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Mitigating Construction Delays: Lessons from the COVID-19 Pandemic on Material Supply Disruptions

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Abstract: The COVID-19 pandemic affected all urban and rural areas across the globe. Particularly, the pandemic disrupted the material supply impacting all project schedules and project decisions. The purpose of this study is to analyze the materials delay impact due to COVID-19 pandemic on construction projects in terms of their schedule decisions. This study used an online questionnaire survey to collect the data from executive members of the construction companies within the United States. The survey focused on material supply and delivery delay questions organized in two subgroups using the Construction Specifications Institute MasterFormat divisions: (1) Facility Services and (2) Site and Infrastructure. Thirty-two responses from diverse company executive members were analyzed using t-test. The findings indicated that most of the projects were delayed due to either “Material and Labor” or “Material, Labor, and Equipment.” Thus, the two groups were analyzed in depth. The analysis shows that the mean delays were significantly higher for the “Material, Labor, and Equipment” group than the “Material and Labor” group. This is an important finding, suggesting that if similar situations arise, the project managers and/or the decision-makers should consider dedicating their time to the equipment required for those divisions and therefore mitigate delays. The study identifies crucial insights for successful project management during the pandemic, emphasizing the necessity of collaborating with subcontractors to secure essential equipment and address delays. It suggests expediting contract buyouts and submittals in vulnerable divisions to enhance resilience against material supply disruptions. Timely material procurement following project approvals for various durations is vital for minimizing pandemic-induced delays. Additionally, the study recommends adjusting lead times for materials with extended delivery timelines to mitigate construction delays associated with the pandemic. The lesson learned and recommendations from this study contributes to the body of knowledge in project management and project decision making by helping project managers and engineers to understand the impact and awareness of the challenges in material supply disruption during COVID-19 pandemic that could assist managers formulate appropriate strategies on future potential outbreaks.

Keywords: Material Supply Disruption, Construction Delays, COVID-19 Impact, Project Management

1. Introduction

Millions of lives in urban and rural areas across the globe have lost due to the Coronavirus pandemic, also known as COVID-19, and that has generated greater challenges among construction workers and businesses. Medical researchers, scientists, and economists warn about the global recession and financial losses due to COVID-19. While many countries imposed a closure on most of the industries to stop the spread of the virus, the construction sector is considered to remain open in most of the countries partly due to the need for temporary quarantines and hospitals to cope with the situation arising from COVID-19 [1]. Many studies suggest that although safety is becoming a top priority in construction industries, safety and health in construction get the least importance in many countries and not at a satisfactory level [2, 3].

According to the Center for Diseases Control's (CDC)

COVID Data Tracker, the U.S. COVID-19 total cases were over 33 million and the total deaths were over six hundred thousand [4]. Pasco et al [5] mention that construction workers are more likely to be hospitalized for COVID-19 as compared to other non-construction occupations. Brown et al. [6] found that nearly 60% of the construction workforce has at least one risk factor that makes them vulnerable for severe illness from COVID-19, including older age, racial and/or ethnic minorities, and smoking and e-cigarette use. Other studies show that COVID-19 impacted performance, suspension of projects, workforce shortage, and time and cost overruns [7, 8].

To minimize the risk of COVID-19 spread and minimize the loss of lives, the CDC has provided several safety measures and prevention procedures. However, safety measures such as travel restrictions, social distancing, and quarantines have resulted in unprecedented construction delays, material disruption, labor shortage, and availability of governmental personnel for project inspections [9, 10]. Contractors and project managers are facing such unprecedented challenges in their construction projects and are spending additional resources to manage such risks.

Based on the literature available, most of the studies have focused on the health and wealth of the workforce. However, none of the studies have focused on the schedule impacts due to the pandemic on these three Construction Specifications Institute Master Format: (1) facility services and (2) site and infrastructure. Therefore, the importance of this study.

It is beneficial for construction professionals to understand how the COVID-19 pandemic has impacted their daily lives and affected their construction schedule so that they are better prepared for future projects during a similar pandemic. This study discusses how the COVID-19 pandemic has impacted material supply disruption in the facility services divisions and site and infrastructure divisions of the construction industry and how it has affected construction projects in terms of schedule delays.

