Factors Affecting Inspection Staffing Needs for Highway Construction Projects

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Abstract

Highway construction and maintenance projects have been witnessing a significant expansion across the United States. This expansion, coupled with the ongoing problem of labor shortages, adds pressure on state Departments of Transportation (DOTs) to complete more complex projects under more strict cost and schedule constraints. In recent years, construction inspection has been particularly impacted by DOT labor shortage, creating a major need to understand inspection staffing in highway projects. This paper fills the literature gap through evaluating the staffing needs for highway construction inspectors. Data for 266 highway construction projects from 15 different DOTs were collected to identify factors that affect highway inspection staffing for Junior, Intermediate, and Senior inspectors. The analysis showed that inspection staffing depends on project type, level of complexity, and project size. The results also suggested that projects that experience cost or schedule overrun tend to hire more inspectors than projects that are completed within budget or on time. The identification of such factors can assist DOTs in quantitatively modelling and predicting the full-time equivalents (FTE) needs of highway construction inspectors on future projects.

Keywords

Inspectors; Staffing; Resource Allocation; Highway Construction Projects; Department of Transportation

1 Introduction and Background

Highway projects in the United States (U.S.) are among the most visible assets of infrastructure, stretching out over five million miles across the country [1]. The U.S. public sector spent nearly $92.5 billion U.S. dollars on highway construction projects in 2018. With the ongoing U.S. economic expansion, the demand for highway construction projects continues to increase. Highway and road construction put in place in the U.S. is forecast to grow to 107.74 billion in 2024 [2]. This significant expansion along with the increased complexity of highway projects has placed more pressure on state Departments of Transportation (DOTs) to ensure adequate staffing on their highway projects [3].

Staffing is an important resource to construction projects, and a shortage in the staffing needs of any activity during the construction process can lead to cost and schedule overruns as well as decreased safety performance [4]. Highway staffing into three construction categories [5]: (1) administration where construction staff handles administrative tasks such as planning, scheduling, change orders and budget management, (2) engineering where construction staff deals with tasks such as design, estimation, traffic control and conflict resolution, and (3) inspection where construction staff oversees the ongoing operations to ensure the work is performed as required in the contract.

Highway staffing, whether administrative, engineering or inspection, need proper planning for productivity, scheduling, and estimating manpower requirements to economically match the requirements for each activity. This is especially important in a time where DOTs are managing increased lane miles with reduced staff [5]. Between 2000 and 2010, state-managed lane-miles increased by an average of 4.10%, whereas the number of full-time equivalents (FTEs) decreased by 9.68% [5]. When FTEs are normalized across the managed road system, the responding transportation agency's FTEs per millions of U.S. dollars of disbursement on capital outlay decreased by an average of 37.26% [5].

Proper planning with staffing can thus be a major challenge for the construction industry. This is especially true in the current climate where workers are not attracted to the construction industry; the dynamic nature of construction, work settings, attire, technology, job hazards, and environmental conditions play an important role in creating a labour shortage problem for the construction industry [6]. State DOTs are no exception to the above problems, especially that the current evolution in their projects comes at a time when they face high staffing turnover [5].

1.1 Factors Affecting Construction Staffing

With the increasing demand for highway projects and the declining level of in-state staff, one solution developed by DOTs to solve staffing shortage is forecasting tools. Forecasting tools allow DOT personnel to estimate staffing levels needed for a construction project, facilitate the management of this project, and protect the related firms from the damage caused by efforts to undertake projects when labour resources are not available [7]. The South Carolina Department of Transportation (SCDOT) investigated different projects to determine manpower requirements for construction project management [8]. Using data from 130 completed highway construction projects and over 11,000 employee payroll entries, regression analysis models were generated to predict overall manpower requirements for projects of a given type and cost. These overall requirements were then adjusted to predict manpower requirements for individual employee classifications using typical task allocation percentages obtained from questionnaire data [8]. The Texas Department of Transportation (TxDOT) performed a similar study in 2016 [9]. The primary purpose of the study was to assess the staffing requirements for transportation construction projects done by TxDOT to estimate staff needs for future work. Project completed between 2001 and 2011 were examined to study the impact of project characteristics and location and a regression model for CE staff hours was developed. Results of the model indicated that construction cost increase the demand by a power factor of 0.66, project type is a key factor in increasing or decreasing the demand, so does the degree of urbanization or the location of the project where metropolitan areas need more CE staff hours than those in urban and rural areas [9]. Another study [10] developed a protocol to provide Indiana Department of Transportation (INDOT) with a risk assessment framework to guide the inspection process and prioritize the allocation of limited inspection resources. The proposed novel risk-based prioritization approach for construction inspection assessed the risk associated with 90 critical inspection activities while considering quality, safety, cost, and time [10].

