Preliminary modeling of Coronavirus (COVID-19) spread in construction industry

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ABSTRACT

The construction industry creates 1.3 trillion revenue each year in the United States. After Coronavirus (COVID-19) becoming a pandemic virus, many industries are shutting down and being on lockdown. This situation can lead to millions of people becoming unemployed and eventually causing a financial recession. Although the government and health organizations have issued guidelines to prevent the spread of the virus in the jobsites, there have not been any specific guidelines for construction industry workers. The contribution of this research is to develop a preliminary model and indicator of coronavirus (COVID-19) spread in the construction industry. This paper investigates the preliminary indexes, which can affect the spread of coronavirus in the construction industry. The developed model would act as a guide for stakeholders to take the most appropriate precautions in the jobsite with the available equipment and facilities.

Key words: construction industry, pandemic virus, simulation, Coronavirus, COVID-19

INTRODUCTION

Pandemic outbreaks are considered significant challenges to societies. The new coronavirus (COVID-19) is the latest pandemic outbreak that has disrupted life around the globe in many ways. Italy has been on total lockdown and quarantine. The United States declared a national emergency on March 13, 2020, after 1,588 confirmed cases were reported as a result of the new virus.[1,2] As a result of this outbreak, many schools, universities, and workplaces around the country have been shut down and changed to online platforms. Social events have been canceled, and significant leagues suspended their activities until further notice.[3] This results in a massive loss in revenue and has negative consequences on the economy and may lead to a recession or even financial depression.[4,5]

Construction plays a crucial role in the United States' economy. This industry has over 680,000 employers and more than 7 million employees. The services done in construction have entitled this industry to revenue of nearly $1.3 trillion each year.[6] COVID-19 has affected the construction industry in other countries, by the end of February, 50,000 construction workers in Hong Kong had been laid off as a consequence of the coronavirus. Another 80,000 had their hours significantly reduced.[7]

However, currently, the construction business is operating as usual, while officials are vigilant on the spread of the virus.[8] Amid this outbreak, the Center for Disease Control (CDC) has created an interim for business and employers as following[9]:

- encourage sick employees to stay home;
- separate sick employees;
- emphasize staying home when sick, respiratory etiquette, and hand hygiene by all employees;
- perform routine environmental cleaning;
- advise employees before traveling to take specific steps; and

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- notify the supervisor if the worker or a relative in the family has been diagnosed with the virus.

In addition to the above-mentioned measurements, the Occupational Safety and Health Administration (OSHA) has also issued a safety precaution for the jobsite, which are mostly the same as the CDC guidelines. OSHA also recommends creating safety training sessions by employers for workers and employees.[10] Many businesses can be performed remotely and can offer employees the work-from-home option.[11] However, the nature of construction jobs requires workers to be on-site, and staying home when sick is not always a viable option, especially for hourly workers or anyone without paid sick days. To the best of our knowledge, there is no specific guideline for construction workers on how to deal with the COVID-19 on the workspace.

This research develops a preliminary model and indicator of coronavirus (COVID-19) spread in the construction industry. This paper investigates the preliminary indexes, which can affect the spread of coronavirus in the construction industry.

RISKS OF CORONAVIRUS IN CONSTRUCTION

Construction sites especially residential and commercial projects, are mostly inside a currently built and occupied environment, surrounded by neighborhoods. Therefore, if the jobsite is not protected adequately, the infectious can easily spread, either from a contaminated jobsite to the neighborhood or vice versa.

Figure 1, developed by NYTimes, shows the exposure to the disease for each profession.[12] Each bubble on this chart represents an occupation, and the size of the bubble represents the number of employees in the job. The Y-axis shows how often workers in a given profession are exposed to disease and infection. The X-axis defines the proximity of employees working together. As seen in this figure, the construction laborer, while their exposure to the virus is at the 25 percentiles, is at significant risk of spreading the virus as they work closely with each other moderately close (at arm's length). In addition to the factors defined by the World Health Organization (WHO), CDC, and OSHA, the type of work environments plays a crucial factor in accelerating the rate of the COVID-19 virus spread.

