Using Machine Learning CART Decision Trees for Predicting the Causes of Delays in Projects from the Construction Industry

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Abstract: Construction projects are complex endeavours, with potential obstacles that can cause delays which can have particularly profound implications potentially impacting on company's financial health, business continuity and reputation. It is becoming increasingly recognised that delays are context-specific and multifaceted, requiring more industry-oriented perceptions. This work proposes the exploratory use of Machine Learning based on Classification and Regression Trees (CART) Decision Trees (DT) to assess the predictive analysis of these approaches, considering surveys (primary data) collected from 100 specialists with different backgrounds and experiences in the construction industry. Survey responses are discussed, followed by the CART DTs, which are used as predictor for clarifying underneath relationship among different variables in a project environment. The major issue presented is related to Project Design, with "The firm is not allowed to apply for an extension of contract period", with two possible predictors, firstly, as the main factor it is found "Mistakes, inconsistencies, and ambiguities in specification and drawing", while other aspect highlights "Poor site supervision and management by the contractor". The results indicate that the correct use of Artificial Intelligence techniques with relevant data are potential tools to support the analysis of scenarios and avoidance of project delays in Project Management.

Keywords: Project Management, Project Delay Management, Decision Trees (DT), Machine Learning (ML).

1. Introduction

Construction projects are often complex endeavours, fraught with countless potential obstacles and challenges that can cause delays (Abdul-Rahman, 2008). The impact of these delays can be far-reaching, including cost overruns, missed deadlines, legal disputes, and reputational damage for the entities involved (Olalusi & Otunola, 2012). As per the construction with the expansion of the application of new technologies, the continuous emergence of new methods, and the rapid changes in the market. The parties in the construction industry urgently need to reshape the knowledge structure and professional connotation to deliver project results in a more agile, innovative and efficient way. (Project Management Institute, 2021)

Although various studies have investigated construction delays, they have typically adopted a generalised approach. Often, they have used broad-brush techniques that look at causes on a national or global scale rather than focusing on specific regions or contexts (Haseeb et al., 2011). However, it is becoming increasingly recognised that construction delays are context-specific and multifaceted, requiring more nuanced, localised understandings (El-Razek et al., 2008).

One of the critical areas for improvement of current studies is the need for a comprehensive framework for identifying, analysing, and assessing the impacts of causes of construction delays (Kazaz, Manisali & Ulubeyli, 2008) and this is intrinsically related with the project management methodology adopted in the project (Marques et al., 2023). Many existing studies have focused on the identification or impact analysis of causes, but only some within the same framework (Marzouk & El-Rasas, 2014). This research gap prevents a comprehensive understanding of the interconnections between causes and their impacts, which is crucial for developing effective mitigation strategies.

The use of Artificial Intelligence (AI) based on Machine Learning (ML) techniques are becoming popular as predictive tools for managerial decisions and are already used in many different areas, from stock investment decision (Lin & Lobo Marques, 2023), consumer ad preferences (Marques et al, 2024) and project management planning (Elmousalami, 2020).

Considering a primary data source collected from 100 specialists with different backgrounds and experiences in the construction industry, the main objective of this work is twofold. Firstly, the use Machine Learning based on Classification and Regression Trees (CART) Decision Trees (DT) to assess the predictive analysis of design-related delays in construction. Second, to propose a potential solution with risk mitigation analysis for the design-related delay.

In the remaining of this work Section 2 provides a literature review on the area, followed by the proposed methodology in Section 3. In Section 4, the results are presented in discussed. Finally, the Conclusion is presented in Section 5.

2. Literature Review

Construction projects face significant challenges related to delays, which can have substantial implications for project success, cost, and overall economic development. Understanding the causes of delays is crucial for developing effective strategies to mitigate their impact.

