Predicting the trends and cost impact of COVID-19 OSHA citations on US construction contractors using machine learning and simulation

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Hooman Sadeh and Claudio Mirarchi
Department of Architecture, Built Environment and Construction Engineering, Politecnico di Milano, Milan, Italy
Farzad Shahbodaghlou
Department of Engineering, California State University East Bay, Hayward, California, USA, and
Alberto Pavan
Department of Architecture, Built Environment and Construction Engineering, Politecnico di Milano, Milan, Italy

Abstract

Purpose – Occupational Safety and Health Administration (OSHA) of the U.S. government ensures that all health and safety regulations, protecting the workers, are enforced. OSHA officers conduct inspections and assess fines for non-compliance and regulatory violations. Literature discussion on the economic impact of OSHA inspections with COVID-19 related citations for the construction sector is lacking. This study aims to investigate the relationships between the number of COVID-19 cases, construction employment and OSHA citations and it further evaluates the total and monthly predicted cost impact of OSHA citations associated with COVID-19 violations.

Design/methodology/approach – An application of multiple regression analysis, a supervised machine learning linear regression model, based on K-fold cross validation sampling and a probabilistic risk-based cost estimate Monte Carlo simulation were utilized to evaluate the data. The data were collected from numerous websites including OSHA, Centers for Disease Control and the World Health Organization.

Findings – The results show that as the monthly construction employment increased, there was a decrease in OSHA citations. Conversely, the cost impact of OSHA citations had a positive relationship with the number of COVID-19 cases. In addition, the monthly cost impact of OSHA COVID-19 related citations along with the total cost impact of citations were predicted and analyzed.

Originality/value – The application of the two models on cost analysis provides a thorough comparison of predicted and overall cost impact, which can assist the contractors to better understand the possible cost ramifications. Based on the findings, it is suggested that the contractors include contingency fees within their contracts, hire safety managers to implement specific safety protocols related to COVID-19 and request a safety action plan when qualifying their subcontractors to avoid potential fines and citations.

Keywords COVID-19, Construction industry, Monte Carlo simulation, Machine learning, Cost analysis, OSHA, Safety, Risk management, Risk-based cost estimate

Paper type Research paper

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Introduction

COVID-19 has had a major, adverse worldwide impact on economic, social, environmental and health elements since the start of the spread, and specifically after the World Health Organization (WHO) announced it as a global pandemic on March 11th, 2020. There is no place or industry that has not been affected or has remained intact by negative factors associated with COVID-19 globally (Biwas *et al.*, 2021). It has attributed to a steep decline in production and construction throughout the world, which could result in the most elucidating event in terms of economic and social phenomenon for many years to come (Laing, 2020). The pandemic has effects and ramifications that could be classified into two main categories of public health and safety and economic impact (Simpeh and Amoah, 2021).

Although the economic impact of COVID-19 has been catastrophic for many industries, not all businesses have experienced a negative monetary consequence. Some have prospered financially including online retailing, supermarkets, Zoom video conferencing and hand-sanitizing products (Arora, 2021). In the meantime, the construction sector has been greatly affected in a negative way by the pandemic due to its multi-dimensional nature as well as its complex, strategic, tactical, internal and transactional relationship within the supply chain. The construction sector contributed $900 billion to the US economy with a workforce of 7.64 million people in the first quarter of 2020. Consequences of COVID-19 has caused the sector to suffer a loss of $60.9 billion in GDP and shrinkage of the workforce to nearly 6.5 million, essentially eliminating two years of GDP gains and four years of job growth (Meisels, 2021). Alshareff *et al.* (2021) found that market unpredictability, shortage of personal protective equipment (PPE) and government restrictions were the main causes of disruption within the construction sector. Moreover, schedule delays, losing efficiencies and cost impacts due to the pandemic and its related regulatory responses are expected within the industry (Deloitte, 2020).

Concerning the crises caused by the pandemic, many businesses had to adjust their business models and strategies. Likewise, disruption due to the pandemic is also reshaping the construction sector. While economic impact has been felt across the industry, there are opportunities and emerging trends that could be utilized to influence the outlook of the value chain. COVID-19 plays a big role as a change agent during these crises that affects the prospects for the industry. According to Page *et al.* (2021), there are nine shifts that will drastically change the project delivery methods including, "... productization and specialization, increased value-chain control, and greater customer-centricity and branding. Consolidation and internationalization will create the scale needed to allow higher levels of investment in digitalization, R&D and equipment, and sustainability as well as human capital". Further, increased digitization, rebalanced supply chains toward resilience, augmented consolidation, vertical integration, investments in digitization and innovation of building systems, increase in off-site construction and acceleration toward sustainability are among the immediate and future directions for the industry (McKinsey and Company, 2021).

In response to health and safety concerns of the pandemic, Occupational Safety and Health Administration (OSHA), which is part of the US Department of Labor, proposed and enacted some guidelines for all industries. OSHA ensures workplaces are safe and hazard free for all workers by setting and enforcing standards. Any workplace found not adhering to OSHA standards is subject to hefty penalties and citations. As of February 2022, a total of $10,135,925 in citations has been issued to employers that violated OSHA safety protocols related to COVID-19 in the United States (OSHA, 2021b). The construction industry is also subject to OSHA inspections and has had 516 complaints related to COVID-19 violations, according to OSHA. Consequently, these penalties could have major cost implications for construction contractors, particularly for small and medium-sized enterprises.

Currently, there is a lack of research on cost analysis of OSHA inspections related to COVID-19 violations for the US construction contractors. There are no studies that investigate the cost impact and the potential economic ramifications of OSHA citations for the industry.

A few studies that were conducted on OSHA safety protocols only examined the types of complaints (Hatoum *et al.*, 2021) and employers' readiness and compliance with those protocols (Koshy *et al.*, 2021). Additionally, it is not clear what factors may have an impact on possible increase or decrease of OSHA citations. To bridge this research gap, this study aims to: (1) establish if there are any statistically significant relationships between the potential cost impact of OSHA COVID-19 related citations, number of monthly COVID-19 cases, and monthly construction employment, (2) predict the monthly COVID-19 cost impact of OSHA citations and (3) estimate the overall cost impact of OSHA citations for the construction industry since the start of the pandemic. The rest of the paper is organized as follows: background, methods and materials, results and discussion, contributions and limitations and conclusions.

