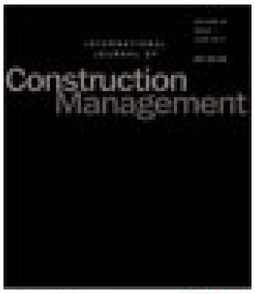

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Construction cost performance under quality-gated framework: the cases of Norwegian road constructions

Alemu Moges Belay[a] and Olav Torp[b]

[a]Smart Innovation Norway, Halden, Norway; [b]Department of Civil and Environmental Engineering, Norwegian University of Science and Technology (NTNU), Gløshaugen, Norway

ABSTRACT

Cost increase during the planning phase of major infrastructure projects is a crucial challenge which is typical in construction management. This research aims to provide a better understanding of the cost development of road-construction projects and enhance the knowledge on various project attributes that affect cost development. A detailed cost development study (quantitatively chart the cost- trends) and analysis on cost departures at each key-milestone starting from the initial to the final cost is conducted. The impact of different project attributes/settings (size, location, and quality assurance) on cost development are investigated. The research used a dataset of 110 projects from the last two-decades and analyzed using various statistical tests such as trend-analysis, probability-plots, and cost development overtime at the different project milestones.

The results showed a decrease in cost-deviation after quality assurance scheme implemented (except few projects). The overall cost development showed an average increase of 5%. The research found different project-setting affect cost development at different magnitude. It provides new insight for construction managers, quality assurers, and cost-estimators to consider different project settings at the early-phases of the project. It helps to understand the individual and combined effects of project-settings and enable decision-makers to act proactively in cost decisions.

KEYWORDS

Construction; cost development; projects setting; trend analysis; quality assurance (QA); infrastructure

Introduction

Public investment projects require knowledge-based decisions at all process steps. However, decisions at the front end of the project are crucial. This is because front-end decisions determine the fate of the project either to continue or halt the process from going forward to the next step. However, before deciding the fate of the project and making such a critical decision, it is paramount to understand a set of project settings and their impact on cost performance.

One prominent consideration for such a vital decision is to look systematically at the cost attributes (project size, location, etc.) and see the impact on cost development from the initial estimates to the final cost. The general literature showed some endeavours to analyze factors influencing project cost estimates (Kaming et al. 1997; Akintoye 2000). However, there is limited focused research on project-related factors under the name 'project scope'. In this regard, Jørgensen et al. 2012 and Chan et al. (2004) listed the attributes to measure project scope, for example, size of the project, type of project, nature of the project, complexity of projects, among others.

More specifically, and somehow in line with our research, Mahamid (2013) studied the effects of a project's physical characteristics on cost departure by considering more than 74 road construction projects. Having better know-how on the physical characteristics of a project could help managers to obtain and execute an effective cost decision starting from the early stage such as in early cost-benefit analysis (CBA), budgetary decision and cost control. However, still to understand and deal with the cost development challenges is not easy and sometimes not straightforward as many projects are complex with the technology advancement.

One challenge is the lack of ability to identify and know exactly the interplay between the real causes of the development and their impact on the actual cost departure. In the literature, several reasons are discussed for the cost development. Some of them are lack of standard measurements, deficiencies in cost estimates, design changes, material selection, involvement of several stakeholders, optimism bias (Arditi et al. 1985; Flyvbjerg et al. 2004; Shehu et al. 2014). One can imagine how the combination of two or more of these cost drivers could expose project owners and construction managers to multifold challenges, such as cost overrun, shortage of resources and project delay.

Typically, Flyvbjerg (2007) summarizes that projects tend to underestimate the cost and overestimate the benefits (optimism bias) at early phases. However, there are also other research in support of the same but approached differently. Some of these approaches focus on inadequate analysis at the early phase (strategic), poor cost and benefit estimations (methods and tools), delay in planning and prolonged project implementation (operational). Datta (2002) claims that delays between the planning and actual implementation is a ubiquitous problem and result in large cost and time overruns. Similarly, Flyvbjerg et al. (2004) argue that sluggishness in the planning and implementation phases are expensive in large infrastructure projects. In addition, they indicate the importance of looking at

CONTACT Alemu Moges Belay alemu.belay@smartinnovationnorway.com

different sizes of the projects and the risks of cost escalations. Another thematic research finding by Antoniou et al. (2018) depicted that cost distribution (cost overrun/underrun) are linked with operational activities, the volume and the type of material used. More recently, Mwelu et al. (2021) extended cost and project performance deviations using cross-sectoral success factors study on public road construction projects by incorporating other important aspects on project executions such as contracts, monitoring activities and regulatory frameworks.

Welde and Odeck (2017) studied 42 Norwegian road construction projects and conclude that cost estimates for Norwegian road projects presented at the time of the decision to build are accurate and unbiased and that cost underruns are more common than overruns. The large Norwegian public projects are going through a quality assurance scheme, including Quality Assurance 1 (QA1) before concept selection, and Quality Assurance 2 (QA2) before the final decision to fund the project. Welde and Odeck (2017) indicated that the Norwegian system for cost estimation and external quality assurance may increase the quality of the basis for decision making through more realistic budgets. However, Welde and Odeck (2017) found that cost estimates in projects' front-end phase are inaccurate and heavily biased. One of the reasons why projects tend to grow in scope is the Norwegian planning and building act which gives local authorities a strong influence on road alignment and other issues that may affect the total costs, which also points to a lack of efficient project ownership.

As discussed above, the causes for cost departure are different and vary from project to project. These divergent views on the causes of cost departure by themselves create a challenge for project owners and managers while making cost decisions. Therefore, it is important to look over and analyze cost development challenges using specific project settings, which is in line with our research objectives. Unlike the previous research which focused on the only cost overrun (Flyvbjerg et al 2003; Odeck 2004; Abdul Rahman et al. 2013 and Siemiatycki 2009), this research wants to investigate the cost development, i.e. cost departure/deviation from the early-stage estimates. This is because cost deviation and development include both the cost overrun and the cost underrun. Typically, this provides room for improvement and learnings from one cost milestone to another milestone (at different stages of the projects).

To respond to the challenges discussed above and related thematic concerns, it is important to carry out systemic cost development studies by deeply analyzing the cost development trends. The research has two overarching objectives:

- Quantitatively chart cost performance and deviations of infrastructure projects that undergo a quality assurance scheme.
- Investigate the influence of project size, location, and quality assurance gates on cost departure of infrastructure projects.

To achieve these overarching objectives, we set out the following guiding research questions:

- RQ1: How is the cost performance and cost development trends of road infrastructure projects?
- RQ2: How do different project settings affect the cost performance of road infrastructure projects?

In addition to the cost trend study, a detailed investigation is carried out (from well-documented and completed projects) to find the actual impacts of the different project settings (size, location, quality assurance) on cost development. This would help to consider these settings to fix cost problems at the early stage of the upcoming projects and consistent cost estimates.

Literature review on factors affecting cost overrun in road construction

A large number of publications could be found on cost overrun in projects, and more specifically on cost overrun in construction projects. In this regard, the general literature (for example, AbouRizk et al. 2002; Ashworth and Perera 2015) showed different estimate classes that cost departure goes through from early estimates with an accuracy of +/- 50% to detail design estimates with accuracy on +/- 10%. Flyvbjerg et al. (2002) and Odeck (2004) defined cost overrun as the percentage difference between the forecast and actual construction costs. A common practice is to use the budget at the time of the decision to build something like the reference cost for calculating the size of overruns.

It seems according to Flyvbjerg et al. (2002) that cost underestimation has not decreased over the past 70 years. Both Odeck (2019) and Flyvbjerg et al. (2002) concludes that the overruns are higher for rail construction than for road construction projects. Odeck (2019) remarked that overruns are higher in Asia and rest of the world, while second highest in Europe, while North America has the lowest mean cost overrun.

Durdyev (2021) investigated the causes of project cost overruns that have been reported in project management articles since 1985. The first assessment of the studies in terms of the countries they reported from reveals that this problem mainly occurred in developing countries, in which the project cost overruns are attributed to resource-related, economic/financial as well as political problems. Durdyev (2021) listed the top ten causes of cost overruns with the highest number of citations to be: design problems and incomplete design, inaccurate estimation, poor planning, weather, poor communication, stakeholder's skill, experience and competence, financial problems/poor financial management, price fluctuations, contract management issues and ground/soil conditions.