Projects with effective planning should stay on schedule without adjustments and complete their tasks with minimal delay, and contractors prefer to work on projects where the plans have been done properly, and there will be no more revisions or interruptions. In a perfect world, construction projects would be completed without any delays, adjustments, or disturbances, and most contractors would prefer to run projects to completion without alterations, despite the widespread misbelief that they "make their money" during the changes of a project (Molner, 2007).

While this would be the case, in theory, only some major construction projects start with all drawings fully completed and authorised. The project's significant stakeholders should agree on who will be responsible for making and implementing changes, while the owner and the contractor will benefit from this, creating a perception of a win-win situation. The constant pursuit of excellence necessitates adopting modifications, even though they may cause some disruption to the works in progress. Nevertheless, the end outcome after incorporating the adjustments is likely to be better than the first, and obtaining a better final product makes the modifications more acceptable than no modifications.

Changes introduced late in the project's development are more likely to add unnecessary complexity, alter the timeline, and lengthen the time it takes to finish the project. Ultimately, unsuccessful works, modifications, and changes add to the project's overall cost, resulting in Owners' dissatisfaction, since "changed work" adds more effort, raises prices, and causes delays. (Molner, 2007).

2.1 Types of Project Delays

As a preliminary analysis, in this work, project delays include critical and non-critical delays, non-excusable/excusable delays, and compensable and non-compensable delays.

Determining whether a delay is essential or non-critical is a prerequisite to understanding its effect on the project. In addition, there is no such thing as an acceptable amount of uncertainty. There are two types of delays, excusable or not, depending on whether they co-occur. There are two types of holds: those that are compensated for and those that are not.

2.1.1 Critical & Non-Critical Delays

Program delays can be evaluated relative to the importance of individual tasks. The crucial path is included in the contract-compliant baseline master program. The most symbolic link in a network is called the "critical path." Project delays arise when a crucial path operation is delayed, causing ripple effects. These tasks, known as critical operations, are essential and must go without interruptions along the critical path.

The whole project suffers when critical path tasks go behind schedule. Therefore, examining the essential functions and determining if they can be rescheduled for efficient project management is necessary. Rearranging the order of building tasks is vital to efficient project management. When resequencing tasks, planners must identify each activity's influence on those after it, while activities' statuses must also be established (Koo et al., 2007).

Planners must know the reasoning behind and the order in which activities occur to identify their purpose and priority. Using precedence logic and relationships, the critical path method (CPM) determines the order of tasks and ranks their importance in terms of deadlines. Therefore, monitoring the sense and order of individual activities in complicated and massive projects is impossible to conduct manually.

The critical path is used to determine how long the project will take. Activities off the critical path may experience delays, and these non-essential tasks become crucial as the project progresses if they become a component of the project's new trajectory. The utilisation of tasks' floats is a contentious topic in construction projects. Still, current scheduling methods indicate that allotted float time belongs to the project and can be used by both owners and contractors to cushion the blow of delays. Consequently, the "first-come, first-served" principle applies to float usage (de la Garza et al., 2007).

Any party responsible for a delay in the later stages of the project will be held liable for the entire delay since the protocol and concept of first come, first served basis exploitation of float make it clear that the float is to be used in this order. As a result, disagreements arise whenever a project is delayed over who is responsible for the float and how it should be used.

The critical path technique of developing project schedules calls for introducing the idea of pre-allocating float and its management. In addition, the liability for any resulting delay in the project and the principles of pre-allocation and supervision of "total float" must be agreed upon in a written contract. The total float is an asset for both sides, but all involved must acknowledge this for the concept to work.

The critical route scheduling method has become a standard practice for project management. This approach to scheduling is also extensively used for requesting additional time and assessing delays using impact software. After making changes to the critical route method schedules, it may be necessary to provide evidence of which tasks are essential versus those that can wait.

The owners sometimes use the available float for less critical tasks to make the most of the situation. "Owners will occasionally take advantage of the float time of low-priority jobs to further their agendas. They could incur additional expenses as a result. In the case of a cost-plus contract, the owner is often responsible for covering these overages. In the case of a fixed-price contract, any overages must be paid for by the contractor. Such expenses may be reasonable claims for delay or impact in the latter scenario. (Householder, 1990).