1.1. COVID-19 Pandemic

The coronavirus disease 2019 also known as COVID-19 is a respiratory illness caused by the virus named severe acute respiratory syndrome coronavirus 2 (i.e., SARS-CoV-2) [4, 11]. The Centers for Disease Control and Prevention (CDC) states that the coronavirus is confirmed as being transmitted from human to human and results in symptoms including fever, dry cough, fatigue, and shortness of breath [4]. The CDC stated that, "recent studies indicate that the virus can be spread by people who are not showing symptoms. Older adults and people of any age who have serious underlying medical conditions may be at higher risk of severe illness from COVID-19" [4]. Many countries have been experiencing economic slowdowns, financial and labor burdens associated with project delays, cost escalations, lack of supplies, and worker's safety and health problems [12-15].

COVID-19 transmission is primarily airborne as droplets from person to person such as coughing [4]. Since the virus can remain in the air and transmit through self-inoculation such as nose and mouth, or by hand contact, the strategy for prevention has been to limit the person-to-person contact, either through social distancing or completed reduction in social contact such as lockdowns or shut down of workplaces and public events. The CDC guideline is to wear a mask, maintain at least a 6-foot social distance, cleaning of contact surfaces, and do handwashing [4].

1.2. Impact on Construction Due to COVID-19 Pandemic

Many studies have presented the impact of the COVID-19 pandemic on construction. This paragraph provides a summary of those studies. In the early stage of the COVID-19 pandemic in 2020, a significant number of construction workers reportedly tested positive for COVID-19 [16, 17]. Pasco et al. [5] emphasized that the risk of COVID-19 infections among construction workers was about five times more likely to be hospitalized because of COVID-19 than workers in other industries. Although an important component of a COVID-19 protection plan is to educate workers with information on the most current science and protective practices to reduce disease spread [18], research shows that levels of workplace safety literacy and risk perception in the construction industry are influenced by factors such as safety training, hazard recognition, risk-taking behaviors, attitudes, and the dynamic nature of the profession [19-23]. Studies have highlighted varieties of issues in construction such as aging workers and entrance of "Gen Z" into the workplace, technological modernization, improving efficiency, and use of sustainability and renewable products [24-27].

1.3. Project Delay Due to Supply Chain Disruption During COVID-19 Pandemic

Timely completion is one of the success parameters of a project. However, the majority of the projects get delayed due to unforeseen factors (site conditions, environmental concerns, natural hazards, pandemic etc.). Assaf and Al-Hejji [28] defined construction delay as —the time overrun either beyond completion date specified in a contract, or beyond the project delivery date as agreed by parties. In other words, additional days of work are required to perform or complete the work of the contract. Literature shows that many delay factors are grouped into categories such as material, labor, and equipment [29-31].

COVID-19 pandemics increased a major challenge in supply chains in all industries. Many firms experienced greater challenges in recovering from the pandemics [32] because such outbreaks have severe and long-term impacts on businesses and their operations and generally require more robust recovery strategies [33]. Due to unexpected problems encountered during conception, designing, and construction phase often led to unwanted delay in project completion [34]. Furthermore, these delays are likely to have a significant negative effect on revenue, the firm's reputation, buyers and suppliers' wellbeing and the supply chain's overall success [35]. Literature shows that these detrimental impacts are the product of direct effects on supply chain networks, such as supply, delivery and transportation links become unavailable

[36]. Since the COVID-19 pandemic has impacted global supply chains substantially [37-39], it is vital to identify potential supply chain recovery challenges and their influence on post-disaster recovery to ensure supply chains formulate the appropriate strategies to overcome such issues [33, 40].

1.4. Urban Planning and Construction Decisions

The construction industry is continually disturbed by poor decisions resulting in a low performance with increased cost and time delays [41]. To survive in the conditions of challenges, tough competition, enterprises have to implement a set of measures and use special management tools, one of which is the involvement of specialist consultants to solve emerging problems, whose professional assistance is needed to find a way out of difficult situations [42]. While some of the decisions in the construction projects are relatively straightforward, many are very challenging due to numerous factors affecting a decision, including environmental conditions, human influences, and information availability [43].

For example, better understanding of the underlying patterns of pandemics, their effects on projects, preparation strategies, and adaptation measures is needed for informed decision-making during pandemics. The recent pandemic offers an unprecedented opportunity to understand how cities might be affected by pandemics and what actions are needed to minimize the impacts and enhance urban pandemic resilience [44].

A national emergency was declared on March 13, 2020, when the rapid spread of the COVID-19 cases seen in the United States. Due to lockdown measures, countries across the globe limited the flow of products. This caused a significant difficulty for suppliers and their logistical teams [36] in decision-making. COVID-19 has halted manufacturing, and demand for some goods has decreased considerably [45]. Due to the pandemic outbreak, workers are trapped under lockdown [46]. According to the U.S. Bureau of Labor Statistics, U.S. experienced a record-high unemployment rates, 3.8% in February 2020 went up to roughly 14.7% in April 2020, which devasted many industries including manufacturing and retail. During this period, many businesses had to shut down that caught the decision makers off guard about what to do next. Any immature decisions could cause their project schedule to overrun, cost overrun, and disputes.