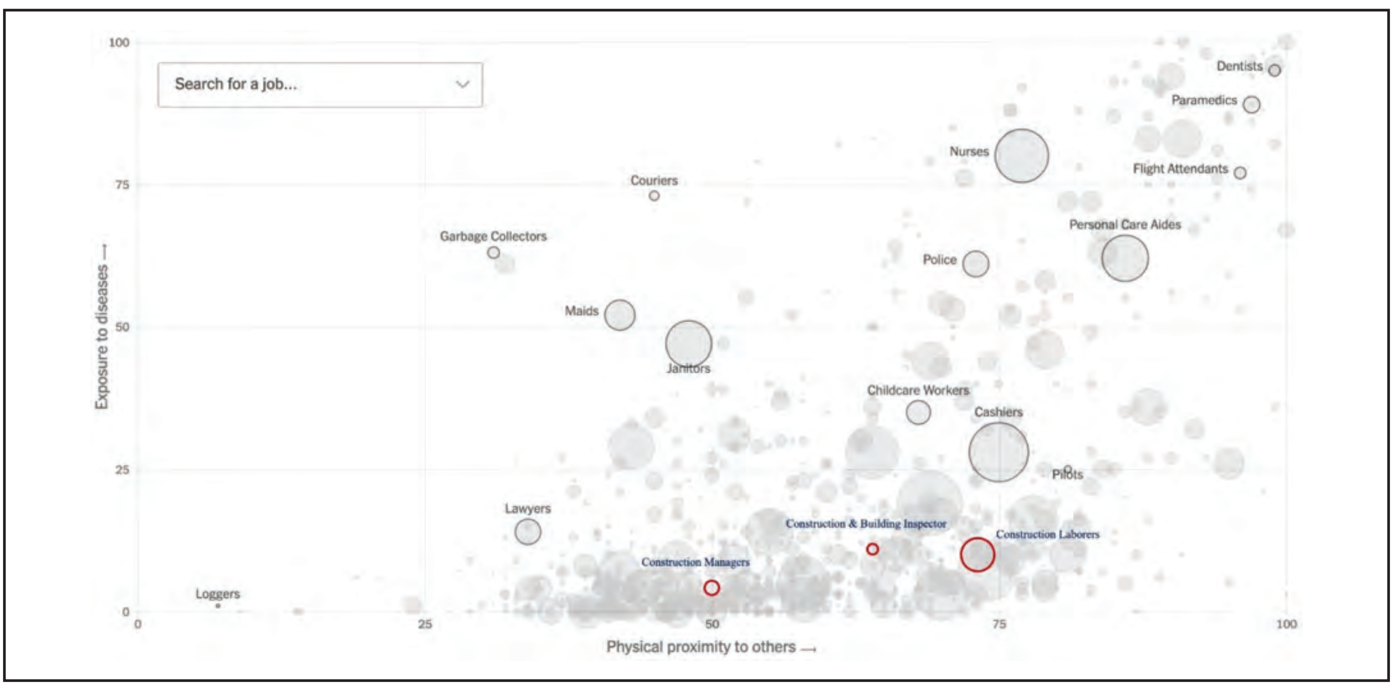

Figure 1. Workers who face the highest coronavirus risk.[2]

Region

The first positive case diagnosed with the virus in the United States was confirmed on January 15 in Washington state, and the virus has been spreading throughout the country ever since.[9] The chart below shows the trend of the cases growth in the top five states of most construction activities. This chart shows the temporal visualization of confirmed cases from January 15 to March 13 data that was extracted from the department of public health for each state.[13-17] The top states with the most construction activities were selected based on the average amount of construction spending they had in the last 5 years.

Based on Figure 2, the spread rate of the virus follows an exponential curve and can increase significantly in the following days, weeks, or even months. This will make the chance and probability of construction workers and the crew being infected extremely higher in these areas.

Climate

While there has not been any verified evidence, the COVID-19 virus has shown a seasonal pattern on its spread, and it is more rapid in mild and humid temperatures.[18,19] Based on the climate region map of the United States, as shown in Figure 3, this type of climate is in Zone 4.[20]

As shown in Figure 3, this type of climate exists around the country. A strap of mild humid-temperature weather stretches from west to east of the country. This type of weather will raise the severe impact and accelerate the effect of the virus on people living in these areas. Like so many dense, high rise buildings such as Seattle, Nashville, Philadelphia, and New Jersey being in the region, the risk of construction workers becoming infected in these areas are higher than the rest of the places.

Construction site features

Construction sites area is limited, finite spaces that are home to materials, equipment, temporary facilities, and numerous workers.[21] Depending on the type and size of the project, the number of crew for each jobsite may vary. The chart below is a representation of construction occupation based on their number. The data are a representation of the Bureau of Labor Statistics by type of job in the construction industry.[22]

