Winter 1-31-2023

An Artificial Intelligence Tool for the Selection of Delay Analysis Technique in Construction

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الجامعة الأمريكية بالقاهرة

Graduate Studies

An Artificial Intelligence Tool for the Selection of Delay Analysis Technique in Construction

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TO THE

The Department of Construction Engineering

in partial fulfillment of the requirements for the degree of
Master of Science in Construction Engineering

[Fall 2022]

Declaration of Authorship

I, Mostafa Ahmed Farouk, declare that this thesis titled, "***An Artificial Intelligence Tool for the Selection of Delay Analysis Technique in Construction***" and the work presented in it are my own. I confirm that:

- This work was done wholly or mainly while in candidature for a research degree at this University.
- Where any part of this thesis has previously been submitted for a degree or any other qualification at this University or any other institution, this has been clearly stated.
- Where I have consulted the published work of others, this is always clearly attributed.
- Where I have quoted from the work of others, the source is always given. With the exception of such quotations, this thesis is entirely my own work.
- I have acknowledged all main sources of help.
- Where the thesis is based on work done by myself jointly with others, I have made clear exactly what was done by others and what I have contributed myself.

Signed:

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Date:

25 December 2022

Abstract

The increasing complexity and magnitude of projects impose greater impact of delays on stakeholders. Construction delays are a major source of disputes in construction projects. Since a construction project depends on interactions and shared responsibilities among parties, research works were directed toward identifying delay causes, quantifying their impacts, and proposing ways to deal with them. Several delay analysis techniques (DATs) are available, but when applied to the same project's delays provide different results. Thus, the selection of the DAT to use in evaluating delays becomes vital. Reviewing the literature, it has been realized that often there are disagreements, which lead to escalating a claim into a dispute on which DAT to be used. A dispute results in additional costs, time, and, in some cases, negatively impacts the relation between the parties. Some research was conducted to gather experts' opinions on the best technique to be used; however, little research was done to quantify the reasons behind the selection and transform it into a numerical model. This research is an attempt to support different parties in selecting the most appropriate DAT for a claim by building an artificial neural network (ANN) model that utilizes data collected through experts' judgements on various factors that influence the selection of DATs. To gain as much understanding on the topic, data were collected through several interviews and two surveys which were used to build the model. Results of these surveys were compared to other surveys conducted in several countries to come up with the final list of factors affecting the selection of DAT decision. In addition, this research provides an analysis of how different factors are perceived through different law systems.

A simple additive weighing model that quantifies experts' opinions to score different DATs was established and used to generate dataset to train the ANN model. After the ANN model was trained, both models were tested by comparing their results to those of actual case studies. Results show that the ANN model can be a useful tool for DAT selection, as it provides acceptable level of support to users in choosing the best DAT to be applied in analyzing their claims. The ANN model is developed using MS Excel and Palisade software NeuralTools which is an add-in to Microsoft Excel and has data mining capabilities. Because of its wide array of functions and availability, MS visual basic programming language was used to create the user interface for the model and to generate the data set required for the ANN model.

Acknowledgements

I would like to express my deepest gratitude to my advisor Dr. Ossama Hosny for his full support, expert guidance, understanding and encouragement throughout my study and research.

I would also like to thank Dr. Ahmed Alhady for his continuing support, encouragement, and mentoring during my work on this thesis. Moreover, I would like to express my gratitude to Young Expert Programme and Mott MacDonald B.V. which have facilitated my work-study experience. Also, special thanks to Rob Nieuwenhuis and Paul Van Koppen for their guidance and encouragement on the course of my graduate studies.

I owe this MSc thesis to my family and friends for their unconditional love and support that provided me with strength to complete and present this work and for my university which supported my academic journey in many ways.

Finally, many thanks for the experts for their valuable input and the authors of the papers that were used in the comparison part of this research. They are immensely appreciated for their contribution as it paved way for this humble contribution to the literature on the delay analysis techniques selection factors topic.

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List of Abbreviations

AI	Artificial Intelligence
DAT	Delay Analysis Technique
ANN	Artificial Neural Network
IAP	Impacted As-Planned
CAB	Collapsed As-Built
APvAB	As-Planned Vs. As-Built
TIA	Time Impact Analysis
WA	Windows Analysis
SVM	Support Vector Machines
DGP	Data Generation Process
SCL	Society of Construction Law
AACE	American Association of Cost Engineering
EOT	Extension of Time
DE	Delay Event
EDE	Employer Delay Event
CDE	Contractor Delay Event
SAW	Simple Additive Weighting
TP	True Positive
TN	True Negative
FP	False Positive
FN	False Negative
VBA	Visual Basic for Applications

Chapter 1

Introduction

1.1 Delay Analysis in Construction Industry

Various statistics indicate growth in the Egyptian construction industry. This growth can be attributed to increasing population, a growing market need for buildings and infrastructure, and technological advances which allows building higher, bigger, and more complex structures. As construction projects get more complex, the occurrence of delays becomes more frequent and critical as it may have severe financial implications on all parties involved in the project (Sambasivan and Soon, 2007; Abdelhadi et al., 2018). Construction Delay is defined as "a situation where the contractor and the project owner jointly or severally contribute to the non-completion of the project within the agreed contract period" (Aibinu and Odeyinka, 2006). Construction delays often need to be analyzed through examining the alternating impact of delays on total project duration. This analysis is vital as there is usually a dispute regarding the accountability of the delay by the different parties (Chambers, 2017). Delay analysis investigates events using scheduling methods to establish the cause and extent of delays and to determine the amount to be claimed as an extension of time or as liquidated damages associated with that additional time.

1.1.1 Delay Types

Delays may be classified into four major groups, critical and non-critical, excusable, and non-excusable, compensable, and non-compensable, and concurrent delays (Trauner et al., 2009). When demonstrating that a delay is both excusable and compensable, the delay must be on the critical path or extends a non-critical path with more than its total float. There are several tests which must be satisfied for a delay to be considered excusable and compensable (Keane & Caletka, 2009; SCL, 2017; Kamandang and Casita, 2018). If a delay event is excusable and non-compensable, it can be called a neutral event which entitles the contractor to extension of time but not to monetary damages. Contract terms dictate whether a delay event is excusable or not. Events caused by force majeure, exceptionally adverse weather conditions and the like are considered neutral events; however, what qualifies to a force majeure should better be defined in the contract to avoid conflicts.

1.1.2 Delay Causes

From an Egyptian perspective, a thorough ranking of delay causes after the Egyptian revolution was conducted by Marzouk (2014) who identified and ranked 43 causes of delays. Those 43 causes were grouped under seven main groups: owner, consultant, contractor, labor and equipment, external, material, and project related categories.

In their work, Deep et al. (2017) highlights critical delaying variables from research works conducted in United States, Turkey, Saudi Arabia, Nigeria and Canada between 1971 and 1998. Similar to those works, they carried out a survey from the Indian perspective in which they identified fifty-one (51) causes of delay. It was noted that the most significant causes of delays were: (i) Subsidizing issues; (ii) Lack of equipment; (iii) Poor site administration; (iv) Improper project scheduling; (v) Change orders; (vi) Late conveyance of materials.

1.1.3 Background on Delay Analysis Techniques

According to AACE's "Recommended Practice on Forensic Schedule Analysis", RP 29R-03 (AACEI, 2011), there are several techniques to perform the delay analysis; however, it breaks the methods into four major families: The As-Planned versus As-Built (As-Planned vs. As-Built/MIP 3.2), the Contemporaneous Period Analysis (CPA/MIP 3.5, sometimes commonly called the "Windows" method), the Retrospective Time Impact Analysis (TIA/MIP 3.7), and the Collapsed As-Built (CAB/MIP 3.9). Different delay analysis techniques (DATs) load delays on either a baseline programme or an as-built schedule. A sound baseline programme should follow the contract requirements, contain all the scope of works, and be validated through an agreed upon set of standards such as AACE Source Validation Protocol or DCMA 14-point assessment (Berg et al., 2009).

It is essential for a forensic schedule analyst to have professional judgement that is derived from both experience and knowledge. This research focuses on five of CPM-based DATs which have been identified as the commonly used DATs (Magdy et al., 2019; AbouOrban, 2018; Braimah, 2013). These five techniques are also referenced in AACEI (2011) and in SCL protocol (2017). These techniques are impacted as-planned (IAP), collapsed as-built (CAB), as-planned versus as-built (APvAB), time impact analysis (TIA) and Window analysis (WA). WA technique is arguably a derivative of the other techniques but since its widespread it has become recognized as a primary method on its own (Keane & Caletka, 2009). Each of the primary techniques has acquired different names over the course of its application (Braimah, 2013). Secondary derivatives are highlighted through the work of Keane and Caletka (2009). It shows that the IAP has two derivatives while TIA can be applied in four ways, CAB in three ways, APvAB in five ways and WA in two ways. It is important to highlight that different DATs applied to the same project's delays may provide different results (Braimah 2013; Al-Gahtani and Mohan 2011).

On the one hand, some DATs are performed prospectively, analysing in real-time a delay event that is on-going or is anticipated in the future of the project. This kind of prospective analysis requires that the analyst estimates to the best of his/her efforts future events. On the other hand, some DATs are performed retrospectively after a delay event impact is known.

1.2 Selection of Delay Analysis Techniques

Choosing a delay analysis technique is a subject of great debate in the construction industry (Keane & Caletka, 2009). When given a choice between different options, one ought to consider those options in light of some criteria that influences that choice. Pursuing that logic, it is vital to consider the different factors that influence the selection of a delay analysis technique. Some of those factors are availability and reliability of records, purpose of the analysis, amount in dispute and size of the dispute, complexity of the dispute, type and number of delay events, skills of the delay analyst, capabilities of the method and contract conditions that may be relevant to delay analysis such as EOT conditions.

