Since January 2020 Elsevier has created a COVID-19 resource centre with free information in English and Mandarin on the novel coronavirus COVID-19. The COVID-19 resource centre is hosted on Elsevier Connect, the company's public news and information website.

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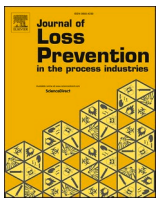

Industrial construction safety policies and practices with cost impacts in a COVID-19 pandemic environment: A Louisiana DOW case study

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ABSTRACT

There are always significant challenges in improving the safety culture by changing and adding additional safety protocols. The unknown impacts of COVID-19 and how it quickly spreads led the industry to institute essential safety protocols. This paper addresses two problem statements. The first problem statement is: what are the additional safety protocols for process safety, construction & maintenance, and personal protective equipment requirements? The second problem statement is: what are the cost and schedule impacts of industrial construction projects resulting from implementing safety protocols and process safety during construction with the added PPE?

While complying with added safety protocols, the industrial construction industry cannot forget that it has a distinct reputation for high incident rates and less than desirable safety performance. In 2017, the construction industry suffered 971 fatalities. This alarming number is compared to 1123 total fatalities in 2017 for the Gulf Coast States. The objective is to share the rationale and practices of social distancing, required additional PPE, and personal hygiene practices to reduce spreading and outbreaks during a pandemic within an industrial construction environment. Before any construction work, the process safety teams must clear, isolate, and tag out process lines, equipment, and instruments to be repaired or replaced. The information presented demonstrates the significant cost and schedule impacts that industrial construction companies will encounter during a pandemic like COVID-19.

This paper aims to improve safety processes, cost & schedule impacts, and prescribe additional personal protective equipment in industrial construction during a pandemic such as COVID-19. The COVID-19 pandemic spread globally in a very short period. The reactions in mitigating the spread were suggestive, with little to no data on safety protective equipment and practices. The contribution this paper addresses are how to employ efficient safety practices and policies during a pandemic in an industrial construction environment.

1. Introduction

The construction industry encounters over 55,000 fatal injuries each year in the global construction industry (Elsafty et al., 2012). Thus, construction hazards contribute to 49.6% of these fatalities (Becker, 2001). In the US from 1992 to 2005, the construction industry accounted for over 16,000 deaths (Hatipkarasulu, 2010). This is approximately 1142 deaths per year (Hatipkarasulu, 2010). From 2014 thru 2018, the Gulf Coast States experienced a total of 5415 work-related fatalities referenced in Table 1. In 2017, the US Bureau of Labor Statistics reported 971 fatalities within the construction industry alone, refer to Table 2 (Passmore et al., 2019). Also, in 2017, the fatalities for industrial, construction, and manufacturing totaled 1,414, refer to Table 2.

In February 2020, we added another serious hazard called SARS-COv-2, which causes Corona Virus Disease (COVID-19) (Burdorf et al., 2020). The COVID-19 pandemic, in a short period, reached the US from China (Sohrabi et al., 2020). In March 2020, this pandemic, and its ability to cause severe symptoms leading to possible fatality for some, led to a complete lockdown throughout the US and brought the world to a halt (Sohrabi et al., 2020; Alauddin et al., 2020). The concerns of outbreaks and infection control resulted in many projects and industrial companies ceasing all work. The need for improved risk management

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Table 1
Fatal occupational injuries in Gulf Coast States, 2014–2018.

Fatal occupational injuries by state and year, 2014–2018						
YEAR	2014	2015	2016	2017	2018	TOTAL
US Total	4821	4836	5190	5147	5250	25,244
Alabama	75	70	100	83	89	417
Florida	228	272	309	299	332	1440
Louisiana	120	112	95	117	98	542
Mississippi	75	77	71	90	78	391
Texas	531	527	545	534	488	2625
TOTAL	1029	1058	1120	1123	1085	5415
Percent of US Total	21%	22%	22%	22%	21%	21%

Note: Data retrieved from US Bureau of Labor Statistics https://stats.bls.gov/iif/state_archive.htm.

Table 2
US fatal work injuries by industry sector, 2017

Number of fatal work injuries by industry sector, 2017	
Industry sector	Count
Construction	971
Manufacturing	303
Mining, quarrying, and oil and gas extraction	112
Utilities	28
Total	1414

Note: Data retrieved from US Bureau of Labor Statistics https://stats.bls.gov/iif/state_archive.htm.

approaches to process safety in industrial plants was evident (Alauddin et al., 2020). One such model that improved the forecasting of dynamic risk was the susceptible, exposed, infected, quarantined, recovered, deceased (SEIQRD) model (Alauddin et al., 2020).

In 2018, there were about 7.5 million construction workers employed in the U.S. (Passmore et al., 2019). Construction labor accounts for approximately 5% of U.S. Labor (Becker, 2001). In January of 2020, the US Bureau of Labor Statistics reported the unemployment rate for construction labor was at a concerning rate of 16.6% (McPhillips, 2020). The unemployment rate within the construction industry reached alarming numbers, about 1 million (McPhillips, 2020). The layoffs due to the lockdown reached alarming numbers. The construction workforce, who were at home around others who possibly were infected, triggered the need for pre-screening measures, social distancing, and additional PPE before returning to industrial construction work.

During COVID-19, the industrial sector still needed to execute construction projects to safely maintain reliable equipment and employ process safety guidelines in preventing a catastrophic chemical event. To allow construction workers to return to work, there needed to be infection prevention and control (IPC) guidelines that incorporated federal and state guidelines to prevent the spreading of COVID-19. Until COVID-19, there were no impactful IPC guidelines in place for industrial construction. The construction workforce is accustomed to working through cold and flu season. The compensation of construction laborers only applies to actual hours worked. If they call in sick, they do not receive compensation.

The IPC from each organization needed to address how they would comply with the Dow Louisiana Operations (LAO) COVID-19 policy. The submission of the contractor's IPC was time-sensitive and critical as we saw cases and outbreaks increasing in Louisiana from March to the end of July among construction workers (Christopher Eddy and Sase, 2020). Compliance and obtaining the required PPE proved challenging for most contractors in the earlier months of the COVID-19 lockdown. In March 2020, shortages of N95 protective masks were becoming unavailable and designated only for healthcare and first responders (Ballard et al., 2020).