In addition to the research conducted in the highway sector, various studies were performed worldwide to analyse and forecast labour in construction projects. A study done in Hong Kong developed a simple regression relationship from 123 construction projects which were completed between 1995 and 2001, in which it estimates the labour demand from the cost of the contract [11]. Another study went even further by developing a multivariate regression analysis based on data collected from 54 projects [12]. The models developed by the authors predicted labour demand based on project type, contract amount, construction methods, degree of mechanization, management attributes, expenditure on electrical and mechanical services, project complexity, and the physical site location [12]. A third study [13] analysed the impact of 12 different factors to develop a future model that predicts workforce demand in Poland using fuzzy analysis. They concluded that the deadlines set for the implementation of various works, the contractual deadline for completion of construction, the amount of work, and the construction technology used are the four factors that significantly impact the planned workforce. They also concluded that availability of workers, degree of cooperation between the designer and the contractor, and contract value are three factors with the least impact on planning workforce [13].

1.2 Gap and Objective

DOTs are facing significant challenges when it comes to staffing of administrative, engineering, and inspection, leading them to hire Construction and Engineering Inspection (CEI) consultants [14][15].While previous research endeavours have evaluated and forecast construction staffing requirements for highway projects, no research has yet focused on understanding and examining the factors that impact highway construction inspection staffing needs. This paper contributes to the exiting body of knowledge by filling a gap in the extant literature by investigating the factors that impact the staffing of highway construction inspectors. The identification of such factors can assist DOTs in quantitatively modelling and predicting the FTE needs of highway construction inspectors on future projects.

2 Methodology

To achieve the objective of the paper, a literature review was first conducted to identify the factors that affect the staffing of highway construction inspectors. A data-collection survey was then developed to collect project and staffing data from DOTs. Next, bivariate analysis was utilized to understand the effect of single independent variable (i.e. factors that can impact the staffing of highway construction inspectors) on the FTE needs of highway construction inspectors.

2.1 Level of Inspectors

To maximize the value of the data, analysis was performed for three levels of inspectors: Junior, Intermediate, and Senior [15]:

- **Junior** level inspectors hold a high school diploma, general education development (GED) or high school equivalence test (HiSET) and less than 2 years of experience. Sample duties include performing on site measurements and computations, preparing final plans, change orders and estimating contract payments and engineering costs.

- **Intermediate** level inspectors hold a high school diploma, GED or HiSET, and have worked between two and four years. Their duties include inspecting construction materials such as asphalt or Portland cement, grading and bases, etc. These inspectors handle projects such as small to medium scaled bridges, roadside development and erosion control measures.
- **Senior** level inspectors hold a high school diploma, GED or HiSET, and have at least four years of experience. Hired in large scaled highway projects and critical structures, these inspectors are responsible for duties such as supervising the routine layout and staking, serving as party chief, technical expert and can perform duties of resident engineer's during their absence.

3 Data Collection

An online survey was distributed to different DOTs across the U.S. A total of 266 responses were recorded from 241 project managers and resident engineers across 15 different states highlighted in Figure 1. Respondents provided information about the type of the project, size of project, level of complexity, cost and schedule performance, and whether the project was fully staffed or not. They also provided the FTE of Junior, Intermediate, and Senior inspectors of the corresponding projects.

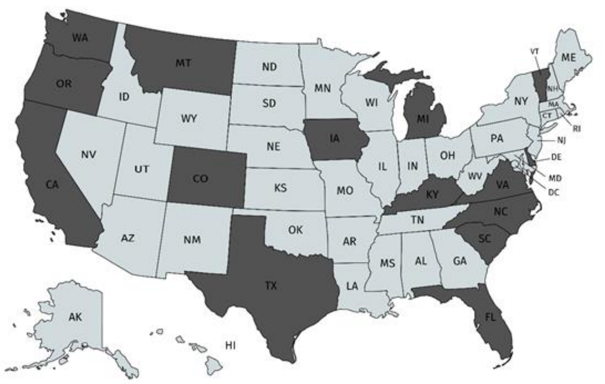

Figure 1. States that participated in the study (generated by MapChart.net)

The survey questions discussed different aspects of a specified projects, all of which are discussed in the following sections.

