-quality data set within a research field where there is a need for more empirical research. Hence, we have responded to calls for more empirical research on the relationship between collaboration and project performance as raised by (Bond-Barnard et al., 2018, Silva and Harper, 2018, Meng and Gallagher, 2012). We have tested a part of the theoretical framework suggested by Eriksson and Westerberg (2011) and found evidence supporting their proposed relationship between collaboration quality and project success in terms of quality. The recorded data has been validated by CII, which has created the questionnaire based on three decades of research. We also claim that our study contributes to validating parts of the research by others such as Bond-Barnard et al. (2018) Silva and Harper (2018), Asmar et al. (2013) and Eriksson and Westerberg (2011). Our research makes a contribution to the body of knowledge dedicated to collaboration as proposed by (Busi and Bititci, 2006), as we share collaboration performance details from 142 projects.

When it comes to practical implications, we propose that project managers can use the collaboration quality construct that we established in this paper to measure the collaboration quality in their project. The 18 questions from the 10-10 questionnaire that constitute the construct are listed in **Table *3-1*** and can be applied by practitioners to measure collaboration quality. Our findings suggest that collaboration is strongly related to the quality side of the iron triangle.

More than a decade ago, Josephson and Saukkoriipi (2005) published a report of waste in Swedish construction projects and found that 10% of the total construction cost for projects at the time was related to control and repair poor quality. Hwang et al. (2009) claimed that direct costs related to rework are on average 5% of the construction cost. Large productivity benefits can be achieved if the quality of the project deliverables are improved through collaboration (Barbosa et al., 2017, Fulford and Standing, 2014). In this paper, we have established an indicator for measuring collaboration quality that project managers can use to measure the collaboration quality in their project. Since we also found a strong correlation between collaboration and the quality of the project deliverables, we propose that project managers can use the collaboration quality indicator as an early warning sign for the level of quality of the project deliverables from their project. If projects score low on the collaboration quality indicator in an early phase of the project, this may be a warning sign that the project may be heading in a direction where the deliverables may not be in accordance with specifications and client expectations. Hence, the project manager can take necessary actions at this stage to ensure that the desired quality level is achieved upon the delivery of the project.

6 Conclusion, limitations and recommendations for further research

The purpose of this paper was to investigate the relationship between collaboration and project performance in terms of cost, time and quality. We have analyzed a set of data from 142 Norwegian construction and infrastructure projects that utilize the 10-10 benchmarking tool developed by the Construction Industry Institute (CII). This is a high-quality dataset where certified coordinators in the participating companies collect data.

We have investigated the following research questions:

RQ: What is the relationship between collaboration quality in projects and project performance in terms of cost, schedule and quality?

We did not find evidence for a relationship between collaboration quality in projects and cost performance. Projects with high collaboration quality did not experience less cost growth than projects with lower collaboration quality. When it came to scheduling performance, we found similar results. Projects with high collaboration quality did not experience less schedule growth than those with lower collaboration quality.

However, we found a strong, and statistically significant, the relationship between collaboration quality and project quality performance. Projects with good collaboration experienced few errors and deviations and more often delivered according to requirements and client expectations than projects with poor collaboration.

Our main theoretical contribution is that we have provided empirical analyses of the relationship between collaboration and project performance based on what we consider to be a high- quality dataset. Hence, we contribute to increasing the number of empirical studies on a topic where several authors have highlighted the need for more empirical studies (BondBarnard et al., 2018, Silva and Harper, 2018, Meng and Gallagher, 2012). Furthermore, we have proposed an indicator to measure collaboration quality that can be used by project practitioners.

Although we consider the dataset to be of high quality, it has certain limitations. The data have been collected from only Norwegian projects. However, the 10-10 tool that was used to collect data has been developed by CII based on their research on project best practices (Yun et al., 2016). Another limitation is that one can argue that projects that use the 10-10 benchmarking have taken an action toward continuous improvement purely by participating in this benchmarking program. There is a risk that low-performing projects are less likely to take part and register their data with the 10-10 benchmarking tool and that such projects may, therefore, be less represented in the dataset than high-performing projects. We see that the performance data for the projects in our dataset follow a similar distribution as data published in studies from other countries. We, therefore, argue that our findings can be generalized, at least to a certain extent, outside the Norwegian context and the 10-10 benchmarking program,

Another potential weakness is that companies that use the benchmarking tool used repeatedly for new projects. Participants are therefore aware of the measured metrics in the benchmarking tool and they may know what will be measured. This can lead to what Meyer (2002) calls "perverse learning", a phenomenon where people adjust their behavior to ensure that they perform well on tasks that they know will be measured while other areas not measured will suffer.

As the size of the dataset increases with more registered projects, it would be interesting to perform longitudinal research on the same dataset to explore developments of trends. For example, how has the relationship between collaboration quality and project performance developed over time? Since we found no correlations with cost and schedule performance in our dataset, it would be welcome if other researchers with access to similar datasets conducted similar bivariate analyses and compared those with our findings.

As most of the studied cases in our research utilized design-build or design-bid-build as a delivery method it would be useful if future studies on the relationship between collaboration and performance included more cases that utilized more collaborative delivery methods such as IPD to see if the results will be different.

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