The contribution of this paper will outline safety processes & protocols during COVID-19 from January to December 2020. The industrial projects discussed will center around mechanical, piping, structural steel, valves, equipment, electrical, and instruments typical of industrial construction. From a safety aspect, the spread of COVID-19 at Dow in Louisiana was controlled and mitigated to an astonishingly low number compared to statewide and gulf coast cases.

2. Background

On December 31, 2019, WHO received the first initial reports of clusters of SARS-CoV2, which causes COVID-19, from Wuhan, China (Sohrabi et al., 2020; Christopher Eddy and Sase, 2020). WHO declared COVID-19 an international public health emergency by January 30, 2020 (Sohrabi et al., 2020; Mushi and Shao, 2020). On March 11, 2020, the WHO officially announced COVID-19, a global pandemic (Sohrabi et al., 2020; Christopher Eddy and Sase, 2020).

Shortly after, the Governor of Louisiana declared a state of emergency on March 11, 2020 (Lousiana Department of He, 2020). The initial cases in Louisiana started in six parishes, one of which is New Orleans parish. This parish saw the most initial cases resulting from large gatherings of tourists worldwide participating in Mardi Gras during February 2020 (Anne Schuchat, 2020). The CDC also reported this large gathering of over 1 million participants played a notable role in the early US spread of COVID-19 (Anne Schuchat, 2020). Since Mardi Gras, Louisiana saw increased cases reported by the Louisiana Department of Health (LDH). As of July 25, 2020, LDH had reported 94,892 cases and 3462 deaths (Lousiana Department of He, 2020). The US is one of the few countries that have recorded the most diagnosed cases worldwide (Burdorf et al., 2020). A study published in April 2020 reported that 8.3% of the 5.9 million construction workers during the pandemic would be exposed once a month (Baker et al., 2020).

According to Louisiana Economic Development (LED), more than 300 industrial facilities are located in Louisiana (Louisiana Economic Develo, 2016). Of these 300 facilities, Dow Chemical is in six sites across Louisiana. Dow Chemical produces more than 50 chemical products utilized to make respirators, PPE, pharmaceuticals, food-grade plastics packaging, and household goods (Louisiana Economic Develo, 2016). In Louisiana, Dow Chemical was considered an important and critical infrastructure site by the US Government. Essential and critical infrastructures defined by the Department of Homeland Security (DHS) is Chemical, Communications, Energy, Dams, Emergency Services, Financial Services, and Food & Agriculture.

With the above DHS criteria, Dow received approval to continue operations and continue reliability, environmental, health, and safety construction projects. Dow Chemical, specifically for COVID-19, published new safety policies and procedures for entry screening, social distancing measures, quarantining infected or at-risk personnel, mandated additional PPE for all personnel to perform work at Dow Louisiana. The dissemination to all contractors of the new Dow COVID-19 policy and procedure occurred in March 2020, at Dow Louisiana. The next step was for the contractors to review and grasp the new policy and then provide Dow with their COVID-19 Social Distancing and PPE plan. The approval of their plan had to occur before being cleared to work. Also, contractors are required to pass a medical pre-screening at the badging entry locations. The pre-screening of contractors consisted of temporal thermometer reading and questioning if they have any of the symptoms in Table 1. Those acknowledging a symptom will be required to quarantine and denied entry.

3. Methodology and Practices

The research questions motivating this work are: what science-based safety protocols are appropriate for limiting the workplace spread of COVID-19 for operating industrial process facilities? Following the implementation of these protocols, what are the costs of implementation, as generally experienced at Dow facilities in Louisiana? This paper will present information on the engineering and administrative controls

practiced at Dow in Louisiana. The engineering controls are the safety protocols put into place by Dow Louisiana for site entry, pre-screening, quarantine, social distancing, personnel protective equipment (PPE), and sanitizing practices in response to the COVID-19 pandemic. The engineering controls prescribed affect the work processes of construction and process safety. During the early stages of the COVID-19 pandemic, we learned that social distancing, PPE, disinfecting, and sanitization are highly recommended to mitigate against outbreaks and infection to workers (Gamage et al., 2005). This practice's purpose is that the virus can live on surfaces for at least 48 h (Gamage et al., 2005).

The administrative controls are the policies & procedures issued to all contractors in the above engineering controls practice. These administrative controls are very similar to infection prevention and control (IPC) guidelines, which are guidelines to reduce the transmission of infections (Houghton et al., 2020). Another administrative control implemented by Dow was to reduce the number of administrative workers in the physical workplace. This administrative control allowed individual employees to work from home. Also included are individuals considered to be at high risk of contracting COVID-19 and develop severe symptoms that would degrade their health (Barnes and Sax, 2020).

The rationale for each protocol is presented in this paper, followed by a description of the best practices implemented and measures for associated cost & schedule impacts. Details discussing reasonable cost and schedule impacts to an industrial construction project are provided based on implementing the safety protocols in spring and summer 2020. A hypothetical project case study demonstrates the estimation of the additional cost associated with additional PPE and Fit Testing requirements in a COVID-19 environment in Louisiana.

The contribution of this paper is to provide relevant information on successful construction safety policies & practices and recommended PPE that was instrumental in mitigating the spread of COVID-19 in an industrial construction environment in Louisiana. Considering the discussed safety policies and procedures can be applied in the gulf coast region at other industrial facilities as a foundation during a pandemic. The gulf coast region has similar climates to Louisiana and the demographics of transient construction workers. These policies & procedures should have a high consideration to be used during the cold and flu season to mitigate outbreaks.

On average, the cold and flu season can impact one person's absenteeism for three days (Xue et al., 2010). A study conducted by Xue et al. from 1998 to 2006 predicted that the cost of working days lost in productivity was, on average of $231 million (Xue et al., 2010). The prescribed social distancing and recommended PPE, such as face shields and goggles, can reduce outbreaks of viruses (Barnes and Sax, 2020). The wearing of the additional PPE can also reduce visibility and productivity for construction workers and process safety teams (Andersen, 2019). We will also discuss the process and valuable contribution that hygiene and disinfection applications have on COVID-19 (Andersen, 2019).