Another research by Herrera et al. (2020) pointed out the five most important and frequent causes of cost overruns, (1) failures in design, (2) price variation of materials, (3) inadequate project planning, (4) project scope changes, and (5) design changes. Susanti et al. (2021) studied construction projects in Indonesia, and found 15 factors, site availability delay; site conditions; social site conditions; change order; rework; subcontractor and/or vendor performance; approval/permit delay; inaccuracy in budgeting; scheduling and resource planning; materials price fluctuations; rules and regulations; owner additional requirements; inflation; delay in payment; weak cash flow and bad weather, where rework is pointed as the most important factor.

Creedy et al. (2010) found from a study of Australian Highway construction projects that owner risk variables contribute to significant cost overrun, changes in project designs and scope changes during project development to be the most important factors. The research showed a weak correlation between the size of highway projects and the size of cost overruns. Asiedu and Adaku (2019) found poor contract planning and supervision; change orders; weak institutional and economic environment of projects and lack of effective coordination among the contracting parties to affect the cost overruns of projects in Ghana.

Zafar et al. (2016) found factors like non-availability of suitable contractors, project location, idling cost of plant and equipment due to security threats, differing site conditions in a project and inaccurate survey and site investigation due to security threat. Some research focused on project locations (Fraundorf et al. 1984; Makarachi and Tillotson 1991)

Unlike other causes for cost departure, the involvement of government, regulations and laws, financial challenge, contractual agreements, and pressure have a critical role in cost deviations (Raykar and Ghadge 2016). In line with this, weak governmental budgeting and outdated terms in contracts caused project delay and cost overruns. Samarghandi et al. (2016) showed in their regression model that these factors caused a change between the initial and final project duration and cost with an average delay of 5.9 months per year and an increase in the overall cost overrun by 15.4%.

Besides the impacts of government involvement on cost development, the geographical location of the project and quality assurance have been discussed in the literature and contributed to the cost overrun. According to Assaf and Al-Hejji (2006), and Battaineh (1999) complexity of the project based on their geographical location could cause a delay and cost overrun (e.g. in Saudi Arabia the cost overrun was between 10% and 30%). Flyvbjerg et al. (2004) highlighted the challenges of attributing the causes of cost escalation if it was linked with ownership alone or whether the geographical location. Another study by Karunakaran et al. (2018) claimed geographical location/project topology, inaccurate site investigations are common critical factors that affect cost overrun of infrastructure projects.

Quality assurance is one factor discussed in construction literature (Nyakala et al. 2019, Gidado 1996). In this regard, Mahmood et al. (2014) indicated the relevance of quality assurance in built environment and help to determine cost of poor quality and its overall consequences on productivity and profitability which is more linked to operational activities. However, the Norwegian Quality Assurance Scheme which constitutes two extensive appraisal studies followed by external quality assurance reviews in major investment project's planning process[1]. Both the government, geographical location, quality assurance, project sizes have impacts on cost. These give a new research insight and a need to investigate the individual and combined effects of different project settings (size, location, and quality assurance).

Indeed, the needs for joint effort and collaboration between different stakeholders including the government, public and academic institutions (Hampton et al. 2012; Doloi 2013). In this connection, this paper considers the Norwegian state project delivery model, including the quality assurance (QA) Scheme[2]. In 2002, the concept research program was initiated to develop knowledge contributing to better concept selection, resource usage (including costs/budget) and effect of large public investments. Basically, the program is a framework agreement on QA signed between Norwegian Ministry of Finance and Norwegian constellations of consultants to perform external QA in the planning process of major public investments. The program researches the Norwegian QA scheme and some of previous research showed positive results after implementation of the Quality Assurance Scheme (e.g. Welde and Odeck 2017).

The project delivery model for Norwegian road construction projects has four cost milestones, from the first milestone is when the project enters the National Transport Plan (NTP), a plan for investments in transport for the following10 years, to the projects reach the final cost. In this regard, the Norwegian Public Road Administration (NPRA) follows these four milestones. However, this paper mainly focuses on the last two cost milestones, i.e. between when the final budget is allocated (Granted) to the final cost of the construction.

Previous studies on factors of cost overruns in construction projects are based on both literature review (Adam et al. 2017; Odeck 2019; Durdyev 2021), and expert interviews or questionnaires (Asiedu and Adaku 2019; Susanti et al. 2021). A large variety of factors are found to contribute to cost overruns in infrastructure projects, from inaccurate estimation, poor planning, scope changes, site conditions, delay, material prices etc. We found both strategic factors and operational factors, factors related to the project owner, project management and factors related to the contractor. On an overall level, the factors identified through the literature review gives us a basis for understanding results from our empirical findings in the next sections.

Research methodology and data collection

The research employed a mixed strategy which comprises of literature review focused on cost overrun attributes and descriptive statistical analysis. For review, carefully selected peer-reviewed journal articles and conference papers which focused on the cost performance of construction projects are used.

The literature review aimed to identify previous research findings on factors for cost overrun in road construction projects. The ambition was not to cover every source of information, but rather to make a base of reference for discussion of our empirical findings. The literature review was performed with the use of the university database Oria and Google Scholar. Search words used were Cost Overrun, Construction, Factors and Road. Cost Overrun and Construction gave more than 35 000 hits on Oria, and close to 100 000 hits in Google Scholar. Adding the word Factors to the search gave 80 000 hits in Google Scholar and close to 15 000 hits on Oria. Limiting the search with the word *road* gave around 5000 hits on Oria and 48 000 hits on google scholar. Still, it is too many hits to go through all the sources of information.

By zooming in on the most recent review articles, the appropriate literature was selected based on the abstracts and content analysis. Durdyev (2021) and Odeck (2019) recently summarized literature on the topic of cost overruns and factors affecting cost overruns. Our research used these, but also other sources of information from the literature review, all specific within road and transport infrastructure area.

For the quantitative analysis, the research used descriptive statistics analysis including trend analysis, box plot to check skewness of the data, cumulative distribution function (CDF) plot to check the normality of the data. A two-decades cost data from Norwegian public road construction projects which are registered in a central database and historical data sources such as annual report and trend analysis used.

The study extracted and analyzed both primary and secondary data of road construction projects from the Norwegian Public Road Authority (NPRA). The data comprises both projects which undergo quality assurance and those without quality assurance. Additional historical documents also considered such as trend analysis and annual reports. To address the research questions, the paper organized the data into three datasets (clusters). The number of projects with respective cost data information and the intended purpose at different cost milestones is shown in Table 1.

The project delivery process in Norway

One initiative to obtain better cost performances in Norwegian large investment projects emerged in early 2000 (Klakegg et al. 2008). The background for the initiative was a governmental study on the cost performance of Norwegian public projects at the end of the 1990s, showing a trend on cost escalation

Table 1. Data set based on purpose and research focus at different cost milestones.

No.	Project dataset	Purpose of the data set	Available cost data and research focus on cost milestone
1	110 construction projects	To analyze the general cost development trends. All projects' sizes, location, and projects with and without QA scheme	Between the granted milestone and final cost
2	75 construction projects	To analyze the influence of project location (city vs. rural) and the effect of project sizes.	Between the granted milestone and final cost
3	46 construction projects	To analyze the impact of the QA scheme (both QA1 and QA2), project size (Large vs. smaller), and location.	Cost at all cost milestones (National transport plan, action plan, granted and final cost)