Many construction contracts do not include conditions that specify a certain DAT to be used; however, relevant conditions such as EOT conditions may provide guidance on whether prospective or retrospective analysis is required. Further inference may provide that a periodic analysis is needed and thus TIA or WA may be used. Still, if the conditions are contradicting or require the usage of prospective DAT while the delay event has already occurred, the analyst should not accept the contract conditions blindly without applying and providing his/her professional judgement (Abdelhadi, 2021).

An analyst should consider who will evaluate the delay analysis. For instance, an analysis used in litigation would be expected to include thorough substantiation and supporting documents. An analyst should expect to demonstrate a clear logic for any of the assumptions he/she did in analysis. However, if the analysis is carried out for the purpose of project team's review or because the client, who acknowledges the existence of delay from his/her side, asked for an analysis, it would be still required to demonstrate logic, but the level of details required would be much less given that the parties involved already understand the issue behind the delay. This may accordingly reflect on the selection of the DAT to be used for the evaluation. The complexity of the dispute also contributes to the choice of the DAT to be used. In some cases, simplifying complicated matters is needed through delay analysis. In other cases, an analyst may decide against using a simple DAT for the analysis as it would not suit the delay events being evaluated. Also, the amount in dispute affects the DAT selection especially when considered with the amount of budget and time required to carry out the analysis. When the amount in dispute is relatively low it may be unnecessary to perform an analysis that requires dedication of a lot of resources.

The timing, type, and number of delay events may influence the selection of the DAT to be used for the analysis and the level of details. A high number of delay events may require a DAT like the WA. However, given that the majority of the delay events occurred towards the end of the project, the analyst may use uneven windows. Some DATs demonstrate concurrency better than others, when such a demonstration is needed the analyst ought to put this into consideration.

No one method fits all cases. Different methods hold different advantages and disadvantages as highlighted in the literature and presented in this research. Thus, an analyst should be aware of the strengths and weaknesses of each DAT. He should be ready to provide support for those weaknesses while accentuating on the strengths. Finally, proper application of a DAT, while not easy, is a subject of careful consideration. It is fair to say that the factors affecting the selection of a DAT is a subject that is equally as important and thus necessitates further investigation.

1.2.1 Problem Statement

The selection of the delay analysis method to be used remain mostly influenced by personal experience which leaves room for disagreements that might lead to escalating a claim into a dispute. A dispute results in additional costs, time, and in some cases negatively impacts the relation between the parties as it goes up the ladder of dispute resolution. Although the selection of most suitable DAT is addressed in the literature, few papers were identified that utilizes experts' opinions in developing a decision-making mechanism such as Perera et al. (2016) who developed a model using simple additive weighting method. The surveyed literature shows a need to put effort into enhancing the DAT selection decision making through modelling and artificial intelligent (AI) techniques (Abouorban et al., 2018; Magdy et al., 2019). Given the intricacy of the topic, it is reasonable to assume that many new practitioners in this field find it difficult to choose a DAT and to support that choice. It is important to have a robust way for non-experts, on the delay analysis topic, to arrive at a quick judgement on whether a DAT presented to them fits the case for which it is presented or not.

1.3 Research Objectives

This research has three objectives. The first objective is to determine most influential factors that influence the selection of the DAT. This was further elaborated by comparing the research in the Egyptian construction industry to similar research in different countries to provide further insight to the global construction industry. The second objective is to contribute to transforming the selection of the most suitable DAT from a siloed approach based on experts' opinions to a more quantifiable approach by building an automated user-friendly model. Finally, the third objective of this research is to put several research works in comparison to examine the distinction, if any, between common and civil law countries regarding the factors impacting the selection of DAT.

1.4 Research Methodology

<u>This research passed through the following phases:</u>

Phase one: Reviewing the literature to group and analyze research efforts that tackle factors that influence the DAT selection from both common and civil law perspectives.

Phase two: Conducting structured interviews with three construction experts to filter the factors identified through the literature review. The filtration aimed mostly at excluding factors that are not dominant in the literature or consistently scored relatively low. The filtration was done so that conducting a survey to rank the factors is time efficient as surveying all the factors in the literature can be time consuming and hinder the performance of the model.

Phase three: Developing surveys and sending them to experts in various positions in the construction field. The surveys and the interviews were used to come up with factors' weights and sub-weights for the criterions in each factor.

Phase four: Developing a numerical model using simple additive weighing (SAW), based on the weights obtained from the surveys.

Phase five: Testing the SAW Model and validating the SAW model through the case study of Perera et al. (2016).

Phase six: Establishing a dataset, based on the amalgamation of experts' opinions upon which the SAW model was built.

Phase seven: Building an ANN model using the established data set from phase six.

Phase eight: Testing the ANN model through actual case studies and validating the ANN model through the case study of Perera et al. (2016).

1.5 Thesis Organization

As shown in Figure 1, this thesis is organized into five chapters. Chapter 1 provides a general introduction about delay analysis, the problem statement, research objectives and research methodology. Chapter 2 presents a review of the delay analysis techniques, the dominant factors presented in the literature that influence the selection of DAT, artificial intelligence (AI) techniques used in construction industry and the previous research efforts made in these topics. Chapter 3 discusses the data collection that paved way for model development. Chapter 4 presents application and validation; where the model was applied on a real construction case and the results are analyzed to validate the model. Chapter 5 provides summary, concluding points of this research and recommendations for areas of future research in the DAT selection topic.

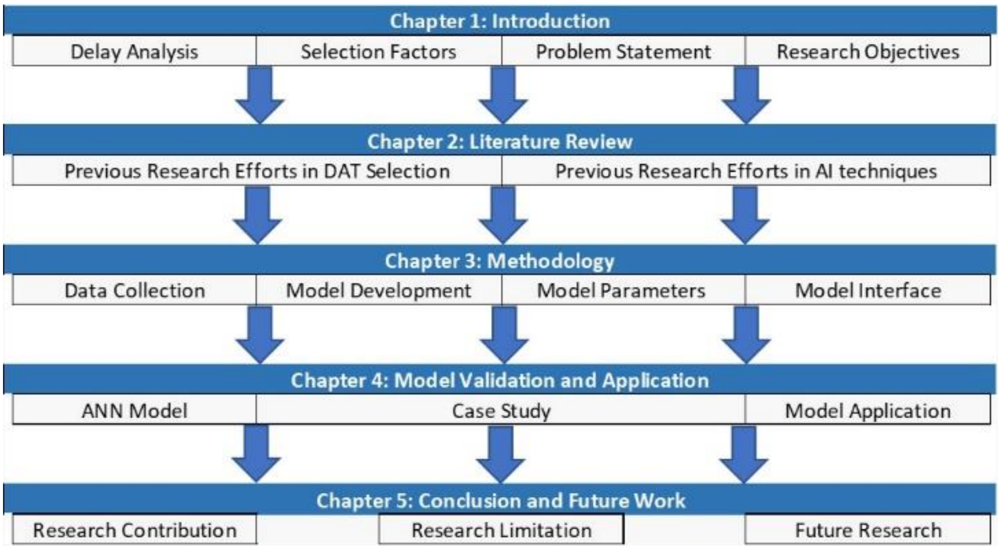


Figure 1: Thesis Organization/Structure Flowchart

Chapter 2

Literature Review

This chapter highlights the reviewed literature on DATs in light of their application framework and advantages and disadvantages. Also, it highlights factors affecting DAT selection and how they are viewed based on countries from different legal systems perspectives . Finally, it covers the research done in artificial intelligence and its applications in construction projects and delay analysis.

2.1 Analysis of Existing DATs

2.1.1 Impacted As-Planned

A prospective delay analysis technique that depends on inserting or adding activities, fragnets representing delays or changes into the baseline program to determine its relevant impact, impacted as-planned (IAP) maybe considered the simplest form of critical path-based analysis as it involves the least number of variables (Parry, 2015). According to the SCL Protocol (2017) and the US the AACEI RP-FSA (2011), which refers to this technique as the 'Modelled/Additive/Single Base (MIP 3.6), this technique is one of the primary delay analysis techniques. However, the theoretical nature of the projected delays of the IAP technique as well as its uncertainty as to the feasibility of the contractor's as planned programme restrict its use. Also, the assumption that the delays modelled Employer Delay Event (EDE), or Contractor Delay Event (CDE) were the only delays which occurred and all else went to plan subjects IAP technique to criticism by courts and commentators (Arditi and Pattanakitchamroon, 2006; Keane & Caletka, 2009). As simple as it may be, IAP can still be used to demonstrate what if scenarios. IAP analysis requires a baseline programme that is compliant with the contract conditions. If such programme does not exist or contains either logical or duration errors the program should be revised before applying IAP analysis.

2.1.2 Collapsed As-Built

The collapsed as built method (CAB) is a retrospective technique which is applied on as-built programme and considers the duration of all delays. Opposite to the IAP philosophy, the CAB approach is a deductive approach and carried out on as built programme. The CAB analysis is a 'multi-iterative process involving rapid modelling' to reveal faulty or incomplete logic.

SCL protocol is cautiously recommending the CAB method but for the simplest, intuitive, and linear of projects (Keane & Caletka, 2009). It seems difficult to recommend an analysis method that is dependent on "multi-iterative process involving rapid modelling" to uncover flawed logic. The analyst can modify the input as the process could theoretically be reiterated until it reaches a satisfactory result from the client's point of view (Keane & Caletka, 2009).

2.1.3 As-Planned Vs. As-Built

The as-planned Vs as-built (APvAB) DAT compares the planned programme duration to the actual as-built programme duration through a graphical presentation that shows when the activities actually occurred in comparison to the planned dates and asserts the delays are both excusable and compensable (Enshassi and Jubeh, 2008).

According to Keane and Caletka (2009), claiming delay entitlement using the APvAB based on a total time comparison and support of a full excusable and compensable extension of time, the claimant must be able to present:

- Reasonable original as-planned programme;
- The critical delay(s) is not his own act;
- The claimant is entitled to time and money for all delay events identified along the as-built critical path;
- The APvAB analysis is the only way to demonstrate cause–effect; and
- A total conformity with contract responsibilities such as delivering a notice within the specified time frame, all relevant details and documents that support delay claim, proofs of efforts exerted to mitigate the delay's impact, etc..