3.1 Type of Projects

The projects were distributed among four distinctive types (Figure 2):

- **Bridges** including all projects that involved constructing new bridges, and replacing or performing rehabilitation works on existing ones
- **Roadside (R.S.) Safety** including all project regarding guardrails, lights, signals, stripes, signs, and landscape
- **Roadside (R.S.) Enhancements** including all projects regarding ramps, curbs, shoulders, sidewalks, drainage, and retaining walls
- **Roads** including all projects that involved constructing new roads, and expanding, resurfacing or performing rehabilitation works one existing roads

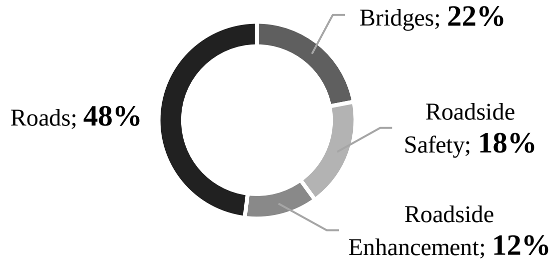

Figure 2. Distribution of projects by type

3.2 Size of Projects

The size of project varied based on the contract cost of the project (Figure 3):

- **500k & Less** for a cost of $500,000 or less
- **500k – 1M** for a cost between $500,000 and $1,000,000
- **1M – 5M** for a cost between $1,000,000 and $5,000,000
- **5M – 10M** for a cost between $5,000,000 and $10,000,000
- **10M & More** for a cost of $10,000,000 or more

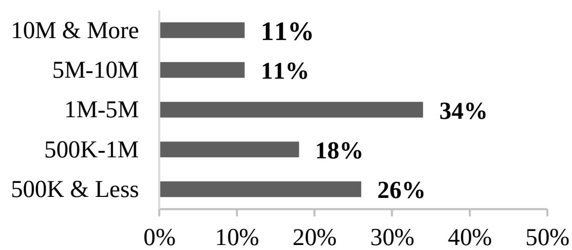

Figure 3. Distribution of projects by size

3.3 Complexity of Projects

The level of complexity of each project varies between minor, moderate and major based on a description adopted from (Li et al. 2019):

- **Minor Projects** include maintenance betterment projects, overlay projects, simple widening without or with slight right-of-way (or very minimum right-of-way) take; non-complex enhancement projects without new bridges (e.g., bike trails), categorical exclusion.
- **Moderate Projects** include no added capacity, minor roadway relocations, non-complex bridge replacements with minor roadway approach work, non-complex environmental assessment required.
- **Major Projects** include new highways; major relocations, new interchanges, capacity adding, major widening, major reconstruction, congestion management and/or complex environmental assessment required.

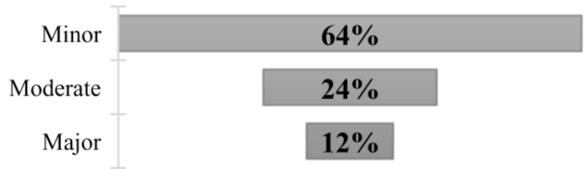

Figure 4. Distribution of project complexity

3.4 Cost and Schedule Performance

Data for the cost and schedule performance were collected as percentage overruns. For cost performance (Figure 5), negative percentages indicated that the project was under budget, a value of zero indicated on-budget, and a positive percentage indicated over budget. These terms were changed to binary values during analysis. For cost performance, projects that were on-budget or under budget were considered "within contract amounts" and assigned a binary integer of 0, while projects over budget were considered "above contract amounts" and assigned a binary value of 1.

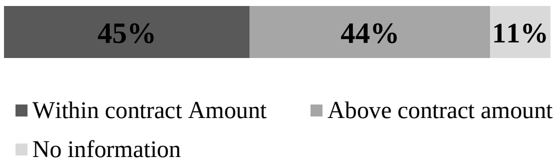

Figure 5. Distribution of cost performance

As for schedule performance (Figure 6), negative percentages indicated that the project was ahead of schedule, a value of zero indicated as scheduled or on-time, and a negative percentage indicated behind schedule. These terms were also changed to binary values during analysis. Projects that were on-time or ahead of schedule were considered "within schedule" and assigned a binary value of 0, while projects "behind schedule" were assigned a binary value 1.

