Employing Predictive Trend Analysis to Decrease Construction Schedule Delay

Vivian Austin
Department of Engineering Systems and Environment
University of Virginia
Charlottesville, USA
vma2kg@virginia.edu

Zachary McLane
Department of Engineering Systems and Environment
University of Virginia
Charlottesville, USA
ztm5xq@virginia.edu

Caroline O'Keeffe
Department of Engineering Systems and Environment
University of Virginia
Charlottesville, USA
cmo2ck@virginia.edu

Diyar Rashid
Department of Engineering Systems and Environment
University of Virginia
Charlottesville, USA
dsr9jy@virginia.edu

Ariana Zimmerman
Department of Engineering Systems and Environment
University of Virginia
Charlottesville, USA
acz3kb@virginia.edu

Diana Franco Duran
Department of Engineering Systems and Environment
University of Virginia
Charlottesville, USA
dmf8a@virginia.edu

Arsalan Heydarian
Department of Engineering Systems and Environment
University of Virginia
Charlottesville, USA
ah6rx@virginia.edu

Todd Bagwell
Vice President of Preconstruction Services
Hourigan
Richmond, USA
todd.bagwell@hourigan.group

***Abstract*—Construction projects of all kinds are plagued by inefficiencies, creating excess risk, and leading to delays and cost overruns. Existing research has focused on analyzing delays in completed construction projects for forensic claims disputes. However, this data could also be used to decrease the risk of future schedule delays through the use of predictive trend modeling and data analysis. This form of data analytics is becoming increasingly prevalent and valuable in the construction industry as a means of identifying and allowing for the prevention of potential delays. An interdisciplinary team at the University of Virginia (referred to as the capstone team) seeks to provide insight into delay causation and prevention for Hourigan, a general contracting and construction firm. This work focuses on the analysis of scheduling data and project teams' input from three medium-sized construction projects recently completed by Hourigan, referred to by the placeholder names projects A, B, and C. These data sets were interpreted using statistical analyses to assess correlations between owner, designer, or contractor-related delays and frequent delays. Interviews with the project team for each Hourigan project were conducted to obtain qualitative data regarding specific delay events. The main causes of delay for Project A were found to be the owner and designer; for Project B the designer and subcontractors; and for Project C the subcontractors, materials, and external factors. The capstone team also identified that Hourigan would benefit from recording more data related to project schedules as well as costs incurred due to specific delays. These findings will allow Hourigan to better manage, avoid, and overcome future challenges due to project delays.**

Keywords—Construction Projects, Schedule Delay Analysis

I. INTRODUCTION

Construction delays are a seemingly unavoidable aspect of construction projects, regardless of the project's size. They cause deviation from a project's as-planned schedule due to various factors such as extreme weather, design changes, or labor shortages, and can be attributed to the project owner, the general contractor, or any number of subcontractors, as well as to outside forces. Project cost is a vital component in the construction industry and because time is directly linked to money, delay events have an enormous impact on not only the project's planned completion date but also the final cost [1]. The overarching effect of construction delays is cost escalations, resulting in reduced project profit, a decrease in the quality of work, and potential tension between different stakeholders of the project. Several delay analysis methods currently exist to analyze construction delays and they are employed after construction is complete to quantify the time and cost effects of the delays [2]. For delay analysis while construction is still occurring, the typical approach is for contractors to react to delays using experience-based judgements [3]. Formal delay analysis methods are limited in that their main purpose is to simply determine legal liability for delays and they are applied after construction is already complete. Analyzing and managing delays in-situ with only personal experience as a resource poses a problem with continuity; each team member brings their own unique experience to the project and will therefore react differently to the same delay event. To address these limitations and allow for the prediction and prevention of construction delays, this capstone project employs the use of data analytics and recommendations for best practices.

Hourigan is a construction and development company based in Richmond, Virginia that operates in the Mid-Atlantic region of the United States. They are involved in commercial, corporate, education, and healthcare markets, among others [4]. As a smaller, privately held firm, Hourigan is an ideal candidate for the implementation of data analytics in the area of construction delays. Because Hourigan does not have access to the same degree of resources as larger construction firms to perform complex data analysis of delays, small to medium-sized companies such as themselves stand to benefit greatly from automated approaches to onsite data collection, which can reveal problem areas in their construction processes and inform improvements.