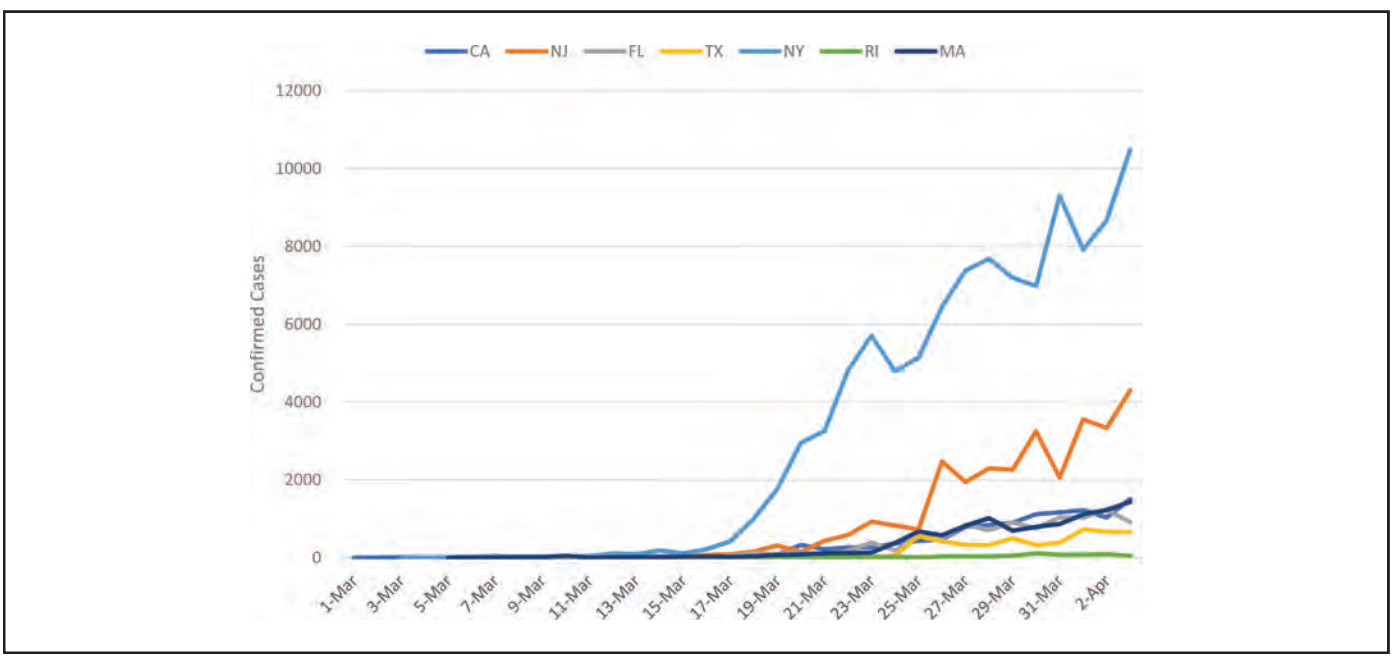

Figure 2. Number of confirmed cases for the top five cities with the most construction activity.

As depicted in Figure 4, the top six professions in the construction industry are as follows:

1. Laborers

2. Carpenters

3. Supervisors

4. Managers

5. Electricians

6. Painters and Paper Hangers

7. Plumbers

There are numerous tools and software available to make project management more efficient (RS means, Procore, Insight, etc.). However, the characteristics of professions in the construction industry require them to

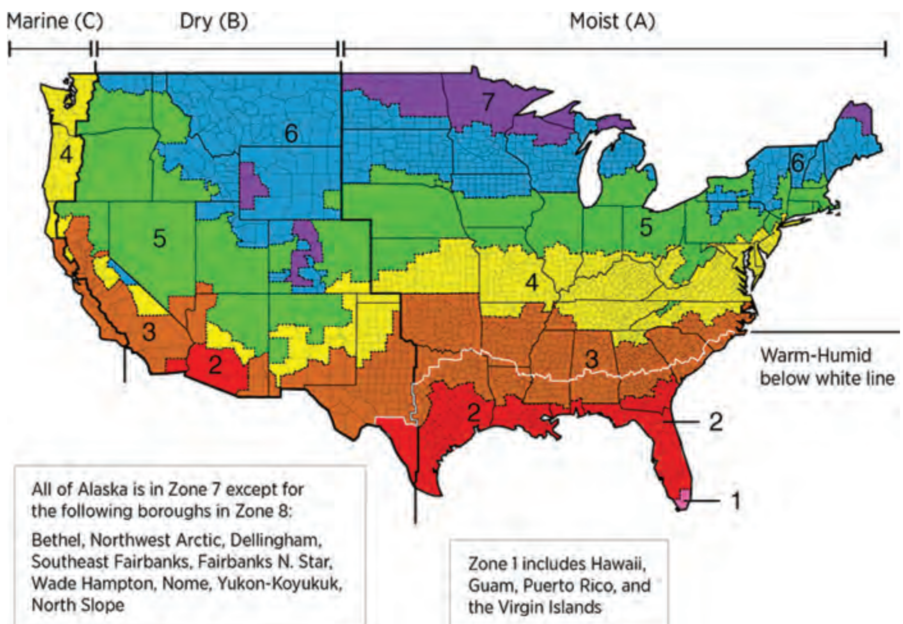

Figure 3. The United States climate zone map.

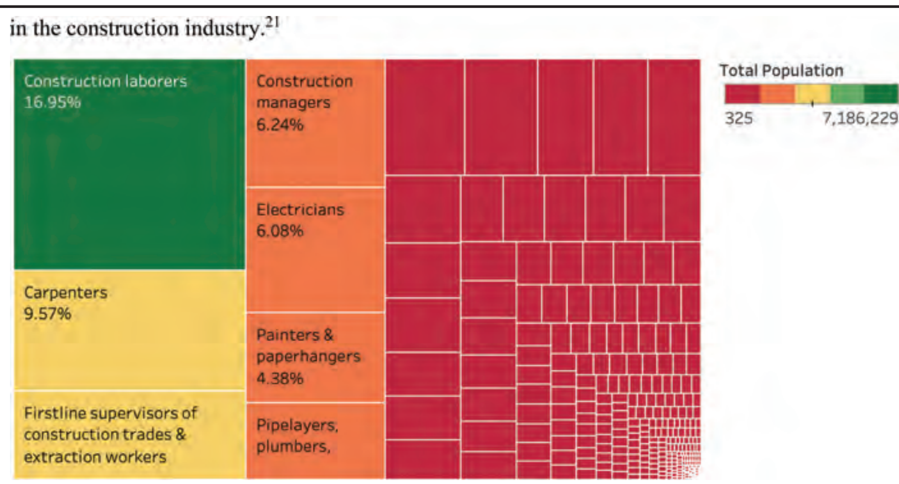

Figure 4. Percentage of workers in jobsite by profession.[22]

be performed on the jobsite. This increases the chance of getting infected as laborers, supervisors, carpenters, and the rest will be working in a workspace at the same time.