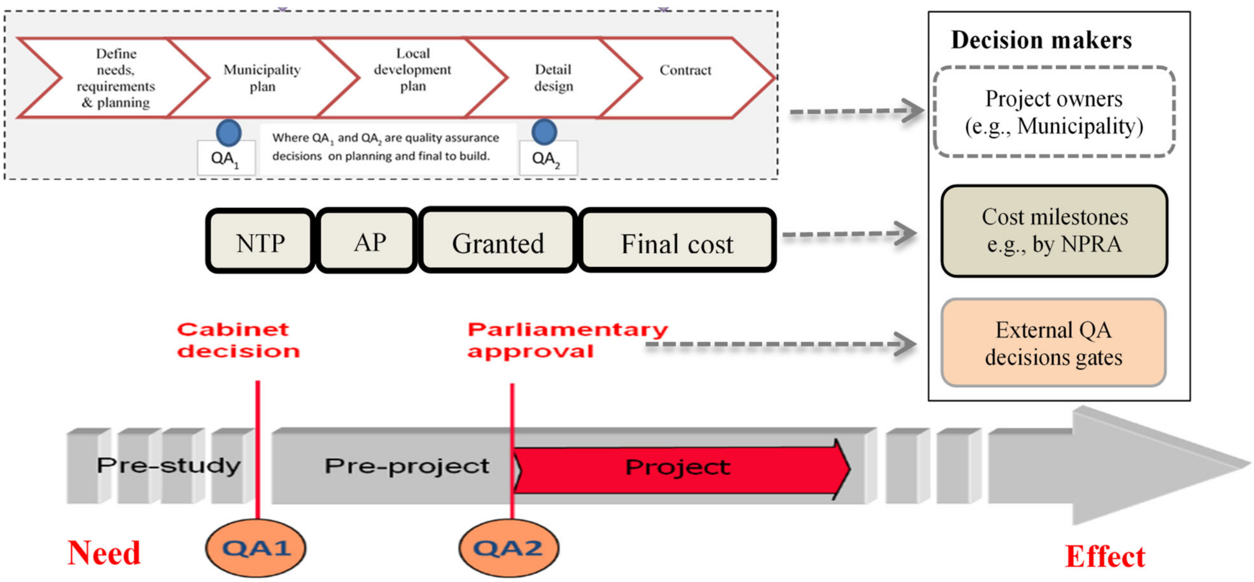


Figure 1. The project delivery process in Norway with cost milestones and QA.

(departure) from initial estimates. Following this escalation, Norwegian Ministry of Finance implemented a quality assurance scheme for the large public projects, including an external quality assurance prior to the final decision to fund the project, now called QA2. In the year 2000 Ministry of Finance engaged consultant companies, for each project one of these consultant companies were hired to do external quality assurance. The quality assessment result served as input to the decision to fund the project. In 2004, new framework agreements were signed, and the QA regime was revised to include quality assurance of the basis for concept selection prior to the decision to start the pre-project, called QA.

According to Samset and Volden (2013), 'a project model is a standard classification of project phases with specific decision points and corresponding documentation requirements'. Every Norwegian public construction project goes through three major project phases (Pre-study, Pre-project, and Project implementation). Throughout these phases, measuring cost performance starts at the Pre-study phase (Samset and Volden 2013; Torp et al. 2016). All Norwegian construction projects also need to go through formal steps according to the Norwegian Planning and Building Act. This is described in the top part of Figure 1, where the projects, after defining the needs, needs to go through a municipality plan and a local development plan before they get approval to go into detail design and construction.

Every 4 years, a National Plan for Transport (NTP) is developed and decided upon by the cabinet, as an overall plan for the investments in transport in the coming 10 years. Large projects enter NTP with a cost estimate. With more detailed information, the project goes to the action plan (AP), which is the road projects to implement in the next 4 years. At a point, the parliament makes the final decision to fund the single project (Granted). This process is quality assured by the external body at to gates, after the Pre-study (QA1) and after the Pre-project (QA2).

National Transport Plan (NTP) is the only milestone document that provides the Norwegian funding and budgetary authorities a comprehensive overview of the existing plans for road investments for the coming 10–12 years. Therefore, NTP is the first crucial step for every transport construction project. Action plan (AP) is the planning step where more information would be available, and it includes the projects to be started in the next four years. Within these four years, the project continues to the granted stage, see the third cost milestone in Figures 1 and 2. Before the final decision to fund the project, the project goes through QA2 to assure all the necessary cost information and make the necessary adjustments. After the project gets funding, the project goes to the implementation phase, normally with detailed design and construction.

Our research focuses on cost development study from the National Transport Plan (NTP) to the final cost documents. It specifically focuses on costs departure from the milestone Granted (budget set) to the final cost.

In connection to cost development study in the planning phase of the Norwegian Public Road Administration (NPRA); initial cost estimates, National Transport Plan (NTP), action/appropriation plan (AP), granted (GTD) and final cost (FC) are the major cost milestones that all projects pass on (Figure 1).

Our research background is embedded with major cost development milestones and the quality gated project delivery model, including the QA Scheme. Torp et al. (2016) showed the general cost escalation between different milestones and found there is a significant cost change between NTP and AP. Torp et al. (2016) also showed there is a difference in cost development between medium-sized and large projects. In medium-sized projects, the cost development was higher than the large projects at the first two milestones but later the cost development declined a bit. In the case of larger projects, the first two milestones showed an increase in cost deviation similar to the medium-sized projects, but the cost continues growing at a lower rate. For example, the larger project case is showed in (Figure 2).

Unlike the previous study that projects undergo only QA2, this research included recently completed projects that undergo both QA1 and QA2 and investigated the impact of the QA scheme on cost performance and other important attributes like location and project size.

Data analysis and discussion

The analysis is organized to make sure the two major objectives and sub-objectives are addressed. The first part of the analysis and discussion covers the general cost trend analysis and performance. The second part deals with cost development and performance with more detailed project settings, such as project size, location, and a two-stage external quality gated assurance scheme.

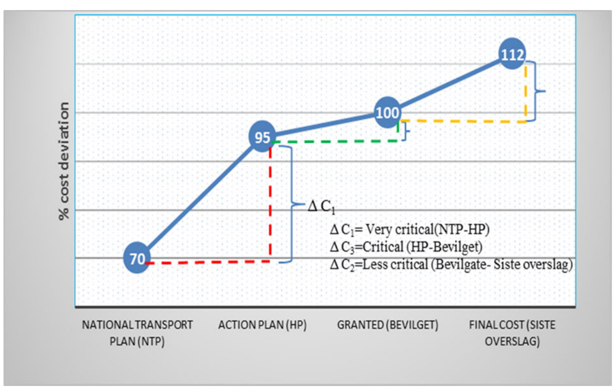


Figure 2. cost development at different cost milestones (Torp et al. 2016).

How is the cost development (departure) trend in construction projects?

The cost developments at different cost milestones are noticeable in some projects and it seems to be beyond the project uncertainty or estimation errors. Therefore, it is important to look at the development trends and analyze cost deviation at each milestone. Figure 4 shows the cost change between milestones granted milestone and final cost (Figures 1 and 2), Figure 6 shows the cost deviation between initial estimate and final cost.

We looked at the overall cost development trends, absolute change in cost departure at specific but crucial cost milestones (between granted and final cost) and highlight cost development trend over time (considering projects over the last 20 years). Although the dyadic relationship of cost and time are the two most inherent attributes in construction literature, the trend of cost over time is not much discussed.

To have a general overview of cost departure, we first go through the normality test on 110 projects using the Andersen-Darling test, which is designed to detect all departures from normality. The Anderson-Darling test measures how well the data follow a particular distribution (normal distribution in this research case). Figure 3 shows that the Andersen-Darling test rejects the hypothesis of normality because the p-value is less than 0.005. This allows us to state with 95% confidence that the data does not fit the normal distribution. This implies that the change between granted and final costs of the projects are not aligned and some of the cost of the project deviates from the theoretical line. This allowed doing more detailed investigation and have a closer look at some of the projects with a larger cost departure. The normality test gives insight that other project attribute, such as project size, geographical location, would contribute to the cost deviation (Torp et al. 2016).