4. Case Study

The case study presented is aligned with a typical scope of work, resources, equipment, and duration within a chemical process plant. The name of the proposed company is fiction to protect the proprietary cost and work processes of actual construction companies employed by Dow. Company ABC Construction, LLC, is bidding on a 4-week project working four days, 10 h each day. The project scope is installing 1,000lf pipe, welding of flanges for bolt-up connections, installing valves & instruments, civil work for structural steel, tubing for air & conduit for cabling. The project is a compliance project and requires immediate mobilization within ten days of the accepted bid. The bid package specifies that the company must practice social distancing, sanitization, and hygiene, be fit tested and have the required PPE per the Dow COVID-19 Policy. The company's estimator would need to estimate as he would any other job to establish a baseline cost. From this baseline cost, he would need to add the additional itemized costs for COVID-19 compliance. Table 4 below has the baseline and itemized COVID-19 costs for reference. Table 5 shows the cost of just the baseline in a non-COVID19 environment.

5. COVID-19 Dow Louisiana entry procedures

In March of 2020, Dow Louisiana imposed several entry procedures for all personnel gaining entry to the site, Dow personnel included. The CDC and the state of Louisiana established a predetermined number of people who can work on Dow LAO as declared as essential and infrastructure. For this paper, we will count the number of contractors to include direct supervision. The number of contractors that entered the site daily from March to June peaked into the thousands.

The number of contractors concerned Dow, but the projects were of priority. The number of cases reported in Louisiana for industrial work (692), construction sites (79), and worksites (291) is a total of 1062 cases, refer to Table 6 (Lousiana Department of He, 2020). The environments that displayed the most cases and outbreaks were bars, food processing, and industrial sites (Lousiana Department of He, 2020). Industrial and construction worksites reported a total of 771 cases (Lousiana Department of He, 2020). Table 6 total cases reported in the listed categories is 3939. The industrial and construction sectors were 19.5% of the total cases reported.

5.1. Background

A study done by Huang et al. in the Journal of Medical Virology said that 98% of the sample patients who tested positive for SARS-CoV-2, also known as COVID-19, had fever and body chills (Huang et al., 2020). Of the 98% who had a fever, 78% had a fever of 100.4° or higher (Sun et al., 2020a). Since no vaccines were available for COVID-19 at this time, the best means to control the spread is through early diagnoses (Sun et al., 2020a). The facts supporting a high percentage of known cases having a fever have a high probability of having COVID-19 because of infrared temporal temperature check as part of pre-screening. According to the U.S. Centers for Disease Control and Prevention (CDC), the following symptoms are indicators of having COVID-19; Fever or chills, Cough, Shortness of breath or difficulty breathing, Fatigue, Muscle or body aches, Headache, New loss of taste or smell, Sore throat, Congestion or runny nose, nausea or vomiting, and Diarrhea (Sohrabi et al., 2020).

5.2. Dow Louisiana best practices

5.2.1. Stage 1: Resource planning

Stage 1 consisted of identifying the number of contractor resources based on project priorities. There were restrictions on how many personnel could be onsite at a given time. State and federal guidelines imposed these restrictions to comply with COVID-19. Dow had numerous meetings with contractors and stakeholders to determine an agreeable workforce to support the project list. The approved projects had to meet state, federal, and Dow criteria. Based on approved projects

Table 3
COVID-19 symptoms (Sohrabi et al., 2020).

Symptoms
Fever or feeling feverish (chills, sweating)
New cough
Difficulty breathing
Sore throat
Muscle aches or body aches
Vomiting or diarrhea
New loss of taste or smell
Congestion and running nose
Traveled outside the country

Table 4
Estimate Project Cost for 40-Man crew for 4-weeks during COVID-19.

Labor & Equipment	QTY	Unit Cost	Total
Fit Test	40	$45	$1800
N95 Respirator	40	$45	$1800
P100 Filters (3 prs)	40	$40	$6400
Face Shield Kit	40	$25	$1000
Face Shield (4 Per)	40	$10	$1600
Latrines	8	$150	$4800
Safety Observer	2	$95	$30,400
QC Tech	2	$95	$30,400
Hand Wash Stations	6	$150	$3600
Cleaning & Sanitization Crew	4	$65	$41,600
Supervision	4	$95	$60,800
Direct Labor	40	$95	$608,000
Inefficiency Performance Factor	1	5%	$30,400
		TOTAL	$822,600

Table 5
Estimate Project Cost for 40-Man crew for 4-weeks Non-COVID-19.

Labor & Equipment	QTY	Unit Cost	Total
Fit Test	1	$45	$45
N95 Respirator	1	$45	$45
P100 Filters (3 prs)	1	$40	$160
Face Shield Kit	5	$25	$125
Face Shield (4 Per)	5	$10	$200
Latrines	4	$150	$2400
Safety Observer	1	$95	$15,200
QC Tech	1	$95	$15,200
Hand Wash Stations	2	$150	$1200
Supervision	4	$95	$60,800
Direct Labor	40	$95	$608,000
		TOTAL	$703,375

Table 6
Number of cases in Louisiana as of 12/22/2020 (Lousiana Department of He, 2020).

SETTING	CASES
Bar	537
Casino	295
Child Daycare	147
Construction Site	79
Food Processing	923
Gym/Fitness Setting	62
Industrial Setting	692
Office Space	157
Other Worksite	291
Recreation	36
Religious Services/Event	335
Restaurants	304
Social Events	81
Total	3939

that met the requirements, an approved safe work plan was submitted for each project. The work plans consisted of how many personnel, equipment, subcontractors, personnel, and social distancing, and PPE procedures they will follow. The site leadership managed the total number of personnel allowed at Dow LAO. Any additional resources had to go through a request and approval process. The resource numbers were kept to a minimum and validated to ensure that social distancing compliance was not hindered by too many personnel in one area. For the pre-screening and contraflow through the entry gates to be successful, the data of allowed personnel assisted on the entry schedule. The term used is activity-based sourcing for each project. Activity-based sourcing is a term used to assign critical resources to each activity in the schedule's work breakdown structure. The activity-based planning also includes equipment, tools, and materials needed by the contractor that isn't Dow provided.