2. Methodology

The study conducted an online questionnaire survey to the executive members of the construction companies. The survey consists of a questionnaire that focused on schedule impact due to material supply disruption in the CSI divisions. The study focused on two subgroups of CSI Master Format divisions: (1) facility services subgroup (Div. 21 through Div. 28), and (2) site and infrastructure subgroup (Div. 31 to Div. 35) as shown in Table 1. This study used a quantitative approach (descriptive and t-test) to analyze the responses collected from the questionnaire survey.

The questionnaire consists of two major sections: demographic information and construction delay information. The survey focused on construction delays due to material disruptions among facility services and site and infrastructure subgroup as shown in Table 1. The survey questionnaire was designed online using the Qualtrics tool.

Table 1. *Two subgroups survey of the CSI MasterFormat.*

Facility services	Site and infrastructure
Div. 21- Fire Suppression, Div. 22-Plumbing, Div. 23- Heating, ventilating, and air conditioning, Div. 25-Integrated automation, Div. 26- Electrical, Div. 27-Communications, Div. 28- Electronic safety and security	Div. 31- Earthwork, Div. 32 – Exterior Improvements, Div. 33 – Utilities, Div. 34 – Transportation, and Div. 35 – Waterways and Marine Construction

3. Data Collection

The questionnaire was distributed to fifty (50) construction company executive members in the United States from which thirty-two (32) valid responses were received and analyzed. These thirty-two responses (32) correspond to sixty-four (64%) of the targeted participants which is significantly higher than the average response rate for an external survey which is at 10-15% [47].

The number of valid questionnaire responses for this study was based on the formula below that has been used in multiple literatures such as Ali et al. [48], Cherkos and Jha [49], Kish [50], and Tripathi and Jha [51].

$$n = \frac{n'}{[1+\left(\frac{n'}{N}\right)]} \quad (1)$$

and

$$n' = \frac{(p \ x \ q)}{V^2} \quad (2)$$

where n = the required sample size, n' = the first estimate of sample size, N = targeted population size, p= portion of the characteristic being measured in the target population, q=1-p, and V= standard error of sampling population. As recommended in literature, the values of p and q were taken as 0.5 to get the maximum sample size and standard error was set to 7% while the maximum allowable value of standard error is 10% [49, 51]. Using the target population N is 50 executive members of the construction companies and plugging the values in Eqs. (1) and (2), the required sample size (n) was 25. This study analyzed 32 responses for executive members which is higher than the required sample size computed.

The data collection was focused on information related to the COVID-19 pandemic delay on the projects, the duration of the active projects during the pandemic, and the reason behind the delay. Besides, most of the questionnaire was divided according to the construction divisions and the respondents were asked to provide the delay in calendar days during COVID-19 because of the material supply disruption in the building construction divisions.

4. Results

The survey was filled out by twenty-two (68.8%) General Contractors, six (18.8%) Sub-Contractor, and four (12.5%) other organizations totaling thirty-two responses as shown in Table 2. Two of the four other organizations were construction professional organizations and the other two were owner's representatives. These four other organizations beyond the contractors/sub-contractors were included in the participants to expand the breadth of the possible responses. Since the companies were allowed to indicate as many sectors as they worked on, the total number of sectors selected exceeded the thirty-two total responses as some companies work in multiple sectors. As shown in Table 2, many of the executive members surveyed worked in the commercial sector (93.8%).

The age of the surveyed participants was very evenly distributed, mainly ranging from 30 years old to over 50 years as shown in Figure 1A. The experience of the participants was very high with most of them in the 10 to more than 20 years of experience (Figure 1B). The level of education was mainly two- and four-years degree (Figure 1C). The gender of the participants mimics the construction industry dominated by male with a small percentage (10.3%) of females (Figure 1D).