Contractors may submit higher bids when the tender documents explicitly state that the owner will be responsible for float.

Delay claims and their analysis depend heavily on how responsibility for project delays is divided between the owner and the contractor. The critical route approach highlights the crucial and non-critical tasks in the project schedule. It shows how much time can be added to each activity's float or how much of a delay in one action will not influence the project's completion date. Assigning responsibility for the float and agreeing on its use can settle the disputed ownership problem.

2.1.2 Non-Excusable & Excusable Delays

Project delays directly attributable to contractors are unacceptable. The contractor assumes entire liability and risk for the delay, and the owner is entitled to demand damages under the contract's terms and conditions if the project is delayed. When a contractor is late, the owner often files a claim for monetary compensation in fines or punitive damages. Delays in starting work at the site, improper coordination that slows down the job, an inability to finalise, order, and purchase in time, and a lack of workers are common reasons owners cite why contractors are running behind schedule.

Delays are common in any project, from constructing a single structure to building a nuclear power station. It is essential to identify and categorise the critical contributors to non-excusable delays (Majid & McCaffer, 1998). The client's delays are compensable delays over which he has more control and thus more opportunity to take prompt corrective action. The contractor's delays are not reimbursable and cannot be excused, so it is in the contractor's best interest to take all necessary precautions to avoid them.

While there have been many investigations into the causes of these delays, comprehensive research has yet to determine the root causes of delays that cannot be justified. To better identify and solve the issues that contractors confront on building sites, it is essential to understand the underlying reasons for non-excusable delays (Majid & McCaffer, 1998).

Recent developments and disappointing project outcomes in the contracting construction sector provide an opportunity to reflect on the nature and scope of the industry's perennial issues. The contractor has visited the site and is familiar with the conditions there; therefore, these unknowns are included in the contract. Following the terms and circumstances of the agreement, the risk associated with any buried power or water lines that are not visible from the surface transfer to the contractor and the project manager is solely and entirely responsible for any delay caused. "Clauses that waive the contractor's obligations and rights to lien the job from the start. Economic factors have mostly prompted these shifts, increasing the contractor's risk exposure." (Shumway, 2004)

Various distinguishing features of contaminated site restoration projects set them apart from more typical building projects, such as authoritative regulatory procedure control and a need for more information about underground utilities and soil conditions. The recommended solutions may need to address the requirements identified adequately. Features that are out of the ordinary for remediation projects suggest that contractors' novel approaches may prove more valuable and practical.

According to (Ruff et al., 1996), an analysis of sixty finished remediation projects was conducted to determine and record the effect of various project planning modules and contracting tactics on project outcomes. The research showed that restoration projects frequently experience scope changes, delays caused by numerous stakeholders, cost overruns, disagreements, and modification orders. Turnkey and partnering arrangements and cost-plus-fee contractual schemes were more adaptable to project scope changes than rigid approaches to project administration. Overall, the best results were shown with the turnkey and architecture construction organisations out of all the reported managerial practices. Project success, as measured by criteria such as budget and time, was greatly aided by mechanisms encouraging partnership and teamwork.

In addition, (Schumacher, 1995) states that the contractor is responsible for the claims made by the owner or subcontractors due to the contractor's controllable delays. Delays induced by the contractor, such as those resulting from late deployment, late material deliveries, or an insufficient project workforce, are not covered by the contract and are therefore not compensated. Architects risk delay claims from subcontractors and owners punitive damages (or payment of damages if there is no civil penalty provision) for not excused delays.