APvAB analysis, as reliable and effective as it seems, is refuted by commentators who always focus on any deviation or breach to the above parameters.

2.1.4 Time Impact Analysis

Time Impact Analysis (TIA) can be used prospectively or retrospectively (El Nemr, 2019). As a prospective method, it is an evolution of the IAP method. The TIA method depends on a similar technique to IAP which is to add activities, fragnets representing delays or changes, but the main difference is that these fragnets are added to baselines that are updated just before the event occurs. The TIA technique is distinct from the IAP technique in that it utilizes several baselines instead of depending only on the original as-planned baseline to assess the anticipated effects of delay events (Keane & Caletka, 2009). The TIA forecasts or predicts a delay's effect on a project's completion date. The TIA approach, when used appropriately, can be a very effective way to show how delays affect a schedule. Since there are many different ways to conduct a TIA and many assumptions that must be made, it is equally vulnerable to examination and criticism (El Nemr, 2019). When the underlying assumptions are successfully contested, flaws might be accentuated. This technique, alike prospective techniques, best to be applied when mutual pre-agreement between parties.

Prior to the introduction of delay events, a project's base schedule should outline the contractor's plan to finish the outstanding project's activities. Each party will need to depend on projected impacts for delay events when conducting a TIA prospectively while the project is ongoing. When TIA is carried out retrospectively, all parties shall acquire more knowledge about the true coherent order in which the delay events occurred, the activities that were dependent on them and delayed by them, and the precise length of each delay event (Keane & Calteka, 2009). Applying TIA retrospectively subjects the analysis to less challenges than applying it prospectively (Livengood, 2017; El Nemr, 2019).

2.1.5 Window Analysis

Window Analysis (WA) is an observational and dynamic method that is based on the analysis of real-time progress data and takes into account the dynamic nature of the critical path as-built, which shifts from time to time for a variety of reasons (Keane & Caletka, 2009). The strategy is based on the justification of variations and modifications that are seen in real-time program upgrades. Carrying out WA in construction contracts requires contemporaneous progress programs to be updated on a regular and frequent basis. If such updates are not available, the contemporaneous windows analysis may be ineffective (Parry, 2015). Because it employs contractor data and depends on an as-built critical path to show the true impact of delays, some employers prefer this approach to delay analysis. The impact of concurrent delays or events, such as design activities, that are not fully anticipated in the construction management plan or progress reports, might be hidden by this technique, which may be a reason behind some contractors not preferring it (Keane & Caletka, 2009).

2.1.6 Supporting Data on DATs

2.1.6.1 Application Steps

Keane and Caletka (2009) provides details about the steps in applying the different DATs. The first step to use IAP technique is to have a baseline programme that shows a logical sequence of activities and meets all the contracts requirements. The second step is to add delay events caused by either, or both, the employer and contractor to the baseline programme. If both employer and contractor delay event are to be added, then chronological order should be followed. The third step is to insert activities representing the allocated delay impact and tied logically to other activities in the baseline programme. The fourth step is to record the impact of each delay event successively on the completion date. Finally, the total number of days extended beyond the completion date due to delay events for each party is recorded (Keane & Caletka, 2009).

According to Parry (2015), there are at least four steps to applying the TIA technique. The first step is to gather the updates on all the activities and update the program just before the delay event took place in order to determine the completion date right before the delay event occurred. The second step is to add the delay event into the schedule by either, or both, adding a new activity linked to other activities logically, or by adjusting the duration of existing activities or altering the as-planned sequence. The third step is to calculate the new completion date which relies on the duration and sequence of the remaining project activities. The second and third steps should be repeated for all the delay events. The final step is to identify the origins, causes of each delay, and apportion the responsibility of each delay event to a party.

According to Braimah (2013), the first step to applying WA is to divide the total project duration into a number of time periods. The second step is to update the schedule within each time period to show the real durations and sequence of activities at the time of the delay occurrence. The as-planned schedule beyond that time period is left unchanged. Completion date is checked to measure any change in the project duration or in the critical path. Finally, the new completion date is compared to the completion date prior to performing the analysis to measure the amount of delay during that time period. CAB technique starts with generating an as-built schedule or refining an already existing one. This refinement of the as-built schedule should include the delay events tied logically to other activities. Once the as-built schedule is complete, the delay events are removed one by one to show the project completion date that would have been but for each of those delay events (Lovejoy, 2004).

The first step to use APvAB technique is to have a baseline programme that shows a logical sequence of activities and meets all the contracts requirements. The second step is to create or refine an already existing as-built schedule to reflect the actual sequence through which the work was implemented. It is important that the as-built schedule reflects the same or higher level of details as the as-planned schedule. Third step is to insert delay events and other complementary activities that lead up to the delay. Fourth step is to deduce the most logical critical path based on the sequence of the work. The final step is to measure the delays by the difference between late dates in the as-planned schedule and actual dates in the as-built schedule.

2.1.6.2 Advantages and Disadvantages

Table 1 and Table 2 show compiled lists of advantages and disadvantages for each of the five DATs (Magdy et al., 2019; Chambers et al., 2017; Keane & Caletka, 2009; Strumpf, 2000). From the literature, it can be noted that most of the authors consider the ease and swiftness with which IAP, CAB and APvAB can be prepared to be an advantage that is not granted when using TIA or WA. Another point of advantage for a DAT is not needing both as-planned and as-built schedules. This makes it less demanding yet makes the DAT vulnerable to criticism. Another point of advantage is the simplicity and ease of presenting and understanding the DAT. This supports the conclusion that it is important to remember that presenting a delay analysis to a judge in litigation can be different from presenting it to the engineer for a claim.

Another point which considers legal perspective into the DAT selection is the view of the court of the selected DAT. For instance, Arditi (2006) states that TIA is highly regarded in courts, which is an advantage of the technique, while IAP is consistently rejected in courts. Since the view of the court may change from time to time, it is essential to review the relevant case law. A major point of consideration is the ability of a DAT to measure concurrency. Although literature includes several works that conclude that all DATs can measure concurrency, some DATs like TIA, WA and APvAB are more favored for their ability to measure concurrency than others. Time and cost associated with preparing the analysis make some DATs more favorable than other. For instance, more complex DATs like TIA and WA require more time and money to prepare than IAP or APvAB which makes the later two techniques more favorable in some instances.

Table 1: Advantages of Delay Analysis Techniques

DATs / Advantages	Impacted As Planned	Collapsed As Built	As-Planned Vs. As-Built	Time Impact Analysis	Windows Analysis
Easy to prepare	(Abouorban et al., 2018) (Magdy et al., 2019)	(Abouorban et al., 2018) (Magdy et al., 2019)	(Chambers et al., 2017) (Abouorban et al., 2018)	-	-
Easy to understand	(Keane & Caletka, 2009)	(Keane & Caletka, 2009) (Magdy et al., 2019)	(Keane & Caletka, 2009) (Chambers et al., 2017)	(Keane & Caletka, 2009)	(Keane & Caletka, 2009)
Can identify concurrency	-	-	(Keane & Caletka, 2009)	(Keane & Caletka, 2009) (Chambers et al., 2017)	(Magdy et al., 2019)
Considers Dynamic Change of Critical Path	-	-	(Keane & Caletka, 2009)	(Keane & Caletka, 2009) (Magdy et al., 2019)	(Keane & Caletka, 2009) (Magdy et al., 2019)
Can be carried out contemporaneously	(Keane & Caletka, 2009)	-	-	(Keane & Caletka, 2009) (Chambers et al., 2017)	(Chambers et al., 2017)
Accepted by many courts and agencies	-	-	-	(Chambers et al., 2017) (Magdy et al., 2019)	(Chambers et al., 2017)
Does not require progress updates	(Keane & Caletka, 2009)	(Keane & Caletka, 2009) (Magdy et al., 2019)	(Keane & Caletka, 2009)	-	-
Conclusions are supported by as-built records	-	(Keane & Caletka, 2009)	-	(Keane & Caletka, 2009)	(Keane & Caletka, 2009)
Does not require as-built programme	(Keane & Caletka, 2009)	-	-	-	-
Does not require a baseline programme	-	(Keane & Caletka, 2009)	-	-	-

Table 2: Disadvantages of Delay Analysis Techniques

Disadvantages \ DATs	Impacted As Planned	Collapsed As Built	As-Planned Vs. As-Built	Time Impact Analysis	Windows Analysis
Complex to prepare; Needs highly qualified practitioners	-	-	-	(Keane & Calteka, 2009) (Magdy et al., 2019)	(Keane & Calteka, 2009) (Abouorban et al., 2018) (Magdy et al., 2019)
Difficult to Present; Time Consuming to Perform	-	(Keane & Caletka, 2009)	-	(Chambers et al., 2017)	(Chambers et al., 2017) (Abouorban et al., 2018)
Cannot identify true concurrent delay	(Keane & Caletka, 2009) (Magdy et al., 2019)	-	(Abouorban et al., 2018)	(Magdy et al., 2019)	(Chambers et al., 2017)
Does not take into consideration the dynamic nature of the critical path	(Magdy et al., 2019)	(Magdy et al., 2019)	-	-	-
Assumes a perfect baseline schedule that was followed accordingly without any changes	(Abouorban et al., 2018)	-	(Abouorban et al., 2018)	-	-
Consistently rejected by courts	(Arditi, 2006) (Magdy et al., 2019)	-	(Chambers et al., 2017)	-	-
As-Built programme required	-	(Keane & Caletka, 2009)	(Keane & Caletka, 2009)	-	-
Can be susceptible to manipulation	(Keane & Caletka, 2009)	(Magdy et al., 2019)	(Chambers et al., 2017)	(Chambers et al., 2017)	-
Not suitable for complicated projects or projects built significantly different than planned	-	-	(Chambers et al., 2017)	-	-

2.2 DAT Selection Factors

Different factors influencing the selection of the most appropriate DAT have been highlighted in several research. Many of the scholars have based their research survey and/or interviews on specific country's construction industry practitioners (Enshassi, 2008; Braimah, 2013; Perera, 2016). Through the literature review, a list of most dominant factors was compiled. One of the early works in identifying DAT selection factors was the work of Braimah and Ndekugri (2008) in which they conducted a nationwide survey of construction organizations in the United Kingdom. They identified eighteen (18) factors that affect the choice of the DAT to be used. Two of the most widely used industry references and standards on delay analysis have also been investigated. Namely, the Recommended Practice No. 29R-03 (RP-FSA) of the American Association of Cost Engineers (AACE) (AACEI, 2011), and the Delay and Disruption Protocol of the Society of Construction Law (SCL) 2nd edition (SCL, 2017). Together, these two sources were particularly investigated as they combine legal and technical perspectives. Also, they are published by well-established entities which vouches for the review on the content presented in them.