Table 2. *Company's sector.*

Occupation	Total	Percent	Residential	Commercial	Transportation	Industrial	Other
General Contractors	22	68.8%	6	21	4	4	1
Sub-Contractor	6	18.8%	2	5	1	2	
Other	4	12.5%		4	3	3	
Total	32		8	30	8	9	1
Percent	100%		25%	93.8%	25%	28.1%	3%

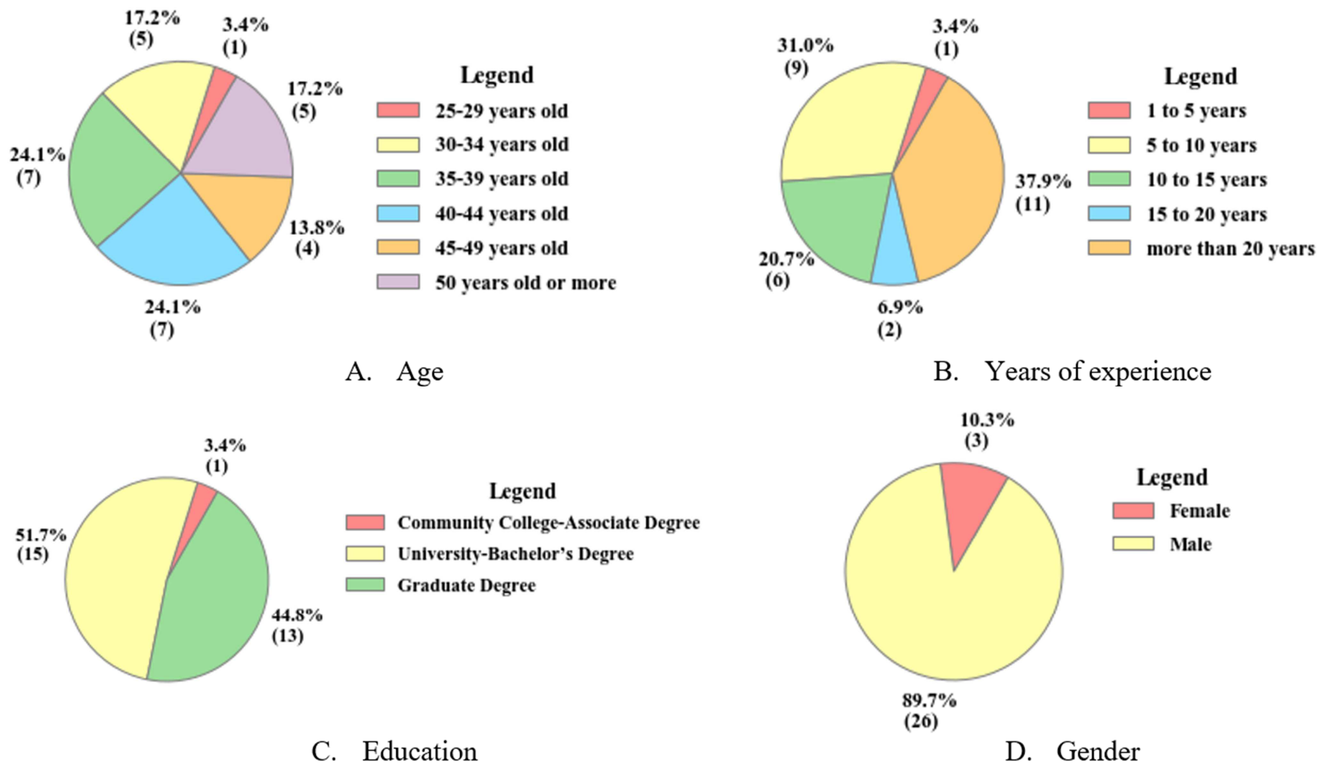

***Figure 1**. Demographics of respondents.*

Based on the survey question "How many calendar days (in average) was the estimate overall duration of your active projects during the COVID-19 pandemic?", the result shows that the overall project durations varied from less than two months to 2 years or more. Most of the companies had a project duration of one year to one and a half years duration as shown in Figure 2.

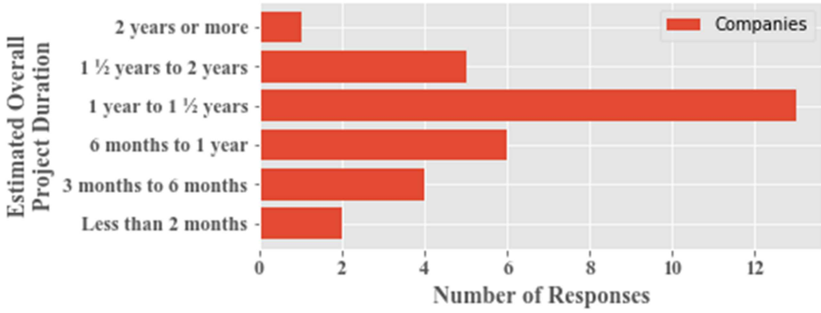

Figure 2. *Active projects duration during COVID-19 pandemic.*

Based on the survey question "How many calendar days (in average) did the COVID-19 pandemic delay your active projects?", the result shows that the projects were delayed from less than 5 days to more than 56 days. Among those projects delayed, most of the projects were delayed between 6 to 15 days as shown in Figure 3, followed by less than five days and 26 to 35 days.