Thank you, Hourigan, for sponsoring this project.

II. Literature Review

A. Delays and Disruptions

Delays and disruptions are often thought to be identical, but they are two different occurrences. As a verb, delay means "to make (someone or something) late or slow" [5]. As a noun, delay means "a period of time by which something is late or postponed" [5]. To better understand delays, delays are often compared to the "As-Planned schedule, what was intended before any delay occurred" [5]. Disruption is better defined in the scope of construction as "a disturbance of the contractor's regular and economic progress and/or delay to a non-critical activity even though, on occasion, there is no or only a small ultimate delay in completion" [5]. Disruptions are measured in relation to the "planned productivity of the affected parts of the work and in relation to the cost of carrying out the work" [5].

Project delays can be characterized in various ways. Compensable delays are when a contractor is entitled to financial recovery in form of direct and indirect time-related costs due to an owner risk event [6]. Compensable delays are owner-caused. Non-compensable delays are when a contractor is not entitled to additional compensation resulting from an excusable delay [7]. Non-compensable delays are caused by "third parties or incidents beyond the control of both the owner and the contractor" [7]. Concurrent delays happen when there are two or more independent delays during the same time period. These delays are significant when each delay is a risk from the owner and the contractor [6]. Critical delays are delays to an activity which causes delay to project completion time [6]. Excusable delays are when a contractor will have relief from potential financial responsibility, an extension of time, or both based on contractual circumstances [6]. Non-excusable delays are delays in which the contractor is entirely responsible for the extension of the project's duration and will be held liable for any costs incurred by the delay [6]. Non-excusable delays are caused by the contractor or its suppliers [7]. In short, compensable and non-compensable delays are linked to money, whereas excusable and non-excusable delays are linked to time. For example, "the late release of drawings from the owner's architect" would be considered a compensable delay [7]. Examples of excusable but non-compensable delays include strikes and abnormal weather [7]. Examples of excusable and compensable delays include labor strikes or natural disasters.

B. Data Analytics and Machine Learning

One of the most useful ways to address the above types of delay risk is to use data analytics and machine learning. Abbaszadegan and Grau (2015) assessed the influence of automated data analytics on project cost and schedule performance. Retrospective data from 78 projects was collected to assess the benefits of information integration and automated data analytics, with 60 projects being owner projects and 18 projects being contractor projects. Projects were categorized as either having very good or very poor integration and automation capabilities. Non-parametric statistical hypothesis testing methods allowed these capabilities to be contrasted with project performance. Projects using automation were shown to have a 5.31% better schedule performance and 3.34% cost performance than those without [8]. The results were not statistically significant, but the results did demonstrate the potential of automated data analytics to have a positive impact on project performance. Therefore, the automation of the work done by the capstone team could theoretically be beneficial to Hourigan's future projects.

Gondia, Siam, El-Dakhakhni, and Nassar (2020) identified and developed machine learning models for accurate project delay risk analysis and prediction. The study first identified delay sources and factors, then a data set was made compiling project time performance and delay risk sources. Decision tree and naïve Bayesian classification algorithms were used on the data set to predict project delay extents. The predictive performances of both models were evaluated with cross-validation tests. The results indicated the naïve Bayesian classification algorithms were a better predictor of performance for the data set [9].

III. Methods

This project was completed based on three projects (here referred to as Projects A, B and C) which all experienced significant delays. All three projects were completed by the same contractor, Hourigan Group, which is a mid-size company based in Richmond, VA with offices in Hampton Roads, VA and Charlottesville, VA. Project A is an expansion to a research lab complex for a University which had 72 activities that experienced delay. Project B is a mixed-use development which had 273 activities that experienced delay, and Project C is an office building development which had 258 activities that experienced delay.

A. Compiling Database of Delays

The capstone team built a database of delayed activities among the three projects by examining Hourigan's completed project schedules. This spreadsheet database will be referred to as the "Delay Summary Spreadsheet". Hourigan recorded schedule data in the Phoenix Project Manager software on activity title, activity code, work breakdown structure (WBS) category, original activity duration, actual activity duration, and critical path status. The team elected to import this information into an Excel spreadsheet where the quantitative values "Days of Delay" and "Relative Delay Percent" columns could be added. Relative Delay Percent is here defined as the length of the delay divided by the original duration. It measures how unexpected the delay was compared to its planned duration. For instance, if an activity is planned to take only 10 days, but it ends up taking 40 days, the relative delay would be 300%.