Compared to other industries, construction has a low rate of labor productivity,[23] which means that in order to complete a specific task, either more laborers have to be assigned or they need to allocate more time to it. In order to reach optimum productivity, project managers and supervisors assign different teams of workers and laborers to the workspace. This will lead to a crowded area of people in close contact, increasing the risk of contracting any disease.

Age

The risk of illness increases with age.[24] Researchers reported, based on the cases, that around 90 percent of the cases which have been infected are between 30 and 79 years old.[25] Therefore, it is essential to protect this range of employees and workers with even higher measures. The chart below shows the age distribution of construction professions in the United States in 2019. The data were driven from the Bureau of Labor and Statistics.[26] There is a high number of elder work-forces in the construction industry. In the case of any pandemic disease or injuries, especially respiratory causes, the aging workforce is more susceptible to being infected.[27]

Based on Figure 5, the age range of workers who are 45 years old and higher is 66 percent. This is alarming as these people are more prone to pandemic diseases and can be easily compromised by respiratory viruses such as COVID-19.

Materials and equipment

From preconstruction activities such as preparing jobsites all the way to the completion of the project, lots of materials are going in, and out of the construction site.[28] Depending on the type and size of the project, the amount of used material will vary. While the virus does not last for a long time in the air, it can

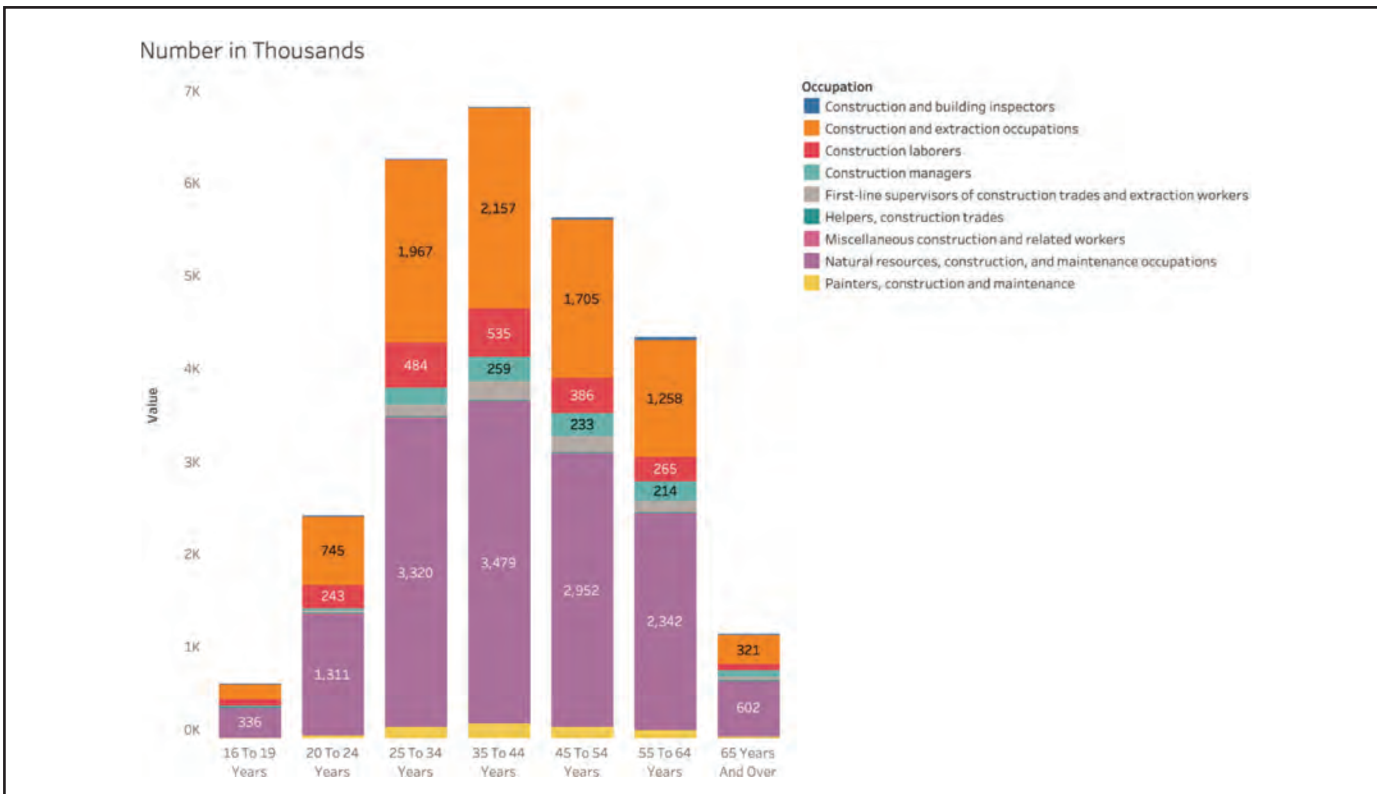

Figure 5. Age distribution of construction employees in the United States based on their profession.

