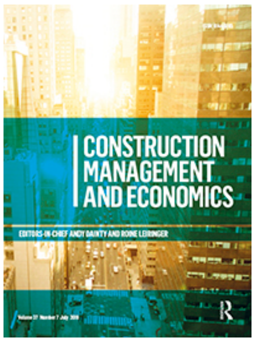

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Effect of project complexity on cost and schedule performance in transportation projects

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ABSTRACT
Project complexity is a contributing factor to project performance. Understanding how project complexity interacts with management actions and project performance is imperative. This study fills this knowledge gap by empirically exploring the relationship between construction project complexity and project performance and their interaction with resource allocation. Empirical data were collected from 79 transportation projects. Due to its capability to build several regression models by adding independent variables to previous models, moderated hierarchical regression analyses were conducted to identify the underlying effect of resource allocation on the project complexity and performance relationship. The results show that: (i) project complexity was significantly correlated with schedule growth (positive correlation) but not significantly correlated with cost growth; (ii) resource allocation was significantly correlated with schedule growth (negative correlation) but not with cost growth; and (iii) resource allocation had a buffering effect where increasing resource allocation significantly decreases the effect of project complexity on schedule growth. The findings from this study contribute to the extant literature on construction project complexity by empirically showing that the impact of project complexity on schedule performance interacts with the level of resource allocation. This understanding of the role of resource allocation may help construction managers and engineers to better administer and manage their complex transportation projects. The findings also imply that organizations should appropriately evaluate project complexity to allocate necessary resources to achieve project success.

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Complexity; resource allocation; cost performance; schedule performance; transportation projects

Introduction

The complexity of a construction project has increased in many sectors because of various causes such as funding constraints, technical concepts, or regulatory and environmental issues. Research has shown that a lack of managing project complexity is one of the major factors contributing to project failure (Miller and Hobbs 2005; Brady and Davies 2014; Bakhshi *et al.* 2016; Mirza and Ehsan 2017; Shenhar and Holzmann 2017). According to U.K. government departments, project complexity has increased considerably over the last decade, but the subject has received inadequate attention, with a negative impact on project outcomes (Chapman 2016). The complexity is even more for infrastructure projects because of their typical large scale and risk and uncertainty involved in the project development process. For example, uncertainty in budget, project scope and delivery selection together with technological advances, economic liberalization and globalization and environmental issues resulted in the growing complexity of infrastructure projects (Gidado 1996; Chen *et al.* 2004; Naderpajouh and Hastak 2014). Recent studies on megaprojects indicated that complex infrastructure projects become more commonplace despite their performance problems (Flyvbjerg 2014; He *et al.* 2015; Eriksson *et al.* 2017; Söderlund *et al.* 2017). Specifically, although large and complex infrastructure projects play a vital role in any society, their cost overruns, schedule delays, and exaggerated benefits are the norm rather than the exception (Flyvbjerg *et al.* 2009; Locatelli *et al.* 2017). As such, both practitioners and academics are interested in understanding project complexity (Cooke-Davies *et al.* 2007; Geraldi *et al.* 2011; Shenhar *et al.* 2016).

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Project complexity has been extensively explored in the literature. For instance, various studies have recognized the importance of assessing and measuring project complexity (Baccarini 1996; Williams 1999, 2017; Xia and Lee 2005; Vidal and Marle 2008; Daniel and Daniel 2018). Further, Sinha *et al.* (2006) argued that the measurement of project complexity would help address the cause of many engineering and management-related problems in projects. Kim and Wilemon (2003) suggested that more research is needed to investigate the role that complexity plays in the successful delivery of projects.

A number of definitions and measurements related to project complexity have been proposed (Qazi *et al.* 2016). While project complexity is widely recognized as a source of poor project performance, little empirical evidence has supported this contention (Xia and Lee 2004). In construction projects, Antoniadis *et al.* (2011) found that project complexity has been conducted mainly from a technical perspective and not directly addressing the effects of complexity on project performance. The assumed linkage between project complexity and project outcomes lacks theoretical base and empirical evidence (Floricel *et al.* 2016). Accordingly, it is crucial for improving the current understanding of managing complex projects (Flyvbjerg 2014; Eriksson *et al.* 2017; Luo *et al.* 2017a). In particular, the understanding of how project complexity interacts with management actions and project performance is imperative.

This study fills this knowledge gap by empirically exploring the relationship between construction project complexity and project performance and their interaction with resource allocation. This study aims at investigating how the levels of project complexity and resource allocation correlate with project performance and the moderating role of resource allocation in the relationship between project complexity and performance. Cost growth and schedule growth were the two performance metrics used in this study. Although project performance can be evaluated in a variety of metrics, cost performance and schedule performance are the dominant measures (Puddicombe 2012). The unit of analysis of this study was construction transportation projects recently completed in Vietnam. The rest of this paper proceeds as follows. The next two sections describe theoretical background that derives the research hypotheses and the research methodology. These are followed by results and discussion. Conclusions are drawn and provided in the final section.

Theoretical background and research hypotheses

The complexity of a project is not well-understood in the project management community and it takes a variety of perspectives (Padalkar and Gopinath 2016; Dao *et al.* 2017; Shenhar and Holzmann 2017; Daniel and Daniel 2018). For example, Girmscheid and Brockmann (2008) proposed the four different types of complexity for international large scale engineering projects including overall, task, social and cultural complexity. Bosch-Rekveldt *et al.* (2011) found 50 elements contributing to the complexity of engineering projects. These elements were categorized as technical, organizational and environmental complexity. Kiridena and Sense (2016) proposed three levels of the project complexity profile, namely *complicated systems*, *complex systems* and *complex adaptive systems*. Some researchers suggested that the level of project complexity needs to be identified early in the project development process (Gidado 1996; Eriksson *et al.* 2017).

Resulting from extensive research in the area of project complexity, systematic reviews of project complexity studies were conducted in the past years. Geraldi *et al.* (2011) reviewed 27 papers published from 1996 to 2010. The authors found that the forms of project complexity have evolved over time, from structural complexity in the mid-1990s to multifaceted complexity (e.g. structural, uncertainty, dynamic, pace and socio-political complexity) in the late-2000s. It is noted that there are two streams of work related to project complexity identified in the literature: "complexity in projects" and "complexity of projects". While the first stream views projects through various complexity theories, the second stream aims to find the characteristics of complex projects and how project teams respond to these characteristics (Geraldi *et al.* 2011). This current study is built upon the understanding from the second stream of project complexity. Luo *et al.* (2017a) conducted an extensive review of project complexity from 74 published articles in the past two decades. The authors found that these studies have chiefly focused on four areas: (i) factors affecting project complexity; (ii) the effect of project complexity on project success; (iii) methods for measuring project complexity; and (iv) approaches to managing project complexity. It is important to note that previous studies did not explore the relationship between different types of complexity and project performance (Luo *et al.*, 2017a). More recently, de Rezende *et al's* (2018) bibliometric analysis indicated that the focus of project complexity research was changing from project control to project adaptability.

Apparently, more research on project complexity is needed to understand its impact on project outcomes and the role of project management actions in alleviating its negative impact. For example, Davies *et al.* (2016) highlighted that the complexity facing project-based organizations depends on their dynamic capabilities to simultaneously exploit and explore. Pich *et al.* (2002) found that the experience and problem-solving capacity of an organization would determine the levels of uncertainty, ambiguity, and complexity that the project team faces. Chapman (2016) observed an increasing assertion that the management of complexity is a prerequisite for project success. Further, Eriksson *et al.* (2017, p.1520) suggested that "*the higher the complexity, the more flexibility-focused project management practices are needed*". In line with this argument, this study empirically investigated (i) the relationship between project complexity and project performance and (ii) how resource allocation interacted with the connection between complexity and performance.