B. Project Division and Subcontractor

The capstone team then analyzed each delay and determined what project division each activity was a part of. Project divisions include concrete, metals, HVAC, outdoor improvements, and other similar categories. Complete subcontractor task responsibility data was also included in the Project C Phoenix schedule. Projects A and B had incomplete data, so this could not be analyzed. This information was very useful in drawing conclusions about which subcontractors presented the highest risk of schedule delay, so was also imported into the Delay Summary Spreadsheet.

C. Delay Source and Delay Factor

The capstone team determined that a standardized system of classifying delays would be necessary to evaluate which types were most common between projects. To do this, the following delay factor table shown in Table 1 below was adapted from the study by Yaseen et al in 2019 [10].

TABLE I. DELAY SOURCE AND DELAY FACTOR CATEGORIZATION

Delay Source	Delay Factor
Owner	Owner financial problems
	Inadequate experience of the owner
	Issuing of change orders by the owner
	Delay in decision making procedure
Designer	Delay in the preparation of design documents
	Defects in the design and ambiguity of design drawings
Contractor	Ineffective project planning
	Financial contractor difficulties
	Rework due to defects in executed work
	Ineffective supervision and site management
	Poor communication between contractor and project parties
Project	Period of contract is very short
Material	Delay in supplying materials
	Ineffective quality of materials
	Poor storage of materials
Equipment	Poor efficiency of equipment
Labor	Inadequacy of workforce
	Lack of labor
External Factors	Unpredicted surface conditions
Subcontractor	Rework due to defects in work executed by subcontractor
	Inadequacy of subcontractor
Compounding Delay	Delays in prerequisite activities
Unknown Source	Unknown delay factor

Table adapted from Ref. [10].

D. Project Team Interviews

The capstone group met with all three project groups over the span of several weeks to interview them about the stories behind each of the delays. Each interview lasted one hour, directed by a preliminary question list as well as a list of more specific questions relating to their project. The interviews were recorded for documentation purposes, and specific information from them was later used to draw conclusions about the delay sources and factors for each of the delays.

E. Data Visualization

After conducting project team interviews and adding delay sources and factors to the Spreadsheet, the team constructed tables of descriptive statistics examining days of delay and relative delay percentage by both delay source and delay factor for each project.

F. Determining Delay Correlation with Minitab

Based on the data that was received, the capstone team elected to utilize either analysis of variance (ANOVA) or Kruskal-Wallis tests to explore if the days of delay or relative delay percentage experienced any significant differences based on its delay source or delay factor. This analysis was performed on data sets from each project separately as subcontractors, time periods, and other contextual situations vary from project to project. ANOVA was performed first and the capstone team evaluated if the test satisfied certain assumptions that influence the confidence in a result. In the case that assumptions were not met, the team then performed analysis with the Kruskal-Wallis test, which has its own set of assumptions. By performing these tests, the capstone team was able to conclude if, for a specific project, the delay source and/or factor caused significant differences in days of delay or relative delay percentage. If the null hypothesis of either of these tests is rejected ($p<0.05$), the capstone team is able to conclude that the means (for ANOVA) or the medians (for Kruskal-Wallis) are different for each level of the independent variable, delay source or delay factor. These tests, however, do not determine how the levels differ, but only if they do or do not. To test the differences between levels, Tukey's test was performed, which separates the levels into different groups, allowing for individual analysis. The capstone team may then make conclusions from the data on the most significant factors affecting activity delay to help influence final recommendations. Unfortunately, more advanced statistical analysis could not be performed as items such as cost and resources were not included in the data provided to the team by Hourigan.

IV. RESULTS

Each project of Hourigan was analyzed to determine the source and factor of delay within each respective schedule. As a result of the data analysis performed, suggestions for how Hourigan should proceed in their future projects were deduced in order to avoid delays where possible. In addition to the statistical analysis, the capstone team also deferred to anecdotal evidence obtained from the project team interviews to create a more holistic approach. Table 2 shows the statistical analysis of delays for Project A.