2.1.3 Compensable & Non-Compensable Delays

In the analysis of Compensable and Non-Compensable Delays, the perspective of delay's time and money effects are on the owner's side. The owner may be liable for the contractor's claims of interference, late delivery of owner-purchased equipment or supplies, and other delays induced by the owner's acts or omissions. Despite being able to restrict its culpability, a property owner cannot contract out of its need to pay for compensable delay. Any provision in a building contract that claims to waive, release, or extinguish a contractor's, subcontractor's, or supplier's entitlement to damages or an appropriate settlement arising out of excessive delay in performance where such delay is induced by the acts or negligence of the contractor or individuals acting for the contractor is contrary to public policy and therefore unlawful.

The client's request for a change order is the most typical cause of project delays, and the issue of the modification order impacts the completed work. The change approval stipulates that new work be performed, current work be modified, and the results be removed and reinstalled. A critical path analysis must be completed to prove the delay in receiving compensation for lost time and money. Another aspect to be aware of is the variation in time loss due to efficiency loss. Due to its qualitative nature and the difficulty of attributing the production loss to a specific cause, inefficiency can only be measured indirectly. The data was gleaned from contractor data, and there are disparities between the contractor's claims and the entitlement per the owner. Client sources such as regular updates, drawings, requirements, and change orders inform a statistical model that attempts to estimate productivity loss. Loss of productivity due to the modifications is also quantified, and a model is constructed to support this estimate.

From the work of (Serag, 2008), relevant aspects were examined, such as "(1) characteristics that predict which party—the owner or the construction company to the productivity loss and (2) variables that predict, from a legal standpoint, productivity deficits for which only the proprietor is accountable. It revealed a discrepancy between the contractor's requested compensation and the amount they are legally entitled to. This concept provides an objective means for the owner and contractor to settle their differences by calculating the cost of lost productivity caused by modification orders".

From a legal perspective, nominations are determined at the beginning of the project and involve both the client and the consultant. Since the final scope of work has yet to be determined, the customers must confirm their selections of contractors, each of whom will get a provisional sum from the contract.

Customer and consultant work on completing the scope of works, bidders, selections, and certifications around the time the candidacy is due, which might cause a delay in the process.

Regarding the procurement management area, the standard method of construction procurement has no unique elements and is ideal for projects with a clear scope of work. In such procedures, one step must be finished before the next one can begin, creating a logical and sequential flow of labour. After a project has started, any changes made during development only add extra work and cost.

The customer can integrate the contractor's design at any point. There is room for scope definition on multiple levels thanks to the design-and-build methodology. The project would profit from such a setup since design and construction would be integrated immediately (Chritamara et al., 2001). To cut down on wasted time and money, clients often choose the design and build procurement method for projects. Usually, scope specification by the customer, adjustments adopted, how those changes are reflected in the sophistication of the project, and successful coordination with key stakeholders are relevant elements that affect time and cost efficiency. While it is known that the variables above will impact the project's early-stage budget and schedule, the total amount of that impact has yet to be determined. Simply put, the most efficient way to save money is to use the time-tested process of design and building known as "design and build" (D/B), while the most efficient way to save time is to use the expedited method of D/B construction utilising a design and set of parameters that have already been finalised.

According to (Chritamara et al., 2001), fast-track construction with a defined design, procurement, and construction schedule is the most efficient at reducing construction time, while D/B using the conventional approach is the most cost-effective. Due to design delays, nominations have been pushed out, although having specialist contractors provide advice for specific activities early on in the design process would have been beneficial.

Specialist contractors have the expertise and knowledge to contribute to the early design and engineering stages. Nevertheless, their participation in the early stages of the design process has expanded, suggesting a shift in the status quo. Involving vendors in the creation and production of products is a profitable strategy. There were increases in process efficiency and enhancements in product quality, according to reports from studies that emphasised the achievements of the early design phase by speciality contractors. Companies are stepping up the communication between their design teams and their subcontractors.

In addition, specialised subcontractors might be implemented to lessen the impact on the project's schedule. With their extensive knowledge, specialised contractors can anticipate potential issues and plan accordingly. The duration and importance of activities must be evaluated for project risk management. However, there is a significant dependency between task durations, which might significantly affect the results (Yang, 2007). When actual data is lacking, and planners must rely on educated guesswork, they need the leeway to provide varying durations for the activities.