Relationship between project complexity and project performance

Project complexity is widely assumed to have a negative association with project performance and success. This construct has been extensively explored in the literature due to its contribution towards cost and time overruns of major projects (Qazi *et al.* 2016). Project complexity is a major source of uncertainty and risk, which results in additional costs and has a substantial impact on project performance if a project team fails to address it from the early phase of project life cycle (Williams 1999; Shenhar *et al.* 2002; Floricel *et al.* 2016). For example, Tran *et al.* (2015) found that project complexity is a key factor affecting cost and schedule performance in the project delivery selection process. Mirza and Ehsan (2017) suggested that growing complexity is one of the main causes behind the failure of many projects. Similarly, Liu (1999) argued that challenging goals are more likely to improve project performance in less complex projects.

Previous studies explored the impact of complexity in different types of projects such as new product development (NPD) and information systems development (ISD). Complexity can delay the NPD process and adversely affect NPD performance (Kim and Wilemon 2003). Likewise, Tatikonda and Rosenthal (2000) conducted a survey of 120 high-tech NPD projects and found that project complexity was negatively associated with unit-cost outcomes. The complexity poses vulnerabilities to the success of major NPD projects (Qazi *et al.* 2016). Similar to NPD projects, from the correlation analysis of 541 ISD projects, Xia and Lee (2004) found that overall ISD project complexity was negatively associated with delivery time, cost, functionality and user satisfaction. In contrast, Tatikonda and Rosenthal (2000) found that the aggregate project complexity dimension was not associated with the achievement of the time-to-market objective of NPD projects.

In the construction industry, the relationship between project complexity and their performance and success has also been explored in recent literature. Antoniadis *et al.* (2011) conducted five case studies in construction projects and showed the inverse correlation between complexity of interconnections and project performance. Through interviews and conducting six case studies in the architecture, engineering and construction (AEC) industry, Senescu *et al.* (2013) revealed a positive trend between complexity and communication problems. Technical complexity affected project performance from an analysis of more than 1300 construction projects in process industries (Puddicombe 2012). Floricel *et al.* (2016) conducted a canonical analysis of 81 questionnaire responses in various sectors (energy, transportation infrastructure, water infrastructure, etc.) and concluded that complexity factors were collectively and negatively associated with completion performance. Luo *et al.* (2017b) collected 245 valid responses through a web-based questionnaire to understand the relationship between project complexity and project success from the perceptions of practitioners in China. The authors found that project success was significantly correlated with project complexity.

Due to the lack of empirical project data, researchers used simulation to demonstrate the relationship between project complexity and performance in addition to opinion-based data (e.g. surveys and interviews) discussed previously. System dynamics simulation showed that project complexity factors including project uncertainty, infrastructure newness, infrastructure interconnectivity, and infrastructure size had an inflating effect on project cycle time (Lebcir and Choudrie 2011). Using a dataset generated from Monte Carlo simulations, Kennedy *et al.* (2011) illustrated the influence of project complexity on the communication-performance relationship.

In summary, the literature has either assumed or demonstrated the negative effect of project complexity on project performance with little empirical evidence from analysis of project data. To fill this knowledge gap, this study has the following hypotheses to examine the relationship between project complexity and project performance for transportation projects.

Hypothesis 1a (H1a): Project complexity is significantly positively correlated with project cost growth.

Hypothesis 1b (H1b): Project complexity is significantly positively correlated with project schedule growth.

As defined later in the Methodology section, cost growth and schedule growth are inversely proportional to cost performance and schedule performance, respectively.

Relationship between resource allocation and project performance

Resource allocation plays an important role in project delivery. Project managers, therefore, need to assess the consequence of resource shortage in complex projects (Ivory and Alderman 2005). In a broader view, Bertolini and Salet (2008) argued the need to commit the management of a complex project in order to overcome political, social, legal and financial obstacles. Project management is solving problem needs (Joham *et al.* 2009) that typically require sufficient resource allocation (Gransberg *et al.* 2013). From a study of 18 complex transportation projects in Canada, the U.K. and the U.S., Gransberg *et al.* (2013) emphasized that for a given project, the resource needs must be effectively prioritized within the population of other project resource needs because of the finite project's pool of resources. Allocating resources is an important decision that connects different parts of large and complex engineering projects with each other (Girmscheid and Brockmann 2008).

Resource capacity plans and allocation policies have a positive impact on project outcomes and success (Tag 2015). The availability of resources helps success even in large, complex projects (Williams *et al.* 2012). The cost and schedule required to deliver a project depend on the number of tasks, their duration and the way that different tasks interact (Clark 1989). Organizations that had comprehensive project management methodologies were associated with project success (Joslin and Müller 2015). In fact, project governance had a positive association with project performance (Sirisomboonsuk *et al.* 2018). Similarly, Hung and Shiu (2014) showed that accumulative experience enabled research and development projects to be successfully delivered in human resource departments. Klingebiel and Rammer (2014) found a positive relationship between resource allocation and performance across innovation projects with data from the German section of the European Community Innovation Survey. From a survey of 108 business managers, Engelbrecht *et al.* (2017) found that business managers' information technology (IT) competence could have a crucial impact on project success. Yaghootkar and Gil (2012) suggested that the project schedule performance can be at risk if an organization has no available resource capacity. Similarly, proper resource management can improve schedule performance by increasing resource quantity, productivity and utilization (Lee *et al.* 2007).

The positive relationship between resource allocation and performance can be applicable to complex transportation projects. This positive relationship is particularly true in circumstances where multiple and concurrent projects compete for scarce resources (Tag 2015). AEC firms typically execute and manage a portfolio of projects with various levels of complexity. From the case study of a complex rail project in the U.K., i.e. High Speed Two, Chapman (2016, p.952) stated that "*it is critically important for the efficient delivery of the project that it acquires and develops the required people and capabilities in sufficient time to deliver the project to schedule. Achieving the required headcount represents a number of challenges in terms of estimating the required headcount, the availability of the skills in the market place and the ability to attract and retain high calibre personnel*". To empirically investigate the relationship between resource allocation and project performance, the second hypothesis from this study is presented as follows:

Hypothesis 2a (H2a): The level of resource allocation is significantly negatively correlated with project cost growth.

Hypothesis 2b (H2b): The level of resource allocation is significantly negatively correlated with project schedule growth.

The role of resource allocation in the relationship between project complexity and project performance

Successfully delivering a highly complex project relies on appropriate project and construction management actions. On the one hand, project complexity should be analyzed and evaluated to identify appropriate approaches for reducing complexity (Chryssolouris 1994; Sinha *et al.* 2006). On the other hand, Zhu and Mostafavi (2017) asserted that the extent of the impacts of complexity on project performance depends upon the capacity of the project

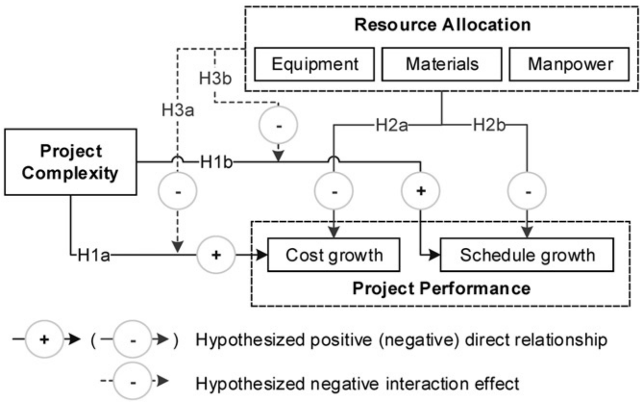

Figure 1. Conceptual framework and research hypotheses.

management system to cope with complexity. Müller *et al.* (2012) found the interaction effect of leadership and complexity on project success. Project complexity also moderated the relationship between team flexibility and performance (McComb *et al.* 2007). Therefore, selecting appropriate people at the appropriate time is critical in delivering a complex project successfully (Shane *et al.* 2015).

Highly complex projects tended to be more sensitive to project manager autonomy (Shenhar *et al.* 2002). By evaluating the complexity level in early phases, organizations can select the right project manager who can subsequently tailor project management practices to fit the project conditions (Eriksson *et al.* 2017). i.e. project managers play a significant role in estimation and appropriate allocation of resources in delivering projects (Nair *et al.* 2012). Project managers can optimize resource utilization through their resource allocation policies among project activities (Lee *et al.* 2007). Mapping complexity also helps project teams rationally allocate available resources and identify the needs for additional resources (Shane *et al.* 2015).