From the reviewed literature, several sources on the factors affecting the selection of DAT are presented. Table 3 shows examples of some sources that represent the common law perspectives. Braimah and Ndekugri (2008) identified 18 factors that influence the selection of DAT. Those same factors were used in the works of Enshassi and Jubeh (2008), Perera and Sudeha (2013) and Parry (2015) with the exception that Perera and Sudeha (2013) included additional seven factors. Those papers conducted separate surveys and interviews and arrived at different rankings of the factors from the different parties' perspectives. Arditi and Pattanakitchamroon (2006), included four additional factors. The SCL delay and disruption protocol identified nine factors that affect the selection of DAT while AACE's 29R-03 (2011) identified 11 factors that influence the selection.

Table 3: Common Law Sources on DATs Selection Factors

Common Law							
U.S.A	**Sri Lanka**	**Gaza**	**UK**	**UK**	**UK**	**U.S.A**
Arditi (2006)	**Perara (2013) ***	**Enshissa (2008)**	**Parry (2015)**	**Braimah (2008)**	**SCL 2nd Edition Delay and Disruption Protocol (2017)**	**AACE (2011)**
Availability of information	Updated programme availability; Records availability				Nature, extent, and quality of records available	Source data availability and reliability
N/A	Complexity of the Project; Size of project				Nature of the project	Complexity of the dispute
Time-Cost effort	Time availability for delay analysis *				Time available	Time allowed for forensic schedule analysis
N/A	Skills of the analyst				(Implied in the text)	Expertise of the forensic schedule analyst and resources available
N/A	Form of contract				Relevant conditions of contract	Contractual requirements
Time-Cost effort	Cost of using the technique				N/A	Budget for forensic schedule analysis
N/A	The number of delaying events				Nature of causative events	N/A
N/A	Nature of the Delaying events				N/A	N/A
N/A	The amount in dispute				To ensure a proportionate approach, the value of the project or dispute	Size of the dispute
Capabilities	Reason for the delay analysis				N/A	Purpose of analysis
N/A	Duration of the project				N/A	N/A
N/A	Dispute resolution forum				Forum in which the assessment is being made	Forum for resolution and audience
Time of analysis	Time of the delay				N/A	N/A
N/A	Nature of baseline programme				Nature, extent, and quality of the programme information available	N/A
N/A	Baseline programme availability				N/A	N/A
N/A	The other party to the claim				N/A	N/A
N/A	Applicable Legislation				N/A	Legal or procedural requirements; Custom and usage of methods on the project or the case
N/A	Nature of proof required *; Public project or private project *; Type of project *; Simplicity *; Fast track project or not *; Level of exposure of the responsible party *				N/A	N/A

Table 4 shows civil law countries' perspectives which can be perceived through the works of Perera et al. (2016) where 13 factors, expanded to 23 sub factors that affect the selection, were identified. Abdelhadi et al. (2018) identified 10 factors, Abouorban et al. (2018) identified 14 factors, and Magdy et al. (2019) identified 8 factors.

Table 4: Civil Law Sources on DATs Selection Factors

Civil Law			
UAE	**UAE**	**Egypt**	**Egypt**
Abdelhadi et al. (2018) (10 factors)	**Perera et al. (2016) (23 factors)**	**Abouorban et al. (2018)**	**Magdy et al. (2019) (8 factors)**
Available records	Availability of other records (e.g., daily records)	Project documentation / regular periodic updates	Availability of programme updates; Availability of project records
Project complexity	Complexity of the project; Size of the project; Value of the project; Obscurity and sophistication of issues in prolongation claims	Project Type (size, location, complexity)	Project size and complexity
N/A	Concern for time to be spent for analysis	Time & cost accompanied required to carry out the analysis	N/A
Skills of the analyst	Experts Skills	N/A	Availability of skilled resources for carrying out delay analysis
Contractual requirements	Analysis method defined in the contract	Contract particular conditions	N/A
	Concern for cost of analysis method	Time & cost accompanied required to carry out the analysis	N/A
Number of events	Number of events claimed and to be analyzed	Number of delay events and size of delay impact	N/A
Concurrent Delays	Concurrency and float ownership defined in the contract; Need of showing concurrent delays/mitigation	Concurrency of delay events	Concurrency of delays
N/A	Amount of cost (of prolongation) claimed	N/A	N/A
Capabilities of the method	N/A	N/A	N/A
N/A	Duration of the project; Amount of time claimed	Project duration	N/A
N/A	N/A	Time of delay occurrence	Time of occurrence
Status of project	Status (prevailing stage of the project)	N/A	N/A
N/A	Baseline program type	N/A	N/A
N/A	Baseline program availability	N/A	N/A
Attitude of the opponent party	N/A	N/A	N/A
Ownership of the float	Concurrency and float ownership defined in the contract; High quality of transparency (Clearly established causation); As-built periodical updates of program; As-built periodical updates of program (mutually agreed); Need to illustrate isolated delay effects; Need of sequential (chronological) analysis	Delay type; Party carrying out the analysis; Materialization of delay impact; Reliability of project schedules; Reasons behind delay	Adequacy and skills of project management office (PMO) personnel; Availability of a robust construction program

*Wordings are used as is from their corresponding reference and interpreted to the best ability of the author.

2.2.1 Analysis of DAT Selection Factors

Some DATs cannot be utilized in the absence of records which is a possible reason behind having the availability of records factor mentioned in all the civil and common law sources. DATs can provide unreliable results when the records are not updated or more prone to interpretation. The project complexity factor shows up in all of the sources while having the AACE relate the dispute complexity to the selection of the DAT. Some sources mention project size along with project complexity which contributes to the idea that complexity can be perceived as a factor with sub factors such as project size, project type, interdependency, and interaction between project parts, etc... (Wood and Gidado 2008). Perera et al. (2016) related project complexity to mechanical and electrical works difficulty. While this can be true for one project type or one specific contractor, it cannot be generalized. In most of the sources, time availability for conducting the analysis is established as a factor that contributes to the selection. Some DATs like IAP take less time in comparison to more sophisticated ones like WA (Keane & Caletka, 2009; Abouorban et al., 2018).

Most of the sources mention budget availability to conduct the analysis as a factor. Of those sources, Arditi (2006) and Abouorban et al. (2018) set the time and cost availability as one factor assuming that they carry equal weights. Some of the sources referred to the time and cost factors as those required while other referred to them in terms of availability. Both are different ways to arrive at the same conclusion. All of the sources clearly established that the skill of the analyst is a factor that contributes to the selection. Having a more capable analyst makes more DATs options for selections.

Contractual requirements factor is set as a major factor that affects the selection. Although cases in the literature that showcases the overturning of a DAT selection clause were not found, in some cases the selected method can be prone to legal challenges in courts (El Nemr, 2019). El Nemr elaborates on four legal challenges that can be raised against the use of TIA which are accuracy of the As-Planned Schedule and Updates, the analysis can be considered hypothetical, use of prospective TIA after-the-fact and susceptibility of a TIA to manipulation. Livengood (2017) highlights that retrospective TIAs have suffered certain challenges in US courts, which begs the question whether the selection of DAT should be influenced by law systems. Moreover, Keane and Caletka (2009) states that the DAT is specified in many of today's larger international engineering and construction projects. Although (Parry, 2015) suggested that one DAT, namely, WA can be fit for all cases, several research show that one DAT is not fit for all cases or claims (Abouorban et al., 2018).

Most of the sources that are based on common law countries set the dispute resolution forum in which the delay analysis arguments are going to be presented by both parties as a factor in selecting the appropriate DAT. When considered in light of the work of El Nemr (2019), this can relate to how important it is to remember how presenting a delay analysis in front of a judge in litigation can be different from presenting it to the engineer/consultant for a claim. Also, how important it can be to survey the previous rulings of a certain country regarding issues as concurrency, float ownership, etc... None of the civil law sources includes dispute resolution form as a factor. Capabilities of the method and purpose of delay analysis factors were mentioned in few sources. Although it isn't clearly stated, it was inferred that purpose of delay analysis had a direct correlation with the capabilities of each method. Almost all sources considered duration of projects as a factor in their works. Perera et al. (2016) referred to amount of time claimed to be a factor in the selection as it wouldn't be justifiable to spend considerable level of resources on a claim that provides a low value of entitlement. Similar reasoning applies to the amount in dispute which was set as a factor in several common law sources while it was only mentioned in Perera et al. (2016), a civil law source, as a factor.

Concurrency of delay events was referred to as a factor in all of the civil law sources. Although several research tackles concurrent delay events in common law cases, the need to properly show concurrency of delay events is not considered in the common law sources as a factor but instead was referred to as an example illustrating the nature of delay events factor (Keane & Caletka, 2009; Parry, 2015). Arditi and Pattanakitchamroon (2006) and Perera et al. (2016) highlighted that float ownership affects the selection. According to Arditi and Pattanakitchamroon (2006), the varied positions concerning who owns float can influence the result of delay analysis. In their article, they showcase how different float ownership scenarios can lead to different results. Perera et al. (2016) highlights that float ownership doesn't affect the outcome of the analysis when APvAB is used. Table 5 shows an overall ranking of factors gathered from six of the sources in the literature as these were the ones that had a clear ranking of the factors. For each source, each factor obtained a value score by dividing the factor's rank over the total number of factors in that source. The highest-ranking factor is the one with the least average score among the six sources.