Background

To fully understand the impact of COVID-19 on the construction industry, the following four dimensions were reviewed: COVID-19 definition and statistics, the economic impact for the construction industry, OSHA, health and safety implications, proposed mitigation remedies and relevant variables and research gap.

COVID-19 definition and statistics

COVID-19 is a contagious disease caused by an acute respiratory syndrome coronavirus 2 (SARS-COV-2) (Page *et al.*, 2021; CDC, 2020a, b; WHO, 2021). According to Centers for Disease Control and Prevention (CDC), it commonly spreads by close contact within six feet via respiratory droplets during coughing, sneezing, talking and breathing. It can sometimes be spread by airborne transmission and cause infection in people who are more than six feet away from the infected person due to a concentration of droplets remaining in air for minutes to hours (CDC, 2020a, b). The symptoms include fever, chills, coughing, shortness of breath, fatigue, muscle aches, headache, loss of smell or taste, sore throat, congestion, nausea and diarrhea (CDC, 2020a, b). As of March 4, 2022, there have been 440, 807, 756 confirmed cases worldwide with 5,978,096 deaths expanding in 223 countries and territories (WHO, 2021) and 79,078,932 reported cases in the US with 955,135 deaths and 254 million total vaccines administered (CDC, 2020a, b).

Economic impact for the construction industry

COVID-19 has a grave economic impact on the construction sector in so many ways, which can result in financial losses. Project delays and suspensions, a shortage of materials, low productivity, material cost inflation, revenue shrinkage, supply chain disruption and cost and time overruns have been sustained by the industry as the result of the pandemic (Alsharef *et al.*, 2021; Gamil and Alhagar, 2020; Shafi *et al.*, 2020). According to the Al Mansoori *et al.* (2021), the increase cost of construction projects and labor has gravely crippled the UAE's economic sector. King *et al.* (2021a) also emphasized on the economic impact in terms of reduced foreign investment and demand in the construction industry. Further, bid prices and input costs have risen since the start of the pandemic by 0.5 and 12.8%, profit margins have experienced a downward pattern, and some firms have suffered financial losses (Choi, 2021). Moreover, Al Amri (2021) criticized that the rising oil prices is one of the major contributing factors to economic downturn of the construction industry in Oman.

Furthermore, construction contracts could also impact the project budget negatively and have incurred costs for the contractors during the pandemic. Yadeta (2020), Casady and Baxter (2020) and Hansen (2020) examined the impact of COVID-19 in construction projects by looking at contractual obligations, namely, "Force Majeure". Force Majeure is a contract clause which is applicable in situations that are unforeseeable, unavoidable, uncontrollable, impactable and beyond responsibility of any party. However, as Yadeta (2020) pointed out, it only calls for an extension of time for contractors without considering any compensation for monetary loss. Besides the negative economic impacts in the short term, supply and demand could be affected in the long term, which would potentially change the framework and dynamics of future investments (McKinsey and Company, 2021). Moreover, public–private partnerships are also facing collapse and failures and a need for collaboration and strategic partnership is imperative to save these types of projects (Casady and Baxter, 2020). While the pandemic has had both good and bad effects for the construction sector, the companies are advised to build a culture based on plasticity with pliable capabilities so they could adjust and change accordingly to new conditions and consequences such as one brought upon by COVID-19 (Assaad and El-adaway, 2021).

OSHA, health and safety implications

In addition to the economic impact, COVID-19 also poses a great health risk for construction workers, which could result in severe sickness and extensive absenteeism from work. Construction workers were among the highest number of reported positive cases compared to other sectors and five times more likely to need hospitalization (Alsharef *et al.*, 2021). Olanrewaju *et al.* (2021) referred to construction sites as an "epicentre" for spread of infectious diseases, which result in an increase in project cost and skilled labor shortage by 20 and 40%, respectively. Moreover, the upper management's lack of experience in dealing with COVID-19 has made construction sites less safe and construction workers more susceptible to anxiety and mental health problems (Pamidimukkala and Kermanshachi, 2021).

The OSHA, which was passed by the US Congress in 1970, requires companies to follow the safety and health standards and regulations communicated and proclaimed by OSHA. Furthermore, the Act's General Duty Clause, Section 5(a) (1), requires employers to provide a safe and hazard free workplace for all the employees. Performing job hazard analysis can identify what construction activities require a close contact; if not critical, those activities could be postponed for a later date (OSHA, 2020a). In addition, per Section 9 of the OSHA Act of 1970, if any employer is found to have violated any provisions within the OSHA Act or any regulation pursuant to this Act, they should be issued a citation. Section 9 states, "each citation shall be in writing and shall describe with particularity the nature of the violation, including a reference to the provision of the Act, standard, rule, regulation, or order alleged to have been violated." Moreover, Section 17 expresses, "any employer who willfully or repeatedly violates the requirements of Section 5 (duties) of this Act, any standard, rule, or order promulgated pursuant to Section 6 (health and safety standards) of this Act, or regulations prescribed pursuant to this Act, may be assessed a civil penalty of not more than $70,000 for each violation, but not less than $5,000 for each willful violation" (OSHA, n.d). According to Hatoum *et al.* (2021), most of the OSHA COVID-19 related complaints that result in citations are related to workers not adhering to safety measures and showing up to work after having tested positive.

As it is evident, all the above-mentioned safety factors could have major cost implications for construction contractors in terms of project delays, shortage of labor and significant fines and penalties by OSHA.

Proposed mitigation remedies

In response to the COVID-19 pandemic, many studies have been conducted on prevention, mitigation, risk assessment and ways to slow the spread of the virus for the construction industry by both government organizations as well as academia. For example, OSHA has established some guidelines regarding the roles of employers and workers which include some of the following: (1) assignment of a workplace coordinator, (2) identification of workplace hazards related to COVID-19, (3) identification of measures that limit the spread of the virus, (4) protections for workers at higher risk for severe illness, (5) establishment of a communication system, (6) education and training on COVID-19, (7) isolation and quarantine instructions for infected employees and (8) enhanced cleaning and disinfection of the facilities (OSHA, 2021a). Additionally, OSHA has also defined construction work tasks based on risk levels of exposure as a tool for contractors to assess and prioritize risks accordingly as shown in Table 1 below.