Previous studies indicated the interactive effect of resource allocation and project complexity on project outcomes. Antoniadis *et al.* (2011) observed that project performance dropped as the effects of complexity on each activity increased, and it was maintained when remedial actions were implemented. Floricel *et al.* (2016) found that project performance was improved when appropriate resources were allocated to the presence of high levels of project complexity types. Eriksson *et al.* (2017) verified that flexibility-focused project management practices improved the time performance of complex infrastructure projects. To investigate the role of resource allocation in the relationship between project complexity and project performance, the third hypothesis of this study is:

> *Hypothesis 3a (H3a)*: The level of resource allocation has a buffering effect where increasing resource allocation significantly decreases the effect of project complexity on cost growth.

> *Hypothesis 3b (H3b)*: The level of resource allocation has a buffering effect where increasing resource allocation significantly decreases the effect of project complexity on schedule growth.

Figure 1 illustrates the conceptual framework and research hypotheses. Resource allocation studies often focus on a single resource type (e.g. money, labor, equipment, or managerial effort) because different resource types may have unique impacts on performance (Lee *et al.* 2007). This study considers the three most common resource types, i.e. construction equipment, material/capital and manpower/project team in the construction management of transportation projects. The two project performance metrics are cost growth and schedule growth. They are defined in the next section.

Methodology

Measure

The following measures were used to investigate relationships among project complexity, resource allocation and project performance.

Project complexity

The two explanations of complexity are "descriptive complexity" that considers complexity as an intrinsic property of a system and "perceived complexity" that considers complexity as a subjective judgment of an observer (Schlindwein and Ison 2004). Vidal and Marle (2008) confirmed that both explanation approaches could be relevant to project complexity. Nguyen *et al.* (2015) integrated the two approaches to propose a model for measuring the complexity of construction

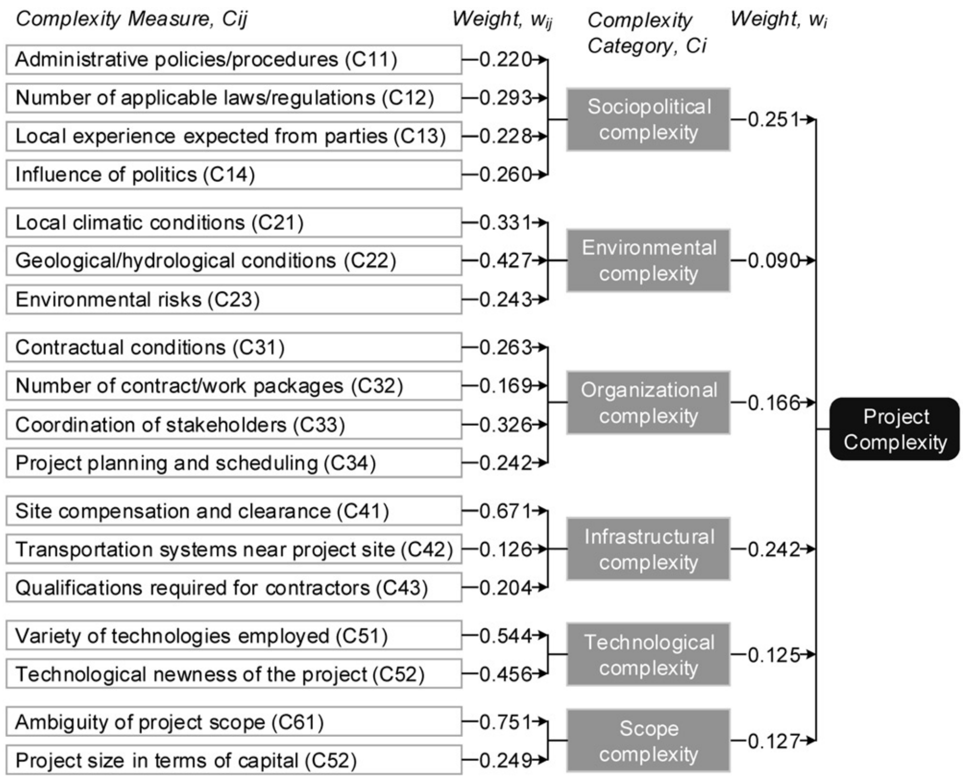

Figure 2. Project complexity measures and their weights.

transportation projects. These authors used the Fuzzy Analytic Hierarchy Process and principal component analysis to structure the project complexity and tested with data collected from transportation experts in Vietnam.

This study adopted the approach proposed by Nguyen *et al.* (2015) to evaluate the complexity of transportation projects. Figure 2 summarizes the hierarchical structure of transportation project complexity developed by Nguyen *et al.* (2015). The six complexity categories are *sociopolitical*, *environmental*, *organizational*, *infrastructural*, *technological* and *scope*. Each category has two to four measures for a total of 18 measures. The local weights of the measures (w_{ij}) and categories (w_i) were determined based on fuzzy pairwise comparisons (Figure 2). The normalized global weight (W_{ij}) of measure *Cij* is determined using Equation (1) (Nguyen *et al.*, 2015).

$$Wij = w_i \times w_{ij} \qquad (1)$$

For example, the global weight of "administrative policies/procedures" (*C11*) is $W_{11} = w_1 \times w_{11} = 0.251 \times 0.220 = 0.055$. The global weights of all 18 complexity measures are available in Figure 3.

To determine the complexity level of a certain project, the project manager evaluates the degree of complexity (k_{ij}) for each measure based on the scale of 0 to 10, i.e. from "extremely low" (0) to "extremely high" (10). The overall project complexity (*CL*) is also on the same scale of 0 to 10 and is determined by Equation (2), where *n* is the number of measures within a main complexity category (Nguyen *et al.* 2015):

$$CL = \sum_{i=1}^{6} \sum_{j=1}^{n} \left(W_{ij} \times k_{ij}\right) \qquad (2)$$

Figure 3 demonstrates the determination of the complexity level of an example project. The degrees of complexity k_{ij} were evaluated by the project manager of this project. The overall complexity level of this project was 7.24, which meant moderately high complex.

It is important to note that Nguyen *et al.* (2015) proposed a model to measure the complexity of transportation projects but did not investigate the impact of project complexity on project performance, which is the main goal of this current study.

Resource allocation

The level of resource allocation is measured on the scale from "1" to "3" where: "1" = "less than expected"; "2" = "as expected"; and "3" = "more than expected". For a given project, a manager was asked to evaluate the allocation level of three major resources, including

Complexity measure *Cij*	C11	C12	C13	C14	C21	C22	C23	C31	C32
Global weight W_{ij}	0.055	0.073	0.057	0.065	0.030	0.038	0.022	0.044	0.028
k_{ij} for an example project	8	9	6	3	7	9	8	5	7
$W_{ij} \times k_{ij}$	0.440	0.657	0.342	0.195	0.210	0.342	0.176	0.220	0.196
Complexity measure *Cij*	**C33**	**C34**	**C41**	**C42**	**C43**	**C51**	**C52**	**C61**	**C62**
Global weight W_{ij}	0.054	0.040	0.162	0.030	0.049	0.068	0.057	0.095	0.032
k_{ij} for an example project	6	7	10	9	9	8	6	4	8
$W_{ij} \times k_{ij}$	0.324	0.280	1.620	0.270	0.441	0.544	0.342	0.380	0.256
***CL* of the example project**	0.440 + 0.657 + … + 0.380 + 0.256 = **7.24**								

Figure 3. Estimating the complexity level for an example project.

construction equipment (Equip), material/capital (Mat), and manpower/project team (Team).

Project performance

This study used cost growth and schedule growth as the two measures of project performance. Puddicombe (2012) noted that cost and schedule are the dominant measures although project performance can be evaluated in a number of different ways. Cost growth and schedule growth are calculated based on Equations (3) and (4), respectively:

$$\text{Cost growth} = \left[(AC - OC)/OC\right] \times 100\% \tag{3}$$

$$\text{Schedule growth} = \left[(AD - OD)/OD\right] \times 100\% \tag{4}$$

The original contract price (OC) is the contract amount at the time the project was awarded to the contractor. The actual contract price (AC) is the total payment for a contract including approved change orders. The original contract duration (OD) is the baseline contract duration specified in the contract. The actual contract duration (AD) is the total duration to complete the project from the construction start date to the substantial completion date.