5.2.2. Stage 2: Contractor prescreening

Stage 2 began once Stage 1 was complete. In Stage 2, Dow advised each contractor the maximum number of employees they could have onsite at any given time. The contractor was responsible for identifying which employees would be part of the approved list authorized by Dow. Each company screened their employees internally before submitting the named list to Dow. For example, if contractor A were permitted to have 45 workers, the 45 employees were then pre-screened by contracted health professionals and tested for COVID-19 symptoms before entry. The employer would advise Dow that all personnel on their list passed the medical pre-screening and not symptomatic for COVID-19. Ensuring that non-infected personnel is a critical step and objective of this pre-screening process. Dow would be conducting their pre-screening as each vehicle entered with passengers. The purpose of requiring employers to screen their employees before entering the site is to identify anyone infected or have symptoms. This would allow them to have ample time to replace the employee and prevent an infected employee from showing up at the Dow pre-screening. This is also a practice for preventing the spread and an outbreak at the site.

5.2.3. Entry schedule and locations

Dow designated separate locations and times in which entry was allowed. Entry point 1 was for essential Dow personnel such as security, medical, leadership, fire safety, and designated personnel. The essential Dow personnel could enter at a given time and window. All essential support staff was allowed to enter during their given time and window. Entry point 2 was for suppliers, vendors, and contractor personnel. Entry point 2 had designated times for contractor entry on a staggering time of entry. The rationale behind this is to allow Dow security to maintain contraflow and traffic control through these entry points. When exiting the site, all personnel exited their designated entry point during regular working hours. The exiting of personnel after hours exited through a designated exit point.

At each entry point are security guards and medical screeners, each with a digital temperature thermometer. Upon entry, all passengers had to have an approved facial covering and exit the vehicle one at a time to be screened. Those contractors who use bus and passenger van entry must have all passengers wear an approved facial covering and use staggered seating. The staggered seating is a requirement for maintaining social distancing. The medical person at the entry point will board the bus and conduct the pre-screening. For vans, each passenger must exit one at a time except for the driver. For single cab trucks, there can only be two passengers. For extended cab trucks and four-door vehicles, there can only be four people in those vehicles.

5.2.4. Entry prescreening

All personnel, including contractors, who gain entry to Dow Louisiana will undergo a temperature check. All personnel attempting to gain entry must have a temperature reading less than 100.4° and be asked all pre-screening questions referenced in Table 3. A "yes" response for any of the pre-screening questions and a temperature higher than 100° will result in denied entry. In addition to denying entry, the person must quarantine for a minimum of 14 days. Before anyone can return, they must be free of any of the symptoms listed in Table 3 and provide a negative COVID-19 test result from any designated testing center. Dow Louisiana medical staff will review the case and provide their recommendation. The medical profession has defined the best way to control the spread of COVID-19 to have strategies for early diagnosis, reporting, isolation, and testing (Sun et al., 2020a). The medical staff, occupational health, and safety professionals at Dow have also influenced the requirement for pre-screening at the entry locations.

5.3. Cost and Schedule impacts

The cost of executing this procedure is substantial and not in the normal budget. Dow, per the new COVID-19 policy, required the staffing

of medical screening technicians. The number of medical screeners needed to support the entry schedule is a minimum of (8) medical screeners working 12 h s a day, seven days a week. This potential cost could be approximately $760,000 for three months to support eight screeners. The cost impact is minimal if it turns away anyone who was potentially infected to spread and initiate an outbreak. Any site's impact by having to shut down operations and projects can lead to a cost impact in the millions per day. The schedule impacts are just as impactful. Most compliance projects have no later than a date to comply and are planned by phases. These planned phases are centered around specific dates that must meet compliance dates and outage windows. The compliance projects directed by federal and state agencies provide the compliance dates. Those projects executed during an outage window are essential maintenance and construction projects. The projects and turn-around activities have been planned and scheduled years in advance.

6. Quarantine and COVID-19 test procedure

6.1. Rationale

The definition of quarantine by public health professionals is to separate persons or communities who have been exposed (Parmet and Sinha, 2020). Also, the definition of isolation is to separate persons known to be infected (Parmet and Sinha, 2020). Quarantine and isolation can be voluntary or involuntary (Parmet and Sinha, 2020). Per the CDC website, severe acute respiratory syndromes fall into involuntary quarantine diseases (Parmet and Sinha, 2020). It is highly recommended and emphasized that anyone who has any flu-like symptoms should stay home to prevent exposure & spread (Belingheri et al., 2020). As mentioned earlier, Dow avoided this initial measure as much as possible by having the contractor do a pre-screening within their company employees.

6.2. Dow Louisiana best practices

All Dow and Contractor employees who, through the entry pre-screen with a temperature of 100.4° or answers yes to the entry medical questionnaire, will be required to be quarantined for a minimum of 14 days. The 14-day quarantine time frame must be consecutive with no symptoms. Upon completion of the quarantine with no symptoms, the employee must inform their immediate supervisor. Contractors will report all quarantine or symptomatic employees to their Dow Contract Administrator. All personnel must be cleared through Dow Medical to return to the site for work. The site manager for that employee submits a request to the Dow Contract Administrator, acknowledging the employee has been quarantined and has no symptoms. The employee can submit a copy of their negative results to Dow Medical. DOW employees must clear through their supervisor and DOW Medical. DOW employees with a negative test result will submit a copy to DOW Medical. At any given time that a DOW employee or contractor has any symptoms, they must report it and quarantine for 14 days. Even if the employee has a negative test result but displays any of the symptoms referenced in Table 3, they must quarantine.