After we checked the normality test using the probability plot, we quantitatively charted the absolute cost departure by sorting the data in ascending order of the project size (Figure 4). The result shows that as the sizes of the project increases, the cost departure increases. The increasing trend on the absolute cost departure allows us to investigate further and look at the effects of project size on cost development. In this regard, this research looked in detail at the spread of cost deviation concerning

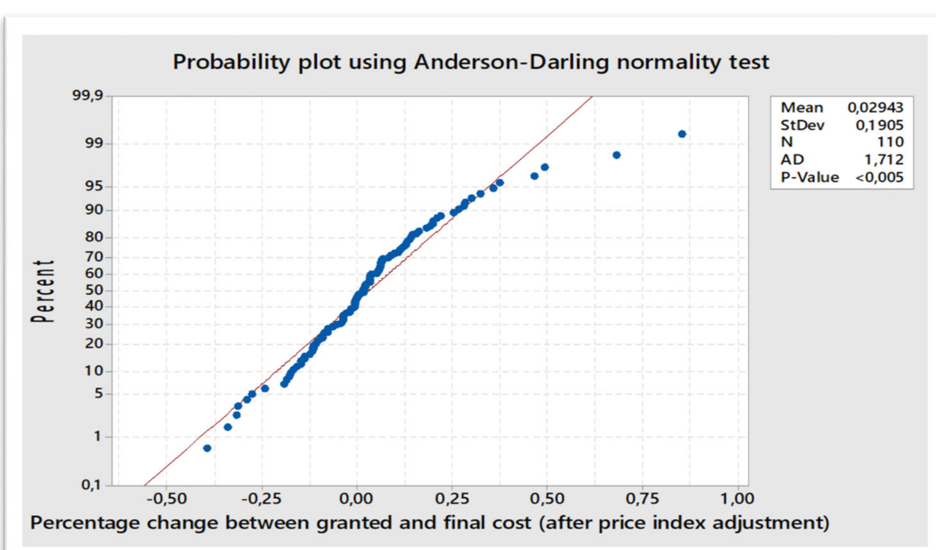


Figure 3. A probability plot for cost departures of 110 Norwegian construction project.

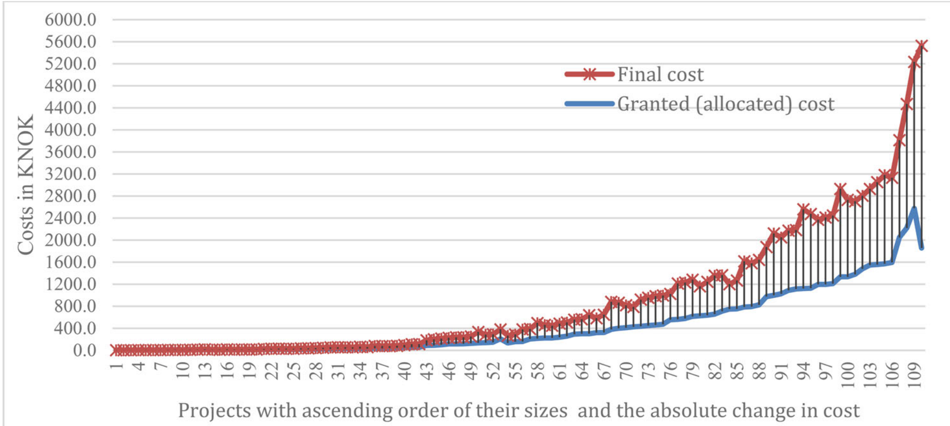


Figure 4. Cost departure from the milestone 'granted' to final cost estimates (project size in ascending).

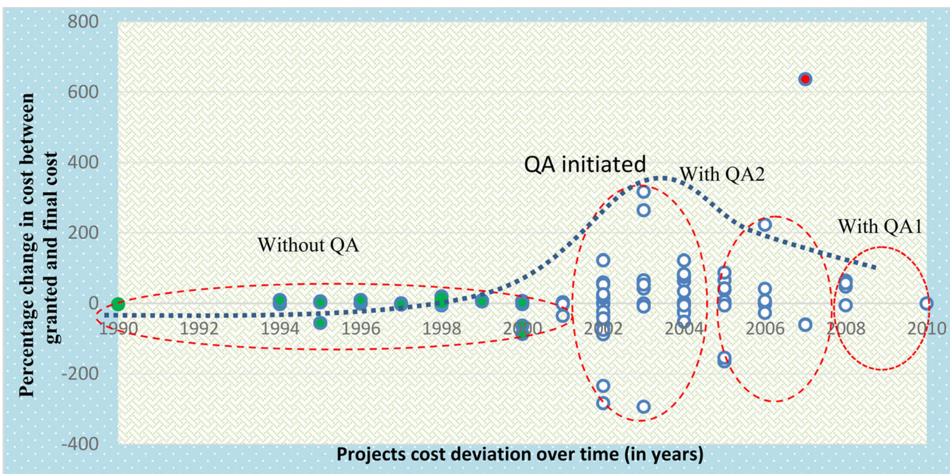


Figure 5. Cost departure over time and quality assurance scheme intervention.

project size later in Section 'Impacts of project size, location, and external quality gated assurance scheme'.

To obtain a better understanding of cost departures over time (to check if there is a time barrier on cost), we carried out a two-step investigation. In the first step (projects between the early 1990s and mid-2000s), the average cost increase of these construction projects was about 3% with appropriate cost index adjustments of the Norwegian road construction concerning the calculated year. Extending these number to 110 projects (including small and large projects), we found a relatively higher cost escalation, about 5% on average. The result showed higher trend change starting early 2000s, between the end of the green, marked data points and beginning of blue circles in Figure 5. This could potentially be due to the market conditions at the mid-2000s financial crises started, see Figure 5 with cost departure marked by a red dotted circle. In general, compared to other construction projects studied by other researchers with higher cost departure (Samset 2010)., the Norwegian projects seem steady except few projects (Odeck 2004). However, some projects registered large deviation although the average of the majority has registered smaller cost deviations.

This indicates that attributes studied by (Akintoye 2000; Abdul Rahman et al. 2013; Torp et al. 2016) are not the only attributes that affect cost development. Therefore, it is important also to look at the time aspect when the cost estimates are made and analysed with necessary price adjustments. This helps to consider an appropriate price index and carry out respective price rectification. However, analysing in detail price and market conditions would be beyond the scope of this study and perhaps, it would require looking at its relationship with other cost attributes.

Impacts of project size, location, and external quality gated assurance scheme

This research extended the qualitative study of Torp et al. (2016) and focused on the three major project settings.

Effects of project size on cost in general

Torp et al. (2016) showed that project size (in monetary terms) and project site (location) are major critical factors for cost deviation, especially at the early construction planning phase. In addition to that, looking at some large cost deviation from our dataset allow us to make a close study at cost deviations and learn the influence of size on the cost development trends. As a starting point, Figure 6 showed the majority of small projects registered a higher spread on cost deviation as compared to the larger projects (referring between the initial milestone NTP and final cost). However, this is just by looking only at the cost deviation and would not reflect the overall impact of each project on the budgetary cost of the public authority. The reason is a smaller change in large projects have a bigger influence on

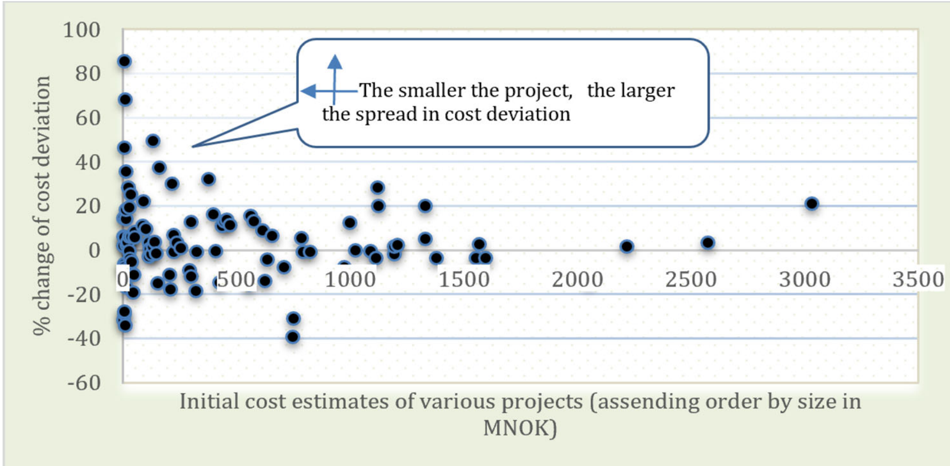


Figure 6. Trends on cost percentage change from initial cost estimates.