TABLE 2. STATISTICAL ANALYSIS OF DELAY FACTOR FOR PROJECT A

Project A				
Delay Source	***Delay Factor***	***Affected Activities***	***Avg. Days of Delay***	***Relative Delay %***
Owner	Delay in Decision making procedure	8	22.63	**429%**
Designer	Overall	**19**	**38.26**	404%
Designer	Delay and prep of design documents	16	35.86	426%
Labor	Lack of Labor	11	12.73	104%
Subcontractor	Inadequacy of subcontractor	18	17.78	139%

As shown in Table 2, the designer had the highest number of affected activities due to delay as well as the highest average days of delay. Additionally, the delay in the decision-making process for the owners had the highest relative delay percentage. Therefore, the owner and the designer should be held most responsible for the delays which occurred in Project A. To support these findings, further analysis with ANOVA and Kruskal-Wallis was performed.

Initial ANOVA tests for Project A had to be reconsidered, as the residuals of the data were not of a Gaussian distribution. A subsequent Kruskal-Wallis test was performed, and it was concluded that at least one median of days of delay was statistically significantly different from the others, by delay source. However, these results cannot be made with confidence since they violate the assumptions of the Kruskal-Wallis test. To combat these issues, a Box-Cox transformation was performed, and it was determined that a logarithmic transformation would be ideal for the days of delay data. After performing the transformation, another ANOVA determined that there was a statistically significant difference between delay sources ($F(7,64)=3.97$, $p=0.001$). A Tukey test for Project A, depicted in Figure 1, shows how these sources differ, for means that do not share a letter are significantly different.

Delay Source	N	Mean	Grouping	
4 Project	1	1.763	A	B
2 Designer	19	1.3978	A	
1 Owner	9	1.307	A	
9 Subcontractor	18	1.1080	A	B
7 Labor	11	1.0127	A	B
11 Unknown	1	0.9031	A	B
3 Contractor	11	0.754		B
5 Material	2	0.6901	A	B

Fig. 1. Project A Grouping Information Using the Tukey Method and 95% Confidence. Means that do not share a letter are significantly different.

These results weakly support the above claims that the designer and owner had the most significant impact. The Tukey test shows that for days of delay, the designer and owner had a significant difference from the contractor, but the same cannot be said for the other sources. Therefore, the designer and owner had statistically similar effects on the delay of the schedule, solidifying their negative contributions to the overall project duration. Similar analysis was performed for relative delay percentage, however the capstone team failed to reject the null hypotheses ($p>0.05$) for both ANOVA and Kruskal-Wallis tests, even after Box-Cox transformation of the data.

Project B was analyzed in a similar fashion to Project A. The completed project schedule was analyzed to determine the delay sources and delay factors for the job. Table 3 below shows a breakdown of the most impactful delays.

TABLE 3. STATISTICAL ANALYSIS OF DELAY FACTOR FOR PROJECT B

Project B				
Delay Source	***Delay Factor***	***Affected Activities***	***Avg. Days of Delay***	***Relative Delay %***
Owner	Inadequate owner experience	35	10.57	168%
Designer	Overall	**88**	13.82	343%
Designer	Delay and prep of design documents	17	11.59	**712%**
Designer	Defects in drawings	71	14.35	255%
Subcontractor	Inadequacy of subcontractor	45	**22.76**	409%

From this, the capstone team could see the three main sources of delay are the owner, designer, and subcontractor. The designer had the highest number of affected activities due to delay, the subcontractor had the highest average days of delay, and the designer's responsibility for the delay in preparation of design documents had the highest relative delay percentage. Therefore, these two actors should be held responsible for the delays which occurred in Project B. Again, ANOVA and Kruskal-Wallis tests were performed to further analyze these results.