6.3. Cost and Schedule impacts

Any contractor with an outbreak will be required to quarantine those infected and anyone in general contact. The impact of this scenario is impactful for those projects that have a small crew. For example, a 4-week compliance project with a crew size of 14 direct laborers and five indirect leadership would be postponed for a minimum of two weeks. Let us assume the fines and penalties from the EPA is $1000 per day. For one person to be infected would potentially shut that one project Down for 14-days. The penalties would cost $14,000 and the daily profits to Dow for not bringing that section unit up to compliance. The cost impacts at this point would be in the millions of dollars. The schedule impacts other successor projects that cannot begin until this one is complete. It is a chain reaction that also leads to more cost impacts. The impacts on morale within the laborers are also a concern and have a monetary impact as well. Those workers who are quarantined and not infected will lose daily wages. This is an impact at about $60 per hour worked up to 40 h and $90 per hour for overtime for a welder. The employee's cost is $4800 for the two weeks of lost pay for a 40-h workweek. For a 50-h workweek, this will be an additional $1800 for a total of $6600 of lost wages. Those employees who sustain that loss of wages will potentially go work elsewhere.

7. Social distancing and personnel protective equipment (PPE)

7.1. Rationale

The acceleration of COVID-19 caused occupational hygienists to introduce simple & effective measures such as social distancing to reduce exposure (Semple and Cherrie, 2020). In addition to healthcare employees, other workers, such as construction, are at risk of getting COVID-19 (Semple and Cherrie, 2020). The standard PPE for all work in a process area is wearing steel toe boots, long-sleeve fire resistance (FR) shirt and pants, a hard hat, safety glasses, and chemical protective goggles. The FR shirt and pants must be CAT Level 1 and NFPA 2112 compliant. As of March 2020, COVID-19 appeared in 76 countries (Semple and Cherrie, 2020). The secretion of microbial pathogens from an infectious person's respiratory tract normally passes in the air through sneezing and coughing (Nishimura et al., 2013). Through violent respiratory events such as coughs and sneezes, the spread of infectious respiratory diseases occurs (Bourouiba and DehandschoewerckerJohn, 2014). The information we have eludes us to prescribe certain PPE at certain social distance requirements. Through the input of occupational hygienists and safety professionals, Dow has prescribed mandatory PPE at certain distances, per Table 7. The distance is a factor as coughing and especially sneezing by an infected person can release many airborne droplets where the nuclei contain COVID-19. The inhaling of these infected nuclei is one of the primary transmissions of COVID-19.

7.2. Best practices

From what we have learned in a short period, the infectious disease COVID-19, related to SARS-CoV-2, can be spread through the small and large droplets from an infected person (Dhand and Li, 2020; Lindsley et al., 2013). Large droplet expulsion is generally measured with a mass median aerodynamic diameter (MMAD) of >10 μm μm, and particles with MMAD <10 μm sometimes defined as droplet nuclei (Memarzadeh and Xu, 2012). In Fig. 1, we learned the distance in which the droplets travel. The droplets from a cough can travel as far as 2 m or 6.6 feet (Dhand and Li, 2020; Lindsley et al., 2013). The droplets from a sneeze can travel farther than a cough, up to 6 m or 19.8 feet (Dhand and Li, 2020; Lindsley et al., 2013). The alarming information is that the cough has about 3000 droplets and a sneeze has about 40,000 droplets (Dhand and Li, 2020). The exhaling of droplets can travel up to 1.5 m or 4.11 feet

Table 7
PPE requirements for Social Distancing.

Equipment	6 ft	6 ft–3 ft	3 ft to 0 ft
Fit Test			X
N95 Respirator			X
Face Mask	X		
Face Shield	X	X	
Steel Toe Safety Boots	X	X	X
Safety Glasses	X	X	X
Hard Hat	X	X	X
Safety Gloves	X	X	X
FR Shirt and Pants	X	X	X

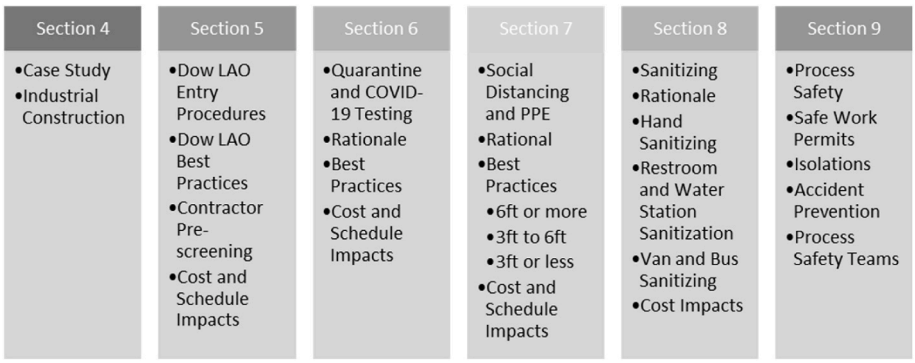

Fig. 1. Overall Framework of COVID-19 Protocols.

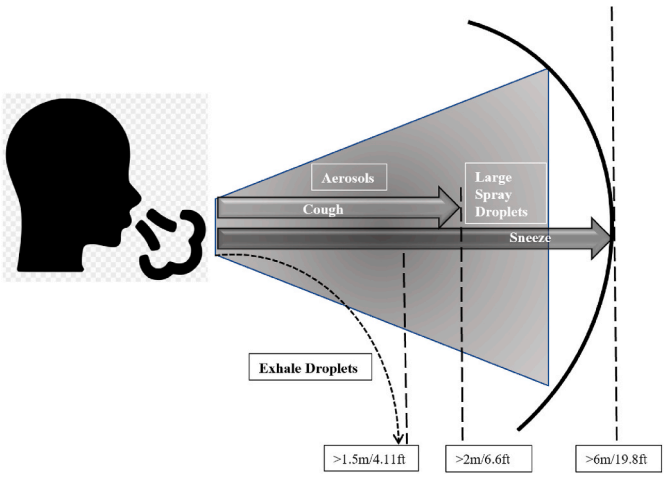

Fig. 2. Visual Aid on the travel distance of a cough and sneeze (Dhand and Li, 2020) (Lindsley et al., 2013).

before descending to the ground (Dhand and Li, 2020; Lindsley et al., 2013) (see Fig. 2).