Clients in the construction industry need to learn the hard way that basing their choice of contractor on the lowest bid may result in costly delays and subpar work. Consequently, value for money is maximised when the best contractor is chosen, and the practice of assessing contractors using a variety of metrics is gaining traction. (Singh & Tiong, 2005). Due to the unpredictability of building projects and the owners' discretion, contractor selection in multi-criterion environments is highly subject to these factors. In their work, (Singh & Tiong, 2005) proposes a systematic process grounded in fuzzy set theory for determining whether or not a contractor's capabilities are compatible with those of the building's owner. Each criterion's global value or relative importance in reaching the ultimate decision-making goal is calculated using the Shapley value. This investigation is a component of a larger project to create a fuzzy decision model for choosing a construction firm that considers the client's preferences and several other criteria.

Finally, (Zhao et al., 2007) proposed a three-dimensional model to assess the various elements contributing to the delay in projects, with the findings implying that delays happen at a crucial point in the construction process, considering the contractor and the client primarily to blame but also suffering the most damage. The model creates a ranking with actionable indicators that can be adapted to reduce the effects of or even avoid the most common causes of delays.

3. Methodology

3.1 Instrument and Sample Characterization

For the current work, a quantitative methodology is considered. The study performed a survey data collection shared online for professionals related to project management selected using convenience non-probabilistic sampling, with a population of 100 construction projects' stakeholders. The information gathered provided support to identify root causes of construction project delays in the southern region of China, Province of Guangdong, the region known as the China Greater Bay Area. In addition to the issues under investigation, the study collected data on participants' demographics and company characteristics to perform group analysis and inferential analysis.

The questionnaire was divided into three primary sections:

Section 1: Demographic Information and Organizational Background

Section 2: Evaluation of Delay Causes - Impact

Section 3: Evaluation of Delay Causes – Frequency of Occurrence

The first part aims to gather information about the respondents and their companies. This section included questions on the company's size, the types of projects typically undertaken, and the respondent's role. Sections 2 and 3 contained a series potential causes of delay in construction projects, considering 8 dimensions, with "Design-related" identified dimension 5.

In Section 2, respondents were asked to rate on a 5-point Likert scale, ranging from 1 (Strongly Disagree) to 5 (Strongly Agree), in terms of how significant is the impact of that cause in project delays. On the other hand, in Section 3, respondents were asked to rate on a 4-point Likert scale, ranging from 1 (Rarely) to 4 (Very likely), in terms of the likelihood of occurrence of the delay, based on previous experience of the professionals with different roles and backgrounds.

3.2 Data Analysis – CART Decision Trees

In the overall research, an exploratory data analysis is performed considering multiple data analytics approaches for predictive analysis. In this specific work, Decision Trees are the considered approach for the proposed intelligent support system. Decision Trees can be defined as Machine Learning or Data Mining technique based on hierarchical clustering. The main objective is to determine a hierarchy of clusters by iteratively dividing or merging them based on distance measures.

The results are typically displayed as a dendrogram, or "tree-like diagram," which displays the sequence and locations of merges and splits. Identifying and comprehending the groups or categories within the delay causes in a construction project can be made easier with hierarchical clustering, which can reveal underlying structures and relationships in data (Murtagh & Legendre, 2014; Johnson, 1967).

In the present work, Classification and Regression Trees (CART) Decision Trees (DT) are used, and the gini-index is considered, which indicates a degree of impurity in the data, establishing the hierarchy. The method provides unique insights into the data, helping us understand the patterns and relationships between different causes of delays in construction projects.