live on surfaces for an extended amount of time, even days.[29]

DEVELOP INDICATOR AND MODEL

The spread of a directly transmitted virus in space can be calculated using the effective per capita transmission rate of the disease or β.[30] The spread rate is a function of infection probability p, and individual contact rate C, therefore $\beta = pc$.[31] The contact rate is a nonlinear function of density and tends to increase with the increase of density. Assume that there is N number of people in the jobsite, an infected individual comes into contact with βN other individuals per unit time. As discussed in the "Construction site features," the number of crew for each workspace depends on the type and size of the project. In order to calculate the number of crew for each section of the project, the project supervisor first divides the quantity of the work by production rate in order to achieve the hours need to do the specific job.[32-36]

In the construction industry, the contact rate (C) is a function of the area and type of the project. The authors have used a mathematical simulation to show the spread of a disease in a population, also known as the susceptible infected recovered (SIR) model. This model simulates the spread of a disease in a specific population. In a population with N people, this model consists of infected people (I), susceptible but not infected (S), and recovered people (R),[37] as shown in the following equation:

$$N = S(t) + I(t) + R(t) \tag{1}$$

As the total population is considered constant, each of these three parameters is a function of time (t), and their value changes through periods. In the beginning, everyone is susceptible, a minute number of people are infected, and there are no recovered people. As time progress, some become infected and leave the susceptible pool and start affecting other susceptible. After a period of time, members from the infected group will join the recovery bin. Figure 6 shows the connection between the three categories.

Equations (2)–(4) show the rate of change for these parameters with respect to time. As people come in contact with each other, there is a probability of passing on the virus. The higher the number of people and interaction, the higher are the chances of becoming infected

Figure 6. The process of susceptible (S), infected (I), and recovered (R) transactions in a population.

$$\frac{dS}{dt} = -\frac{\beta SI}{N} \tag{2}$$

$$\frac{dI}{dt} = \frac{\beta SI}{N} - \gamma I \tag{3}$$

$$\frac{dR}{dt} = \gamma I \tag{4}$$

As people recover, they are no longer capable of infecting others. The time period that takes for a person to recover is known as the mean recovery rate, shown here by γ.[38]

In this research, the researchers have used the existing Hill code[39] and modified it to show how the spread happens through time in a construction jobsite. In the Hill's model, the spread of the virus is a function of Contact rate, β, and mean recovery rate, γ. The developed model, as shown in Figure 7, is based on the assumption that a construction jobsite of 150 workers in total. The initial number of infected people is one person. The contact rate is a function of the quantity of the work that needs to be done, labor productivity, and the area of the jobsite. In order to be in conjunction with the RS Means standard, the researchers have used daily output in lieu of productivity. Daily output is the number of units that a specific crew can produce in a job in an 8-hour work shift. The relation between the factors is shown in the following equation:

$$C = \frac{n \times A}{D.O} \tag{5}$$

where n is the quantity of the work that needs to be performed, A is the area of the jobsite, and DO is the daily output of the work crew.

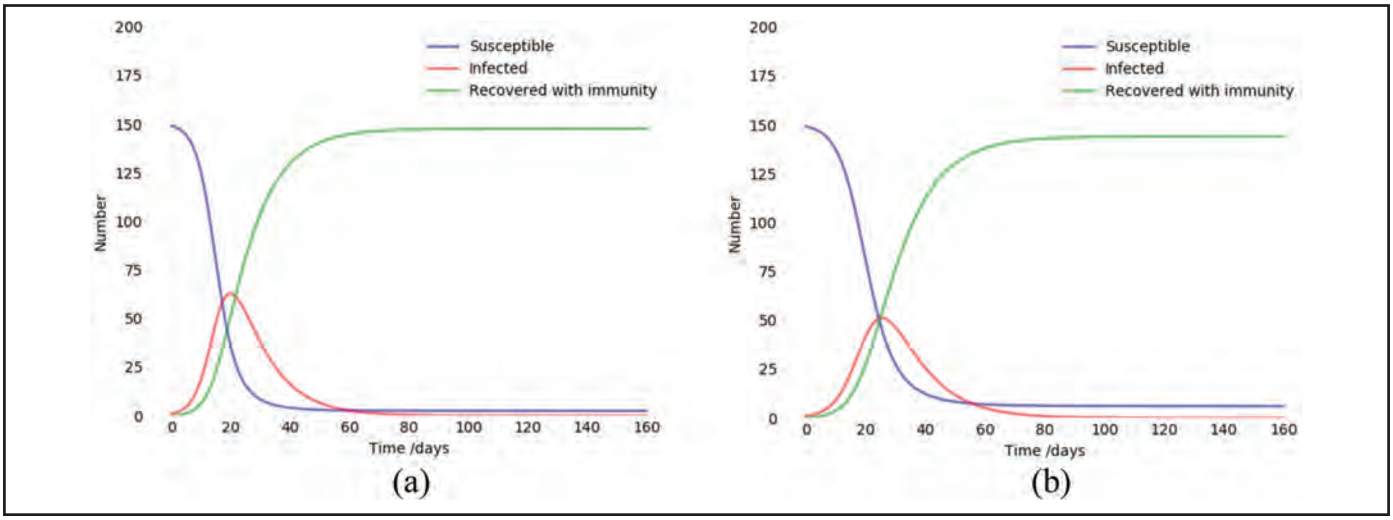

Figure 7. Simulation of how the virus will spread through time if one person is infected: (a) the quantity is 10 units, daily output is 3, and the square footage of the jobsite is 2,000 square feet and (b) the quantity is 4 units, daily output is 1.5, and the square footage of the jobsite is 5,000 square feet.