Sample and data collection

The unit of analysis was transportation projects recently completed in Vietnam. The sample was based on the lists of transportation projects issued periodically by the Ministry of Transport or its Project Management Units. The major criterion for a transportation project to be included in the sample was its completion within five years. As a result, this study formed a sample of 79 projects that spread throughout the country. The authors contacted all 79 project managers to collect data. Empirical records of these projects such as original contract price, actual contract price with approved change orders, baseline contract duration, and actual contract duration were collected to assess project performance. Through a questionnaire survey, the 18 complexity measures presented in Figure 2 and the resource allocation practices were evaluated by 79 project managers based on scales discussed in the previous section. The researchers explained the 18 complexity measures and the scales of project complexity and resource allocation to project managers through face-to-face and/or over the phone. The input of these 79 project managers helped determine the project complexity level and the level of resource allocation for each project.

Table 1 summarizes the 79 sample projects, including the statistics of project costs, durations, and complexity levels. The currency amounts are presented in Vietnamese Dongs (VND) associated with the U.S. Dollars (USD) in parentheses. The average original contract price and duration were 201 billion VND (8.93 million USD) and 22.8 months, respectively. All projects were roadway transportation projects. Most projects (69/79 or 87.3%) were financed by public and delivered under the design-bid-build project delivery method. Only 10 projects (12.7%) were delivered using alternative contractual arrangements, including two Build-Transfer (BT), seven Build-Operate-Transfer (BOT), and one Engineering, Procurement and Construction (EPC).

Analysis approach

A number of statistical analysis techniques, including both descriptive and inferential statistics, were employed to analyze the collected data. This study used descriptive statistics to determine the frequency, mean and standard deviation of data. Before performing these analyses, data of cost growth and schedule growth were checked for outliers. Normal probability plots and authors' closer observation of potential outliers were performed to detect outliers. The non-linear pattern of the normal probability plots indicated that cost growth and schedule growth of the sample projects were not normally distributed. Nevertheless, the lower and upper tails of these plots are a useful graphical technique for detecting potential outliers (National Institute of Standards and Technology 2012).

Table 1. Overview of sample projects ($N = 79$).

Description	Min	Mean	Max	SD
Original contract price in billion VND (million USD)	10.9 (0.48)	201 (8.93)	1639 (72.8)	329 (14.62)
Actual contract price in billion VND (million USD)	9.7 (0.43)	199 (8.84)	1500 (66.7)	311 (13.82)
Original contract duration in months	4	22.8	66	11.6
Actual contract duration in months	6	29.4	78	16.7
Overall project complexity level (CL)	3.58	5.38	7.38	0.97

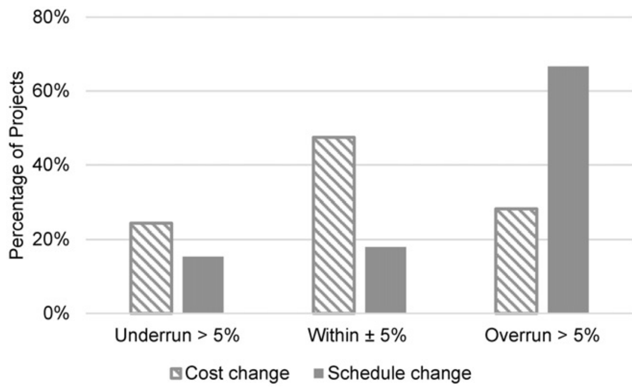

Figure 4. Distribution of projects with different levels of cost and schedule growths.

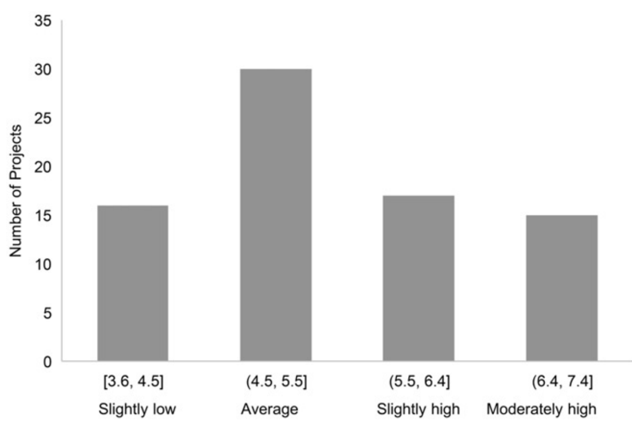

Figure 5. Histogram of the project complexity level.

With a closer look of the normal probability plot of schedule growth, one project at the upper tail was considered as an outlier and excluded from analysis. In fact, its schedule growth was more than 300% and more than six standard deviations (SD) away from the mean of schedule growth. As a result, the remaining 78 projects were included in additional analysis.

Bivariate Pearson correlations and moderated hierarchical regression analysis were used as inferential statistics for hypothesis testing. The Pearson correlation analysis was used to test the hypotheses H1a, H1b, H2a and H2b. This bivariate correlation is a measure of the linear correlation between two variables. It was used to test the possible correlations stated in these hypotheses because each of these hypotheses has two variables, for example, project complexity and cost growth in H1a. Hierarchical regression analysis was used to test the hypotheses H3a and H3b. It enables to build several regression models by adding each independent variable such as project complexity, resource allocation, and the multiplicative interaction of these two variables to a previous model. The main goal of this hierarchical regression analysis is to show if these independent variables explain a statistically significant amount of variance in the dependent variables, i.e. cost growth and schedule growth.

The interaction effect was further assessed by using the PROCESS macro developed by Hayes (2017). The SPSS software version 23 was used as a data analysis tool. The PROCESS algorithm facilitates mediation analysis, moderation analysis and combinations of mediation and moderation analyses (Hayes 2018). This study used the PROCESS macro to conduct moderation analysis that examines how the effect of project complexity on cost growth or schedule growth depends on resource allocation as the third moderator variable.

Analysis and results

Data exploration

Figure 4 displays the distributions of cost growth and schedule growth of the 78 transportation projects. In terms of cost performance, one-fourth (25%) of projects were underrun by more than 5%, 47.4% of projects were within plus/minus 5% of the original contract price and 28.2% of projects were overrun more than 5%. Figure 4 also indicates that two-thirds of projects had the schedule growth of 5% or higher; 17.9% of projects were within plus/minus 5% schedule growth; 15.4% of projects were underrun more than 5%. While reliable statistics for cost growth and schedule growth for construction projects in Vietnam have not been available, a study of 77 building projects completed in the period of 1999–2005 in the southeastern area showed that 66% and 75% of the projects were over budget and delayed, respectively (Le 2017).

The complexity level (*CL*) for each of 78 projects was determined based on Equation (2). As described previously, the project managers were asked to evaluate the 18 complexity measures in detail. Figure 5

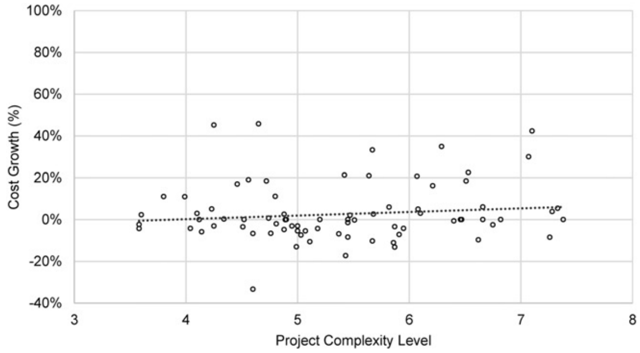

Figure 6. Project complexity level versus cost growth.