Project B experienced the same issues as Project A. Thus, the team conducted a Box-Cox transformation on both the days of delay and relative delay percentage data. From ANOVA with days of delay and delay source, there was an interesting contradiction to the preliminary findings. The ANOVA found that there was a statistically significant difference between groups ($F(6,266)=7.36$, $p<0.001$) and a subsequent Tukey test was performed. For days of delay, the source "Material" was significantly different from all other sources except for the contractor, which only had one instance of delay. While material was only responsible for four delayed activities, it was involved in delays of 193 and 238 days, caused by electrical issues and elevator procurement. During this project, the construction team was using temporary power in the form of generators. As stated by a superintendent, "elevator guys can only go so far before they need permanent power," alluding to how one delayed activity can affect others throughout the project. Another ANOVA was performed for relative delay percentage and delay factor. Using the logarithmic transformation of relative delay percentage, the capstone team found results that mirrored their preliminary findings. The test showed that there was a statistically significant difference in relative delay percentage for delay factor ($F(7,265)=6.67$, $p<0.001$) and the Tukey test, depicted in Figure 2, shows that the factors "Delay in the preparation of design documents" and "Inadequacy of subcontractor" are significantly different from "Inadequate experience of the owner".

Delay Factor	N	Mean	Grouping		
3.1 Ineffective project planning	1	1.380	A	B	C
2.2 Delay in the preparation of design documents	17	0.529	A		
9.2 Inadequacy of subcontractor	45	0.3995	A		
2.3 Defects in the design and ambiguity of design drawings	71	0.1174	A	B	C
1.4 Inadequate experience of the owner	35	0.0128			C
8.3 Unpredicted surface conditions	11	-0.015	A	B	C
11.1 Unknown Delay Factor	89	-0.1308		B	C
5.2 Delay in supplying materials	4	-0.379	A	B	C

Means that do not share a letter are significantly different.

Fig. 2. Project B Grouping Information Using the Tukey Method and 95% Confidence

Because of this difference, the capstone team may conclude that the designer and subcontractor factors were more influential than the owner in terms of relative delay percentage. However, this does not discredit the impact of the owner-caused delay, and the recommendations seek to remedy its impact on future projects regardless.

Lastly, Project C's completed schedule was also analyzed to determine factors for delay. Table 4 below shows the breakdown of delay for Project C as categorized by delay source and delay factor.

TABLE 4. STATISTICAL ANALYSIS OF DELAY FACTOR FOR PROJECT C

Project C				
Delay Source	***Delay Factor***	***Affected Activities***	***Avg. Days of Delay***	***Relative Delay %***
Owner	Issuing of change orders by the owner	26	14.04	179%
Designer	Delay and prep of design documents	7	33.4	137%
Material	Delay in supplying materials	3	**36.3**	526%
Labor	Lack of labor	20	8.75	176%
External Factors	Unpredicted surface conditions	8	15.63	**623%**
Subcontractor	Inadequacy of subcontractor	**44**	12.27	167%

In this project, the subcontractor had the highest number of affected activities due to delay, delay in supplying materials had the highest average days of delay, and unpredicted surface conditions had the highest relative delay percentage. Therefore, the main factors for delay in Project C are the subcontractor, materials, and external factors. However, it is important to note that the owner and designer also had significant contributions to the delays within this project. Although the three projects have variations within their specific delay sources and delay factors, there are three sources which remain consistent: owner, designer, and subcontractor. Like the other two projects, similar analysis was performed for Project C.

A Box-Cox transformation was once again performed on the data, as assumptions were not met for initial ANOVA tests or subsequent Kruskal-Wallis tests. Similar to Project A, relative delay percentage may not be analyzed, for the null hypothesis of the ANOVA test could not be rejected ($p>0.05$) for the transformed relative delay percentage with respect to delay source. The ANOVA test on the transformed days of delay found that there was a statistically significant difference with respect to delay source ($F(9,248)=4.35$, $p<0.001$). The Tukey test, depicted in Figure 3, somewhat contradicts the preliminary findings.

Delay Source	N	Mean	Grouping		
2 Designer	10	1.203	A		
8 External Factors	8	1.015	A	B	
1 Owner	27	0.9179	A	B	
5 Material	12	0.817	A	B	C
9 Subcontractor	47	0.7826	A	B	
11 Unknown	47	0.7368	A	B	C
3 Contractor	30	0.6308		B	C
7 Labor	34	0.6207		B	C
6 Equipment	8	0.470		B	C
10 Compounding Delay	35	0.4053			C

Means that do not share a letter are significantly different.