7.2.1. Within 6 feet

Per social distancing guidelines set forth by the CDC and adopted by Dow Louisiana, any construction work within six feet must have an approved facial covering or face shield. The only time one can remove the facial covering is for lunch and water breaks. For lunch, the lunch tables are marked with an X and designate where personnel can sit. Staggered times are set for contractors to take their lunch break to ensure good sitting. In-office buildings, all personnel must wear an approved facial covering. Conference room tables will have an X for designated seating. The conference room's front door will have a posted sign with the maximum number of people allowed in the room. During water breaks at water stations, everyone must always sanitize their hands before & after and maintain a 6 ft distance. It is essential to practice the recommended social distancing, which will prevent droplet transmission (Belingheri et al., 2020).

7.2.2. From 6 feet to 3 feet

Most activities for industrial construction require personnel to work within this range of social distancing. The bolting up of pipe and valves require proximity work activities. For these activities to occur, the contractors will be required to wear proper PPE. The required PPE for activities from six feet to 3 feet, provided in Table 7. While in this proximity is where the exposure and spread of COVID-19 are dangerous. Wearing a face shield in this range will protect large droplets from being sprayed and reduce infection chances to others. Fig. 1 shows that large droplets can travel up to 2 m for a cough and up to 6 m with a sneeze (Dhand and Li, 2020).

7.2.3. Less than 3 feet

Some activities require workers to be in close proximity to one another. These activities include welding, flange bolt-ups, valve install, instrument install and terminations, safety inspections, quality control inspections, and field supervision direction. The spread of COVID-19 increases when activities require personnel to work within a range of droplets as they exit an infected person's mouth. The recommended means to reduce the spread is to wear an N95 Respirator with P100 filters. Refer to Table 7 for the PPE requirements for activities done from 3 feet to 0 feet. The transmission of COVID-19 in the early evolutionary stages of the disease is not fully understood other than it potentially could spread through large respiratory droplets (Bartoszko et al., 2020). In a study conducted by Bartoszko et al., there are no convincing data that N95 respirators are more effective than medical masks (Bartoszko et al., 2020). The N95 respirator with P100 filters has on average effectiveness of 95% of inhaling or exhaling small respiratory droplets (Semple and Cherrie, 2020). However, the need for medical masks, which are smaller and more comfortable, over N95 will take away from the health workers. Thus, N95 with P100 filters is ideal for industrial construction. The underlying issue with this requirement is the requirement for fit testing and availability.

The requirement of using N95 half-face respirators with P100 filters requires those users to be fit tested per OSHA guidelines. The fit test is done either by qualitative or quantitative testing. In March, we saw a trend of shortages of N95 and medical masks. The US news reported panic buying of N95 and medical masks, causing these shortages (Clemens et al., 2020). As a result of this panic buying the US construction industry had difficulties obtaining N95 respirators (Clemens et al., 2020). For half-mask respirators that cover the mouth and nose, OSHA requires qualitative testing. To be cleared and pass the fit test for the N95, the wearer had to have the respirator he would be wearing. Without the N95 respirator, the contractor or employee could not complete the fit test. The backlog of fit testing and the N95 respirator caused significant impacts in scheduling work activities during the project planning phase. The impacts of mask shortages and required fit testing potentially increased most schedules by a week.

7.3. Cost and Schedule impacts

The potential cost impact for a 40-person project that works five days a week and 10 h per day can increase approximately $190,000 per week. For a four-week project, this cost impact is about $760,000. This is based on a composite rate of $95 per hour. This impact is significant as you may need to start the project installing pipe, but it will take longer to install due to limited welders and pipefitters who are fit tested. This delays welding, bolting up valves, and installing instruments, which require an N95 respirator. The fit test was done by the local safety

council, which had a backlog of availability to comply with social distancing in March. The cost of this fit test, on average, is $50, which includes medical clearance and a qualitative fit test. Table 8 below shows the cost of a 4-week project of a 40-man crew for COVID-19 PPE.

The additional cost for a small project is significant. This information is important to project budgets and estimators during a pandemic such as COVID-19. The estimated composite rate also increases but is not captured in the initial estimate.

8. Sanitizing

8.1. Rationale

It is likely that, per public health guidelines, frequent and thorough handwashing and hand sanitization, maintaining social distancing of at least 6 ft, and isolation are effective risk mitigation measures against COVID-19 (Sun et al., 2020a). Recommended hand sanitizers to use on construction sites are made up of either ethanol, isopropyl alcohols, and hydroperoxides, or combinations (Mahmood et al., 2020). The active ingredients in commercial based hand sanitizers are ethanol or isopropyl alcohol at about 60–95% concentration (Mahmood et al., 2020). For many years' alcohol-based sanitizers have been used against microbial-borne diseases (Mahmood et al., 2020). However, the observation of overusing alcohol-based hand sanitizer should be recognized. The overuse of alcohol-based hand sanitizers can result in toxicity through dermal absorption and become anti-microbial resistance (Mahmood et al., 2020).

8.2. Hand sanitizing practices

All projects at Dow Louisiana requires an adequate number of handwashing stations and hand sanitizer. It is a requirement for all personnel to wash and apply hand sanitizer each time they use the restroom, remove their gloves before and after eating lunch, and use the water station. Hand wash stations are required every 50 ft within the project area.

8.3. Restroom and water station sanitizing practices

In every construction project, you need water stations and restrooms for the workers. These locations usually are socializing points. Being in a social distancing environment requires that only one person at a time and must maintain 6 ft separation. Also, the workers must wash or sanitize their hands before and after getting water. No plastic bottles or containers are permitted. It is allowed to use paper cones or cups but must be discarded after use. The practice of good drinking water, sanitization, and hygiene (WASH) interventions will help prevent diarrhea due to fecal contamination due to poor hygiene (Wolf et al., 2019). In addition to preventing diarrhea, WASH is also important prevention of COVID-19 (Mushi and Shao, 2020). Handwashing with water and soap (HWWS) and WASH practices serve as a critical defense in the transmission of COVID-19 (Mushi and Shao, 2020).

Table 8
COVID-19 PPE and fit test costs.