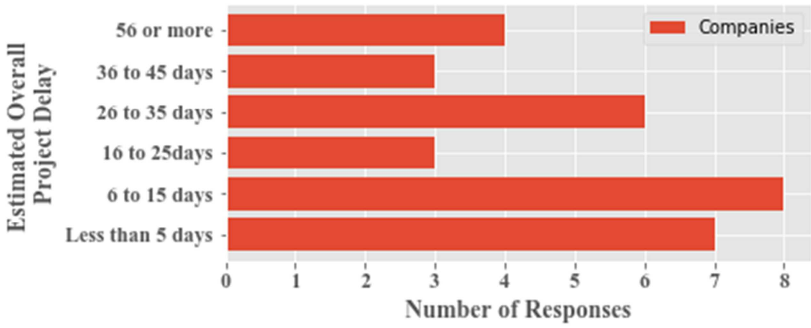

Figure 3. *Active projects delay due to COVID-19 pandemic.*

5. Analysis and Discussion

5.1. Cause of Delays

When asked "What was/were the reason(s) for the construction delay during COVID-19?," fifty percent (50%) indicated that "Materials and Labor (M&L)" were a reason for construction delays during COVID-19 followed by 30.8% indicated that "Materials, Labor, and Equipment (ML&E)" were a reason for construction delays as shown in Figure 4.

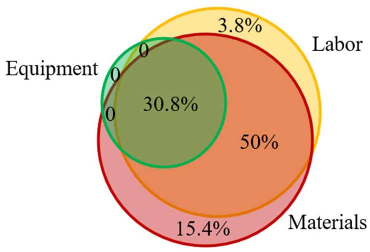

Figure 4. *Construction delay reason(s) during COVID-19.*

The Venn diagram (Figure 4) shows that 15.4% indicated "Materials" only, and 3.8% indicated "Labor" only as a reason for construction delays.

5.2. Project Duration and Schedule Impact

During the COVID-19 Pandemic, most of the active projects of the surveyed companies had an estimated overall duration between 1 and 1 ½ years, and most of them were delayed between 6 and 15 calendar days or less (see Figure 2 and Figure 3). When analyzing the average project duration vs average project delay as shown in Figure 5, the projects with a duration between 6 months and 1 year as well as projects with a duration between 1 ½ year and 2 years had the highest median delay of 26 to 35 days.

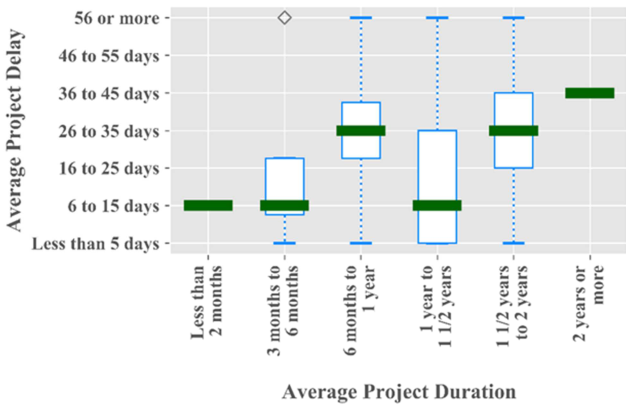

Figure 5. *Project delays due to COVID-19 vs. project duration.*

The projects with a duration of less than 2 months, between 3 months and 6 months, and between 1 year and 1 ½ years had the lowest median delay of 6 to 15 days as shown in Figure 6. Thus, the projects between 6 months to 1 year and 1 ½ year to

2 years were proportionally impacted by COVID-19. Thus, should a situation like COVID-19 outbreaks arise the decision-makers make their main priority to focus on the projects with a duration between 6 months to 1 year and 1 ½ year to 2 years to identify actions to mitigate project delays.