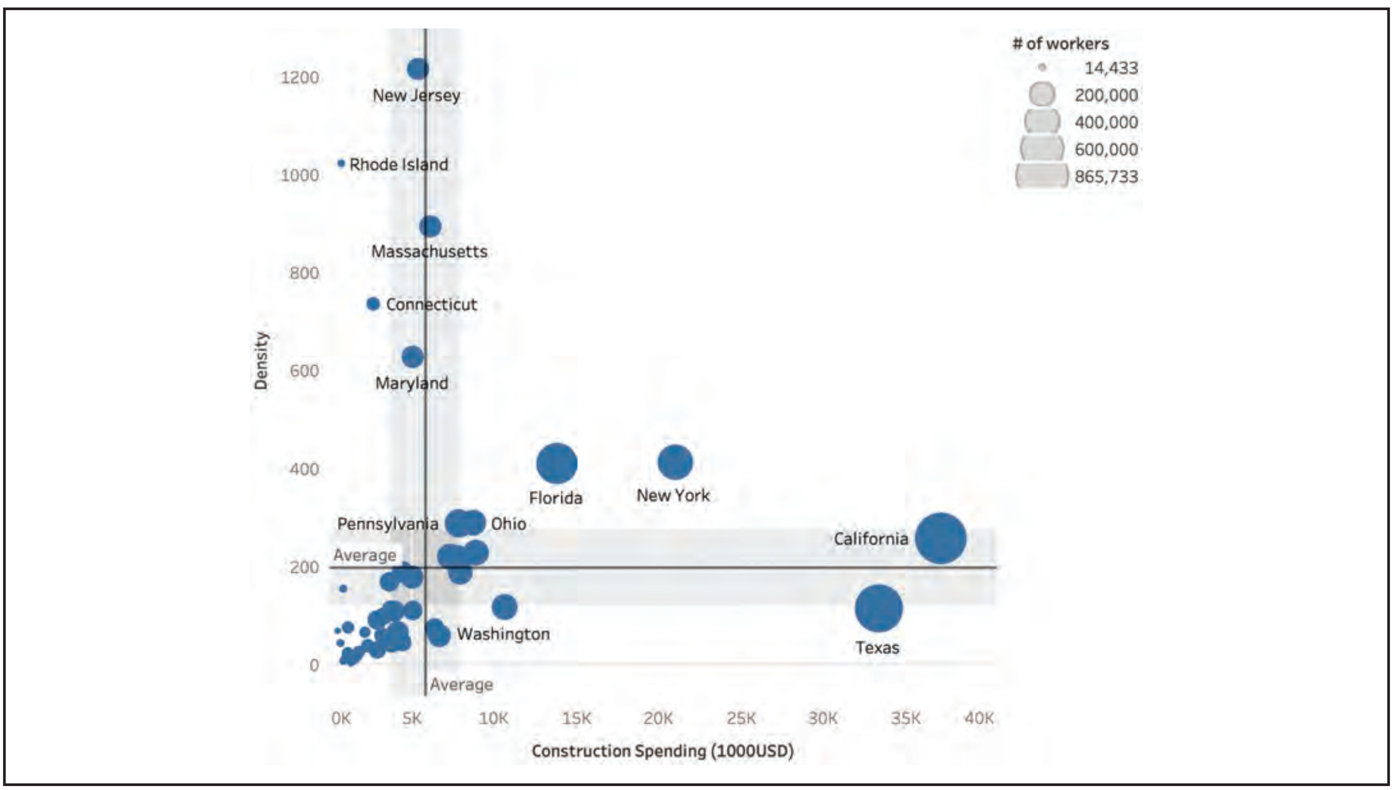

Figure 8. Number of workers for each state per the state density and the construction spending.

In order to show the risk of the COVID-19 spread in construction, the researchers modeled the number of construction workers for each state while comparing the state density and population, which is shown in Figure 8. The horizontal line represents the population of each state. The vertical axis represents the density of each state. Each bubble on this chart represents a state. The bigger the bubble, the more worker do that job. The data are collected from the 2019 archive of Bureau of Labor Statistics and the United States Census Bureau.[26,40,41]

Higher density means more high-rise and/or numerous building projects being built close to each other. Denser places also have higher chances of having big construction projects inside busy, urban areas. The amount of construction spending indicates the level and frequency of construction activities being operating. The average with a 95 percent confidence interval is shown with the ribbons on the figure. Any state outside the average belt is of interest and needs to proceed with caution. In this scenario, Florida, New York, California, Texas, and Ohio are the states which have been founded as outliers.