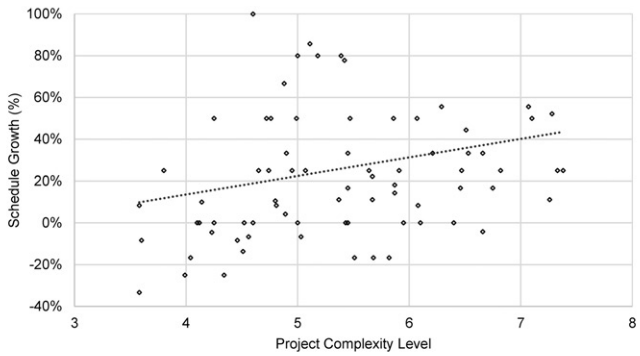

Figure 7. Project complexity level versus schedule growth.

presents the distribution of the complexity level on the scale of 0 ("extremely low") to 10 ("extremely high"). The figure shows that the complexity levels of: (i) 16 projects were evaluated as "slightly low" (3.6–4.5); (ii) 30 projects were evaluated as "average" (4.5–5.5); (iii) 17 projects were evaluated as "slightly high" (5.5–6.4); and (iv) 15 projects were evaluated as "moderately high" (6.4–7.4).

Figure 6 and 7 present the scatter plots of the project complexity level versus cost growth and schedule growth, respectively. A linear trend line for the observed projects is also included for the illustrative purpose. The trend line of the complexity level versus cost growth is slightly upward (Figure 6). The trend line of the complexity level versus schedule growth is considerably more upward (Figure 7). These trends appear to be in line with literature and the research hypotheses. The next sub-sections present hypothesis tests to confirm if those trends are statistically significant.

Correlation between project complexity and project performance

Bivariate Pearson correlation analysis was conducted for cost and schedule growths with each complexity category and the overall project complexity. Table 2 summarizes the results of these analyses and displays the

Table 2. Correlation coefficients between project complexity and performance.

	Project performance	
Complexity category	Cost growth	Schedule growth
Sociopolitical complexity	−0.087	0.330^{c}
Environmental complexity	0.204^{a}	0.184
Organizational complexity	0.040	0.372^{d}
Infrastructural complexity	0.005	0.230^{b}
Technological complexity	0.092	0.290^{c}
Scope complexity	0.157	0.285^{b}
Overall project complexity	0.064	0.396^{d}

$^{a}p \leq .1$; $^{b}p \leq .05$; $^{c}p \leq .01$; $^{d}p \leq .001$.

Table 3. Correlation coefficients between resource allocation and project performance.

	Project performance	
Resource allocation	Cost growth	Schedule growth
Construction equipment	0.110	−0.304^{c}
Material/capital	0.091	−0.195^{a}
Manpower/project team	0.059	−0.333^{c}

$^{a}p \leq .1$; $^{b}p \leq .05$; $^{c}p \leq .01$.

p-value for significant correlations only. Almost all correlation coefficients were positive as expected. However, cost growth was not significantly correlated except for one category, namely environmental complexity. The correlation coefficient between cost growth and overall project complexity was positive but small (0.064). The result implies that Hypothesis H1a which states the significant positive correlation between project complexity and cost growth was not supported.

In contrast, schedule growth was significantly positively correlated with all but one category. The significant level varies with complexity categories as indicated in Table 2. Although schedule growth was not significantly correlated with the environmental complexity, its correlation coefficient was positive (0.184). The overall project complexity and schedule growth were significantly positively correlated at a *p*-value of .001 as shown in the last row of the table. Therefore, this finding supported Hypothesis H1b which states the significant positive correlation between project complexity and schedule growth. Nevertheless, with the maximum correlation coefficient of 0.396 (Table 2), the correlations were not strong but were expected for this type of study. Data from surveys and observational studies "*often show weak associations because it's so difficult to measure reliable responses*" (De Veaux *et al.* 2006, p.176).

Correlation between resource allocation and project performance

Similarly, the bivariate Pearson correlation analysis was conducted for cost growth and schedule growth with

Table 4. Hierarchical moderated regression for testing hypotheses H3a and H3b.

		Cost growth		Schedule growth	
Study variables	Statistics	Model 1a	Model 2a	Model 1b	Model 2b
Project complexity (CL)	Coefficient	0.119	−0.030	0.305[c]	−0.384
Allocation of equipment (Equip)	Coefficient	0.136	−0.128	−0.235[b]	−1.463[b]
Two-way interaction (CL*Equip)	Coefficient	–	0.276	–	1.281[a]
	R square	0.025	0.027	0.180[d]	0.220[a]
	R square change	0.025	0.002	0.180[d]	0.040[a]
	F statistic	0.979	0.692	8.256[d]	6.970[d]
Project complexity (CL)	Coefficient	0.122	0.979[b]	0.329[c]	−0.433
Allocation of materials (Mat)	Coefficient	0.124	1.344[b]	−0.106	−1.190[b]
Two-way interaction (CL*Mat)	Coefficient	–	−1.306[a]	–	−1.161[a]
	R square	0.022	0.070[a]	0.138[c]	0.176[a]
	R square change	0.022	0.048[a]	0.138[c]	0.038[a]
	F statistic	0.841	1.858	6.013[c]	5.276[c]
Project complexity (CL)	Coefficient	0.100	0.551	0.314[c]	−0.361
Allocation of manpower (Team)	Coefficient	0.075	0.792	−0.284[c]	−1.357[c]
Two-way interaction (CL*Team)	Coefficient	–	−0.797	–	1.192[b]
	R square	0.013	0.030	0.207[d]	0.243[a]
	R square change	0.013	0.016	0.207[d]	0.037[a]
	F statistic	0.503	0.752	9.773[d]	7.930[d]

[a]$p \leq .1$; [b]$p \leq .05$; [c]$p \leq .01$; [d]$p \leq .001$.

the allocation of the three resource types (e.g. construction equipment, material/capital, and manpower/project team). Table 3 summarizes the results of these analyses. The correlation coefficients between cost growth and the allocation level of all resource types were positive but not statistically significant. As a result, Hypothesis H2a which hypothesizes the significant negative correlation between project complexity and cost growth was not supported. However, the correlation coefficients between schedule growth and levels of allocations for three resource types were all negative and statistically significant. That is, the level of resource allocation was significantly negatively correlated with project schedule growth as stated in Hypothesis H2b.

The interaction effect of project complexity and resource allocation on project performance

To investigate the moderating effect of project complexity and resource allocation on project performance, hierarchical multiple regression analysis was performed to assess the incremental explanatory power of variables in each block (Cohen, 2003). Specifically, in the first step (Model 1), two variables were included: (i) project complexity (CL) and (ii) allocation of each resource type (i.e. Equip, Mat, or Team). In the second step (Model 2), the multiplicative interaction terms were computed between "CL" and the moderator variable (Equip, Mat, or Team) and entered in the regression equation. All study variables were mean-centered to reduce multi-collinearity (Aiken and West 1991). These two steps were repeated for each resource type and for each of the two dependent variables: cost growth and schedule growth. Table 4 summarizes the results of the hierarchical multiple regression analyses.

In the first group of three regression analyses for testing the Hypothesis H3a, neither Model 1a (without the interaction term) nor Model 2a (with the interaction term) was found significant. When analyzing the "Equip" as a moderator variable, Model 1a had F statistic =0.979, $p = .380$ and Model 2a had F statistic =0.692, $p = .560$. In addition, Model 2a with the interaction between "CL" and "Equip" did not account for significantly more variance than just "CL" and "Equip" alone. The result of R square change =0.002, F = 0.141, $p = .708$ indicated that there was no significant moderation between the allocation of construction equipment and project complexity on cost growth. Similar results were also observed in Model 1a and Model 2a when analyzing "Mat" and "Team" as moderator variables (Table 4). Based on these results, Hypothesis H3a which states the buffering effect of resource allocation on the project complexity-cost growth relationship was not supported.