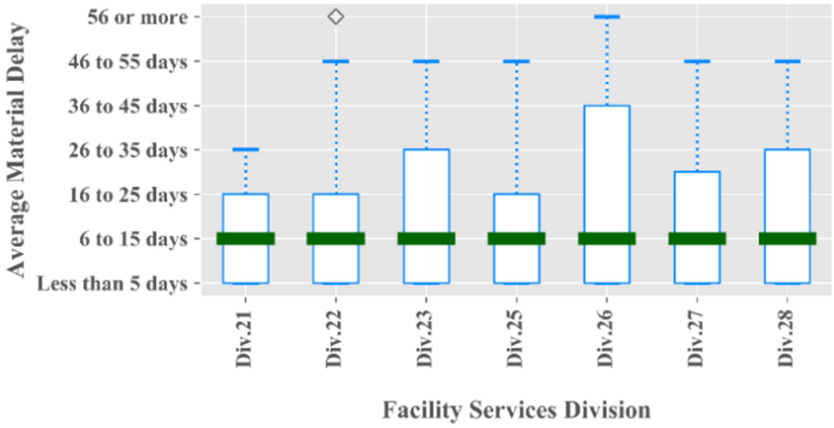

Figure 6. *Material delivery delays – facility services divisions.*

The following sections show analysis and discussions for each of the three subgroups of the CSI Master Format divisions (see Table 1).

5.3. Facility Service CSI Divisions

5.3.1. Material Delays

The materials median delay for the Facility Service CSI Divisions (Div. 21 to 28) was between 6 and 15 days as shown in Figure 6. The division with the most delay variability was the Electrical (Div. 26) ranging from less than 5 days to 56 days or more and the division with the least delay variability was Fire Suppression (Div. 21) ranging from less than 5 days to 35 days.

5.3.2. Material Delays Vs Cause of Delays

During the COVID-19 Pandemic, most of the projects were delayed between 6 and 15 calendar days as shown in Figure 6 and eighty-one percent (from Venn diagram -Figure 4) of the respondents indicated that either “M&L” (50%), or “ML&E” (31%) were the delay causes. However, it is important to understand in more depth the impact of the delay causes on the project delays. Therefore, a t-test analysis comparing delays of the “M&L” groups vs the delays of the “ML&E” group was performed to understand this matter.

The t-test analysis showed that the mean delays of the Facility Service CSI Divisions (Div. 21 to Div. 28) were higher for the “ML&E” group than the “M&L” group in all divisions as shown in Table 3. The 95% Confidence Interval of the mean delay value for the “ML&E” group was higher than for the “M&L” group for all divisions as shown in Table 3.

These differences are statically significant with p values lower than 0.05 for Div. 21 (p=0.003), Div. 23 (p=0.001), Div. 26 (p=0.023), and Div. 28 (p=0.016) all as shown in Table 4. Furthermore, the Cohen’s d, Hedge’s g, and Glass delta values are less than -0.80 indicating a large effect [52] of the cause of delay on the divisions’ delay as shown in Table 4. This is an important finding that if similar situations arise the decision-makers should consider dedicating their time to the equipment required for those divisions and therefore mitigate delays.

Table 3. *Material delays of facility service divisions.*

Division	Div. 21		Div. 22		Div. 23		Div. 25		Div. 26		Div. 27		Div. 28	
Statistics	M&L	ML&E	M&L	ML&E	M&L	ML&E	M&L	ML&E	M&L	ML&E	M&L	ML&E	M&L	ML&E
N	11	6	11	7	11	7	11	6	11	7	11	7	11	7
Mean	0.8	2.3	1.4	2.6	1.2	3.7	0.4	2.3	1.2	3.6	1.2	2.4	1.2	3.0
Std. Dev	0.6	1.2	1.3	2.1	1.2	1.3	2.0	1.6	1.2	2.1	1.2	1.5	1.2	1.7
Std. Error	0.2	0.5	0.4	0.8	0.4	0.5	0.0	0.7	0.4	0.8	0.4	0.6	0.4	0.7
95% Conf.	0.4	1.1	0.5	0.6	0.4	2.6	0.0	0.6	0.4	1.7	0.4	1.0	0.4	1.4
Interval	1.2	3.6	2.2	4.6	2.0	4.9	0.0	4.0	2.0	5.5	2.0	3.8	2.0	4.6

Note: ML=material and labor; MLE=material, labor, and equipment; Div. = Divisions

Table 4. *Facility service division “material and labor” vs “material, labor, and equipment”.*

	Div. 21	Div. 22	Div. 23	Div. 25	Div. 26	Div. 27	Div. 28
Difference (LM vs LME)	-1.515	-1.208	-2.533	-1.133	-1.879	-1.262	-1.750
Degrees of freedom	15	16	16	14	18	17	17
t	-3.491	-1.502	-4.363	-1.715	-2.494	-2.018	-2.672
Two side test p value [a]	0.003	0.153	0.001	0.108	0.023	0.060	0.016
Cohen's d [b]	-1.772	-0.726	-2.109	-0.886	-1.169	-0.960	-1.271