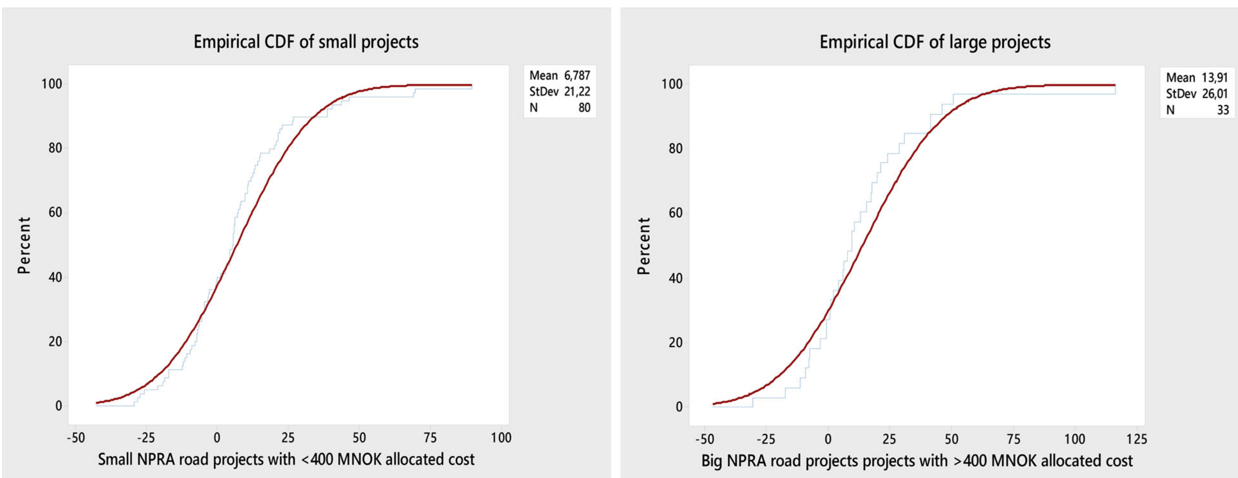


Figure 7. Empirical cumulative distribution function (CDF) analysis for small and large projects.

monetary value (Torp et al. 2016). Nevertheless, regardless of the financial impact of each project, it is important to study the main causes of cost deviation.

Beyond the speculations that larger projects have larger cost deviation than smaller ones as Flyvbjerg et al. (2004) noticed, there is no empirical evidence to prove this hypothesis. However, there are indirect efforts to respond to this discussion. In the same research, they argued large projects have a longer life span and looked at the percentage cost deviation versus length of implementation time (in years). Another comprehensive research by Mahamid (2013) showed smaller projects have a high range and percentage average of cost underestimation.

One reason that exposed smaller projects for high-cost deviation other than underestimation challenge could be the short project life span that does not allow or give the chance for short projects to rectify the cost challenges (Back and Grau 2013; Mahamid 2013). However, Mahamid (2013) did not show cost overestimations for smaller projects. The second reason can be the sensitivity of projects due to external factors, such as the cost price index and inflation. These challenges could be overcome in larger projects as they have a longer life span, this longer duration gives opportunity to use various cost reduction methods over time. Nevertheless, these hypotheses should be supported by doing more empirical and case studies. In this connection, Back and Grau (2013) suggested that small projects are exposed to larger cost deviations due to the inability to rectify negative cost trends in short periods, while longer projects offer the opportunity to identify and mitigate cost deviations during the remaining of the project.

The range spread in Figure 6 showed that there are cost deviation trend differences between smaller and large projects. Therefore, we would like to investigate cost data in detail, analyze it quantitatively, and discuss the influence of size, location and related attributes on cost performance. This will be carried out under the sub-sections below using different methods and statistical tests.

Influence of project expenditure (large vs. small construction projects). Although much of the data were initially from larger projects, this research included several smaller projects to obtain a holistic view of the most developed concerning size. A regression plot from sample projects showed the cost overrun from 'the final bill' of the large projects appears to be higher with the initial granted cost estimates. For example, when we look at the preliminary study of cost departure (projects before 2010), an average cost deviation of about 10% using road construction price index. The spread is greatest for the smallest projects and registered larger cost departure ranges in some of the projects. Cost departure changes when changing the price index (from consumer price index to construction price index) that also brings additional discussion on different sized projects.

To make a closer look at the direct effect of cost development with the size of the projects, initially, we use a threshold value of 400 MNOK to identify and categorize the sizes of the projects. Although there is no standard threshold to classify projects by size (Jørgensen et al. 2012), this research used the NPRA threshold of 400MNOK to classify the projects by their size and fulfil the minimum requirement to be analyzed statistically (>25 data sets). In Figure 7 the research presented the effect of project size on cost deviation using cumulative distribution function (CDF) plot test. This is because empirical CDF is an unbiased estimate of the population (projects) and a consistent estimator of the true CDF at any value of projects. Although the size of the sample data would affect the results of the statistical analysis, the result clearly showed few, but larger projects have a higher impact on the overall change in the actual costs, see Figures 5 and 6. However, it is also important to note that many small projects showed large percentage change in costs. Despite the percentage changes in cost, the trend line of large projects is increasing more than the smaller projects (Figure 7). This implies that project managers should consider project sizes as one factor and consider the impacts and overall cost development trends together with other relevant factors while doing cost estimates.

Because it is difficult to have a solid conclusion from the cost trend in Figure 7, we further analyzed the data in detail using boxplot and descriptive statistics which helps to see if a distribution is skewed, check if there are outliers (unusual data), and summarize the data set considered. The process is done for both settings of project size, location, and quality assurance scheme.

The recent report from the Concept research program and Ministry of Finance showed the threshold point for large projects are 750MNOK to 1 Billion NOK [3,4]. Using this threshold and incorporating other new projects, we looked at the impact of project size on cost performance. To do this, we use the four major cost milestones from public road authority (NTP, AP, GTD and FC) and see the cost development. Figure 8 shows that large projects are underestimated at (NTP) as compared to smaller projects. However, larger projects later registered larger cost deviation at the final cost milestone.

Cost deviation trends per quality assurance (QA) gates and cost milestones

Before we go to the detailed analysis of cost performance, we analyzed our raw dataset using a boxplot to see if QA influences project cost with different project settings. In this case, we refer to QA2 which was the only quality assurance gate with a 450MNOK threshold for large projects. As we see in Figure 9, quality assurance QA2 and project size of the project have an influence on cost but at different magnitude. Typically, smaller projects have a large deviation from the initial estimates, but large projects showed a smaller cost deviation. However, outliners of a large project in the boxplot indicate these projects could have a high impact in monetary terms. Similarly, city projects registered higher deviation without outliners and rural projects showed smaller deviation with five outliners.

It is inherent that construction cost develops over time. However, the cost development varies from one cost milestone to the next milestone. The research analyzed the cost developments of 46 medium and large-sized projects of the threshold value 450 (In Figure 10). These projects undergo through quality assurance schemes. The sets of projects considered are projects completed before and after 2010 which means they undergo both QA1 and QA2 (before QA1 implemented see Figure 1). This allows the study to see the impact of the QA scheme on cost development. Most of the projects from 2002 to 2010 exposed only to QA2 and the recent projects after 2010 undergo QA1 and QA2.

The result shows that there is a positive cost development overtime at different milestones. However, cost development before the implementation of QA (in the case of introducing both QA1 and QA2) showed a steep cost increment. Nevertheless, the steepness of cost development decreases after introducing both QA1 and QA2. In both scenarios, there is a cost change over time but in the latter case, the increment is at decreasing rate (see Figure 11 highlighted with blue and red lines with final cost differences by about 9%).