CONCLUSION

This research develops a preliminary model and indicator of coronavirus (COVID-19) spread in the construction industry. This paper investigates the preliminary indexes, which can affect the spread of coronavirus in the construction industry. The developed model is based on construction spending, the number of workers, and the density of the regions. Moreover, the paper shows the risk for workers and which regions/states are at higher risks. Factors such as the quantity of the work that needs to be performed, the area of the jobsite, and the daily output of the work crew affect the speed of the spread of the virus. Research also shows that because of the age distribution of the construction workers, they are considered at more risk. Future research can contribute toward solutions to control the spread of the virus into the construction site and workers. The authors recommend exploring the use of robotics in the construction field in order to reduce human interaction. Moreover, investigating the use of off-site construction methods such as prefabrication and how they can reduce the spread of any pandemic virus in the workforce. After that, a model can be created by real-time data monitoring of labors' vital signs using the Internet of things IoT-based sensors.

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REFERENCES

1. Live Science Staff: Coronavirus in the US: Map, case counts and news. 2020. Available at *https://www.livescience.com/coronavirus-updates-united-states.html*. Accessed March 14, 2020.
2. The New York Times: Pelosi and trump reach deal on a relief package. 2020. Available at *https://www.nytimes.com/2020/03/13/world/coronavirus-news-live-updates.html*. Accessed March 14, 2020.
3. Tuite AR, Fisman DN: Reporting, epidemic growth, and reproduction numbers for the 2019 novel coronavirus (2019-nCoV) epidemic. *Ann Internal Med*. 2020; 172(8): 567-568. *https://doi.org/10.7326/m20-0358'*.
4. Egan M: Coronavirus could spark another Great Depression, former Trump adviser warns—CNN. 2020. Available at *https://www.cnn.com/2020/03/19/business/great-depression-coronavirus-kevin-hassett/index.html*. Accessed March 21, 2020.
5. Smith E: Analyst anticipates "worst" financial crisis since 1929. 2020. Available at *https://www.cnbc.com/2020/03/20/analyst-anticipates-worst-crisis-since-1929-amid-recession-fears.html*. Accessed March 21, 2020.
6. Associated General Contractors of America: Construction data. 2020. Available at *https://www.agc.org/learn/construction-data*. Accessed March 13, 2020.
7. Schneiderman M: The Impact of Coronavirus on Construction | Fieldwire. 2020. Available at *https://www.fieldwire.com/blog/coronavirus-impact-construction/*. Accessed March 14, 2020.
8. Goodman J: Contractors in US' coronavirus-affected areas say it's business as usual. 2020. Available at *https://www.constructiondive.com/news/contractors-in-us-coronavirus-affected-areas-say-its-business-as-usual/573409/*. Accessed March 16, 2020.
9. Centers for Disease Control and Prevention: First travel-related case of 2019 novel coronavirus detected in the United States. 2020. Available at *https://www.cdc.gov/media/releases/2020/p0121-novel-coronavirus-travel-case.html*. Accessed March 17, 2020.
10. United States Department of Labor: Safety and health topics | COVID-19—Control and Prevention | Occupational Safety and Health Administration. 2020. Available at *https://www.osha.gov/SLTC/covid-19/controlprevention.html*. Accessed March 16, 2020.
11. Hern A: Covid-19 could cause permanent shift towards home working. 2020. Available at *https://www.theguardian.com/technology/2020/mar/13/covid-19-could-cause-permanent-shift-towards-home-working*. Accessed March 13, 2020.
12. Gamio L: The workers who face the greatest coronavirus risk. 2020. Available at *https://www.nytimes.com/interactive/2020/03/15/business/economy/coronavirus-worker-risk.html*. Accessed March 17, 2020.
13. California Department of Public Health: Coronavirus Disease 2019 (COVID-19). 2020. Available at *https://www.cdph.ca.gov/Programs/CID/DCDC/Pages/Immunization/ncov2019.aspx*. Accessed March 14, 2020.
14. Florida Department of Health: COVID-19. 2020. Available at *http://www.floridahealth.gov/diseases-and-conditions/COVID-19/index.html*. Accessed March 14, 2020.
15. IDPH: Coronavirus disease 2019 (COVID-19). 2020. Available at *http://www.dph.illinois.gov/topics-services/diseases-and-conditions/diseases-a-z-list/coronavirus*. Accessed March 14, 2020.
16. New York State Department of Health: Novel coronavirus (COVID-19). 2020. Available at *https://www.health.ny.gov/diseases/communicable/coronavirus/*. Accessed March 14, 2020.
17. Texas Health and Human Services: Coronavirus Disease 2019 (COVID-19). 2020. Available at *https://www.dshs.texas.gov/coronavirus/#casecounts*. Accessed March 14, 2020.