Model 1b in the second group of three regression analyses showed that project complexity and resource allocation accounted for a significant amount of variance in schedule growth (Table 4). When analyzing the "Team" as a moderator variable, for example, Model 1b had F statistic =9.773, $p < .001$. Model 2b with the interaction between "CL" and "Team" accounted for significantly more variance than just "CL" and "Team" alone (F statistic =7.930, $p < .001$). The result of R square change =0.037, F statistic =3.574, $p = .063$ indicated that there was a potentially significant moderation between project complexity and allocation of manpower/project team on schedule growth. That is, the effect of project complexity on

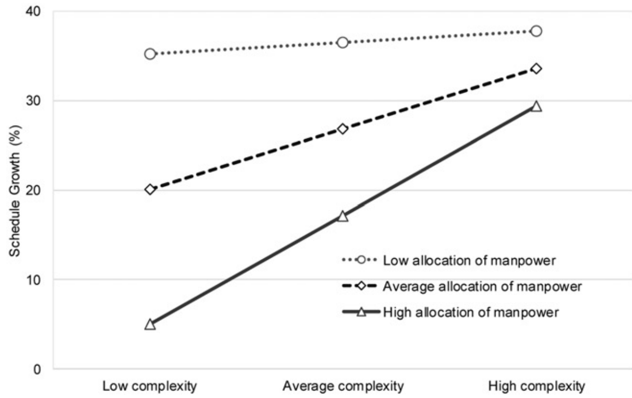

Figure 8. Interaction effect between project complexity and resource allocation on schedule performance.

schedule growth depends on the allocation level of project team. Similar results were found when analyzing the "Equip" and "Mat" as moderator variables (Table 4). The results implied that Hypothesis H3b which states the buffering effect of resource allocation on the project complexity-schedule growth relationship was supported. The strength of the relationship between project complexity and schedule growth was significantly conditional on the level of resource allocation.

To visualize the relationship between project complexity and resource allocation on schedule performance, the interaction effect was further assessed by using PROCESS developed by Hayes (2017). Figure 8 illustrates the results from this assessment for project complexity, allocation of manpower/project team, and schedule growth. In analysis of the interaction effect, Aiken and West (1991) define high and low values as plus/minus one SD from the mean (average) for independent and moderator variables. Accordingly, the PROCESS output reports mean and plus/minus one SD for these variables. The "low complexity" and "high complexity" shown in Figure 8 are –1 SD and +1 SD, respectively from the complexity level average of the sample projects. Similar interpretation is also applied to "low allocation" and "high allocation" of manpower. This interaction plot (Figure 8) showed a buffering effect, whereby: (i) schedule growth increased as project complexity increased; (ii) with the same complexity level, schedule growth was lower as the level of manpower allocation was higher; and (iii) the degree of schedule growth (i.e. slope) was most considerable in high allocation of manpower, followed by average allocation and then low allocation as the complexity level increased. Similar results were observed for the moderating effects of project complexity and allocation of construction equipment or material/capital on schedule growth.

This study lastly assessed the possible compound effect of the three resource allocation variables (i.e. Equip, Mat and Team) on cost growth and schedule growth using hierarchical multiple regression analysis. Accordingly, each of the four independent variables CL, Equip, Mat and Team were entered in each step to form four models (Model 1 to Model 4). With cost growth as a dependent variable, there was no statistical significance in any of the four models. This was expected as these variables were not correlated with cost growth as discussed in the previous two subsections. In contrast, all four models were significant for the dependent variable "schedule growth" (Table 5). The F statistics of Models 1, 2, 3 and 4 were 14.11, 9.712, 6.407 and 5.724, respectively with all p-values $\leq$ .001. In addition, R square change was significant for Models 1, 2 and 4. Specifically: (i) Model 2 (R square change =0.049, $p = .034$) with the level of equipment allocation accounted for significantly more variance than just project complexity alone (Model 1); (ii) Model 3 (R square change =0.000, $p = .836$) with the level of material allocation did not account for significantly more variance than project complexity and the level of equipment allocation (Model 2); and (iii) the level of project team allocation was added to Model 4, which accounted for a significant proportion of the variance in schedule growth (R square change =0.033, $p = .081$). The allocation levels of construction equipment and project team could have some compound effect on schedule growth.

Discussion

The analysis results showed that project complexity was found to be negatively correlated with schedule performance but not with cost performance. Specifically, this study showed a significantly positive correlation between project complexity and schedule growth in transportation projects (Table 2). This empirical evidence confirmed the common perception of construction management professionals and researchers. Antoniadis *et al.* (2011) argued that little research was conducted to determine the exact relationship between project complexity and schedule performance although heuristic considerations suggested an inverse correlation. This finding is also in line with previous studies. Tatikonda and Rosenthal (2000) found that the significant negative associations between project complexity and project outcomes were not at the level of the overall project outcome, but rather at the level of specific project objectives, i.e. schedule performance in this current study.

Table 5. The compound effect of resource allocation variables on schedule growth.

Study variables	Statistics	Model 1	Model 2	Model 3	Model 4
Project complexity (CL)	Coefficient	0.302[d]	0.264[c]	0.261[c]	0.252[c]
Allocation of equipment (Equip)	Coefficient	–	−0.330[b]	−0.317[b]	−0.193
Allocation of materials (Mat)	Coefficient	–	–	−0.038	0.019
Allocation of manpower (Team)	Coefficient	–	–	–	−0.312[a]
	R square	0.157[d]	0.206[b]	0.206	0.239[a]
	R square change	0.157[d]	0.049[b]	0.000	0.033[a]
	F statistic	14.11[d]	9.712[d]	6.407[d]	5.724[d]

[a]$p \leq .1$; [b]$p \leq .05$; [c]$p \leq .01$; [d]$p \leq .001$.

Interestingly, the positive correlation between project complexity and cost growth was not statistically significant. The possible explanation for this finding could be from the cost data. The cost growth was determined from the difference between the original contract price and the actual/final contract price with approved changed orders. This cost difference did not reflect the fact that contractor's expected project cost could be increased due to complexity during the course of construction but could not recover from the owner through change orders due to no variation (e.g. scope change) to the contract. In other words, not all additional costs incurred could be recovered through contract terms.

Similarly, the positive association between the level of resource allocation and schedule performance was found statistically significant. The allocation levels of all major resources (equipment, material/capital, and manpower/project team) were negatively correlated with schedule growth. The performance of a project depends on resource capacity, including quantity, schedule, and properties of the resources required to execute the project (Tag 2015). A project could not be delivered on time if its organization had no available resource capacity (Yaghootkar and Gil 2012). Similarly, Berssaneti and Carvalho (2015) found that top management support and dedicated project manager had a significant impact on the time success dimension but not on customer satisfaction. For the cost performance, despite not statistically significant, the correlation coefficients between resource allocation and cost growth were positive (Table 2). That is, the level of resource allocation might be positively associated with cost growth. This was in fact opposite of what was conceptualized in Hypothesis H2a. Excessive resources may jeopardize the cost performance of complex projects if they were not allocated appropriately.

This study also found the interaction effect of resource allocation and project complexity on schedule performance. The level of resource allocation moderated the relationship between project complexity and schedule growth. With the same complexity level, schedule performance was prone to be better in projects with the higher level of resource allocation. This empirical evidence confirms the preliminary observations of the previous studies (e.g. Antoniadis *et al.* 2011; Floricel *et al.* 2016) as discussed previously in the theoretical background and research hypotheses section. With this understanding of the role of resource allocation, project managers and engineers may find a better way to manage complex construction projects to improve project performance. It is noted that the need for discovering the relationship between complexity and management and how individuals and organizations should act to project complexity have been highlighted in project and construction management communities (Austin *et al.* 2002; Augustine *et al.* 2005; Thomas and Mengel 2008; Daniel and Daniel 2018). The findings of this study have addressed such need.

Finally, project management success is not always equivalent to project success. Previous studies have well documented that project management success is measured against cost, time and quality while project success is measured against the overall objectives of the project (Nguyen *et al.*, 2004). The delays of complex projects are a critical issue because they cause both cost overruns and benefit shortfalls (Flyvbjerg, 2014). This study aimed to improve project management success for transportation projects with different levels of complexity. Nevertheless, the success of complex projects may be possible without the achievement of cost and schedule performance as noted by Turner (2018, p. 236): "*You must not lose control of the time and cost to delivery of a megaproject, because you want them [megaprojects] to deliver positive net present value. But judge them on that; don't say they have failed because they were 30% overspent (which many are)*". For example, the Denver International Airport, Boeing 787 Dreamliner, Channel Tunnel, Hubble Space Telescope and Sydney Opera House projects were complex megaprojects that failed to achieve efficiency goals (e.g. time and cost) but were successful in longer-term dimensions (e.g. societal impact, customer/user impact, financial/business success) (Shenhar and Holzmann, 2017).