Table 5: Overall Rankings of Factors Gathered from Literature

Factors	Reference						Average	Ranks
	Braimah (2008)	**Enshassi (2008)**	**Perera and Sudeha (2013)**	**Parry (2015)**	**Perera et al. (2016)**	**Abouorban et al. (2018)**		
Records availability	0.056	0.056	0.040	0.278	0.042	0.118	0.10	1
Baseline programme availability	0.111	0.111	0.240	0.111	0.167	-	0.15	2
Updated programme availability	0.278	0.222	0.040	0.222	0.125	-	0.18	3
High quality of transparency (Clearly established causation)		-	-	-	0.208	-	0.21	4
As built periodical updates (mutually agreed)		-	-	-	0.208	-	0.21	4
Nature of baseline programme	0.222	0.667	0.040	0.056	0.083	-	0.21	6
Party carrying out the analysis		-	-	-	-	0.235	0.24	6
Concurrency and float ownership defined in the contract		-	-	-	0.333	-	0.33	8
Complexity of the Project	0.389	0.444	0.240	0.389	0.542	0.176	0.36	9
Form of contract	0.611	0.611	0.520	0.167	0.292	0.059	0.38	9
Skills of the analyst	0.444	0.111	0.040	0.778	0.458	0.588	0.40	11
Nature of the Delaying events	0.500	0.333	0.440	0.333	-	0.471	0.42	11
Need to illustrate isolated delay effects		-	-	-	0.417	-	0.42	11
Reliability of project schedules		-	-	-	-	0.471	0.47	14
Need of sequential analysis		-	-	-	0.500	-	0.50	14
Need of showing concurrent delay/mitigation		-	-	-	0.375	0.647	0.51	16
Number of delaying events	0.333	0.778	0.560	0.444	0.708	0.294	0.52	17
Amount in dispute	0.167	0.556	0.240	0.778	0.875	-	0.52	18
Type of project		-	0.880	-	-	0.176	0.53	18
Cost of using the technique	0.667	0.833	0.240	0.556	0.792	0.412	0.58	18
Obscurity and sophistication of issues in prolongation claims		-	-	-	0.583	-	0.58	21
Size of project	0.833	0.278	0.480	0.778	0.958	0.176	0.58	22
Time of the delay	0.778	0.667	0.680	0.444	-	0.353	0.58	23
Time availability for Delay Analysis		-	-	-	0.833	0.412	0.62	23
Status (prevailing stage of the project)		-	-	-	0.625	-	0.63	23
Value of the project		-	-	-	0.625	-	0.63	26
Reason for the delay analysis	0.556	0.389	0.800	0.778	-	-	0.63	27
Materialization of delay impact		-	-	-	-	0.647	0.65	28
Reasons behind delay		-	-	-	-	0.647	0.65	29
The other party to the claim	0.944	0.889	0.040	0.778	-	-	0.66	30
Duration of the project	0.889	0.444	0.560	0.778	0.750	0.647	0.68	31
Dispute resolution forum	0.722	0.944	0.560	0.778	-	-	0.75	31
Nature of proof required		-	0.760	-	-	-	0.76	33
Public project or private project		-	0.840	-	-	-	0.84	34
Applicable Legislation	1.000	1.000	0.720	0.778	-	-	0.87	35
Amount of cost claimed		-	-	-	0.875	-	0.88	35
Amount of time claimed		-	-	-	0.917	-	0.92	37
Simplicity		-	0.920	-	-	-	0.92	38
Fast track project or not		-	0.960	-	-	-	0.96	39
Level of exposure of the responsible party		-	1.000	-	-	-	1.00	40

The 40 factors in Table 5 were categorized into four categories as shown in Table 6. Seventeen factors are Project Related , seven factors are Parties Related, seven factors are Delay Related, and nine factors are Legalities Related.

Table 6: Categories of factors affecting DAT selection

Factors	Category
Records availability	Project Related Factors
Baseline programme availability	
Updated programme availability	
Nature of baseline programme	
Complexity of the Project	
Reliability of project schedules	
Size of project	
Amount in dispute	
Status (Stage at which delay analysis takes place)	
Duration of the project	
Type of project	
Value of the project	
Public project or private project	
Fast track project or not	
As built periodical updates (mutually agreed)	
Amount of cost (of prolongation) claimed	
Amount of time claimed	
Skills of the analyst	Parties Related Factors
Time availability for delay analysis	
Cost of using the technique	
The other party to the claim	
Reason for the delay analysis	
Level of exposure of the responsible party	
Party carrying out the analysis	
Nature of the delaying events	Delay Related Factors
Number of delaying events	
Time of the delay occurrence	
Reasons behind delay	
Materialization of delay impact	
Obscurity of issues in prolongation claims	
Simplicity	
Dispute resolution forum	Legalities Related Factors
Form of contract	
Concurrency and float ownership defined in the contract	
Need of showing concurrent delay/mitigation	
Applicable legislation	
Need of sequential (chronological) analysis	
Nature of proof required	
High quality of transparency (Clearly established causation)	
Need to illustrate isolated delay effects	

2.3 Artificial Intelligence in Construction Industry

The field of computer science known as artificial intelligence (AI) focuses on developing computer programmes that can perform human-like functions, including perception, knowledge representation, reasoning, problem-solving, and planning (Soofi and Awan, 2017)

It is important to recognize the main subfields of AI in order to comprehend the current state of AI in the construction field. In general, the development of AI applications in engineering has given rise to a number of well-known subfields of AI, such as (a) machine learning (b) computer vision (c) natural language processing (e) knowledge-based systems (f) optimization (g) robotics (h) automated planning (Abioye et al., 2021).

2.3.1 AI Applications in Construction Industry

A computer can learn automatically from patterns or features in the data by combining massive amounts of data with quick, iterative processing and sophisticated algorithms such as neural networks, process mining, and deep learning (Sarker, 2021). The solutions each of these algorithms offer cover a wide range of difficult building issues, including knowledge discovery, risk estimation, root cause analysis, damage assessment and prediction, and defect identification.

With the emergence of AI applications during the past few years, a significant transition has occurred (Zhang, 2021). This makes it possible for construction industry practitioners to carry out projects more effectively, boosting both the automation and productivity of the construction industry as well as its competitiveness on a global scale. There are several machine learning algorithms for classification problems.

One of those techniques is logistic regression, which is utilized when the outcome is of binary nature. Logistic regression requires analysis of categorical or numerical independent variables to determine a categorical dependent variable to(Rymarczyk et al., 2019).. Another technique is support vector mechanics (SVM) which uses methods to train and classify data within polarity levels, going beyond X/Y prediction. One of the SVM advantages is its effectiveness in high dimensional spaces, in cases where number of dimensions is greater than the number of samples (Soofi and Awan, 2017).

A third machine learning algorithm is ANN. ANNs are modelled after the biological neural system. They are renowned for being incredibly successful at resolving challenging classification and regression issues (Bishop, 1995). An ANN is made up of three layers: input layer neurons, one or more hidden layers, and output layer neurons. The analyst must make decisions on a number of variables, including the number of hidden layers, the number of neurons at each layer, and the activation mechanisms. An ANN's training procedure aims to create a model that closely resembles the underlying data generation process (DGP) based on prior observations and training data (Abioye et al., 2021). Kim et al. (2004) applies hybrid models of neural network and genetic algorithm to cost estimation of residential buildings to predict preliminary cost estimates. Chau (2007) successfully utilizes particle swarm optimization (PSO) model to train neural network in predicting the outcome of construction claims in Hong Kong. Magnier and Haghighat (2010) presents an approach to optimize thermal need and energy utilisation in residences. The approach depends on distinguishing building behavior through an artificial neural network (ANN) which is combined with a multi-objective genetic algorithm for optimization.

ANN, which takes inspiration from biological neural networks with interconnected neurons, can mimic human learning processes by building correlations between process input and output. It still has some drawbacks, though, including a black box, lengthy computation times, overfitting, and local minimum (Alwosheel et al., 2018).

Chapter 3

Methodology

In this chapter, the data collection process, which involved a mixed method approach that included semi structured interviews followed by two surveys, and the main steps used in the model development are summarized; besides explaining the reasons for selecting the programming language used.

3.1 Data Collection

3.1.1 Semi Structured Interviews

Table 5 in the literature review showed that 40 factors were identified to affect the decision of which DAT to be applied. Analyzing those factors, it can be noticed that some factors were mentioned in only one source. Some others had a very low ranking or are resembling other factors in the list. Therefore, semi structured interviews were conducted with a group of experts (3 experts) to finalize the list of factors to be considered for DAT selection. The three experts each had from 10-15 years' experience from both consultant and contractor sides.

Two experts believe that the party who is going to review the claim is an important point worth consideration by the contractor. The higher the claim goes up on the dispute resolution ladder, the more probable that a party with a legal background will be making the final decision. One of the experts elaborated further that "even when judges issue a reasoned decision they almost never comment on or even mention which delay analysis technique was used in the case."

During the interviews, experts were asked whether contracts specify which method of analysis will be used. Only one expert stated that he has encountered one project implemented in Egypt where the DAT was predefined in the contract. Two of the experts indicated that it is uncommon for a DAT to be specified in the contract in Egypt, but they believed that in the United States several projects are having TIA as the specified DAT. Experts in the interview agreed that Other Party to the Claim factor is one that is not often taken into account; however, when current and future business between the parties are of great significance, acceptance of a DAT by one party may be faced with more leniency from the other party.

Table 7 shows the factors that were omitted and the reasons behind that according to the experts' interviews and the literature analysis.