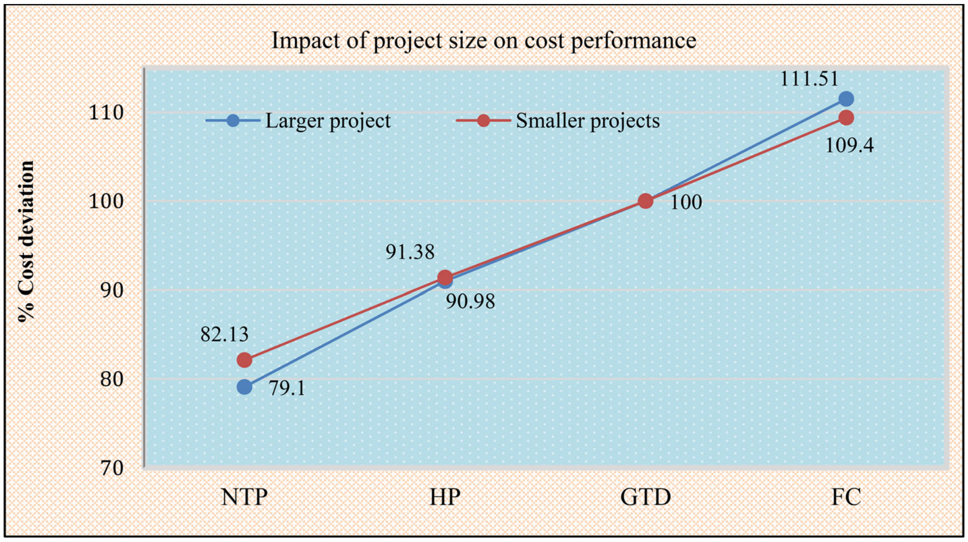
Influence of urban (metropolitan) vs. rural construction projects on cost

In addition to cost departure due to project sizes, we analyzed construction projects based on their geographical settings, see Figure 11. In this regard, projects can be classified as urban (city) projects and rural which are built in a more rural setting. What characterizes the urban projects is that the cost overruns appear to increase more than the case of the rural projects. This is seen in the results of descriptive statistics (in Table 2) and on the boxplot of project location (Figures 11 and 12). Rural and smaller projects are negatively skewed (Figure 13). However, it is difficult to generalize the results from the statistics because the data set for each category are not equal in size (see the width of the boxplot in Figure 13). Some of the main reasons for urban projects to register a higher cost deviation maybe; because they are implemented in a relatively densely populated area, handle large amounts of traffic through or near the site, lack an overview of what is in the ground (existing infrastructures like cables, tubes, and rocks), restrictions concerning blasting, dust, noise, restrictions regarding working hours, etc. Generally, the reasons and changes in cost departures would give decision-makers a signal to consider project size and locational setting of the project during the early planning and initial cost estimations.

The total number of projects considered after QA2 implemented are 75 projects (60 rural and 15 city projects). 8 of the city projects are large and the other seven are smaller. Out of 60 rural projects, 17 were large and 37 smaller projects.

The research further investigated cost performance based on projects locations and analyze cost performance at different project milestones (Figure 14). The result showed city projects have a larger cost departure than the rural ones. At NTP, which is a very early stage, rural projects showed a bit higher cost deviation than city projects. However, a significantly large cost deviation registered in the last three cost milestones including the final cost. It seems like the cost deviations for city projects is high from granted to final cost compared to rural projects. This could be due to complexity under detail planning and construction.

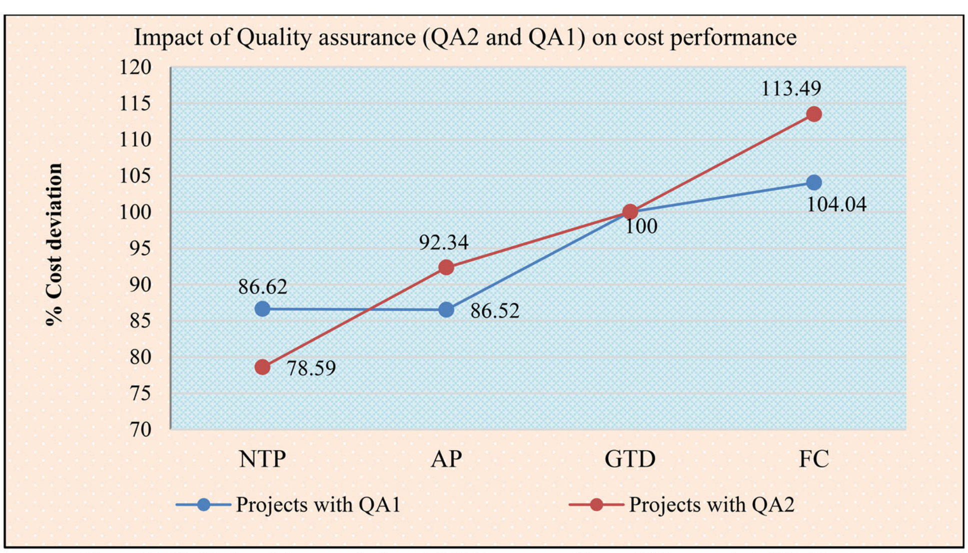
To validate the qualitative results, we carried out a quantitative analysis on different project settings to test how they influence (impact) cost development. Table 2 clearly showed the larger influence on cost performance of larger projects (comparing size in monetary terms), city projects (location), projects with QA2 (comparing the two-step quality assurance scheme). This interesting observation leads to the question: how QA2 showed a significant influence on cost percentage deviation



Where: NTP=National transport plan; AP=appropraition, GTD= granted; FC=Final cost

Figure 8. Impact of project size on cost development at different milestones.

Figure 9. Box plot showing the influence of QA in a different project setting.



Where: NTP=National transport plan; AP/HP=appropraition, GTD= granted; FC=Final cost

Figure 10. Impact of gated quality assurance scheme.

(Figure 9) while the overall QA (both QA1 and QA2) implementation registered a relatively lower impact on the cost compared to other project settings? The possible scenarios could be, a) it could be because the number of smaller projects (without QA) is more than the larger projects considered; b) Most of the projects that undergo both QA2 and QA1 are large and this means a small percentage change in large projects have huge impact on monetary value than smaller projects with higher percentage deviation.; this could be an indicator to further investigate if there is any correlation between project size and external QA scheme by incorporating more large projects which undergo QA1; c) the data itself, i.e. some older projects lacks full information on cost development at the first two cost milestones. Unlike older projects, recent projects undergo a QA1 scheme that helps to trace all cost development and obtain better cost control/management.

For a better understanding of the influence of cost growth using the different project setting at different cost milestones, we compared cost performance first at each milestone. The general trend shows cost evolves. Nevertheless, the change in cost varies from one setting to another and from one milestone to another milestone (see Table 2).

The research carried out a point-to-point cost comparison using a pair of cost milestones, i.e. between NTP and FC, AP, and FC, and finally between GTD and FC. Then it compared the cost change between the results from cost growth calculations (Table 2) and the part of the descriptive statistics of Table 3. It seems both follow a similar trend that still metropolitan projects with large cost deviation.

To summarize the cost development in the three-project setting considered with full cost information, the study uses a line diagram to see the cost trend change at different cost milestones (Figure 15). Although the two most important cost milestone are granted (GTD) and final cost (FC) that the research wants to focus on, looking at the first two milestones could serve as a learning milestone for future accurate cost estimations. As it is highlighted above in Section 'Influence of urban (metropolitan) vs. rural construction projects on cost', there is a relatively closer

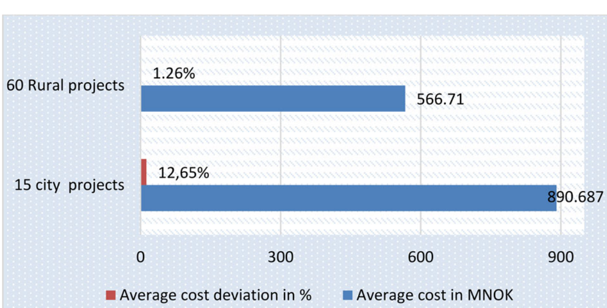


Figure 11. Rural and city projects' cost deviation and average final cost.

and somehow consistent cost growth between NTP, AP, GTD. This is especially reflected when it is looked at the project size and location. But the trend is different in the case of QA2 and QA1. The impact of implementing the concept research program and applying a two stage QA scheme is clearly presented in Figure 15 and the cost development trend in Figure 5. Regardless of the individual project cost performance and direction of cost growth (increase or decrease), there is an overall cost reduction between the GTD and FC milestones (see purple colour in Figure 15 of projects with QA2 and QA1 at the last comparison). This cost reduction due to the concept research program not only strengthen the findings of Welde and Odeck (2017), but also investigated additional settings (e.g. location and size) for better investment decisions on future construction projects.

Managerial implications

By combining the effects of the three project settings (size, location, and quality assurance scheme), we found that project location showed a larger impact on cost development than the other settings (Figure 16). The two-stage quality assurance scheme also showed a positive effect on cost reduction, i.e. projects that undergo in both QA1 and QA2 showed cost reduction. This is mean projects with better control on cost estimation and concept evaluation can register better cost performance than projects that undergo only a single QA2.