4. Results and Discussion

In this section, the focus is on the analysis of design-related delays, which are classified as compensable delays, impacting on the contractor's obligations. The results are presented in three parts. Firstly, the survey results are presented, with a clear descriptive representation of the sample under study. Following that, a predictive analysis of design-related delays in a project based on CART Decision Tree Machine Learning technique is presented. Finally, as part of the major output of the analysis, actionable strategies for delay management, including risk mitigation are proposed.

4.1 Survey Results on Design Changes

As presented in Figure 1, the survey results on the design-related matters are presented. First of all, it is important to highlight that the neutral choice presented the highest percentage for all the questions. Considering the other answers, 38% (24% Disagree + 4% Strongly Disagree) considered that changes in design may not necessarily generate impact in time changes.

Considering the item "firm not allowed to apply for an extension of the contract period", might also have time impact, 37% disagreed and 2% strongly disagreed that this should be a contractual clause, with only 20% agreeing that this might be possible.

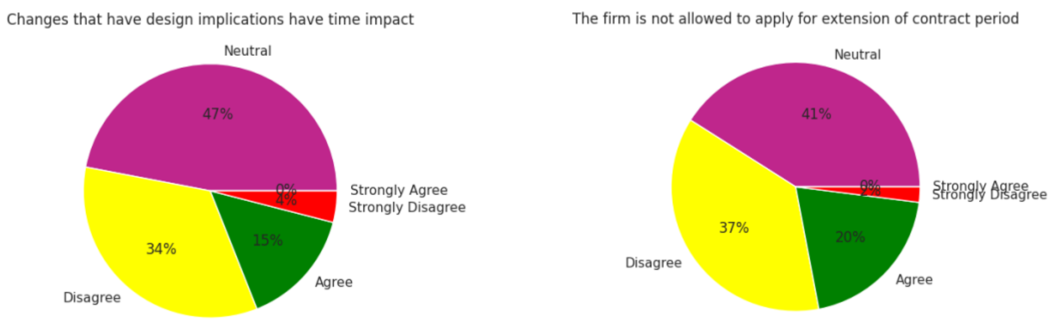

Figure 1: Survey results on design related delays.