Table 7: Factors not included in the Surveys

Factors Not Included in Surveys	(Reason 1) Mentioned in one source	(Reason 2) Received Low Ranking	(Reason 3) Resembles other Factor(s)
1. Amount of Cost (of prolongation) Claimed	✓	✓	Amount in Dispute factor
2. Amount of Time Claimed	✓	✓	Amount in Dispute factor
3. Value of the Project	✓	✓	Size of the Project factor
4. Public or Private Project	✓	✓	
5. Simplicity	✓	✓	Project Complexity factor
6. Fast Track Project or Not	✓	✓	
7. Level of Exposure of the Responsible Party	✓	✓	
8. Reasons Behind Delay	✓	✓	Nature of Delaying Event factor
9. Need of sequential (chronological) analysis	✓	✓	
10. Obscurity of issues in prolongation claims	✓	✓	
11. Reason for Delay Analysis	✓	✓	
12. Need to Illustrate Isolated Delay Effects	✓	✓	
13. Concurrency and float ownership defined in the contract	✓	✓	Need of Showing Concurrent Delay factor
14. Type of project	✓	✓	
15. Materialization of delay impact	✓	✓	Time of Delay Occurrence/Delay Analysis factors
16. Nature of proof required factors	✓	✓	Reliability of Project Schedules factor
17. High quality of transparency	✓		Reliability of Project Schedules factor
18. As built periodical updates (mutually agreed)	✓		Updated Programme Availability factor
19. Party carrying out the delay analysis	✓		*** Accounts for human bias which this tool tries to overcome.**
20. Duration of the project		✓	
21. Applicable legislation		✓	

Accordingly, the remaining 19 factors are the ones that will be further investigated.

1. Records Availability
2. Baseline Programme Availability
3. Nature of Baseline Programme
4. Updated Programme Availability
5. Complexity of the Project
6. Size of Project
7. Skills of the Analyst
8. Form of contract (Contract Conditions)
9. Dispute Resolution Forum
10. Need of Showing Concurrent Delay/Mitigation
11. Nature of Delaying Events
12. Time of the Delay Occurrence
13. Number of Delaying Events
14. Amount in dispute
15. Cost of using the Technique
16. Time availability for Delay Analysis
17. Other Party to the Claim
18. Status (prevailing stage of the project)
19. Reliability of Project Schedules

3.1.2 First Survey

The final list was then included in a survey to score each of the factors contribution to the selection of a delay analysis technique. The survey was distributed to 90 experts, whose major experiences are divided between contractors and consultants.

Type of Construction Organization

The percentages of the participants from each construction organization type are shown in Figure 2.

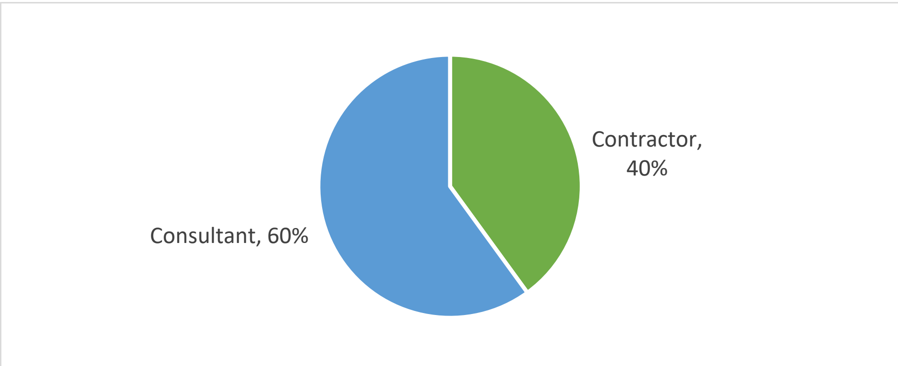


Figure 2: Types of Construction Organizations

Roles of Participants:

The percentages of the positions of the participants are shown in Figure 3. As seen, the majority of the contributors were planning engineers, forensic delay analysts, project managers and contract managers.as their disciplines are highly involved in time-related claims analysis.

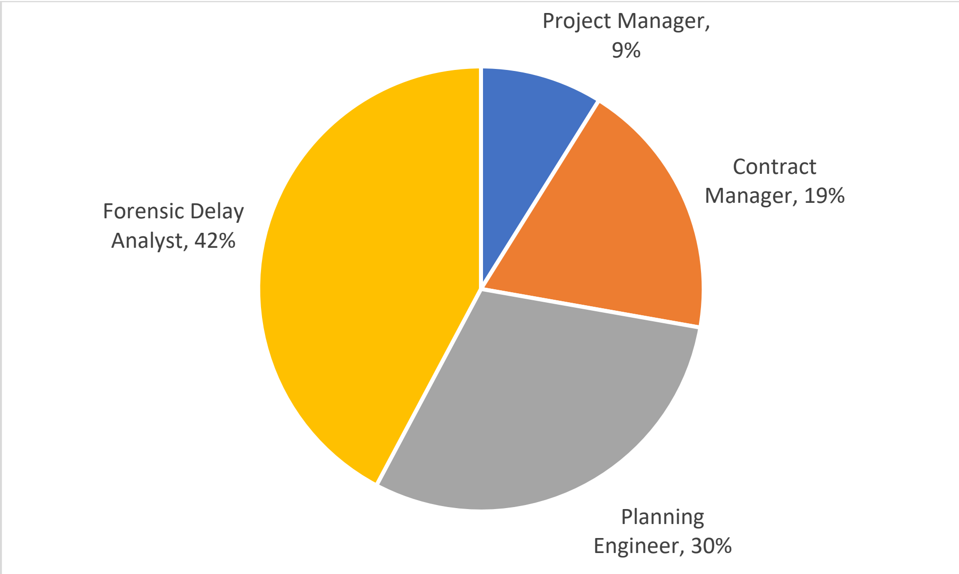


Figure 3: Role of Respondents in the Construction Organizations

Years of Experience of Participants:

Figure 4 shows that the lowest average years of experience was 14 years. This indicates that the participants of the survey were experienced enough to provide responses for this research.

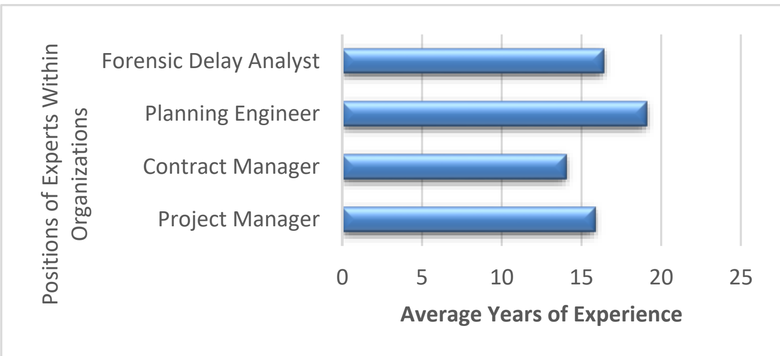


Figure 4: Average Years of Experience of Participants in Each Role

A five-point Likert scale was used in the survey to evaluate the significance of each of the factors on the selection of the DAT. In order to calculate the weighted relative importance index for each factor Equation (1) was used in which the values given by all experts were added, divided by the maximum value a factor could have obtained which equals 450, transformed to percentages and ranked as shown in Table 8.

$$\text{Factor Weighted RII} = \frac{\sum_{i=1}^{i=N} X_i \div (N\times 5)}{\sum_{j=1}^{j=Y}\left(\sum_{i=1}^{i=N} X_i \div (N\times 5)\right)_j} \times 100\% \qquad (1)$$

where:

N = the number of the responses for the first survey.

X = the score given in each response to the factor for which the RII is being calculated.

Y = the number of factors in the survey, which is 19.

Comparing the results of the first survey, shown in Table 8, with the combined ranking of the factors developed in Table 5, shows that the top three factors remain almost the same with the exception that the most important factor is form of contract (Contract Conditions). Although several works highlight how this factor is a major one in the selection, its rank was never the highest. In addition, it can be noticed that complexity of the project factor achieved a higher rank than it was in the combined overall ranking in Table 5. This factor importance was highlighted by Enshassi (2008) who established that the selection of APvAB as the most common DAT in Gaza strip was due to the low complexity nature of projects being conducted there. Status (stage at which delay analysis takes place) factor achieved a high importance which aligns with Abouorban et al. (2018) study that at different project stages, parties might choose different DATs. This was later emphasized through results of survey two.

Table 8: Filtered factors after Ranking according to survey one

Factor	Claimed Statement	Weighted Relative Importance Index	Rank
Form of contract (Contract Conditions)	A clause in the contract stipulating the DAT to be used affects the selection of the DAT	6.62%	1
Records availability	Degree to which existence of project updates affect the selection of	6.44%	2
Baseline programme availability	Availability and use of a baseline program are critically required for some DATs while unnecessary for others.	6.42%	3
Updated programme availability	Availability of such program updates is a must for some DATs.	6.31%	4
Nature of baseline programme	Use of baseline program is critically required for some DATs more than others.	6.30%	5
Complexity of the Project	Degree to which the complexity/project type affect the selection of DAT.	6.19%	6
Status (Stage at which delay analysis takes place)	Some DATs are used retrospectively while others are used prospectively. The Degree to which the timing at which the delay analysis takes place affect the DAT selection.	6.17%	7
Reliability of project schedules	Applicability of some DATs depends on reliability of project updates.	5.91%	8
Dispute resolution forum	An Engineer will accept or reject a DAT based on his experience and evaluation of the claim whereas a judge may accept it based on case law.	5.35%	9
Nature of the Delaying events	Some DATs are more suited to EOT claims while other DATs tackle costs more thoroughly. Type of Major Delay Event (NonExcusable/Excusable Compensable/etc..) is affected as some techniques cover concurrency better than others and thus concurrent delay may provide extension of time but not cost.	5.34%	10
Skills of the analyst	Some DATs are more complex than others. The degree to which level of skills of the team performing the analysis affects the DAT selection.	5.27%	11
Number of delaying events	Some DATs are more effective when there are many claimed events	4.65%	12
Time availability for delay analysis	Some DATs require more time than others to be performed. Degree to which the availability of time affects the DAT selection.	4.33%	13