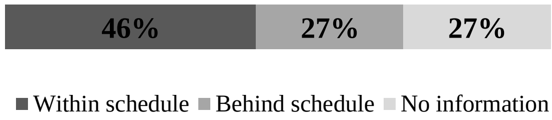

Figure 6. Distribution of schedule performance

4 Data Analysis

Bivariate analysis was used to describe, explore, and summarize the factors that impact the FTE of highway construction inspectors. Different research questions were tested to further analyze the status of Junior, Intermediate and Senior inspectors across the different projects under study:

1. What is the impact of project types on the FTE of junior, intermediate, and senior inspectors?
2. What is the impact of project sizes on the FTE of junior, intermediate, and senior inspectors?
3. What is the impact of project complexity on the FTE of junior, intermediate, and senior inspectors?
4. What is the impact of cost performance on the FTE of junior, intermediate, and senior inspectors?
5. What is the impact of schedule performance on the FTE of junior, intermediate, and senior inspectors?

Due to the qualitative nature of the data, non-parametric tests were used.

Kruskal – Wallis Test: Known as the nonparametric version of the one-way ANOVA, Kruskal-Wallis is used to compare groups of equal or different sizes and indicate that at least one sample stochastically dominates one other sample. A significant p-value indicates that there at least two groups that were significant different than each other.

Conover – Iman Test: When the results of the Kruskal-Wallis test are significant, the Conover-Iman non-parametric post-hoc test is used to compare all possible pairs and identify which pairs are statistically significant. The pairwise comparisons between the studied groups indicate whether the difference is significant or not depending on the p-value.

Kendall's tau-b Test: A non-parametric test that measures the correspondence between the ranking of the dependent and independent variables to test whether the dependent variable significantly increases or decreases as the independent variable changes. Kendall's tau-b hypothesis test produces two statistical metrics: The first metric is a p-value which can be thought of as the probability of having no statistical correlation between the two variables that are being studied. The smaller the p-value, the stronger the evidence of statistically significant correlation between the two variables. The second metric is the correlation coefficient, tau-b (τ_b). This coefficient measures the association between the two variables and ranges from −1 (100% negative association, or perfect inversion) to +1 (100% positive association, or perfect agreement); a value of zero indicates the absence of association.

4.1 Impact of the Types of Project

For every level of inspectors (i.e. Junior, Intermediate, and Senior inspectors), the FTE was measured across the four different types of projects. Figure 7 shows the FTE variation for Junior inspectors with roads being the highest (0.78), followed by bridges (0.63), roadside safety (0.44), then roadside enhancements (0.27). A similar graph was also developed for Intermediate and Senior inspectors. For Intermediate inspectors, the average FTE was highest for bridges (1.43), followed by roads (1.17), roadside enhancements (0.67), then roadside safety (0.54). As for Senior inspectors, the average FTE was also highest for bridges (1.43), followed by roads (1.03), roadside safety (0.76), then roadside enhancements (0.69).

The difference in the FTE of each inspector level across the various types of projects was statically tested using the Kruskal-Wallis test. The results from the Kruskal-Wallis resultant in a significant p-value for all three inspector levels: Junior (p-value = 0.0135), Intermediate (p-value = 0.0159), and Senior (p-value = 0.0316), indicating that there is a statistical significance across all three inspector levels. This implies that the FTE distributions of Junior, Intermediate, and Senior inspectors were not the same across the different types of projects.

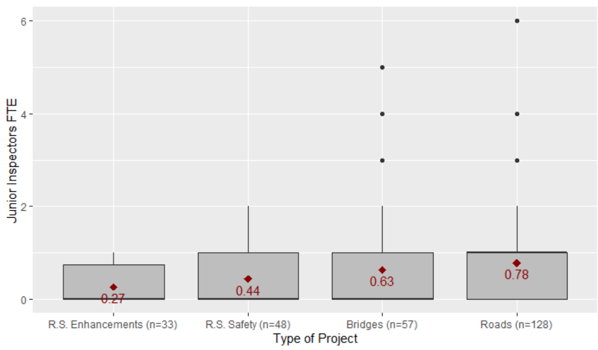

Figure 7. Boxplots showing the variation of the FTE of Intermediate inspectors with respect to the level of complexity of the project and the correlation between both variables

When the results from Kruskal-Wallis showed statistical significance, the Conover-Iman test was employed to perform pairwise comparisons. The results of the pairwise comparisons for Junior, Intermediate, and Senior inspectors are shown in Table 1.