Equipment	Crew Size	Unit Cost	TOTAL
Fit Test	40	$45	$ 1800
N95 Respirator	40	$45	$ 1800
P100 Filters (6 per)	40	$160	$ 6400
Face Shield Kit	40	$25	$ 1000
Face Shield (4 per)	40	$10	$ 1600
		TOTAL	$12,600

8.4. Van and bus sanitizing

The vehicles that transport construction workers to the project sites require sanitization before and after use. The use of an approved disinfectant on all surface areas of the seat and areas that could be touched is necessary to prevent spreading COVID-19 (Kim and Lee, 2020). It is suggested that enhanced hydrogen peroxide be used for large surface areas that need to be disinfected (Kim and Lee, 2020). It is recommended that proper ventilation is available while disinfecting for a minimum of 5 min and allow adequate drying time (Kim and Lee, 2020). To meet these sanitization requirements requires having additional personnel whose primary task is to clean and sanitize. These resources will depend on the project's size and the frequency of the sanitizing per the site occupational hygienist and site policy.

8.5. Cost for sanitization

For projects at Dow LAO, an average of 4 helpers is required to complete the requirement. The increased resources are in addition to normal resourcing to support the project. The additional cost is about $52,000 for a 4-week project that could be added to the project. The cost of a handwash station is around $150 per week for each. This includes the daily maintenance of these handwash stations. The cost of restrooms is also $150 per week for each restroom. Table 9 referenced below will provide the estimated cost for sanitization during a COVID-19 project. The cost per Table 9 could also be used for flu and cold season if desired by the site.

9. Process safety practices during COVID-19

Process safety gained wide-world attention as a result of significant process accidents that occurred from 1960 thru 1990 (Khan et al., 2021). The objective of process safety is to mitigate and reduce the number of industrial accidents in process and chemical plants (Li et al., 2020). In process safety, the contributing factor in process safety events are the result of loss of containment & control (Khan et al., 2021). The improvement of process safety over the years focused on digital and technical aspects, for example installing safety devices (Khan et al., 2021). As the technology of the process safety devices improved so did the process safety management systems (PSM). The PSM's are monitored and operated by the process safety team in a control room setting (Behie et al., 2020). From 2010 to 2019, the Chemical Safety Board database contained 79 catastrophic accidents that resulted in loss of life (Wang et al., 2021). In the chemical and petrol-chemical environments there was an increase of incidents in line equipment openings under the COVID-19 practices.

Over the course of several decades the process industry has seen catastrophic accidents such as personnel poisoning, vapor cloud explosions, and flash fires occur (Sun et al., 2020b). Under normal environments these are challenging and require extensive attention to detail to

Table 9
Cost of sanitization for COVID-19 versus Non-COVID.

Labor & Equipment	COVID-19 Costs			Non-COVID-19 Costs		
	QTY	Cost Per	TOTAL	QTY	Cost Per	TOTAL
Latrines	8	$150	$4800	4	$150	$2400
Safety Observer	2	$ 95	$30,400	1	$ 95	$15,200
Hand Wash Stations	6	$150	$3600	2	$150	$1,200
Cleaning & Sanitization Crew	4	$ 65	$41,600	0	$ 65	$ -
Sanitization Supplies 1Gal	16	$ 30	$480	4	$ 30	$120
Hand Sanitization 1Gal	24	$ 30	$720	8	$ 30	$240
		TOTAL	$81,600		TOTAL	$19,160

overcome windows of opportunity, which can best be described as a gap or failure in process safety in which a catastrophic event can occur (Sun et al., 2020b). Under COVID-19, the lack of trained process safety human resources increased the windows of opportunity in 2020 (Sun et al., 2020b).

The permit writer is an operational technical advisor on the process safety team that reviews the work to be conducted to ensure adherence with that all process safety guidelines to include inspections. The permit writer also ensures that operations personnel tag and identify the isolation and blind points within the process system to ensure safe work activities can be conducted. In process safety, with all the technological advances, the need of the human element to identify hazards, conduct risk assessments, and implement process safety controls is still required (Rusli et al., 2021). The process safety checklists and risk assessments done by process safety teams require them to wear face shields and practice social distancing per the Dow COVID-19 Safety Policy. Any member that would be less than three feet from another team member is required to wear the N95 respirator and be fitness tested. The impact to industrial construction is evident in the delay of getting a safe work permit to execute the construction activity. If the member of the process safety team is not current on the fitness test and the area in question requires an N95 mask, the isolation is delayed awaiting a process safety team member who is fitness tested for an N95 mask.

Sun et al. (2020b) discussed the shortage of human resources as a risk to process safety, concluding that human resource shortages create a challenging environment with additional risk for error in process safety due to limited staff. Identified risk factors such as lack of resources, prolonged wearing of masks, high work stress, and additional unscheduled work hours due to resource shortages increased the probability of an incident as a result of an operational error in the process safety procedure implementation process (Sun et al., 2020b). The wearing of face masks or face shields that constantly fog up has been shown to restrict visual inspections and requires additional time to clear process lines and to ensure their safety. Issues with face shields, safety goggles, and face masks are exacerbated during the summer and high temperature months.

Human resource shortages and COVID-19 compliance measures at the LAO site resulted in permitting and process safety activities taking an additional 1.5 h s to up to 3 h s, and an increase in low-risk process safety incidents in 2020. The Process Safety Team permit writer office only allowed one permit at a time, which proved to be costly and impactful to overall project schedules. However, additional cost and impact to the schedule are far less significant than process safety, which could contribute to a catastrophic event that could occur if the process safety guidelines are overlooked. Refer to Table 10 for all occupational injuries that has occurred from 2014 to 2018 in the industrial, chemical, and manufacturing industries in the Gulf Coast.

Table 10
Fatal occupational injuries: 2014–2018.

Fatal occupational injuries by selected characteristics, 2014–2018						
Sector	2014	2015	2016	2017	2018	TOTAL
Chemical manufacturing	27	28	15	13	18	101
Plastics and rubber products manufacturing	15	17	16	15	12	75
Other plastics product manufacturing	8	10	2	8	–	28
Cement and concrete product manufacturing	30	26	24	21	18	119
Industrial machinery manufacturing	3	1	2	–	6	12
Utilities	17	22	30	28	29	126
Waste management and remediation services	55	67	67	63	89	341
Confined spaces	22	34	44	38	31	169
Explosion	84	75	55	85	71	370
Containers pressurized	10	18	10	17	12	67
Indirect exposure to electricity	67	49	66	55	73	310
Chemicals and chemical products	200	233	267	335	373	1408
Total	538	580	598	678	732	3126

Note: Data retrieved from US Bureau of Labor Statistics https://stats.bls.gov/iif/state_archive.htm.