Furthermore, to curb the spread of COVID-19, OSHA recommends that construction contractors should utilize engineering and administrative controls, apply safe work practices and make use of PPE. These categories include: (1) adhering to standard operating procedures recommended by CDC, (2) employee training regarding the geographical areas of work, (3) examining related risks when work is to be performed indoors, (4) reducing number of workers on any given shift by scheduling workdays, (5) coordinating site deliveries, (6) diligent housekeeping practices and (7) limiting in-person meetings (OSHA, 2021b). In related academic studies, Simpeh and Amoah (2021), Alsharef *et al.* (2021), Stiles *et al.* (2021), Al Mansoori *et al.* (2021), and Biswas *et al.* (2021) called for screening, monitoring the site access, proper handling of materials, diligent workplace sanitation, social distancing, usage of PPEs, face masks, employee training, testing and spreading out construction activities as means of prevention for the spread. While these methods are effective to slow the spread, they do not offer anything beyond what has already been recommended by OSHA and CDC.

As for effective project management strategies to confront the pandemic, King *et al.* (2021b) proposed risk assessment and mitigation, specifically among the low skilled workers, stating that they could potentially save many lives and reduce job losses. Oey and Lim (2021) developed an action plan to combat the effects of COVID-19 within the construction sector. Their strategy called for robust cost control management, smart material logistic management, cash flow management, rigorous project management, improved office management, optimizing manpower management and adapting design to change during the crisis. Moreover, in terms of project planning and management, creating mitigation programs for shutdowns and project restarts, reviewing the projects that could be abandoned, assessment of services that could be performed offsite to avoid time delays, and developing a project start-up plan are among important elements to manage businesses effectively during the pandemic (Deloitte, 2020). Moreover, Araya (2021a) suggested that adding multiple shifts, particularly night shifts, helps with protection of workers in terms of health and safety by 20%. However, it should be noted that applying such strategy would result in cost implications since workers are paid higher wages during night shifts. On the other hand, Amoah and Simpeh (2021) emphasized that workers who do not adhere to safety and health prevention rules should be cited by means of fines and wage reductions.

Other studies have presented technological solutions as means to alleviate the effects of COVID-19 for the construction industry. Jallow *et al.*, 2021 suggested the use of technology

Lower	Medium	High	Very high
• Tasks that allow employees to remain at least six feet apart and involve little contact with the public, visitors or customers	• Tasks that require workers to be within six feet of one another • Tasks that require workers to be in close contact (within six feet) with customers, visitors or members of the public	• Entering an indoor work site occupied by people such as other workers, customers, or residents suspected of having or known to have COVID-19, including when an occupant of the site reports signs and symptoms consistent with COVID-19	• Category not applicable for most anticipated work tasks

Table 1.
Construction work tasks associated with exposure risk levels

and online platforms for effective communications during the pandemic and found that building information modeling (BIM) could be a great tool to control and manage the projects virtually. However, this strategy could only benefit the large construction firms since they have the capacity and capability to utilize such technologies, whereas smaller contractors lack the resources to implement such practices. Osunsanmi *et al.* (2020) also resorted to technology as a mechanism to combat and avert COVID-19 effects. They concluded that involvement of occupants in maintenance management of the smart buildings could be beneficial to slow and intercept the spread. Equally important, Ebekozien and Aigbavboa (2021) found the fourth industrial revolution technologies such as smart construction site, simulation and modeling and digitization and virtualization are useful to amplify COVID-19 mitigations and prevention measures. Further, Araya (2021b) stated that increasing low-risk construction activities could help curb the spread.

Relevant variables for the study and research gap

After reviewing the literature, since OSHA citations influence the projects' indirect costs, the need for a cost analysis and evaluation of OSHA citations was imminent. Cost overrun is one of the most important factors for any construction project (Sadeh *et al.*, 2021). Most of the current studies only discuss the indirect cost impacts of the pandemic in which OSHA penalties were neglected. One of the most important variables that contributes to the potential cost impact of OSHA citations is the number of COVID-19 cases. As the cases increase, more workers could be impacted in terms of health and safety, which could result in sick calls and shortage of labor. The authors wanted to establish if there was a correlation between the number of COVID-19 cases and potential OSHA citations. Other variables thought to be of importance were the number of construction workers and the number of OSHA complaints, which resulted in fines and citations for construction contractors. To build a conceptual model that would establish and test any possible correlations among those variables, the amount of minimum, maximum and most likely citations issued by OSHA and the percentages of complaints that resulted in such fines were also considered to be predominant.

Methods and materials

Data collection

According to OSHA, there were a total of 18,693 COVID-related valid complaints for all industries in the US as of February 2022. These complaints resulted in 780 citations with an initial fine of $10,135,925, averaging $13,000.00 for per violation (OSHA, 2021b). Table 2 shows the variables that were used in the study which can be described as follows: (1) number of monthly COVID-19 cases in the USA, (2) monthly construction employment, (3) monthly OSHA COVID-19 related complaints for the construction sector and (4) potential cost impact of monthly COVID-19 related citations for the construction industry.

The cost impact of monthly citations was estimated based on average OSHA citation amount of $13,000.00 per citation multiplied by the number of monthly complaints. The data were collected from various websites while the number of monthly COVID-19 cases, construction employment numbers and number of OSHA complaints, along with minimum and maximum cost impacts, were all obtained from CDC, US Bureau of Labor Statistics and OSHA, respectively.