Fig. 3. Project C Grouping Information Using the Tukey Method and 95% Confidence

The delay source "Designer" is significantly different from other sources, but not from the ones with higher means. As stated previously, sources such as external factors, the owner, material, and the subcontractor presented as the most influential sources on this project, which is supported by their presence in grouping A from the Tukey test. It is also important to note the influence that poor scheduling may have on these results. Such an example pertains to the "External Factors" source, as a "sanitary conflict" activity was slated to take only one day but was then not completed for 45 days. This 44-day delay impacted both its high placement in average days of delay and average relative delay percentage. From this, the capstone group may make recommendations pertaining to adequate scheduling of activities.

In terms of compensable and non-compensable delays, the percentage of non-compensable days of delay for Projects A, B, and C were found to be 40%, 61%, and 74% of total days of delay, respectively. Delays were categorized as compensable if their delay source was the owner or the designer and categorized as non-compensable otherwise. Across the three projects, this amounts to 5,022 days of non-compensable delays out of 8,223 total days of delay. Subcontractors were the delay source with the greatest number of days of non-compensable delays, causing an average of 40% of all non-compensable days of delay across the three projects. Though Hourigan is not directly causing these delays, they assume risk when hiring subcontractors and therefore bear responsibility and costs for subcontractor-caused delays.

To address the three repeating sources of delays (owner, designer, and subcontractor) throughout all projects, recommendations have been created for Hourigan to follow in the future to avoid similar delay types from occurring. Anecdotal recommendations from interviews with Hourigan employees have also been taken into consideration when creating these suggestions. In terms of the owner, the biggest issue seemed to be the delay in decision making procedures, and consequently the change orders. Although this is something that may not be fully controllable on the contractor's side, it is important to keep this in mind during scheduling. A possible solution could be to build in days into the planned schedule to account for changes in the owner's court, such as allotted time for "days of review from owner". In doing so, the critical path would not be broken if there was already allowable time set in place for them.

Next, for the delay source of the designer, their biggest factor of delay was a delay in preparation of the design documents. As discovered through project interviews, this was mainly due to a lack of designers assigned to the job and therefore an overload for those scarce employees. In order to mitigate this issue, the size of the project needs to be accounted for when hiring the design firm in order to ensure there is enough manpower being dedicated to the job. Additionally, with delay factors like defects in drawings, it is critical that the contractor go through the design documents as early as possible in the project life cycle in order to bring up any questions/issues with the drawings, such as through Requests for Information (RFIs), before the actual activity is performed in order to avoid any delays in the schedule.

Lastly, the main issues with the subcontractors' sources of delays were inadequacy of the work performed. In order to avoid this issue in the future, an internal rating system within Hourigan would be useful to keep a log of subcontractors' performance. This log should include not only anecdotal work experience, but also data driven explanations such as how many days of delays they caused or how many days they ran over schedule. Additionally, a more proactive approach would be to require a work portfolio and references upon contracting the subcontractors to ensure their reliability and work quality.

V. Discussion

When analyzing the reasoning behind delays within the construction industry, it is imperative to examine the external factors that could be affecting the schedule. From interviews with Hourigan's project executives, one topic which was brought to the attention of the capstone team was the issue with labor shortage. After further research, skilled labor shortage is a major problem not only within the Virginia region, but across the United States as well. In fact, 80% of contractors in the US claim it is difficult to hire qualified general construction workers [11]. As seen in Table 3 and Table 4, there were delays in the schedules of projects B and C due to a lack of labor, solidifying this as a real concern. The labor shortage is an important external factor to note when determining the culprit for a construction delay.

Another external factor that is important to assess when analyzing the construction delays is the extent of their current technology, and how effective it is. While construction is known for lacking technological innovation, there has been significant focus on this aspect of the industry within the previous years. In the near future, it is expected that wearable devices will significantly increase the efficiency and safety of construction projects, and it is expected to be worth $53 billion by 2023 [12]. Hourigan executives have noted the positive impact they believe these technologies would have within their company as well. One of the main conversation topics during Project A's interview was an issue with material relocation and the inefficiencies caused by poor location planning. The superintendent stated how devices such as drones, which could map out the landscape of a job site, could be extremely useful in avoiding a mismanagement of materials by allowing for better planning of placement and therefore avoiding delays in the future. As the construction industry begins to change rapidly over these next few years, it will be crucial to recognize the usage of technology when comparing delays pre-technology boom and post-technology boom.