4.2 Decision Trees for Project Design-Related Delay Management

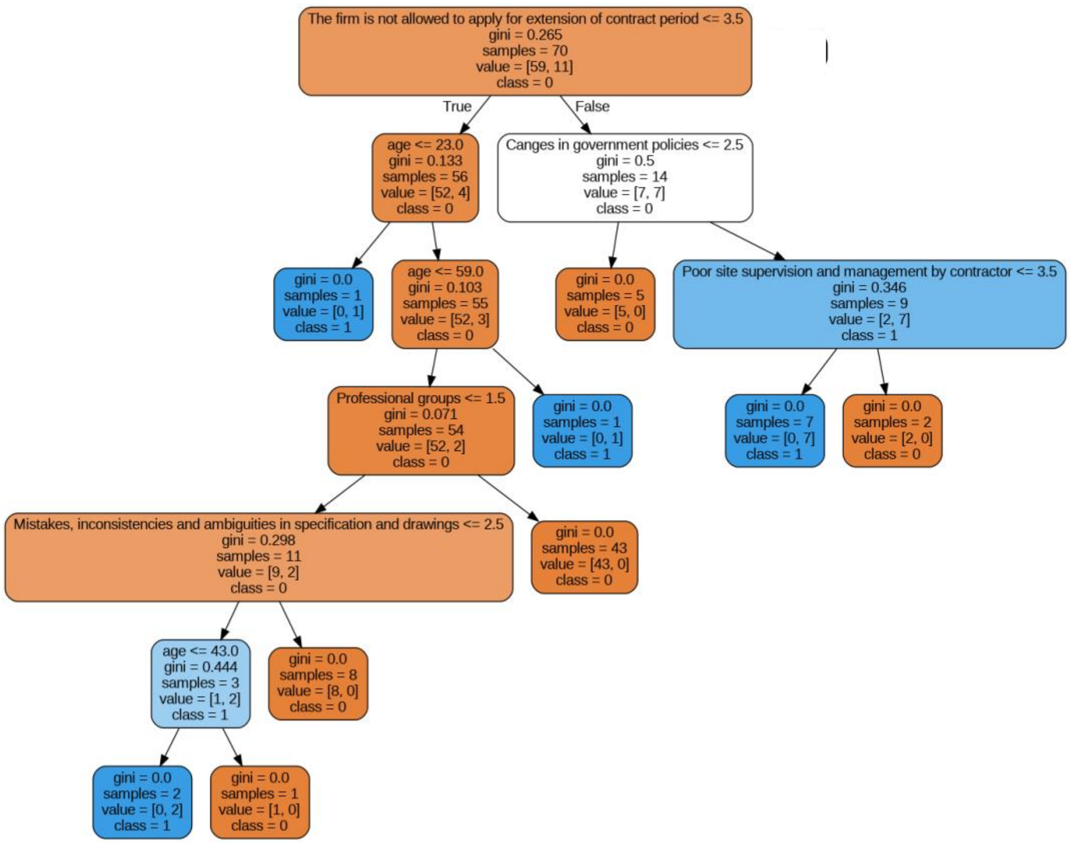

Figure 2: Decision Tree for Design-related Delays.

As presented in Figure 2, the DT allows the evaluation as a potential predictive aspect of the sequence of project decision flow, considering bottom-up analyses. In this work, a contractual constraint regarding the design issue is presented in the survey and identified as “The firm is not allowed to apply for an extension of contract period”, which, if happened, may generate a compensable design-related delay in the project.

Following the specialists’ perception in the collected database, to identify clear predictors for the problem, as presented in the DT, the vast majority of the respondent disagree with that contractual constraint (considering the likert-scale answers <= 3.5), linking the most relevant branch of the DT to “Mistakes, inconsistencies, and ambiguities in specification and drawing”, which is directly linked to scope management, more specifically with requirements definition.

4.3 Mitigation Proposition for Design-related Delays

Considering the predictive analysis proposed by the Decision Tree, in Figure 3, some design changes may cause the Main Contractor to suffer direct loss, so it will directly submit a claim to the client to recover their direct loss, classified as a compensable event. the design-related delay may have caused the parties involved to identify whether it is the employer, consultants, or the contractor's default. Furthermore, in case the delay will impact in the Project Critical Path, the parties should agree in a solution that comprises how to clearly predict the actual delay, provide the solutions and, finally, an extension of time may be granted.

The project triple-constraints are addressed with the contractor claiming on the project duration extension (time constraint) and also the subsequent prolongation costs (cost constraint), and finally in agreement of the design changes with different stakeholders (scope constraint).