Methodology

To achieve the research goals and objectives of this study, the following statistical methods were utilized: (1) a multivariable regression analysis to test the association among the variables, (2) a supervised machine learning regression algorithm to predict the monthly cost

Date	No. Complaints	COVID cases	Cost impact	Employment
4/1/2020	103	876,703	$1,339,000.00	6,516,000
5/1/2020	52	744,061	$676,000.00	7,007,000
6/1/2020	39	860,806	$507,000.00	7,166,000
7/1/2020	36	1,938,390	$468,000.00	7,198,000
8/1/2020	28	1,476,761	$364,000.00	7,222,000
9/1/2020	17	1,219,699	$221,000.00	7,243,000
10/1/2020	25	1,935,156	$325,000.00	7,295,000
11/1/2020	32	4,431,153	$416,000.00	7,313,000
12/1/2020	33	6,370,623	$429,000.00	7,357,000
1/1/2021	29	6,087,993	$377,000.00	7,360,000
2/1/2021	12	2,342,880	$156,000.00	7,308,000
3/1/2021	15	1,795,885	$195,000.00	7,408,000
4/1/2021	17	1,845,302	$221,000.00	7,393,000
5/1/2021	9	899,197	$117,000.00	7,381,000
6/1/2021	2	393,318	$26,000.00	7,378,000
7/1/2021	4	1,381,771	$52,000.00	7,395,000
8/1/2021	19	4,255,224	$247,000.00	7,397,000
9/1/2021	15	4,104,587	$195,000.00	7,427,000
10/1/2021	12	2,437,349	$156,000.00	7,455,000
11/1/2021	7	2,558,529	$91,000.00	7,502,000
12/1/2021	10	6,362,284	$130,000.00	7,528,000
Total	516	54,317,671	$6,708,000.00	

Table 2. Relevant variables used in the study

impact of OSHA citations and (3) a probabilistic Monte Carlo simulation to evaluate the total potential cost impact of COVID-19 OSHA related citations.

Figure 1 below shows the flowchart of the research methodology utilized for this study.

Since this study was based on numerical data and aimed to predict and test the relationships among variables, multivariable linear regression and supervised machine learning linear regression were found to be best suitable for data analysis. In addition, a probabilistic cost estimate based on a Monte Carlo simulation was found to be a powerful tool to evaluate overall cost impact as discussed by Sadeh *et al.* (2021) and Wylie *et al.* (2014).

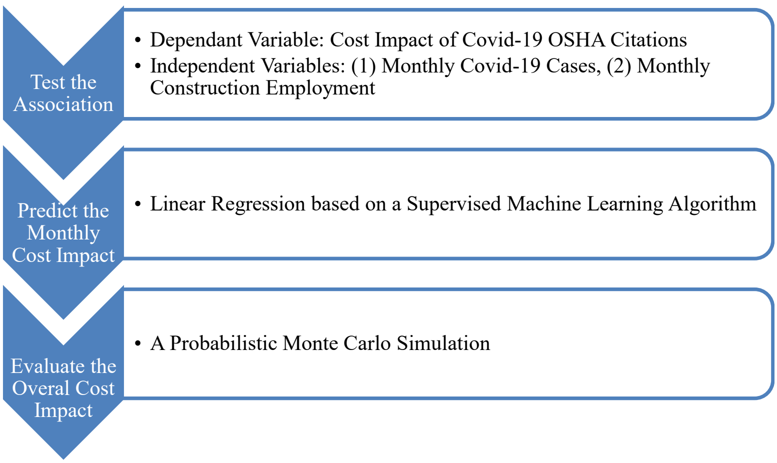


Figure 1. Flowchart of methodology

Linear regression. SPSS 27 was used for the multivariable regression analysis. The potential cost impact of monthly OSHA citations was set as the dependent variable, and monthly COVID-19 cases and construction employment numbers were used as independent variables. The monthly cost impact variable was calculated based on the average amount of each OSHA citation ($13,000.00) * number of monthly COVID-related construction complaints, as stated earlier. The sample size consisted of 21 data points from April of 2020 through December of 2021. Although the sample size was small due to limited data availability, the analysis is still statistically valid and reliable based on Hair *et al.* (2010). They concluded that in multivariable regression analysis, a ratio of 10:1 is desirable for each variable.

Machine learning linear regression. For the supervised machine learning algorithm, monthly COVID-19 cases and construction employment numbers were utilized as features (independent variables) and monthly cost impact was chosen as the target (dependent variable), as they were in the regular regression analysis. Based on Jung (2017), K-fold cross validation sampling technique was used to predict the outcome by dividing the original sample into a training set and a test set for evaluation. The original sample was divided into 10 subsamples and the algorithm was tested by retaining one sample as the validation data to test the model and the remaining samples were used as training data. The model was induced from other folds and the data from the retained fold were classified. This process was repeated 10 times for all the folds, each subsample was used once as validation data, and the results were averaged to produce the final estimate. Table 3 shows the mathematical equations that were utilized for this analysis; to evaluate the performance of the model. R^2 explains the variability in the dependent variable, showing the fitness of the model. Root mean squared error (RMSE) is the standard deviation of the residuals that can be used to see how spread the residuals are from the regression line. Mean absolute error (MAE) examines the magnitude of difference between the prediction of an observation and the true value of that observation.

Monte Carlo simulation. A probabilistic risk-based cost estimate simulation was performed to record risk variability through a range of estimated costs as explained by AASHTO (2009). The method is based on dividing the total cost estimate into smaller elements. These elements are then quantified either by risk experts or objectively, using statistics or historic data, to produce a distribution. The experts are asked to determine the minimum, maximum and most likely cost impact values based on their experience as presented by Sadeh *et al.* (2021). These values can also be obtained based on statistical or historical data to produce a distribution for the simulation. For this study, the minimum and maximum values were calculated based on penalty guidelines set by OSHA as shown in Table 4.

Furthermore, the Monte Carlo simulation samples the data through many combinations to obtain a probability distribution function (Napier and Liu, 2008). According to Sadeh *et al.* (2021), "the model uses three criteria: (1) a deterministic base estimate; (2) cost impact variability (minimum, most likely, and maximum values); and (3) probability of occurrence for each risk."