Conclusions

This research investigated the relationship between project complexity and project performance and the effect of resource allocation on such relationship. A total of 79 transportation projects recently completed in Vietnam were collected as a research sample. Bivariate Pearson correlation analysis and moderated hierarchical regression analysis were employed to test the research hypotheses. Project complexity was negatively correlated with schedule performance while was not significantly correlated with cost performance. This study assessed cost performance through cost growth – a difference in percentage between the original contract price and actual/final contract price. Similarly, the level of resource allocation was positively correlated with schedule performance but not with cost performance. Three main types of resources evaluated in this study included equipment, materials/capital, and manpower/project team. This study found that the relationship between project complexity and schedule performance was moderated by the level of resource allocation.

The results of this study have both theoretical and practical implications. This study is one of the first attempts to empirically examine the role of resource allocation in the relationship between project complexity and project performance. Specifically, the impact of project complexity on schedule performance interacts with the level of resource allocation. This interaction is positive, which means that the impact of project complexity on schedule performance decreases in case of increasing the level of resource allocation. The practical implications include that organizations should evaluate the project complexity carefully to dedicate an appropriate resource capacity needed for successfully delivering their construction projects.

The strengths of this study are the collection of empirical project data and the use of established constructs of project complexity and project performance to yield credible results. This study also has theoretical supports highlighted by its results being in line with related literature. The industry- and country-specific nature of projects investigated has both strength and limitation: a strength because it allows for deriving results at the level of the specific country and industry; and a limitation because it does not allow to generalize the findings to other countries and industries. The limitations of this study also include the relatively small sample size of projects and the calculation of cost growth. While original and final contract prices that were used to determine the cost growth were empirical and hard data, they could not always capture the possibility of increased costs due to project complexity during the course of work. Finally, the complexity level could be subjective as it was determined based on the perception of the manager of the respective project.

Disclosure statement

No potential conflict of interest was reported by the authors.

References

Aiken, L.S., and West, S.G., 1991. *Multiple regression: testing and interpreting interactions*. Thousand Oaks, C.A: Sage Publications.

Antoniadis, D.N., Edum-Fotwe, F.T., and Thorpe, A., 2011. Socio-organo complexity and project performance. *International journal of project management*, 29 (7), 808–816.

Augustine, S., *et al.*, 2005. Agile project management: steering from. *Communications of the Acm*, 48 (12), 85–89.

Austin, S., *et al.*, 2002. Modelling and managing project complexity. *International journal of project management*, 20 (3), 191–198.

Baccarini, D., 1996. The concept of project complexity—a review. *International journal of project management*, 14 (4), 201–204.

Bakhshi, J., Ireland, V., and Gorod, A., 2016. Clarifying the project complexity construct: past, present and future. *International journal of project management*, 34 (7), 1199–1213.

Berssaneti, F.T., and Carvalho, M.M., 2015. Identification of variables that impact project success in Brazilian companies. *International journal of project management*, 33 (3), 638–649.

Bertolini, L., and Salet, W., 2008. Coping with complexity and uncertainty in mega projects: linking strategic choices and operational decision making. *OMEGA Center working paper 2.7*.

Bosch-Rekveldt, M., *et al.*, 2011. Grasping project complexity in large engineering projects: the TOE (Technical, Organizational and Environmental) framework. *International journal of project management*, 29 (6), 728–739.

Brady, T., and Davies, A., 2014. Managing structural and dynamic complexity: A tale of two projects. *Project management journal*, 45 (4), 21–38.

Chapman, R.J., 2016. A framework for examining the dimensions and characteristics of complexity inherent within rail megaprojects. *International journal of project management*, 34 (6), 937–956.

Chen, H., *et al.*, 2004. Cost risk management in West Rail project of Hong Kong. *AACE International Transactions*, IN91-IN95.

Chryssolouris, G., 1994. *Measuring complexity in manufacturing systems*. Greece: University of Patras.

Clark, K.B., 1989. Project scope and project performance: the effect of parts strategy and supplier involvement on product development. *Management Science*, 35 (10), 1247–1263.

Cohen, J., 2003. *Applied multiple regression/correlation analysis for the behavioral sciences*, 3rd ed., Mahwah, N.J.: Lawrence Erlbaum.

Cooke-Davies, T., *et al.*, 2007. We're not in Kansas anymore, Toto: mapping the strange landscape of complexity theory, and its relationship to project management. *Project management journal*, 38 (2), 50–61.

Daniel, P.A., and Daniel, C., 2018. Complexity, uncertainty and mental models: from a paradigm of regulation to a paradigm of emergence in project management. *International journal of project management*, 36 (1), 184–197.

Dao, B., *et al.*, 2017. Exploring and Assessing Project Complexity. *Journal of construction engineering and management*, 143 (5), 04016126.

Davies, A., Dodgson, M., and Gann, D., 2016. Dynamic capabilities in complex projects: the case of London Heathrow Terminal 5. *Project management journal*, 47 (2), 26–46.

de Rezende, L.B., Blackwell, P., and Gonçalves, M.D.P., 2018. Research focuses, trends, and major findings on project complexity: a bibliometric network analysis of 50 years of project complexity research. *Project management journal*, 49 (1), 42–56.

De Veaux, R.D., Velleman, P.F., and Bock, D.E., 2006. *Intro stats*, 2nd ed. Boston, MA: Pearson.

Engelbrecht, J., Johnston, K.A., and Hooper, V., 2017. The influence of business managers' IT competence on IT project success. *International journal of project management*, 35 (6), 994–1005.

Eriksson, P.E., Larsson, J., and Pesämaa, O., 2017. Managing complex projects in the infrastructure sector – a structural equation model for flexibility-focused project management. *International journal of project management*, 35 (8), 1512–1523.

Floricel, S., Michela, J.L., and Piperca, S., 2016. Complexity, uncertainty-reduction strategies, and project performance. *International journal of project management*, 34 (7), 1360–1383.

Flyvbjerg, B., 2014. What you should know about megaprojects and why: an overview. *Project management journal*, 45 (2), 6–19.

Flyvbjerg, B., Garbuio, M., and Lovallo, D., 2009. Delusion and deception in large infrastructure projects: two models for explaining and preventing executive disaster. *California management review*, 51 (2), 170–194.

Geraldi, J., Maylor, H., and Williams, T., 2011. Now, let's make it really complex (complicated): a systematic review. *International journal of operations & production management*, 31 (9), 966–990.

Gidado, K.I., 1996. Project complexity: the focal point of construction production planning. *Construction management & economics*, 14 (3), 213–225.

Girmscheid, G., and Brockmann, C., 2008. The inherent complexity of large scale engineering projects. *Project perspectives*, 29, 22–26.

Gransberg, D.D., *et al.*, 2013. Project complexity mapping in five dimensions for complex transportation projects. *Journal of Management in Engineering*, 29 (4), 316–326.

Hayes, A.F., 2017. *Introduction to mediation, moderation, and conditional process analysis: a regression-based approach*, 2nd Edition. New York, N.Y.: Guilford Press.

Hayes, A.F., 2018. Partial, conditional, and moderated moderated mediation: quantification, inference, and interpretation. *Communication monographs*, 85 (1), 4–40.

He, Q., *et al.*, 2015. Measuring the complexity of mega construction projects in China – A fuzzy analytic network process analysis. *International journal of project management*, 33 (3), 549–563.

Hung, C.L., and Shiu, P.J., 2014. Evaluating project performance by removing external effects: implications to the efficiency of research and development resource allocation. *Research evaluation*, 23 (4), 366–380.

Ivory, C., and Alderman, N., 2005. Can project management learn anything from studies of failure in complex systems? *Project management journal*, 36 (3), 5–16.

Kennedy, D.M., McComb, S.A., and Vozdolska, R.R., 2011. An investigation of project complexity's influence on team communication using Monte Carlo simulation. *Journal of engineering and technology management*, 28 (3), 109–127.