Factor	Claimed Statement	Weighted Relative Importance Index	Rank
The other party to the claim	Attitude of the opponent party may indicate whether there will be future business between the parties or not. Also, it may indicate if the party will generally be lenient with the other party's DAT selection or will require a lot of convincing regarding the validity of the selection.	4.31%	14
Time of the delay occurrence	Time of delay occurrence relative to the stage of the project. Some DATS are more suited to work prospectively or retrospectively.	4.30%	15
Amount in dispute	Some DATs are more effective when the claimed cost is large	4.27%	16
Need of showing concurrent delay/mitigation	Some DATs cover concurrency better than others. Degree to Which the existence of concurrency related clause would affect the DAT selection	4.25%	17
Size of project	Some DATs are more effective for large-size projects	3.79%	18
Cost of using the technique	Some DATs require more resources (team, project updates, software, etc..) than others. Degree to which availability of money affects the DAT selection.	3.78%	19

3.1.3 Second Survey

Table 9 shows the criteria for each of the factors in the first survey. In the second survey, experts were asked to score the contribution of each factor's criteria regarding the selection of the five DATs. The objective of the second survey was to come up with sub-weights for the criteria. These sub-weights were then multiplied by the factors' weights obtained from the first survey to provide the user with a score for each DAT that is based on his/her selection of the criteria for each factor. Some criteria were considered based on the work of Perera et al. (2016) and Abouorban et al. (2018). Other criteria were established based on the semi-structured interviews.

Table 9: Criteria set for each Factor

Factor	Criteria
F1. Form of contract (Contract Particular Conditions)	C1. Contract Doesn't Specify a DAT C2. Contract Specifies a Retrospective Tech. C3. Contract Specifies a Prospective Tech. C4. Contract Specifies a Specific DAT
F2. Records availability	C1. Frequently C2. Occasionally C3. Rarely
F3. Baseline programme availability	C1. Available C2. Not Available
F4. Updated programme availability	C1. No Updated programme Available C2. Updated programme but not most recent C3. Most recent programme available
F5. Nature of baseline programme	C1. CPM C2. Non-CPM
F6. Complexity of the Project	C1. Simple (typical project undertaken before) C2. Complex (specialized project not familiar)
F7. Status (Stage at which delay analysis takes place)	C1. Preconstruction phase (i.e., Design) C2. Amid of Construction Phase C3. Close-Out Phase (i.e., Testing)
F8. Reliability of project schedules	C1. Reliable C2. Not Reliable
F9. Dispute resolution forum	C1. Engineer/Project Management Office C2. DAB/Arbitration/Court
F10. Nature of the delaying events	C1. Non-Excusable C2. Excusable/Compensable C3. Excusable/Non-Compensable
F11. Skills of the analyst	C1. Novice C2. Intermediate C3. Advanced
F12. Number of delaying events	C1. Few C2. Moderate C3. Many
F13. Time availability for delay analysis	C1. Time is not a constraint C2. Time is limited
F14. The other party to the claim	C1. Lenient / seeks fair judgement C2. Not Lenient / seeks own interest
F15. Time of the delay occurrence	C1. Preconstruction phase (i.e., Design) C2. Amid of Construction Phase C3. Close-Out Phase (i.e., Testing)
F16. Amount in dispute	C1. Small C2. Moderate C3. Large
F17. Need of showing concurrent delay/mitigation	C1. Showing concurrency is required C2. Showing concurrent is not required
F18. Size of project	C1. Small C2. Medium C3. Large
F19. Cost of using the technique	C1. Cost is not a constraint C2. Cost is limited

3.1.3.1 Simple Additive Weighting Method in Research Perspective

By bringing together many perspectives from various practitioners and resolving disputes in human perceptions and judgments, simple additive weighting (SAW) aids in selecting the proper option from a range of choices. By giving numerical values to qualitative (subjective) input, SAW facilitated the mixing of quantitative and qualitative data and clearly demonstrated its ability to use mixed methodologies. SAW enables the development of the optimal compromise while allowing for variations in opinion. Such assessments can be quantified using the Likert scale, providing the benefit of comparing such subjective facts and information on an equal basis (Likert, 1932). SAW has the capacity to identify different constructed realities in disparities between practitioners handling delay claims perceptions, judgments, attitudes, and practises. As intangible phenomena, judgments and similar phenomena must first be quantified in order to be employed as variables.

As shown in Table 10, from survey 1, each factor obtained a weight. From survey 2, each sub factor, criterion, obtained a sub weight respective to each DAT. Multiplying the factor's RII by each criterion's RII and adding all multiplications for each DAT. The DAT with the highest value is the one that should be used. The weighted average of each factor and criterion can be represented by Equation (2).

$$\text{Criteria Weighted RII} = \frac{\sum_{i=1}^{i=N} X_i \div (N\times 5)}{\sum_{j=1}^{j=M}\left(\sum_{i=1}^{i=N} X_i \div (N\times 5)\right)_j} \times 100\% \qquad (2)$$

Where:

N = the number of the responses for the second survey.

X = the score given in each response to the criteria respective to each DAT

M = the number of DATs in the survey, which is 5.

Table 10: Sample of SAW calculations

Factor	Weights (Survey 1)	Criteria	Sub Weights (Survey 2)					Scores (Weight X Sub Weight)				
			IAP	CAB	APvAB	TIA	WA	IAP	CAB	APvAB	TIA	WA
Dispute Resolution Forum	5.35%	Engineer/Project Management Office	16.2%	17.4%	20.4%	25.8%	20.3%	0.9%	0.9%	1.1%	1.4%	1.1%
		DAB/Arbitration/Court	12.3%	20.5%	17.4%	25.2%	24.6%	0.7%	1.1%	0.9%	1.3%	1.3%
Nature of Delaying Events	5.34%	Non-Excusable	32.4%	11.7%	19.0%	18.7%	18.1%	1.7%	0.6%	1.0%	1.0%	1.0%
		Excusable/Compensable	24.0%	8.8%	19.8%	23.4%	24.0%	1.3%	0.5%	1.1%	1.2%	1.3%
		Excusable/Non-Compensable	24.0%	9.1%	19.1%	23.9%	24.0%	1.3%	0.5%	1.0%	1.3%	1.3%
Skills of the analyst	5.27%	Novice	33.1%	9.6%	32.1%	15.5%	9.7%	1.7%	0.5%	1.7%	0.8%	0.5%
		Intermediate	21.4%	17.0%	22.0%	21.4%	18.2%	1.1%	0.9%	1.2%	1.1%	1.0%
		Advanced	8.4%	22.8%	13.6%	27.9%	27.3%	0.4%	1.2%	0.7%	1.5%	1.4%

As will be discussed in chapter 4, the SAW model was tested on 142 actual case studies, out of which only 33 cases had different DAT selections between SAW model and the experts' selections. The SAW model was validated through a case study obtained from Perera et al. (2016), and it produced similar results to those of the case study.

3.2 ANN Model Development

3.2.1 Reasoning for Selecting ANN

Given to the intricacy of the problem, the nonexistence of a linear relation between input and output, and the increased capabilities of the artificial neural networks for classification using back propagation (BP) learning algorithm, this research resorted to building a classification model that utilizes ANN to classify the most suitable DAT to be used for a given construction related claim. ANN becomes one of the best options to be investigated as ANN has the ability to work with incomplete knowledge, are able to learn and model complex non-linear relationships. Moreover, ANN can handle large amount of data sets and has the ability to detach implicit non-linear relationship between dependent and independent variables. Once trained, ANN can come up with the output with great accuracies.

3.2.2 Structure of the Model

The developed model consists of three modules: 1) inputs module, 2) classification module, and 3) output module, each of the modules consists of sub-modules as shown in Figure 5. In the inputs module, the user selects a criterion for each of the 19 delay analysis selection factors which are divided into four groups: a) project related factors, which evaluates project current conditions in terms of size, records and complexity, b) parties related factors, which evaluates the available resources to conduct the analysis, the capabilities of the analyst and the attitude of the opposing party, c) delay related factors, which covers time, nature and number of delay events and d) legalities related factor, which deals with the contract conditions and entity evaluating the claim.

In the classification module, the model uses a combination of Excel's visual basic for applications and Palisade software, NeuralTools, which specializes in artificial neural networks to recommend the most suitable delay analysis technique based on the inputs (Holley, 2005).

In the output module, the model outputs the most suitable delay analysis technique based on the inputs and its corresponding advantages and disadvantages and application steps. Also, the model provides recommendations for the user regarding the criteria selected for the factors in order for the user to be aware of possible points of weaknesses that he/she might be challenged with.