Table 3.
The mathematical equations for machine learning

Mathematical equations	
Root mean square error (RMSE)	$\mathrm{RSME} = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(y_i - \widehat{y}_i)^2}$
Mean absolute error (MAE)	$\mathrm{MAE} = \frac{1}{n}\sum_{i=n}^{n}\left\lvert y_i - \widehat{y}_i \right\rvert$
R-squared	$R^2 = 1 - \frac{\sum (y_i - \widehat{y}_i)^2}{\sum (y_i - \mu)^2}$

As demonstrated by Wylie *et al.* (2014), the variability (V_r) for each category (r) is replicated in a symmetric PERT-Beta curve using most likely (ML_r) value, minimum (Min_r) and maximum (Max_r) values. Using a PERT-Beta distribution results in a higher probability that the cost for each category is closer to the most likely value. The probability of occurrence for each risk is presented by a maximum (P_{max}) and minimum (P_{min}). Random probability of occurrence (RPO) is computed via a random value (R_2) using the range stated above. If RPO is greater than the first random number (R_1), then the risk has occurred and cost impact is calculated, otherwise the cost impact is zero. PERT-Beta function uses a third random number (R_3) in addition to minimum (Min), most likely (ML) and maximum (Max) values as input variables to compute cost impact. The following equations are used for the simulation process.

$$\mathrm{Max}_r = \mathrm{ML}_r * (1 + V_r/100) \tag{1}$$

$$\mathrm{Min}_r = \mathrm{ML}_j * (1 - V_r/100) \tag{2}$$

$$\mathrm{RPO} = P_{\min} + (P_{\max} - P_{\min}) * R_2 \tag{3}$$

$$\text{Cost Impact} = f_{\text{PERT-Beta}}(R_3, \text{Min}, \text{ML}, \text{Max}) \tag{4}$$

Results and discussion

Linear regression

The results of the regression analysis are shown in Table 5. Based on the analysis, $R^2 = 0.977$, which indicates a high degree of correlation showing that almost 98% of the variation can be explained by the independent variables. The p-values < 0.001, which indicate that the regression model is statistically significant. Moreover, the variance inflation factor (VIF) values, shown in Table 5, are all between 1 and 5, indicating that multicollinearity is not an issue for the regression model.

Additionally, the P-P plot in Figure 2 shows that points generally follow the normal line with no strong deviation. This shows that the residuals are normally distributed.

Based on the results and as shown in Figure 3, there is negative relationship between construction employment and cost impact of OSHA citations. The construction employment

Type of violation	Penalty minimum	Penalty maximum
Serious	$975 per violation	$13,653 per violation
Other-than-serious	$0 per violation	$13,653 per violation
Wilful or repeated	$9,753 per violation	$136,532 per violation
Posting requirements	$0 per violation	$13,653 per violation

Table 4. Penalty amounts by OSHA

Coefficients[a]

Model		Unstandardized coefficients B	Unstandardized coefficients Std. Error	Standardized coefficients Beta	t	Sig	Collinearity statistics Tolerance	Collinearity statistics VIF
1	(Constant)	10528099.105	526767.874		19.986	<0.001		
	Cases	0.047	0.008	0.310	5.627	<0.001	0.829	1.206
	Employment	−1.415	0.073	−1.064	−19.304	<0.001	0.829	1.206

Note(s): [a]Dependent Variable: Cost
*R-Square: 0.955, R: 0.977

Table 5. Regression analysis cost impact

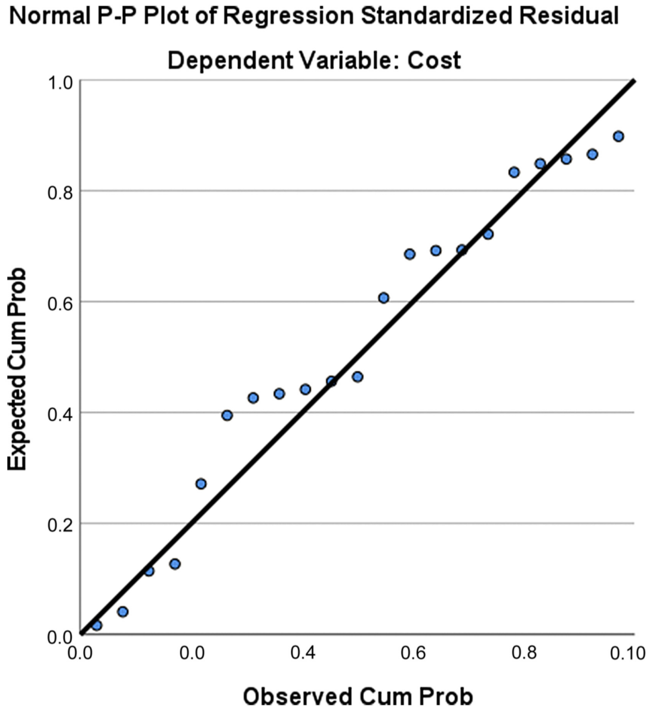


Figure 2.
P-P plot

variable has an unstandardized coefficient value of −1.415. This implies that as the construction employment increases, the cost impact of citations decreases. This could explain that safety measures and guidelines were not enforced in the beginning of the pandemic and that construction contractors did not have any policies in place to protect their employees against the virus which resulted in more initial fines and complaints. As the knowledge about the virus increased and standards and health provisions were put in place, there was a decrease in number of citations in relation to an increase in number of employees. However, as shown in Figure 4, there is a positive relationship between COVID-19 cases and the cost impact of OSHA citations. COVID-19 cases variable has an unstandardized coefficient of 0.047, indicating that as the number of cases increase, there is also an increase in the amount of OSHA citations. This increase could explain that OSHA safety protocols were not fully implemented or followed by all employees or contractors; therefore, resulting in a surge of citation amount.

Machine learning regression model

The result of the machine learning regression analysis is shown in Table 6 below. $R^2 = 0.943$, which shows a high degree of correlation for our model. Additionally, the RMSE value is 66649.8, which is very small and a great fit, considering the target variable is in the range of [26,000– 1339,000]. Similarly, the MAE value is 54081.4, which shows a small error based on the range of values, indicating the regression analysis is a good fit and a high performance by the model.

Furthermore, Figure 5 shows the graphical comparison between the original and predicted values. The predicted values have a higher mean and a lower standard deviation, which shows that the values are less spread closer to the mean, comparing to the cost impact values.