Kim, J., and Wilemon, D., 2003. Sources and assessment of complexity in NPD projects. *R&D management*, 33 (1), 15–30.

Kiridena, S., and Sense, A., 2016. Profiling project complexity: insights from complexity science and project management literature. *Project management journal*, 47 (6), 56–74.

Klingebiel, R., and Rammer, C., 2014. Resource allocation strategy for innovation portfolio management. *Strategic management journal*, 35 (2), 246–268.

Joham, C., Metcalfe, M., and Sastrowardoyo, S., 2009. Project conceptualization using pragmatic methods. *International journal of project management*, 27 (8), 787–794.

Joslin, R., and Müller, R., 2015. Relationships between a project management methodology and project success in different project governance contexts. *International journal of project management*, 33 (6), 1377–1392.

Le, N., 2017. Vietnam construction industry performance issues and potential solutions. *Journal for the advancement of performance information and value*, 9 (2), 7–20.

Lebcir, R. M., and Choudrie, J., 2011. Impact of project complexity factors on project cycle time: a system dynamics modelling approach. In: Proceedings of 2nd International Conference on Construction and Project Management (Vol. 15), 16–18 September 2011, Singapore.

Lee, Z.W., Ford, D.N., and Joglekar, N., 2007. Effects of resource allocation policies for reducing project durations: a systems modelling approach. *Systems research and behavioral science*, 24 (6), 551–566.

Liu, A.M., 1999. A research model of project complexity and goal commitment effects on project outcome. *Engineering, construction and architectural management*, 6 (2), 105–111.

Locatelli, G., *et al.*, 2017. The successful delivery of megaprojects: a novel research method. *Project management journal*, 48 (5), 78–94.

Luo, L., *et al.*, 2017a. Construction project complexity: research trends and implications. *Journal of construction engineering and management*, 143 (7), 04017019.

Luo, L., *et al.*, 2017b. Investigating the relationship between project complexity and success in complex construction projects. *Journal of management in engineering*, 33 (2), 04016036.

McComb, S.A., Green, S.G., and Compton, W.D., 2007. Team flexibility's relationship to staffing and performance in complex projects: an empirical analysis. *Journal of engineering and technology management*, 24 (4), 293–313.

Miller, R., and Hobbs, J.B., 2005. Governance regimes for large complex projects. *Project management journal*, 36 (3), 42–50.

Mirza, E., and Ehsan, N., 2017. Quantification of project execution complexity and its effect on performance of infrastructure development projects. *Engineering management journal*, 29 (2), 108–123.

Müller, R., Geraldi, J., and Turner, J.R., 2012. Relationships between leadership and success in different types of project complexities. *IEEE transactions on engineering management*, 59 (1), 77–90.

Naderpajouh, N., and Hastak, M., 2014. Quantitative analysis of policies for governance of emergent dynamics in complex construction projects. *Construction management and economics*, 32 (12), 1222–1237.

Nair, G., Suma, V., and Kumar, N.R., 2012. Impact analysis of allocation of resources by project manager on success of software projects. In: *Proceedings of* International Conference on Data Mining and Computer Engineering (ICDMCE), December 21-22, Bangkok, Thailand. Planetary Scientific Research Center.

Nguyen, A.T., *et al.*, 2015. Quantifying the complexity of transportation projects using the fuzzy analytic hierarchy process. *International journal of project management*, 33 (6), 1364–1376.

Nguyen, L.D., Ogunlana, S.O., and Lan, D.T.X., 2004. A study on project success factors in large construction projects in Vietnam. *Engineering, construction and architectural management*, 11 (6), 404–413.

National Institute of Standards and Technology (NIST) 2012. *NIST/SEMATECH e-Handbook of Statistical Methods.* Available from: http://www.itl.nist.gov/div898/handbook/ [Accessed 17 July 2018].

Padalkar, M., and Gopinath, S., 2016. Are complexity and uncertainty distinct concepts in project management? A taxonomical examination from literature. *International journal of project management*, 34 (4), 688–700.

Pich, M.T., Loch, C.H., and Meyer, A.D., 2002. On uncertainty, ambiguity, and complexity in project management. *Management science*, 48 (8), 1008–1023.

Puddicombe, M.S., 2012. Novelty and technical complexity: critical constructs in capital projects. *Journal of construction engineering and management*, 138 (5), 613–620.

Qazi, A., *et al.*, 2016. Project complexity and risk Management (ProCRiM): Towards modelling project complexity driven risk paths in construction projects. *International Journal of Project Management*, 34 (7), 1183–1198.

Schlindwein, S.L., and Ison, R., 2004. Human knowing and perceived complexity: implications for systems practice. *Emergence: complexity and organization*, 6 (3), 27–32.

Senescu, R.R., Aranda-Mena, G., and Haymaker, J.R., 2013. Relationships between project complexity and communication. *Journal of management in engineering*, 29 (2), 183–197.

Shane, J., *et al.*, 2015. *Guide to project management strategies for complex projects* (No. SHRP 2 Report S2-R10-RW-2), Washington, D.C.: Transportation Research Board.

Shenhar, A., and Holzmann, V., 2017. The three secrets of megaproject success: clear strategic vision, total alignment, and adapting to complexity. *Project management journal*, 48 (6), 29–46.

Shenhar, A.J., *et al.*, 2016. The challenge of innovation in highly complex projects: What can we learn from Boeing's Dreamliner experience? *Project Management Journal*, 47 (2), 62–78.

Shenhar, A.J., *et al.*, 2002. Refining the search for project success factors: a multivariate, typological approach. *R&D management*, 32 (2), 111–126.

Sinha, S., Kumar, B., and Thomson, A., 2006. Measuring project complexity: a project manager's tool. *Architectural engineering and design management*, 2 (3), 187–202.

Sirisomboonsuk, P., *et al.*, 2018. Relationships between project governance and information technology governance and their impact on project performance. *International journal of project management*, 36 (2), 287–300.

Söderlund, J., Sankaran, S., and Biesenthal, C., 2017. The past and present of megaprojects. *Project management journal*, 48 (6), 5–16.

Tag, P. H., 2015. Improving business project performance by increasing the effectiveness of resource capacity and allocation policies. *In Proceedings of the Winter Simulation Conference* (WSC), December 6-9, Huntington Beach, CA, 856-867.

Tatikonda, M.V., and Rosenthal, S.R., 2000. Technology novelty, project complexity, and product development project execution success: a deeper look at task uncertainty in product innovation. *IEEE transactions on engineering management*, 47 (1), 74–87.

Thomas, J., and Mengel, T., 2008. Preparing project managers to deal with complexity–advanced project management education. *International journal of project management*, 26 (3), 304–315.

Tran, D.Q., Molenaar, K.R., and Alarcön, L.F., 2015. A hybrid cross-impact approach to predicting cost variance of project delivery decisions for highways. *Journal of infrastructure systems*, 22 (1), 04015017.

Turner, J.R., 2018. The management of the project-based organization: a personal reflection. *International journal of project management*, 36 (1), 231–240.

Vidal, L.A., and Marle, F., 2008. Understanding project complexity: implications on project management. *Kybernetes*, 37 (8), 1094–1110.

Williams, T.M., 1999. The need for new paradigms for complex projects. *International journal of project management*, 17 (5), 269–273.

Williams, T.M., 2017. The nature of risk in complex projects. *Project management journal*, 48 (4), 55–66.

Williams, T., *et al.*, 2012. Identifying and acting on early warning signs in complex projects. *Project management journal*, 43 (2), 37–53.

Xia, W., and Lee, G., 2004. Grasping the complexity of IS development projects. *Communications of the Acm*, 47 (5), 68–74.

Xia, W., and Lee, G., 2005. Complexity of information systems development projects: conceptualization and measurement development. *Journal of management information systems*, 22 (1), 45–83.

Yaghootkar, K., and Gil, N., 2012. The effects of schedule-driven project management in multi-project environments. *International journal of project management*, 30 (1), 127–140.

Zhu, J., and Mostafavi, A., 2017. Discovering complexity and emergent properties in project systems: a new approach to understanding project performance. *International journal of project management*, 35 (1), 1–12.