	Div. 21	Div. 22	Div. 23	Div. 25	Div. 26	Div. 27	Div. 28
Hedge's g [b]	-1.682	-0.692	-2.009	-0.837	-1.120	-0.917	-1.214
Glass's delta [b]	-2.513	-0.939	-2.169	-1.097	-1.428	-1.057	-1.538

Note: [a] <0.05 Statistically significant [b] < -0.80 or > 0.80 Large effect intervention

5.4. Site and Infrastructure CSI Divisions

5.4.1. Material Delays

The materials median delay for the Site and Infrastructure CSI Divisions varied by division. Figure 7 shows that the divisions with the longest delay were Utilities (Div. 33) and Transportation (Div. 34) with a median delay of 16 to 25 days.

The divisions with the shortest median delay were Earthwork (Div. 31), Exterior Improvements (Div. 32), and Waterways and Marine Construction (Div. 35) with a median delay of 6 to 15 days. The divisions with the most delay variability was Transportation (Div. 34) and Waterway and Marine Construction (Div. 35) ranging from less than 5 days to 56 days or more.

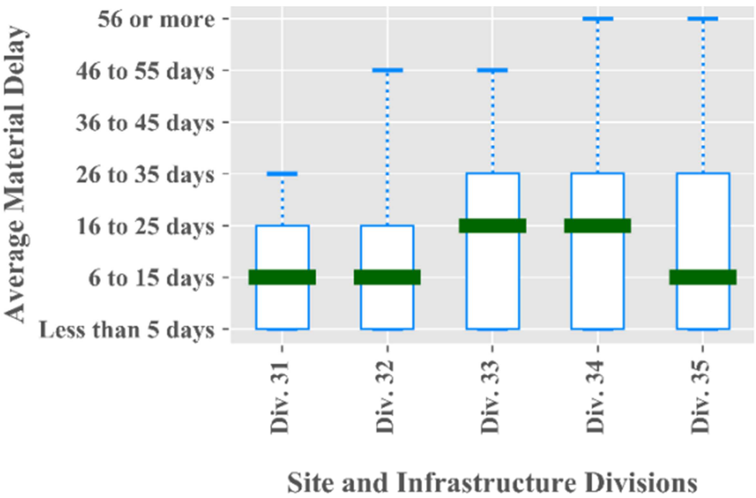

Figure 7. *Material delivery delays – site and infrastructure divisions.*

The division with the least delay variability was Earthwork (Div. 31) ranging from less than 5 days to 35 days as shown in Figure 7.

5.4.2. Material Delays vs Cause of Delays

The t-test analysis showed that the mean delays of the Site and Infrastructure CSI Divisions (Div. 31 to Div. 35) were higher for the "ML&E" group than the "M&L" group in all divisions as shown in Table 5. The 95% Confidence Interval of the mean delay value for the "ML&E" group was higher than for the "M&L" group for all divisions as shown in Table 5.

These differences are statically significant for different for all divisions with p-values lower than 0.05 as shown in Table 6 except for Division 33 (p=0.061). Furthermore, the Cohen's d, Hedge's g, and Glass delta values are less than -0.80 indicating a large effect of the cause of delay on the divisions' delay as shown in Table 6. This is an important finding if similar situations arise the decision-makers should consider dedicating their time to the equipment required for those divisions and therefore mitigate delays.

Table 5. *Material delays of site and infrastructure division.*

Division	Div. 31		Div. 32		Div. 33		Div. 34		Div. 35	
Statistics	M&L	ML&E	M&L	ML&E	M&L	ML&E	M&L	ML&E	M&L	ML&E
N	12	6	11	6	11	7	10	6	8	4
Mean	0.6	2.8	0.5	3.2	1.9	3.6	0.9	4.0	1.0	3.3
Std. Dev	0.7	1.8	0.7	1.8	1.8	1.6	0.9	2.0	1.1	2.1
Std. Error	0.2	0.7	0.2	0.7	0.5	0.6	0.3	0.8	0.4	1.0
95% Conf.	0.2	0.9	0.0	1.2	0.7	2.1	0.3	1.9	0.1	0.0
Interval	1.0	4.8	0.9	5.1	3.1	5.1	1.5	6.1	1.9	6.5

Note: ML=material and labor; MLE=material, labor, and equipment; Div. = Divisions

Table 6. *Site and infrastructure division "material and labor" vs "material, labor, and equipment".*