With the data collected from Hourigan's projects, the capstone team would have ideally employed a predictive trend analysis to make assumptions about future projects. However, there was not enough usable data available to deliver strong conclusions. As a result, aside from the recommendations discovered via the analytical results of the delay data, there are a few general suggestions the capstone team has formulated after working with Hourigan. Recommendations to Hourigan were provided in a separate report, including a uniformed communication protocol between owner and contractor, more proactive and early review of design documents to remedy conflicts, establishing an internal rating system of each subcontractor to monitor their performance across projects, and continuing to update the schedule through the end of the project. Collecting more data throughout the project about the cost of each delay and why it occurred will also help to complete retroactive delay analysis on each project, enabling Hourigan to consistently improve their schedule performance in future projects.

VI. Conclusions

This project addressed a specific need within the company Hourigan for better retroactive delay analysis and new best practices in order to reduce the probability of delay in future projects. A database of delays was created and classification by delay factor was completed to better understand why Projects A, B, and C experienced outstanding delays. Minitab was used to complete statistical analysis (ANOVA, Kruskal-Wallis, Tukey's test, and Box-Cox) on the raw data and several delay factors stood out across all three projects as causing statistically significant different levels of delays, namely delays caused by the owner, designer, and subcontractor. A separate report containing recommendations to Hourigan was completed, as summarized in the discussion of analytic findings. In the future, further work could be completed to analyze the impact of implementing these best practices into Hourigan's future projects.

Acknowledgment

The capstone team thanks Hourigan for the opportunity to work with them throughout the year. More specifically, the team thanks Todd Bagwell for his direction and leadership throughout the project, as well as Jake Althizer, Mason Bowman, Chris Fowler, Paul Hahn, and Ryan Nebel. Without their assistance, this project would not have been possible.

References

[1] Arcuri, F. J., & Hildreth, J. C. (2007). (rep.). The Principles of Schedule Impact Analysis. Blacksburg, VA: Virginia Tech.

[2] Braimah, N., & Ndekugri, I. (2009). Consultants' perceptions on construction delay analysis methodologies. *Journal of Construction Engineering and Management*. https://doi.org/10.1061/ASCECO.1943-7862.0000096

[3] Goss, T. (2011, February 21). Best Methods for Dealing with Project Delays. BrightHub Project Management. https://www.brighthubpm.com/monitoring-projects/107392-ten-ways-to-better-manage-project-delays/.

[4] Mid-Atlantic general Contractor, construction management. (2021, March 08). https://www.hourigan.group/

[5] Baldwin, A., & Bordoli, D. (2014). A Handbook for Construction Planning and Scheduling. Chichester: Wiley Blackwell.

[6] Keane, P. John, et al. Delay Analysis in Construction Contracts, John Wiley & Sons, Incorporated, 2015. ProQuest Ebook Central, http://ebookcentral.proquest.com/lib/uva/detail.action?docID=1895515.

[7] Gajare, Y., Attarde, P., & Parbat, D. (2015). Assessment Of Significant Causes And Effects Of Delays On The Projects Completion Period. International Journal of Modern Trends in Engineering and Research, 2, 88–93.

[8] Abbaszadegan, A., & Grau, D. (2015). Assessing the Influence of Automated Data Analytics on Cost and Schedule Performance. Procedia Engineering, 123, 3–6. https://doi.org/10.1016/j.proeng.2015.10.047

[9] Gondia, A., Siam, A., El-Dakhakhni, W., & Nassar, A. H. (2020). Machine Learning Algorithms for Construction Projects Delay Risk Prediction. Journal of Construction Engineering and Management, 146(1), 04019085.

[10] Yaseen, Z. M., Ali, Z. H., Salih, S. Q., & Al-Ansari, N. (2020). Prediction of Risk Delay in Construction Projects Using a Hybrid Artificial Intelligence Model. Sustainability, 12(4), 1514. https://doi.org/10.3390/su12041514

[11] Brown, A. (2019, August 29). Construction skills shortage in US 'threat to industry'. KHL Group. Retrieved from www.khl.com

[12] Folk, E. (2020, August 23). Wearable technology will grow in the construction industry. Construction. Retrieved from www.constructionglobal.com