Table 1. Results of pairwise comparisons on project types for Junior inspectors

Project Types (Average)		**p-value**	**Significance**
Conover-Iman Test for Junior Inspectors			
Safety (0.44)	Bridges (0.63)	0.9345	Not Significant
Enhancements (0.27)	Bridges (0.63)	0.1904	Not Significant
Roads (0.78)	Bridges (0.63)	0.0653	Significant*
Enhancements (0.27)	Safety (0.44)	0.2318	Not Significant
Enhancements (0.27)	Safety (0.44)	0.0673	Significant*
Enhancements (0.27)	Roads (0.78)	0.0031	Significant**
Conover-Iman Test for Intermediate Inspectors			
Safety (0.54)	Bridges (1.43)	0.0311	Significant**
Enhancements (0.67)	Bridges (1.43)	0.2069	Not Significant
Roads (1.17)	Bridges (1.43)	0.6119	Not Significant
Enhancements (0.67)	Safety (0.54)	0.5141	Not Significant
Roads (1.17)	Safety (0.54)	0.0031	Significant**
Enhancements (0.67)	Roads (1.17)	0.0681	Significant*
Conover-Iman Test for Senior Inspectors			
Safety (0.76)	Bridges (1.13)	0.0154	Significant**
Enhancements (0.7)	Bridges (1.13)	0.0127	Significant**
Roads (1.04)	Bridges (1.13)	0.1575	Not Significant
Enhancements (0.7)	Safety (0.76)	0.7540	Not Significant
Roads (1.04)	Safety (0.76)	0.1376	Not Significant
Enhancements (0.7)	Roads (1.04)	0.0992	Significant*

*Significant at 90% confidence
**Significant at 95% confidence

The ad-hoc Conover-Iman test showed that roads, on average, needed significantly more Junior inspectors when compared to bridges (p-value = 0.0653), roadside safety (p-value=0.0673), and roadside enhancements (p-value=0.0031).

For intermediate inspectors (Table 1), roads, on average, needed significantly more Intermediate inspectors when compared to roadside safety (p-value = 0.0031) and roadside enhancements (p-value = 0.0681), and roadside safety, on average, needed significantly fewer Intermediate inspectors when compared to bridges (p-value=0.0311).

As for Senior level inspectors (Table 1), bridges, on average, needed significantly more Senior level inspectors than roadside safety and roadside enhancements projects (p-value = 0.0154 and 0.0127 respectively).

4.2 Impact of the Size of Projects

The FTE of every inspector level was measured across the five different sizes of projects. Figure 8 shows the FTE variation for Junior inspectors, where the average FTE was 0.29, 0.38, 0.53, 1, and 1.69 for “500k & Less”, “500k-1M”, “1M-5M”, “5M-10M”, and “10M & more” project sizes respectively. For Intermediate inspectors, the average FTE was 0.56, 0.6, 0.92, 1.67, and 3.21 for “500k & Less”, “500k-1M”, “1M-5M”, “5M-10M”, and “10M & more” project sizes respectively. As for Senior inspectors, the average FTE was 0.79, 0.61, 0.94, 1.14, and 1.86 for “500k & Less”, “500k-1M”, “1M-5M”, “5M-10M”, and “10M & more” project sizes respectively. Correlation tests were also performed to test any correlation between the FTE variation and the increase in the cost of the project.

Figure 8 indicates that there is a positive relationship between the FTE of Junior inspectors and the size of the project. Similar positive relationships were witnessed in the boxplots for both Intermediate and Senior inspectors.

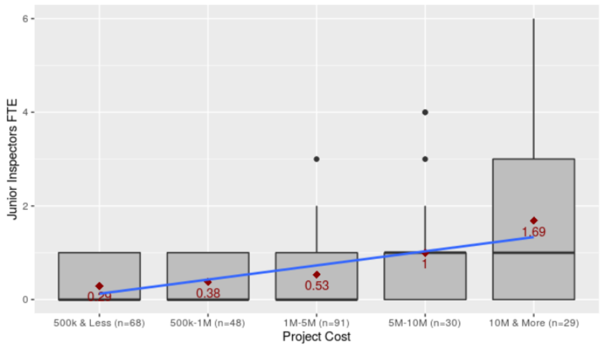

Figure 8. Boxplots showing the FTE of Junior inspectors with respect to the size (or total cost) of the project and the correlation between both variables

The boxplots of all three types of inspectors also showed that projects with 10 million dollars or more needed the highest average of Junior, Intermediate and Senior inspectors with an average of 1.69, 3.21 and 1.86 respectively.