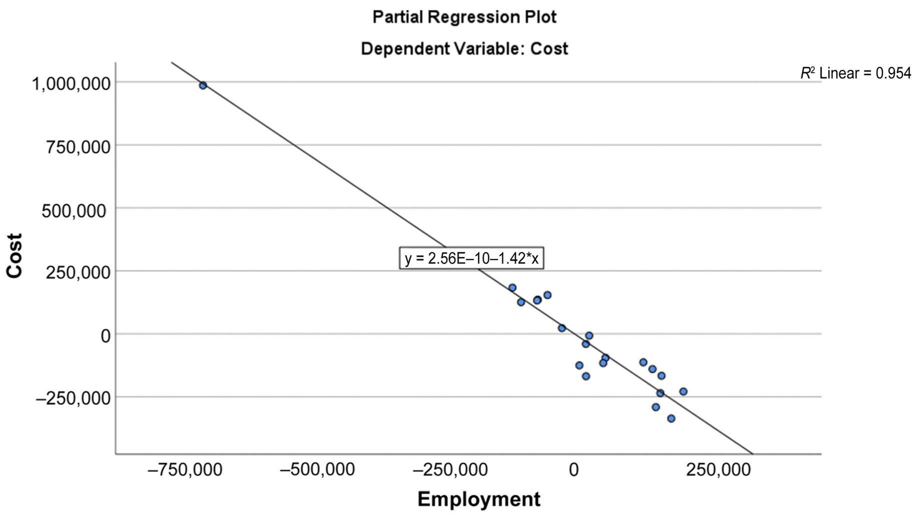


Figure 3.
Regression cost impact and employment

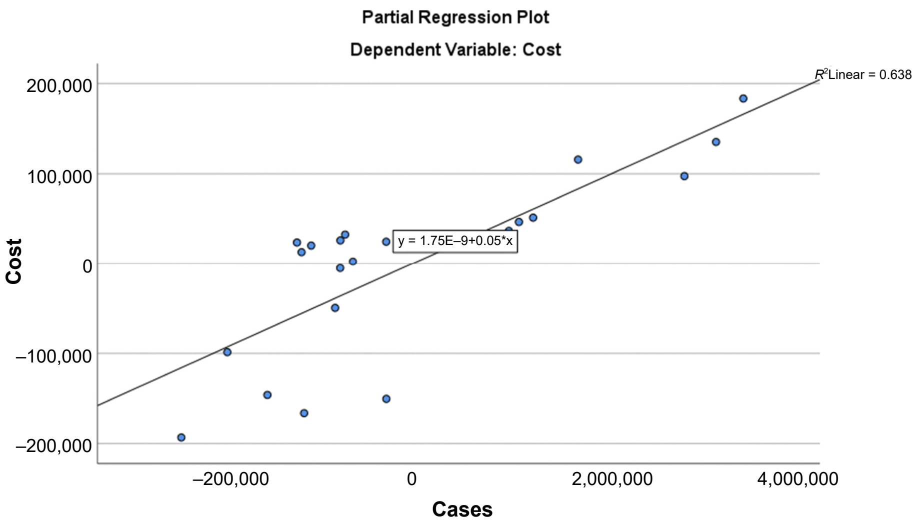


Figure 4.
Regression cost impact and Covid cases

Moreover, Figure 6 represent the graph of actual values vs. predicted values. The *y*-axis represents our dependent variable, and the *x*-axis (unstandardized predicted values) represents our two independent variables that were derived from the regression line.

Monte Carlo simulation

The deterministic estimate was calculated based on the 5% inspections rate set by the new OSHA directive (OSHA, 2021c), which is the percentage of the COVID-19 inspections in relation to the total number of yearly complaints. Therefore, the base estimate was set at $335,400.00, which is 5% of the most likely cost impact of $6,708,000.00 for 21 months. The variability and probably of occurrence were estimated at 10 and 50%, respectively by default for the purpose of this stimulation.

Date	Cost	Linear regression	Fold	COVID cases	Employment
4/1/2020	$1,339,000.00	$1,343,210.00	1	8,76,703	6,516,000
7/1/2021	$52,000.00	$133,702.00	1	1,381,771	7,395,000
9/1/2021	$195,000.00	$210,892.00	1	4,104,587	7,427,000
5/1/2020	$676,000.00	$639,916.00	2	744,061	7,007,000
12/1/2020	$429,000.00	$406,212.00	2	6,370,623	7,357,000
9/1/2020	$221,000.00	$337,236.00	3	1,219,699	7,243,000
3/1/2021	$195,000.00	$128,118.00	3	1,795,885	7,408,000
7/1/2020	$468,000.00	$425,089.00	4	1,938,390	7,198,000
10/1/2021	$156,000.00	$82,047.80	4	2,437,349	7,455,000
5/1/2021	$117,000.00	$123,697.00	5	899,197	7,381,000
8/1/2021	$247,000.00	$257,409.00	5	4,255,224	7,397,000
6/1/2020	$507,000.00	$416,206.00	6	860,806	7,166,000
1/1/2021	$377,000.00	$402,613.00	6	6,087,993	7,360,000
8/1/2020	$364,000.00	$374,811.00	7	1,476,761	7,222,000
12/1/2021	$130,000.00	$181,810.00	7	6,362,284	7,528,000
11/1/2020	$416,000.00	$378,402.00	8	4,431,153	7,313,000
4/1/2021	$221,000.00	$143,195.00	8	1,845,302	7,393,000
2/1/2021	$156,000.00	$306,887.00	9	2,342,880	7,308,000
6/1/2021	$26,000.00	$128,602.00	9	393,318	7,378,000
10/1/2020	$325,000.00	$286,676.00	10	1,935,156	7,295,000
11/1/2021	$91,000.00	$19,297.90	10	2,558,529	7,502,000

RMSE	MAE	R^2
66649.8	54081.4	0.943

Note(s): *Sampling: 10-fold Cross Validation

Table 6.
Supervised regression analysis

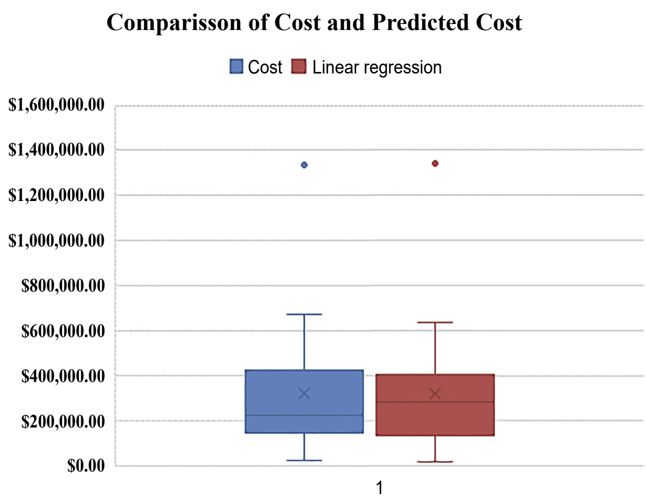


Figure 5.
Comparison of cost and predicted cost impact

The minimum and maximum penalty amounts were calculated according to data provided by OSHA as shown earlier in Table 4. The minimum cost impact for each month was set at $0, and the maximum value was calculated based on the number of valid complaints per month