To sum up the overall results and implications, various project setting together with the cost milestones are used to show the results summarized in Table 4. For example, smaller projects showed slightly higher cost increment at NTP and AP, but the final cost showed lower than the large projects. Similarly, rural projects registered higher increment in early phases (NTP and AP) but showed lower cost deviation at final cost (FC). An interesting observation is projected without quality assurance showed lower cost deviation compared to projects with QA. This deviation may need further research on project characteristics and external factors which contribute to the deviation typically to the projects which are completed before the 2000s which lack complete information and different data registry and repository systems. However, the inflation, project size, technology, and complexity together with other attributes could be some reasons for registering lower cost deviation as highlighted by (Arditi et al. 1985; Wood and Gidado 2008).

Reflections and takeaways

- Generally, construction projects considered in this research showed a decreasing trend in cost deviation, but still registered about 5% cost deviation over the budget (considering

Table 2. Empirical analysis on the combined effects of project settings on cost growth.

Projects data (clusters)	Project Setting	Attributes	**Cost growth rate (%) between granted (initial) and final cost (FC).** n=number of projects $\sum_{i=1}^{n}\left(\frac{FC-GTD}{GTD}\right)X100$
110 projects	Project size (in monetary)	Smaller size project	9.4%
		Larger size projects	11.51%
	With and without QA	Without QA	0.5%
		With QA	1.76%
75 projects	Project location	Rural	5%
		City	24%
46 projects	Projects with QA2 vs QA1	Project with QA2	13.49%
		Project with QA1	4.04%

all projects of different sizes and location). Our closer look at cost development using various settings, such as project size and locations registered different magnitude in cost departure (Figures 8 and 12).

- From the analysis, project size (large vs. small) and geographical locations (city vs. rural) affects the cost development. Smaller projects showed a larger cost departure than the larger projects. However, the impact of smaller projects on the total budget is lower than the large ones. Therefore, managers to need to emphasize the overall impact of the project rather than focusing on the cost deviation. Concerning project locations, city projects registered a larger cost deviation than the rural projects.
- As contribution and studying cost development more holistically, the research highlighted the relevance of investigating specific project settings in detail that would influence cost departure at most. In this connection, it would be important to incorporate attributes, such as cost relative to traffic capacity, production and productivity, price indices, and stakeholder management to see the holistic effects of different variables on cost deviation.

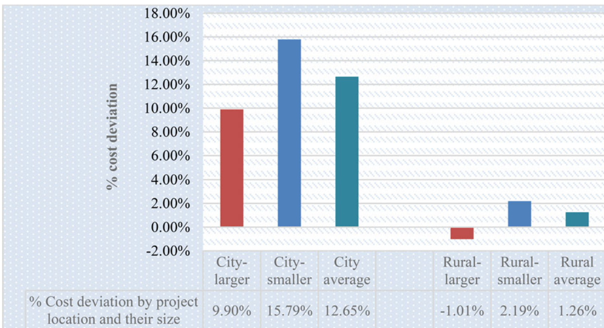


Figure 12. Combined effect of project size and location on cost deviation.

Research findings are supported by the existing literature (e.g. Flyvbjerg et al. 2004; Odeck 2004; Siemiatycki 2009). Although Flyvbjerg et al. (2004) claimed all project sizes and types have a risk of having cost escalation, this research found out that smaller projects showed higher departure than the larger ones. This is in line with Odeck's (2004) findings. Another study by Shrestha (2013)

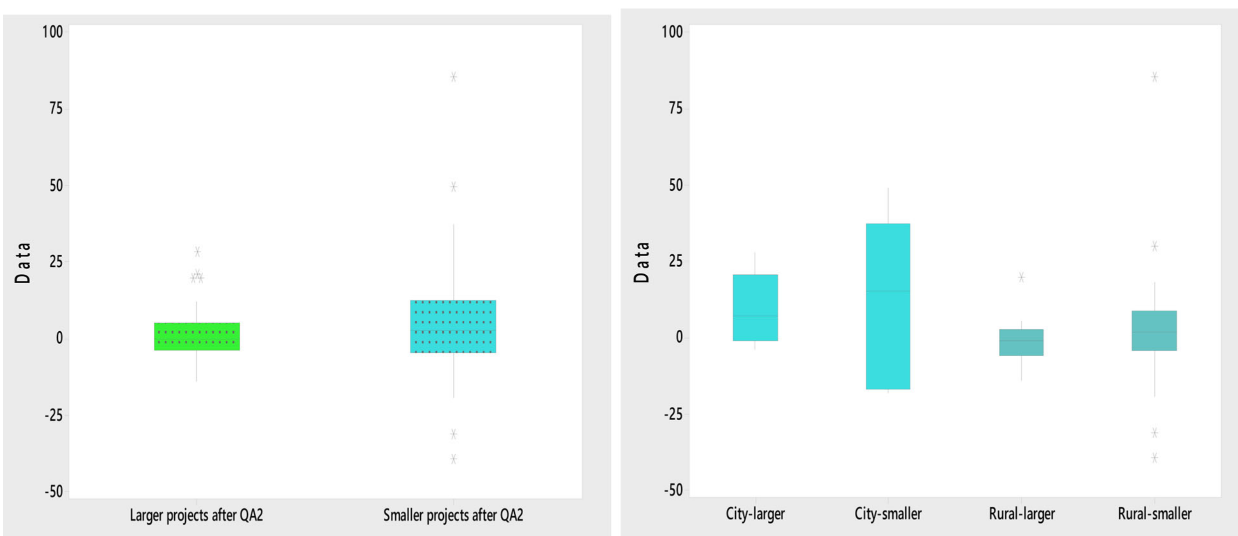
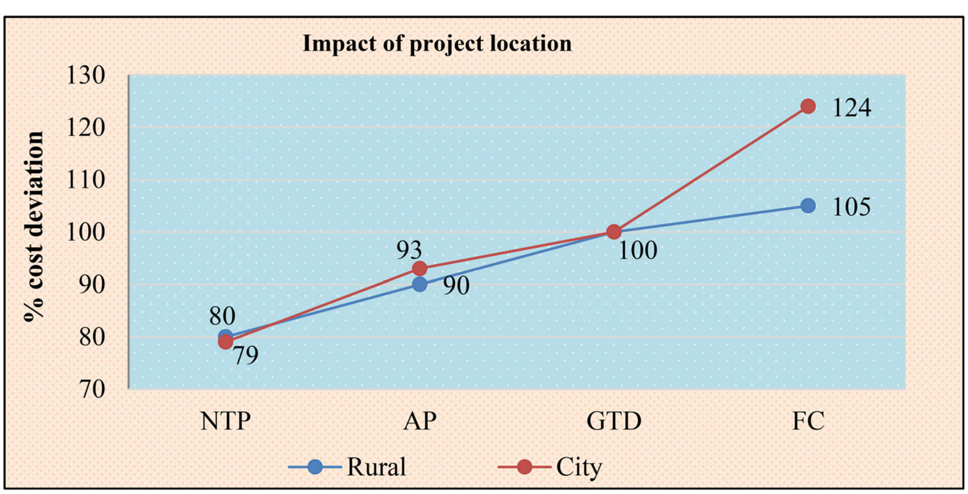


Figure 13. Boxplot of cost deviation concerning project size and project location with QA2 implemented.

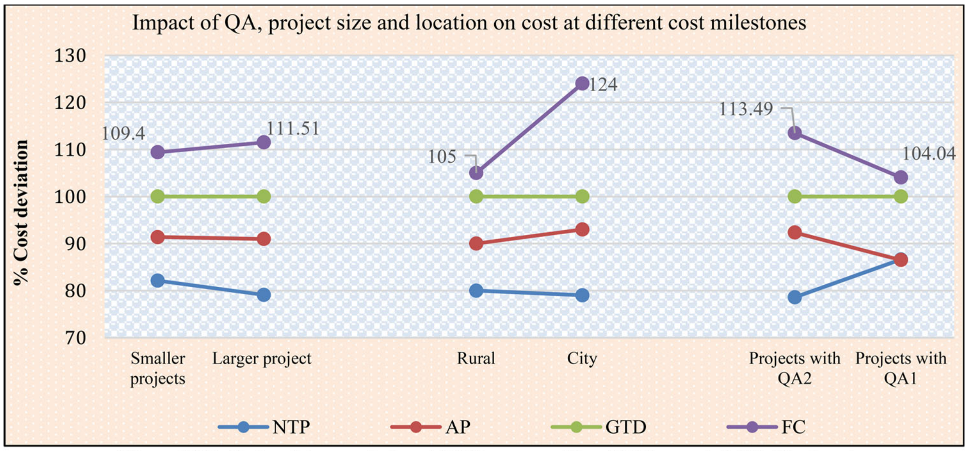


Where: NTP=National transport plan; AP/HP=appropriation, GTD= granted; FC=Final cost

Figure 14. Impact of project location on different cost milestones.