The relationship between the FTE of staffing of all three inspector types and the size of the project was then statistically tested using Kendall Tau-b test, and the results are shown in Table 2. The results of Table 2 provide sufficient evidence to conclude that the FTE of each inspector level and the size of the project are directly correlated. The staffing of Junior, Intermediate, and Senior FTE inspectors increased as the size of the project increased.

Table 2. Results of Kendall Tau-b Correlation tests when analysing inspector FTE and size of project

Inspector Level	Tau-b	p-value	Significance
Junior	0.2742	0.00	Significant*
Intermediate	0.4125	0.00	Significant*
Senior	0.2304	0.00	Significant*

*Significant at 95% confidence

4.3 Impact of the Complexities of Projects

The FTE of every inspector level was measured across the three different levels of complexity. For Junior inspectors, the average FTE varied between 0.52, 0.49, and 1.44 for minor, moderate, and major complex projects respectively. Figure 9 shows the FTE variation for Intermediate inspectors, where the average FTE varied between 0.72, 0.99, and 2.97 for minor, moderate, and major complex projects respectively. As for Senior inspectors, the average FTE varied between 0.79, 0.98, and 1.9 for minor, moderate, and major complex projects respectively.

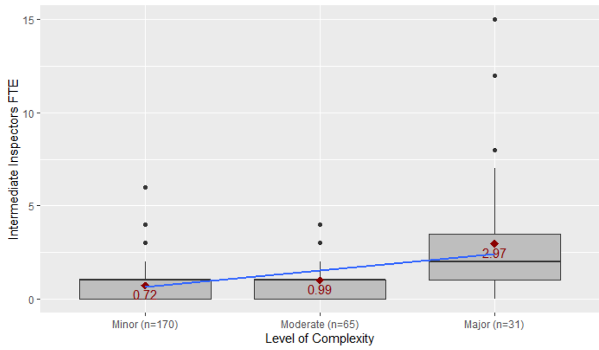

Figure 9. Boxplots showing the variation of the FTE of Intermediate inspectors with respect to the level of complexity of the project and the correlation between both variables

Figure 9 indicates that there is a positive relationship between the FTE of Intermediate inspectors and the level of project complexity, with projects of major complexity having, on average, a higher level of FTE Intermediate inspectors than projects of minor and moderate complexity. A similar positive relationship was witnessed in the boxplots for Senior inspectors, but not for Junior ones.

The boxplots of all three types of inspectors also showed that projects with a major complexity level utilized the highest average of Junior, Intermediate and Senior inspectors with an average of 1.44, 2.97 and 1.9 respectively.

To confirm this positive trend, the relationship between the FTE of staffing of all three inspector types and the level of project complexity was then statistically tested using Kendall Tau-b test, and the results are shown in Table 3.

Table 3. Results of Kendall Tau-b Correlation tests when analysing inspector FTE and complexity of project

Inspector Level	Tau-b	p-value	Significance
Junior	0.0878	0.198	Not Significant
Intermediate	0.2614	0.00	Significant*
Senior	0.2481	0.00	Significant*

*Significant at 95% confidence

The results of Table 3 show that as projects become more complex, more Intermediate and Senior inspectors were needed. This can be attributed to the role of the Intermediate and Senior inspectors as described by [15]. These inspectors have several years of experience and are mostly hired for middle and large-scale projects, which are usually more complex than smaller projects. Moreover, more complex projects call for more experienced personnel especially Senior inspectors who can serve as party chief and are technical experts that can perform duties of resident engineers, making them eligible and important in higher level complex projects.

4.4 Impact of Cost Performance

Every level of inspector FTE was measured across the cost performance groups as shown in Figure 10 for Junior inspectors, where the average FTE was 0.45 for projects within contract amount, and 0.8 for projects above contract amounts. For Intermediate inspectors, the average FTE was 0.78 for projects within contract amount, and 1.35 for projects above contract amounts. As for Senior inspectors, the average FTE was the same regardless of whether the projects were within budget or exceeded it (an average FTE of 1 in each case).