10. Discussion

In March, Dow Louisiana experienced a critical outbreak that impacted over 14 contractors on an essential project. This project was halted and adversely affected for about two weeks. This event fast-tracked the need for stricter social distancing enforcement and more aggressive PPE for protecting the spread of COVID-19. This event also triggered the necessity of improved sanitization practices. The lessons learned is that quarantine practices work against spreading and outbreaks of COVID-19. Since the outbreak of that one event, all positive cases were isolated to individual cases only. What was also evident is that process safety practices took longer to clear, isolate, and tag prior to any construction activities could begin.

From Tables 4 and 5 above, we calculate a difference of $119,225 from the base estimate. The increase is significant, costing the project an additional cost of about $29,806 per week. This is important for the contractor, and the owner should the project go past the 4-week duration. This is either a negative cost to the contractor or a charge to the owner. We can also calculate the burn rate per week for the crew's 4-week project in Table 2, which is $205,565. The impact is calculated to $1093.88 per man-per day on a 40-h workweek. This is important when determining if more resources are needed or reducing the workforce to control cost overruns. We also conclude that COVID-19 adds six resources to your workforce to support additional safety oversight and clean & sanitize water stations.

If the contractor and their estimator are not careful, the estimated cost can easily impact the contractor by not capturing significant costs incurred by COVID-19. The cost impact will require the contractor to seek a change order and lose the owner's confidence in their estimating. The PPE and Fit Test, per Table 3, will cost $12,600 for a crew size of 40 for a 4-week project. This PPE is vital in mitigating the spread of COVID-19 and is important in complying with safety processes during a pandemic.

11. Conclusion

The COVID-19 pandemic reminds us of all the emerging challenges that infectious pathogens impose on communities and countries (Fauci et al., 2020). It is also a reminder of our need to practice good hygiene, wash our hands, sanitize, and social distancing in an infectious or pandemic environment (Fauci et al., 2020). In 1918, the influenza pandemic spread globally and took nearly 50 million lives throughout the world (Murphy et al., 2020). As of September 2021, the WHO COVID-19 Dashboard reports that COVID-19 accounted for nearly 4.66 million deaths (https://covid19.who.int/). The US transitioned from containment to mitigation protocols thru social distancing and isolation of infected persons by quarantining. None of the practices briefly described in this paper go without a price and schedule impact. The impact was not easy to determine as there is no data for cost during a pandemic. The PPE listed in this paper was difficult to obtain as supplies were quickly diminishing due to priority going towards healthcare and first responders. In March, we saw a significant increase in cases and outbreaks. We also know that sneezing and coughing can produce 3000 to 40,000 droplets in the form of large, small, aerosol, and nuclei droplets. These droplets can travel up to 6.6 feet for coughing and as far as 19.8 feet for sneezing.

The PPE needed for a small project of 40 personnel will cost about $7–10,000. The cost and schedule impacts for inefficiencies can be an extra week and a cost of about $190,000. With only 55.4% of all small

businesses in the US still operating and only having about $10,000 operating revenue per week, additional costs can be detrimental (Bartik et al., 2020). As a result of practicing the protocols in this paper, social distancing, wearing proper PPE, sanitizing practices, and medical pre-screening Dow LAO only saw about 132 positive cases of COVID-19. Of the 771 industrial and construction cases reported, Dow LAO is 17%, but only 3% of the total cases reported in Louisiana. Of these cases, all have returned to work once cleared through testing and quarantine. These low numbers are indicative of good safety processes and practices.

The Dow LAO COIVD-19 policy positively impacted the number of cases and saw a significant crucial impact on the number of outbreaks. Dow COVID-19 policy positively contributed significantly to reducing the spread of COVID-19 in a construction environment. We also saw cooperative efforts from owner to contractor in emphasizing a safety culture change that benefited both parties. Like every plan and strategy, there is always room for improvement. However, what we have learned from the safety processes during this pandemic will establish a starting point for the next wave of COVID-19 or the next pandemic.

There are discussions within Dow that the current practices are warranted not just for a pandemic but also for outbreaks during flu season. The discussions are centered around outbreaks where a specific work area is increasing in number of cases where the facial mask, sanitization, and social distancing will be employed to reduce the spread. There is a safety requirement by the owner and the contractor to protect their employees and others when an infectious virus or disease is present. Pandemic is not the only outcry to practice possible safety measures to protect everyone on a project site.

However, the COVID-19 pandemic brought light to some necessary improvements for a safe working environment within the industrial construction environment. The pandemic also brought attention to the delays and schedule impacts because of safe work permitting due to isolations and installing blinds as part of process safety mitigation procedures. The amount of time to ensure process safety guidelines and risk assessments were completed were lengthy, but for very good reason. Only one contractor at a time method was employed to ensure process safety assessments were efficiently conducted. The Process Safety Teams employed in the field had to abide by the same COVID-19 policies that were enforced with contractors. In any environment involving hazardous materials in process or chemical plants, the objective of process safety is to reduce and prevent a catastrophic event (Li et al., 2020). As of December 2020, there were over 150 official vaccine projects (Forni and Mantovani, 2021). Of those 150 vaccine projects, there are about fifty of them that reached human experimentation (Forni and Mantovani, 2021). At this time as vaccines become available, the same pre-entry procedures will require those with symptoms to self-quarantine and work from home till they are symptom-free and cleared by a medical professional. The contribution of the information shared within this paper will serve as a foundation for industrial construction projects that encounter the next wave of COVID-19 or another similar pandemic.

Credit author statement

Brian Briggs: Writing – original draft; Conceptualization; Methodology; Acquisition of data; Formal analysis and Interpretation of data; Validation. **Dr. Carol Friedland:** Writing-Review; Conceptualization; Methodology; Editing; Validation; Supervision. **Dr. Charles Berryman:** Writing-Review; Validation; Supervision. **Dr. Isabella Nahmens:** Writing-Review; Validation; Supervision. **Dr. Yimin Zhu:** Writing-Review; Validation; Supervision.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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