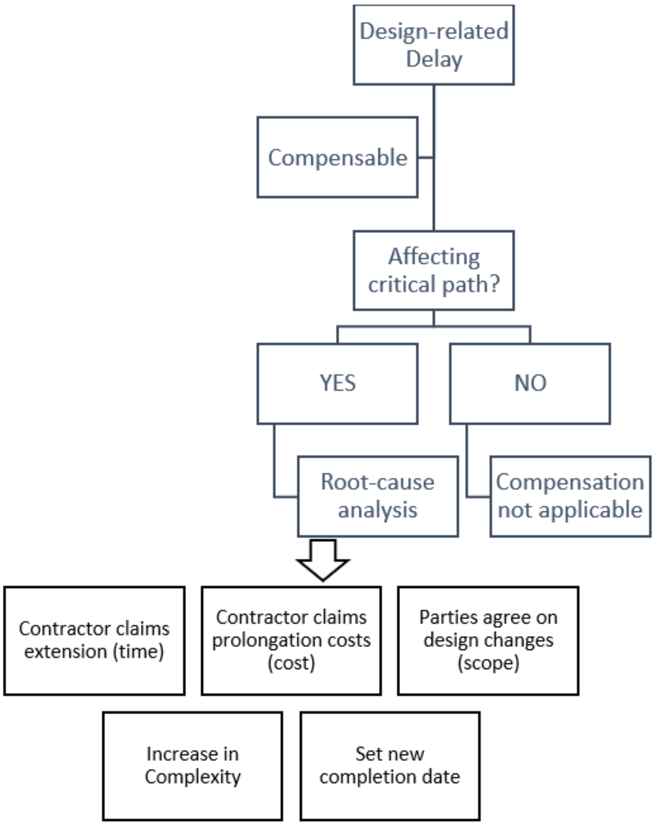

Figure 3: Design-related delay solutions framework.

In a project environment, considering the possibility of mitigation for design-related delay, it is recommended that different stakeholders, such as client, architect, and consultant freeze the design to avoid further design concept modification. In case of continuous changes, they may grant the contractor the eligibility for an Extension of Time and Prolongation cost. Or else, they could have initiated a contract clause called "Delay Recovery Measure Clause", in which they may have the contractor to come up with a delay recovery resolution, pay the contractor for his action in absorbing the delay, and complete on the original completion date, with a conditional, i.e., if the contractor succeeds, full payment should be issued; otherwise, partial or no payment would be paid to the contractor, proportional to the extent of the delay the contractor could recover.

4.4 Discussion

The type of event that typically triggers a construction delay is a design change in the building/civil construction projects. Design changes are indeed a variation towards the construction project, and the meaning of variation includes the following:

- Material- Quality, type and standard change
- Works- quantity- Admission, Omission or Replacement
- Removal of Existing Works, Demolition, Removal of Works

- Architect Instruction's matter- Site Access
- Architect Instruction's matter- Limitation of Working Space
- Architect Instruction's matter- Limitation of Working Hours
- Architect Instruction's matter- Resequencing of Works
- Architect Instruction's matter- Any other Addition/ Alteration/ Omission of obligation/ restriction imposed by the contract

Although design changes are mostly solely involved with variations, they will sometimes involve contractors incurring direct loss and expenses due to undertaking the variation works. Additional tasks, such as re-preparation of material submission, structural calculation, chiselling, and even abortive works, may or may not be related to construction claims. For instance, when the architect issued a new instruction regarding substituting a block wall for drywall, the original block wall was already installed. In this case, the contractor must arrange to hack off the concrete and remove the rebar task before undertaking the variation works. Such an example has described how the contractor has incurred direct loss and expenses.

Whenever there is a design change, it must mostly deal with the client, the architect, and the consultant. Such a delay is considered to be a compensable delay, provided that the contractor has not been time-barred from claiming for the matters mentioned above; otherwise, if the contractor fails to fulfil the notification of delay requirement, his right to claim for loss and expenses would be forfeited, however, under this situation, the contractor will be granted with the extended of time, and a new completion date would replace the original completion date (Ajayi & Chinda, 2022).

5. Conclusion

From the presented results, the use of Decision Trees could establish predictive analysis for the case of design-related delays. As a major conclusion practical contractual aspect such as "The firm is not allowed to apply for an extension of contract period", is potentially predicted by on clear problem from the project design, such as "Mistakes, inconsistencies, and ambiguities in specification and drawing", while the other aspect is focused on operational management, with "Poor site supervision and management by the contractor".

In addition, the work also proposes a general actionable set of potential solutions and mitigation strategies based on the output of the ML system, which may be used for any projects in the construction industry, proposing that the Contractor should initiate claiming for the extension and related costs, agreement between the parties with the new scope, including the changes in complexity, and finally setting a new date of conclusion and restructuring the project expectations.

Finally, it is possible to conclude that the use of Machine Learning intelligent support system for project management is a promising tool for managing project delays.

A limitation of this work is the localized sample from one geographical region, the Greater Bay Area (GBA), in China, which may lead to regional bias. Future works may consider the use of other techniques for detection of other potential predictors and also applying the same questionnaire and analysis in different regions of the world.

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