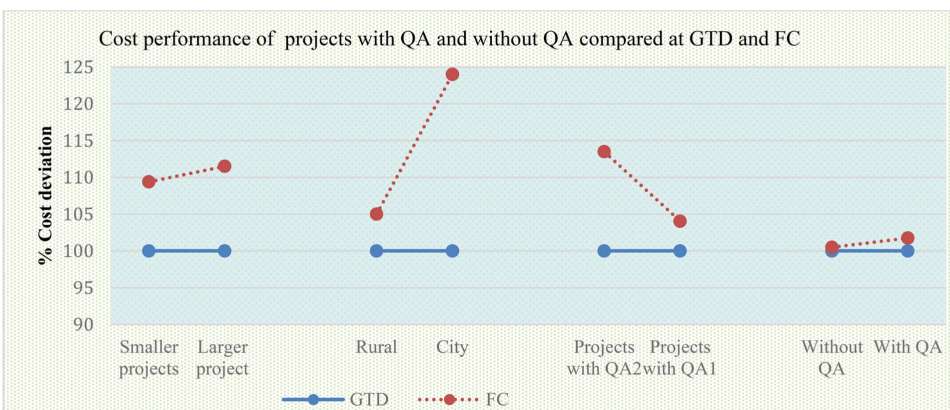
Table 3. Cost at milestones, project setting (project size; location; quality gates), and descriptive statistics.

Cost milestones	Smaller	Larger	Rural	City	With QA2	With QA1	With no QA	With QA
NTP	82.13	79.1	80	79	78.59	86.62	NA	NA
AP	91.38	90.98	90	93	92.34	86.52	NA	NA
GTD	100	100	100	100	100	100	100	100
FC	109.4	111.51	105	124	113.49	104.04	100.5	101.76
From Descriptive statistics								
Std. dev Between	**smaller**	**larger**	**Rural**	**City**	**With QA1**	**With QA1**	**With no QA**	**With QA**
NTP-FC	11.67	13.73	11.09	18.80	14.59	9.070	NA	NA
AP-FC	9.013	10.29	7.64	16.26	10.71	9.17	NA	NA
GTD-FC	6.65	8.14	3.53	16.97	9.54	2.86	0.354	1.24
From % growth GTD-FC	9.4	11.51	5	24	13.49	4.04	0.5	1.76



Where: NTP=National transport plan; AP/HP=appropraition, GTD= granted; FC=Final cost

Figure 15. Cost performance at different cost milestones and project setting.



Where: GTD= granted; FC=Final cost

Figure 16. Cost growth between GTD and FC by considering various project settings.

Table 4. Summary on the influence of project setting at different cost milestone on cost.

Project setting	% cost dev. NTP	% cost dev. AP	% cost dev. GTD	% cost dev. FC
Smaller sized projects	*Higher (slightly)*	*Higher (slightly)*	*Same (Base)*	*Lower (slightly)*
Large-sized project	*Lower (slightly)*	*Lower (slightly)*	*Same (Base)*	*Higher (slightly)*
Rural	*Higher (slightly)*	*Higher (slightly)*	*Same (Base)*	*Very Lower*
City	*Lower (slightly)*	*Lower (slightly)*	*Same (Base)*	*Very Higher*
With QA2	*Lower*	*Higher*	*Same (Base)*	*Higher*
With QA1	*Higher*	*Lower*	*Same (Base)*	*Lower*
With QA (QA1&QA2)	*NA*	*NA*	*Same (Base)*	*Higher (slightly)*
With no QA at all	*NA*	*NA*	*Same (Base)*	*Lower (slightly)*

showed smaller and short duration projects have lesser cost and schedule deviation. Similarly, (Mahamid 2013) found a correlation between project size and cost deviation in the road construction project. However, in addition to Mahamid (2013) finding, this research provided additional dimensions (attributes) besides the sizes of the project, such as project location, considering contracts and other related important consideration in cost development.

The research findings have both theoretical and practical implications. Firstly, this study implies considering cost development systematically using different settings (project size and location; large vs. small and rural vs. urban). This helps to make accurate estimates and create a better understanding of how the actual cost develops starting from the project inception. Second, it helps to identify important attributes in the cost development that have a huge impact on the total costs of the project such as quality assurance, location (city), size (large). Identifying and considering such settings and factors would serve as input for better cost estimates and make critical decisions (e.g. cost-benefit analysis) on the upcoming projects. Thirdly, the research strengthens and complement the cost-related studies to improve project delivery method under the Norwegian concept research program with the close collaboration of the government, public authorities, and academia. These three implications will enable construction managers and project owners to understand major cost attributes using specific project setting which would help to balance the cost departure throughout the project life cycle. The practical implication is mainly linked with helping managers to strengthen cost estimation capabilities at the early project phase through quality assurance (QA) schemes.

Conclusions

The overarching objective of the research is to understand different types of project setting (size, location, quality assurance) which should be considered to manage cost development in road transport infrastructure (road construction). This understanding will enable project owners, construction managers, firms and stakeholders in planning and monitoring the cost development effectively throughout the project life cycle. Indeed, this requires a well-structured systemic cost study, learning from good practices and experiences from a completed and/or ongoing project as this research intend.

The research aimed to obtain an in-depth insight on systemic cost development study by closely looking at the cost development trends using different project settings. Project size, geographical location, the Norwegian quality assurance scheme as was considered as the main settings and analyzed to see the influence on cost departure. In this connection, first, we started by investigating the background of cost development and the challenges that NPRA faced. Then we considered and looked at more than 110 construction projects to conduct various statistical analysis such as trend analysis, and probability plot using empirical CDF, etc.

Generally, the result showed that there is an increase in costs departure between the initial cost estimate and the final costs. However, the increment is at decreasing rate especially after the first quality assurance (QA2) scheme implemented. Using the project settings, the trend analysis (linear, average, and empirical CDF of 110 road construction projects) for small vs. large and urban vs. rural projects showed a significant cost departure from the initial cost estimates. For example, smaller projects registered higher percentage change in cost departure, but they showed lower impact in monetary terms (in line with Torp et al. 2016). Using geographical location as a project setting, city projects registered a high-cost departure than the rural road projects. The two-stage Norwegian quality assurance scheme (QA2 and QA1) clearly showed the impacts on cost departure, regardless of the number of projects which undergo in the two quality gates.

All these thematically relevant results indicate the broadness and challenges in obtaining a systemic cost development study in construction projects. This implies project managers should consider multi-criteria decision making by taking into account different project settings. This research gives practical insight on how to conduct better cost development study using specific or combined project settings. The results could serve as an input for multi-attribute cost decisions. In this connection, the research focused and deeply analyzed the three major project settings. We recommend the results could be further incorporated with other cost attributes even for better decisions at an early stage of the project and overcome proactively the cost challenges during implementation. The research could be replicated using similar settings and further be verified by studying more projects in other countries. This in-depth cost development research would lay a foundation and enable project managers to make better and accurate cost decision on infrastructure projects by considering different project settings, such as project sizes and locations.

Notes

1. https://www.ntnu.edu/concept/qa-scheme
2. https://www.ntnu.edu/concept
3. https://www.ntnu.no/documents/1261860271/1261974602/En-sides+presentasjon+av+Concept+2016+-+engelsk.pdf/ffad6cc1-89c1-47e4-a211-7fc2459e7d25?version=1.0
4. https://www.ntnu.edu/concept/background-and-history

Disclosure statement

No potential conflict of interest was reported by the authors.

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