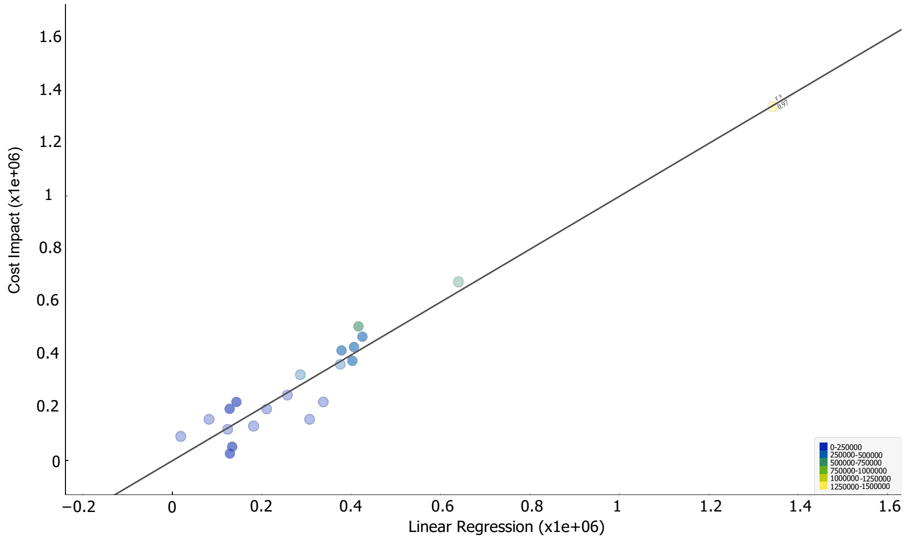


Figure 6.
Actual values vs predicted values

multiplied by the maximum penalty amount of $13,653 for each violation. The most likely cost impact for each month was computed based on the number of monthly violations times the most likely cost of $13,000.00 for each violation as stated earlier. Table 7 shows all the values that were used in the simulation.

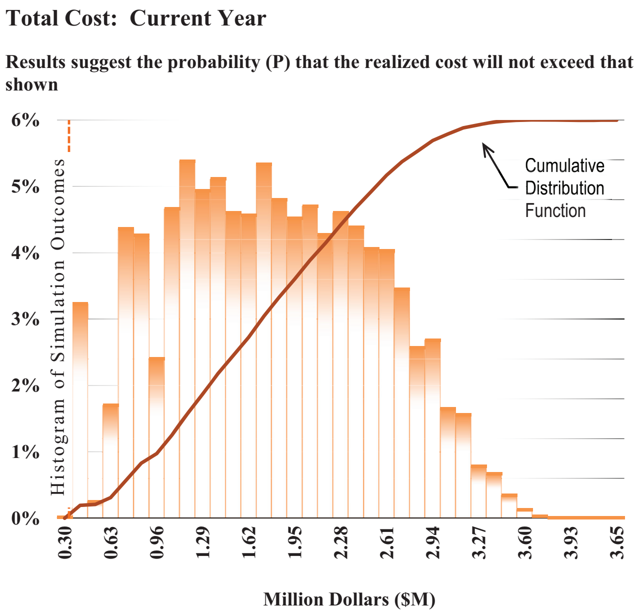
Date	Min ($)	Most likely ($)	Max ($)	Probability
4/1/2020	$0.00	$1,339,000.00	$1,406,259.00	50%
5/1/2020	$0.00	$676,000.00	$709,956.00	50%
6/1/2020	$0.00	$507,000.00	$532,467.00	50%
7/1/2020	$0.00	$468,000.00	$491,508.00	50%
8/1/2020	$0.00	$364,000.00	$382,284.00	50%
9/1/2020	$0.00	$221,000.00	$232,101.00	50%
10/1/2020	$0.00	$325,000.00	$341,325.00	50%
11/1/2020	$0.00	$416,000.00	$436,896.00	50%
12/1/2020	$0.00	$429,000.00	$450,549.00	50%
1/1/2021	$0.00	$377,000.00	$395,937.00	50%
2/1/2021	$0.00	$156,000.00	$163,836.00	50%
3/1/2021	$0.00	$195,000.00	$204,795.00	50%
4/1/2021	$0.00	$221,000.00	$232,101.00	50%
5/1/2021	$0.00	$117,000.00	$122,877.00	50%
6/1/2021	$0.00	$26,000.00	$27,306.00	50%
7/1/2021	$0.00	$52,000.00	$54,612.00	50%
8/1/2021	$0.00	$247,000.00	$259,407.00	50%
9/1/2021	$0.00	$195,000.00	$204,795.00	50%
10/1/2021	$0.00	$156,000.00	$163,836.00	50%
11/1/2021	$0.00	$91,000.00	$95,571.00	50%
12/1/2021	$0.00	$130,000.00	$136,530.00	50%
Total	$0.00	$6,708,000.00	$7,044,948.00	

Note(s): ***Base Estimate*: $335,400.00

Table 7.
Variable used in Monte Carlo simulation

The Monte Carlo simulation was executed 10,000 times to compute the cost distribution as shown in Figure 7. The bars show the total probability distribution of the total cost impact, and the line represents the cumulative distribution function. The y-axis is the representation of the probability of the total cost impact at or under a value given on the x-axis. According to the results, there is a 0% chance that the total cost impact would be at $0.30 million, which was the original base estimate prior to running the simulation and a 50% chance that the total cost impact would be at or under $1.72 million. It is further shown there is a 90% chance that the cost impact would be at $2.74 million or below and there is a 100% chance that it would not exceed $3.65 million. This may not represent a significant amount considering it is distributed within the entire construction industry; however, its consequences for small and medium-sized contractors could result in bankruptcy, should they get audited by OSHA. A fine for a micro contractor, with nine or less employees, could potentially wipe out their entire profit margin significantly.