	Div. 31	Div. 32	Div. 33	Div. 34	Div. 35
Difference (LM vs LME)	-2.250	-2.712	-1.662	-3.100	-2.250
Degrees of freedom	16	15	16	14	10
t	-3.860	-4.457	-2.014	-4.331	-2.551

	Div. 31	Div. 32	Div. 33	Div. 34	Div. 35
Two side test p value [a]	0.001	0.001	0.061	0.001	0.029
Cohen's d [b]	-1.930	-2.262	-0.974	-2.236	-1.562
Hedge's g [b]	-1.838	-2.147	-0.927	-2.114	-1.442
Glass's delta [b]	-3.366	-3.945	-0.946	-3.540	-2.105

Note: [a] <0.05 Statistically significant [b] < -0.80 or > 0.80 Large effect intervention

6. Conclusion

COVID-19 pandemic has impacted construction projects in urban areas. This study collected and analyzed the survey response from 32 construction companies regarding how materials supply disruption caused delays in projects and impacted their schedule in the United States. The findings show that median delay for the Facility Service CSI Divisions was between 6 and 15 days. Similarly, the median delay for Site and Infrastructure CSI Divisions varied from 6 to 25 days with the longest delay observed in the Utilities (Div. 33) and Transportation (Div. 34).

The statistical analysis showed that the mean delays were significantly higher for the "ML&E" group than the "M&L" group in many of the divisions analyzed in this study. This is an important finding that if similar situations arise the decision-makers should consider dedicating their time to the equipment required for those CSI divisions and therefore mitigate delays.

Material shortage, unemployment, scarcity of skilled labor, and logistic issues had a greater impact on the project schedule during this pandemic. Certainly, the need for preparation outline, strategic plans, and best practices to handle this type of situation has arisen. The analysis and findings are helpful to all the stakeholders to understand the unexpected and unprecedented pandemic effect in the construction industry, as described in the lesson learned and recommendation below.

7. Lessons Learned and Recommendation

The literature review and questionnaire survey analysis from this study contributes the body of knowledge in construction project management by helping to understand the potential material delay impact and recovery challenges during/after the pandemic on a project. The COVID-19 pandemic has taught a lesson how difficult it is to obtain construction materials and equipment to install from the global market. The study showed that material delay impacted all construction companies on their projects on all the CSI divisions. The impact ranged from less than 5 days to 56 days or more. These findings will help owners and managers rethink their supply chains and understand the impact on their project schedule, especially while using materials and products from the global market. Stakeholders involved in managing the construction supply chain could use the lesson learned from this study to redesign and come up with alternate back up plan considering potential future pandemics. For example, median material delay in HVAC (Div. 23) in Facility Services subgroup was 6 to 15 days in this study but the Utilities (Div. 33) and Transportation (Div. 34) with a median delay of 16 to 25 days. This shows that if the equipment were to produce and ship from abroad countries then the project schedule was greatly impacted because not only the impact was due to lockdown and shut down of the manufacturing plant, but also the manufacturing plant itself who needed components from other manufacturer (for example, chip shortage) to produce the products were greatly impacted. This ripple effect was quite noticeable during and after the pandemic. Therefore, understanding the impact and awareness of these challenges could assist managers formulate appropriate strategies for future potential outbreaks. This could also assist them set their priorities in allocating resources to handle the project during and after the pandemic.

Based on the results from this study, the following are some recommendations for construction companies to mitigate cost and schedule impact as well as supply chain disruption of a future pandemic:

1) Focus on working with the subcontractors for them to secure their required equipment. This is to overcome the significantly higher delay experienced by the participants that indicated the cause of delay to be "material, labor, and equipment" (Table 3 through Table 6).
2) Expedite the contract buyout and submittal required on divisions that are more susceptible to material supply chain disruption and labor shortage such as Utilities (Div. 33) and Transportation (Div. 34) (see Figure 7).
3) Focus on purchasing materials as soon as contract and submittals have been approved for a project duration that ranges from six months to two years to overcome the "Project delays due to COVID-19 vs. project duration" (see Figure 5).
4) Consider securing additional material storage area for increased uncertainty of delivery or installation dates. This will address the traditional laydown constraints to overcome the "Material delivery delays" because all divisions were impacted during COVID-19 pandemic (See Figure 6, and Figure 7).
5) For those materials that have the greater lead time, increase this time to consider the additional supply chain delivery time. This is to overcome the "Reason(s) for construction delay during COVID-19" (See Figure 4) as shown in the results section of this paper.

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Conflicts of Interest

The authors declare no conflicts of interest.

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