The significance of the pairwise comparison between both cost performance types in terms of inspector FTE average was done using Wilcox test, with results shown in Table 4. The results show that projects that exceeded their budgets needed significantly more Junior and Intermediate inspectors than projects that were completed within contract amounts.

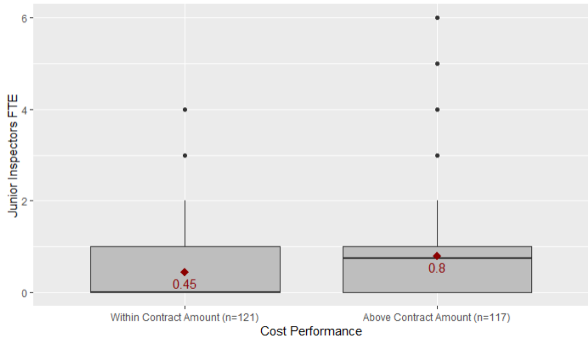

Figure 10. Boxplots showing the variation of the FTE of Junior inspectors with respect to cost performance

Table 4. Results of the Wilcoxon test for cost performance

Inspector Level	p-value	Significance
Junior	0.0073	Significant**
Intermediate	0.0432	Significant**
Senior	0.8322	Not Significant

4.5 Impact of Schedule Performance

Every level of inspector FTE was measured across the schedule performance groups as shown in Figure 11 for Junior inspectors, where the average FTE was 0.56 for projects on time, and 0.72 for projects over time. For Intermediate inspectors, the average FTE was 0.9 for projects on time, and 1.36 for projects over time. As for Senior inspectors, the average FTE was 0.89 for projects within contract amount, and 1.14 for projects over time.

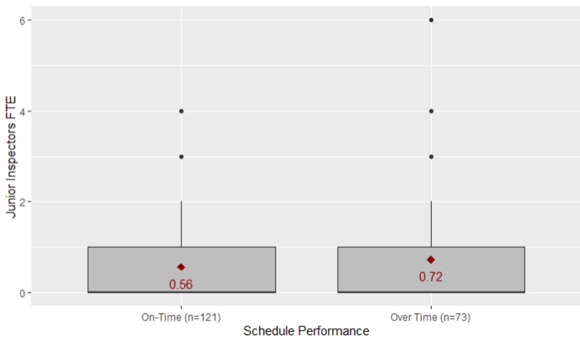

Figure 11. Boxplots showing the variation of the FTE of Junior inspectors with respect to schedule performance

The significance of the pairwise comparison between both schedule performance types in terms of inspector FTE average was done using Wilcox test, with the results shown in Table 5. The results show that projects that exceeded their planned time durations needed significantly more Intermediate and Senior inspectors than projects that finished within contract time. This was similar to what was seen in Table 4.

Table 5. Results of the Wilcoxon test for schedule performance

Inspector Level	p-value	Significance
Junior	0.9042	Not Significant
Intermediate	0.04779	Significant**
Senior	0.02101	Significant**

5 Conclusions, Limitations, and Further Studies

With the current evolution in highway construction projects, DOTs are often under pressure to complete projects as in as short a time as possible. However, the staffing shortage facing these agencies makes it more challenging to finish projects on time and within budget. Inspection is no exception to the problem, and this paper investigated the factors that affect and predict the staffing needs of inspectors. The analysis of the historical data from 266 highway construction projects from 15 different DOTs yielded the following results:

The FTE distribution of Junior, Intermediate, and Senior level inspectors were not the same across the four project types. Some types significantly needed more inspectors than others.

Projects with the highest level of complexity needed the highest FTE of Junior, Intermediate, and Senior inspectors. There was also evidence of a significant correlation between the level of complexity and the FTE of Intermediate and Senior inspectors: as the project became more complex, more Intermediate and Senior inspectors were needed.

As project size increase, more Junior, Intermediate and Senior inspectors were needed.

Projects that exceeded their budget needed significantly more Junior and Intermediate inspectors. Senior inspectors were on average the same regardless of the cost performance. As for projects that exceeded their time, they needed significantly more Junior and Intermediate inspectors.

The findings of the analysis are limited to the data points collected form the surveyed projects, and the use of bivariate analysis. Further studies will perform further multivariate analysis between factors and utilize the information to develop forecasting models to predict staffing for highway construction inspection.

Acknowledgements

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