The findings of this study are unique compared with previous studies on COVID-19 for the construction industry. Previous research did not evaluate the exact economic impact of OSHA citations for the sector; instead, they mostly discussed the general economic impact in terms of project delays, shortages of materials, cost inflation and job losses. Hatoum *et al.* (2021) investigated the OSHA complaints regarding COVID-19; however, they only investigated what safety protocols had been violated rather than the actual cost impact in terms of dollar amounts. Other works investigated safety measures and implementation methods as means to stop the spread, and some discussed usage of technology and strategic partnership among the public and private sector to curb the virus and avoid financial losses. The results of this research could relate to some studies in which innovation and project management methods were discussed to overcome the financial risks during pandemics and by creation of proper safety management protocols and mitigation methods for construction sites. It was established from this study that the OSHA citations declined as the pandemic



Risk Status→ *P*↓	COST
Max	3.65 $M
90%	2.74 $M
80%	2.45 $M
70%	2.20 $M
60%	1.95 $M
50%	1.72 $M
40%	1.49 $M
30%	1.27 $M
20%	1.05 $M
10%	0.76 $M
Min	0.30 $M
Base	0.34 $M

Figure 7.
Risk based estimate simulation

moved forward, which could be due to safety rules and mitigation practices that were implemented by local and federal governments as well as construction contractors.

Moreover, while the findings of this study were unique, the results and the methodology can be applied and generalized to other contexts. Following OSHA guidelines and standards, along with application of safety management plans on construction projects, can minimize safety risks and reduce overall cost impact on projects. OSHA violations and citations are not limited to pandemics; utilizing mitigation plans can reduce other safety related hazards such as falls, risks related to asbestos and led removals, contact by equipment object, and other injuries and fatalities which would in turn result in OSHA related citations. Furthermore, the application of Monte Carlo simulation can be utilized for general risk management on construction projects to elicit and evaluate potential risk cost impacts for the construction sector. Lastly, the application of AI and machine learning can further help the construction sector with the new digitalization movement.

Contributions and limitations

This is the first study that analyzes the cost impact of COVID-19 safety violations in terms of OSHA citations for the US construction industry. It further made a significant contribution to the body of knowledge by evaluating the possible associations between the number of COVID-19 cases, and construction employment. Currently, there is limited research on effects of COVID-19 for the construction sector; majority of studies only discuss prevention means and methods in terms of slowing the spread and a few explore the general economic impact with respect to government lockdowns and disruption of supply chains. The results of the machine learning model along with the Monte Carlo simulation provide a realistic picture in terms of overall cost impact for the construction sector and can serve as a guideline for possible future pandemics. However, it should be noted that these results represent the minimum cost impact and do not capture the whole possible economic effect for the industry. This study was based on the fines issued by the US federal government only. There are currently 23 states and jurisdictions operating OSHA-approved state occupational safety and health programs that cover both the private sector and state and local government authorities (OSHA, 2021d) and conduct their own inspections apart from the federal government, which were not covered within this study. For example, the state of California alone had a total of $4,426,905.00 worth of COVID-19 related citations (Division of Occupational Safety and Health, 2021). Furthermore, this study was limited to the United States only and did not factor in the potential cost impact in the rest of the world. Additionally, there were some limitations in the machine learning model, which included the "assumption of linearity" between the dependent and independent variables. Second, the machine learning regression analysis was prone to outliers which possibly existed within the data due to different lockdown regulations in different states that affected the supply chains, the number of construction projects, construction workers, and monthly COVID-19 cases that were dependent on the size and population of each state. Lastly, the machine learning algorithm for the regression analysis, even though of adequate sample size for its purpose, did not consist of a large data set ideal to produce more accurate results.

There were also no considerations regarding states and localities where complete shutdowns were enforced by state officials and those states that allowed construction work to continue based on local regulations and political affiliations. The suggestion for future research is to re-evaluate the data beyond the first 21 months of the pandemic, and to consider the effects of vaccination roll-out in the United States. Moreover, it is suggested to consider other factors and variables such as the number of vaccinations administered within the construction industry, number of construction workers that tested positive for the virus, the amount of construction put in place during the pandemic along with the actual number of

OSHA complaints that resulted in citations. In addition, contractors' awareness regarding the spread of the virus, mitigating factors and safety precautions that were put in place should also be considered in a form a survey questionnaire to assist and provide for better understanding of these contingent circumstances.

Conclusion

Cost impact could play a crucial role for contractors in terms of loss of profit and in some cases could result in bankruptcy for smaller enterprises. The results of this study can be applied and transferred to the entire construction industry in the US since OSHA penalties and fines are applied equally to all firms of all sizes, i.e. small, medium and large contractors and there are no minimum or maximum amounts based on firm size. Furthermore, the collected data from OSHA were from all industries with different firm sizes and did not apply to a specific group in terms of trade specialty, number of employees, amount of revenue or specific types of construction projects. Based on the findings, the total number of monthly construction employment had a negative association with the amount of COVID-19 OSHA citations. As the construction employment increased, the cost impact of OSHA citations decreased. In addition, the number of monthly COVID-19 cases had a positive relationship with the OSHA citations. As the cases increased, the cost impact of citation also increased, even though the increase was minimal. This pattern could explain the effects of safety measures that were implemented by the construction industry and the federal government to mitigate the risk associated with the virus as well as the potential cost impact of OSHA citations. The overall cost impact of OSHA citations was analyzed by a Monte Carlo simulation model, to predict the potential cost impact, which resulted in a 100% likelihood of cost being at or below $3.65 million. The average cost of an OSHA citation related to COVID-19 for each violation was at estimated to be around $13,000.00. After reviewing different types of citations issued by OSHA, it was concluded that they were mostly related to workers not following the COVID-19 safety protocols or having sick employees reporting for work. Based on the findings of this research, the authors recommend that construction contractors include a contingency fee within their contracts to mitigate and minimize the potential economic loss and cost impact. Furthermore, contractors should hire safety managers to create, implement and monitor safety policies and procedures, including temperature checks and COVID-19 testing for workers that are symptomatic. Lastly, general contractors should request a COVID-19 safety policy and action plan when qualifying their subcontractors.

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Corresponding author
Hooman Sadeh can be contacted at: hooman.sadeh@polimi.it