18. Luo W, Majumder MS, Liu D, et al.: The role of absolute humidity on transmission rates of the COVID-19 outbreak. *MedRxiv*. 2020; 1-7. *https://doi.org/10.1101/2020.02.12.20022467*. Available at *https://www.medrxiv.org/content/10.1101/2020.02.12.20022467v1.full.pdf*. Accessed March 18, 2020.
19. Sajadi MM, Habibzadeh P, Vintzileos A, et al.: Temperature and latitude analysis to predict potential spread and seasonality for COVID-19. *SSRN Electronic J.* 2020; *https://doi.org/10.2139/ssrn.3550308*.
20. International Code Council: 2012 IECC - International Energy Conservation Code. Washington, DC: International Code Council; 2012. Available at *https://basc.pnnl.gov/images/iecc-climate-zone-map*. Accessed March 18, 2020.
21. Guo S-J: Identification and resolution of work space conflicts in building construction. *J Const Eng Manage.* 2002; 128(4): 287–295. *https://doi.org/10.1061/(ASCE)0733-9364(2002)128:4(287)*.
22. Torpey E: Careers in construction: Building opportunity. 2018. Available at *https://www.bls.gov/careeroutlook/2018/article/careers-in-construction.htm*. Accessed March 14, 2020.
23. U.S Bureau of Labor Statistics: Labor productivity and costs. 2019. Available at *https://www.bls.gov/lpc/construction.htm*. Accessed March 15, 2020.
24. CDC Online Newsroom: CDC Media Telebriefing: Update on COVID-19. 2020. Available at *https://www.cdc.gov/media/releases/2020/t0309-covid-19-update.html*. Accessed April 3, 2020.
25. Wu Z, McGoogan JM: Characteristics of and important lessons from the coronavirus disease 2019 (COVID-19) outbreak in China: Summary of a report of 72 314 cases from the Chinese Center for Disease Control and Prevention. *JAMA*. 2020; 50(5): e13233. *https://doi.org/10.1001/jama.2020.2648*.
26. US Bureau of Labor Statistics: Employed persons by detailed occupation and age. 2020. Available at *https://www.bls.gov/cps/cpsaat11b.htm*. Accessed March 15, 2020.
27. Schwatka NV, Butler LM, Rosecrance JR: Aging workforce and injury in the construction industry. 2012. Available at *https://academic.oup.com/epirev/article/34/1/156/496006*. Accessed March 15, 2020.
28. Zhu Z, Ren X, Chen Z: Visual tracking of construction jobsite workforce and equipment with particle filtering. *J Comput Civil Eng*. 2016; 30(6): 04016023. *https://doi.org/10.1061/(ASCE)CP.1943-5487.0000573*.
29. Pekoc K: New coronavirus stable for hours on surfaces. 2020. Available at *https://www.nih.gov/news-events/news-releases/new-coronavirus-stable-hours-surfaces*. Accessed May 14, 2020.
30. Tang B, Bragazzi NL, Li Q, et al.: An updated estimation of the risk of transmission of the novel coronavirus (2019-nCov). *Infect Dis Modell*. 2020; 5: 248–255. *https://doi.org/10.1016/j.idm.2020.02.001*.
31. Hu H, Nigmatulina K, Eckhoff P: The scaling of contact rates with population density for the infectious disease models. *Math Biosci*. 2013; 244(2): 125–134. *https://doi.org/10.1016/j.mbs.2013.04.013*.
32. Dozzi SP, AbouRizk SM: Productivity in construction. 1993. Available at *http://web.mit.edu/parmstr/Public/NRCan/nrcc37001.pdf*. Accessed April 4, 2020.
33. Elwakil E, Zayed T: Construction productivity fuzzy knowledge base management system. *Can J Civil Eng*. 2018; 45(5): 329-338.
34. Elwakil E, Hegab M: Toward smart and sustainable infrastructure solution: Assessment and modelling of qualitative factors affecting productivity in microtunneling projects. 6th IEEE Conference on Technologies for Sustainability, Long Beach, California, April 23-25, 2020.
35. Elwakil E, Zayed T, Attia T: Construction productivity model using fuzzy approach. International Construction Specialty Conference, Canadian Society for Civil Engineers, Ottawa, June 08-10, 2015.
36. Mirahadi S, Elwakil E, Zayed T: An innovative technique for improving productivity forecasting models. Proceedings of 4th Construction Specialty Conference, CSCE, Montreal, QC, Canada, 2013, May 29 to Jun 1, 2013.
37. Keeling MJ, Rohani P: Modeling infectious diseases in humans and animals—Google Books. 2011. Available at *https://books.google.com/books?hl=en&lr=&id=LxzILSuKDhUC&oi=fnd&pg=PP1&dq=Modeling+Infectious+Diseases+in+Humans+and+Animals&ots=VImB3fOOIi&sig=qcZtBEgQRTlIO1khYHlZWy6Y3Ps#v=onepage&q=Modeling Infectious Diseases in Humans and Animals&f=false*. Accessed April 2, 2020.
38. Allen LJS: Some discrete-time SI, SIR, and SIS epidemic models. *Math Biosci.* 1994; 124(1): 83-105. *https://doi.org/10.1016/0025-5564(94)90025-6*.
39. Hill C: Scipy. In: *Learning Scientific Programming with Python*. Cambridge, United Kingdom: Cambridge University Press; 2015.
40. US Census Bureau: Construction Spending Survey. Suitland, MD: US Census Bureau; 2019: 333-380. Available at *https://www.census.gov/construction/c30/c30index.html*. Accessed March 17, 2020.
41. World Population Review: United States by Density 2020. Available at *https://worldpopulationreview.com/states/state-densities/*. Accessed March 18, 2020.