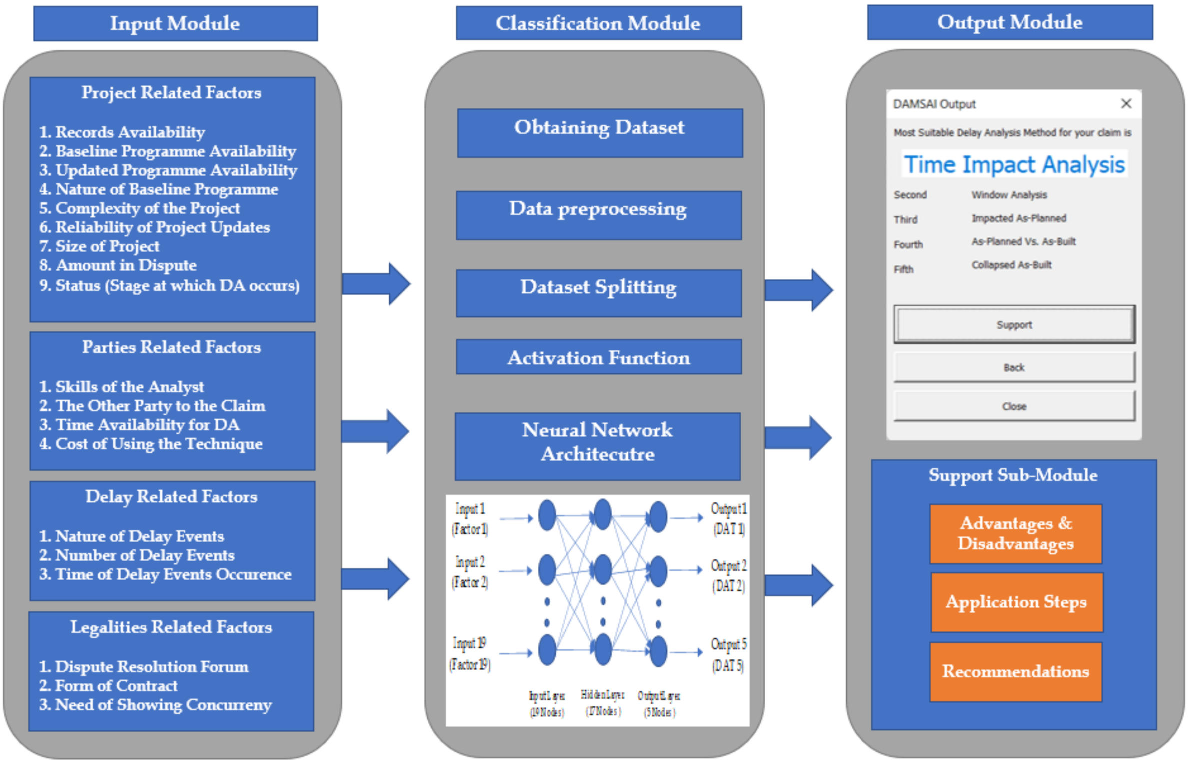


Figure 5: Methodology for the Developed ANN Model

3.2.3 Model Design and Parameters

3.2.3.1 ANN Architecture

The ANN network developed in this research includes 19 input neurons and 5 output neurons. Hegazy et al. (1994) suggested that a single hidden layer can introduce random mapping between inputs and outputs, and that the number of neurons in the hidden layer is between two-thirds to twice the number of input neurons. A major conclusion according to Heaton (2017) is that determining how many hidden layers should be used in an ANN is subject to no specific rule. To determine the most suitable number of hidden layers, one of two alternatives can be used. The first alternative is trial and error, while the second is using optimization techniques such as genetic algorithm. However, as a starting point, several rule-of-thumb approaches can be used to decide on a suitable quantity of neurons to be used in the hidden layer(s) (Heaton, 2017). Some of these rules of thumb are the following:

1. "The number of hidden neurons should be between the size of the input layer and the size of the output layer.
2. The number of hidden neurons should be 2/3 the size of the input layer, plus the size of the output layer.
3. The number of hidden neurons should be less than twice the size of the input layer" (Heaton, 2017).

Palisade software NeuralTools, which is fully integrated with the modeling platforms in Microsoft Excel, is used to perform the ANN analysis (Holley, 2005). The tool can either have the number of hidden layers and neurons inputted by the user or use optimization process to determine these values, in such a case, the values are not shown to the user. According to Heaton (2017) second rule of thumb, the number of neurons in the hidden layer is calculated as follows in Equation (3):

$$\left(\frac{2}{3} \times Number\ of\ Input\ Neurons\right) + Number\ of\ Output\ Neurons = \left(\frac{2}{3} \times 19\right) + 5 = 17 \qquad (3)$$

The number of parameters (weights) is calculated as following in Equation (4):

$$\begin{aligned}&(Number\ of\ Neurons\ in\ Input\ Layer\ \times\ Number\ of\ Neurons\ in\ Hidden\ Layer) +\\ &(Number\ of\ Neurons\ in\ Hidden\ Layer\ \times\ Number\ of\ Neurons\ in\ Output\ Layer)\\ &= (19 \times 17) + (17 \times 5) = 408 \qquad (4)\end{aligned}$$

3.2.3.2 Sample Size

Determining sample size required for an ANN is a challenge in itself. According to Alwosheel et al. (2018), the number of cases in a dataset needs to be at least 50 times larger than the number of weights in the network to enable sufficient performance as indicated in Equation (5).

$$\#\ of\ Observations\ for\ Data\ Set = 50 \times Number\ of\ parameters = 50 \times 408 = 20{,}400 \qquad (5)$$

3.2.3.3 ANN Data Set

To obtain the required number of cases, the researcher followed the several approaches:

1. The first approach was reviewing the literature; however, few papers such as Perera et al. (2016) and Parry (2015) showed details of cases leading to selection of DATs.

2. The second approach was collecting actual case studies from the experts. A total of 142 actual cases was collected.

3. The third approach was investigating case law; however, when judges issue a reasoned decision, they do not mention which DAT was used in the case.

4. The fourth approach was collecting arbitration cases where it was found that only 211 construction related cases were administered by the Cairo Regional Center for International Commercial Arbitration (CRCICA) from 2007 to 2018 as shown in Table 11 (CRCICA Annual Reports, 2022). According to Burr (2005), arbitration cases not becoming public is one reason behind the lack of cases to demonstrate the relation between the DATs and making a successful claim.

Table 11: Cases administered by CRCICA (2007-2018)

Year	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	Total
Total New Cases	67	55	51	66	66	78	73	74	54	91	65	77	**817**
Construction Cases	21	21	29	31	12	11	12	10	13	23	12	16	**211**
% Of total	31.3%	38.2%	56.9%	47%	18.2%	14.1%	16.4%	13.5%	24.1%	25.3%	18.5%	21%	**26%**

The available cases are far below the number needed to develop the ANN. Accordingly, reviewing the literature revealed an approach, synthetic data generation, to overcome the lack of data. Synthetic data generation is needed in areas where data is scarce or privacy of data is of great importance (Liu et al., 2022). Several papers such as those of Petroll et al. (2021), Diffner and Hovig (2020), Feng et al. (2018) and Balog et al. (2017) propose different ways to generate synthetic data to train ANN models. Generally, the approaches depend on determining a valid set of inputs and outputs and then generating random scenarios while excluding invalid scenarios.

For instance, Petroll et al. (2021) generated synthetic data for engine designs. The data generation processes ensured that generated data followed physical and functional constraints and that no duplicate designs were included in the dataset. Balog et al. (2017) imposed constraints on the output value bounding integers to some predetermined range, and then propagated these constraints backward to determine the valid range of inputs for the given output. If any of the inputs were not determined, the whole iteration (case) would be disregarded. Similar to the approaches found in the literature, this research proposes an approach to synthetically generate data as follows:

1. Determine a valid range of inputs. As shown previously, 19 factors were considered for the selection.
2. Determine a valid range of outputs. As shown previously, the five most commonly used DATs were identified.
3. Develop a conceptual model using SAW to generate Input-Output dataset.
4. Test and validate the SAW model (explained in chapter 4).
5. Determine the number of cases needed to be generated.
    - The number of cases needed to train a neural network with 19 inputs is determined as 20,400 cases through Equation (5).
6. Generate cases and then remove duplicates.
    - 30,000 cases were generated. 259 duplicate cases were removed.
    - Figure 6 shows the VBA code that was developed to generate random cases.

```
Sub GeneratingCases()

Dim i As Long
Dim x As Integer
Dim y As Integer
Dim z As Integer

x = 1 'denotes criteria (a)
y = 2 'denotes criteria (b)
z = 3 'denotes criteria (c)

For i = 1 To 30001 'This will itterate for 30,000 cases

Range("A1") = WorksheetFunction.RandBetween(x, z) 'Factor 1
Range("B1") = WorksheetFunction.RandBetween(x, z) 'Factor 2
Range("C1") = WorksheetFunction.RandBetween(x, y) 'Factor 3
Range("D1") = WorksheetFunction.RandBetween(x, z) '
Range("E1") = WorksheetFunction.RandBetween(x, y) '
Range("F1") = WorksheetFunction.RandBetween(x, y) '
Range("G1") = WorksheetFunction.RandBetween(x, z) '
Range("H1") = WorksheetFunction.RandBetween(x, y) '
Range("I1") = WorksheetFunction.RandBetween(x, y) '
Range("J1") = WorksheetFunction.RandBetween(x, z) '
Range("K1") = WorksheetFunction.RandBetween(x, z) '
Range("L1") = WorksheetFunction.RandBetween(x, z) '
Range("M1") = WorksheetFunction.RandBetween(x, y) '
Range("N1") = WorksheetFunction.RandBetween(x, y) '
Range("O1") = WorksheetFunction.RandBetween(x, z) '
Range("P1") = WorksheetFunction.RandBetween(x, z) '
Range("Q1") = WorksheetFunction.RandBetween(x, y) '
Range("R1") = WorksheetFunction.RandBetween(x, z) '
Range("S1") = WorksheetFunction.RandBetween(x, y) 'Factor 19

'copying the randomly generated case (consisting of 19 cells)
ActiveSheet.Range(Cells(1, 1), Cells(19, 1)).Select
Selection.Copy

'pasting the randomly generated case in row (i)
ActiveSheet.Range(Cells(i, 34)).Select
Selection.PasteSpecial Paste:=xlPasteAll, Operation:=xlNone, SkipBlanks:= _
        False, Transpose:=False

're-iterate to generate next random case
Next i

End Sub
```

Figure 6: VBA Code to Generate Random Cases' Inputs

- Figure 7 shows the VBA code that was used to calculate the outputs for the randomly generated cases based on the SAW model.

```
Sub CalculatingOutputForCases()

Dim i As Long

For i = 1 To 30001 'This will iterate for 30,000 cases

'Copying randomly generated case (i)
ActiveSheet.Range(Cells(i, 34), Cells(i, 52)).Select
Selection.Copy

'Pasting the case to SAW model
Range("Y10").Select
Selection.PasteSpecial Paste:=xlPasteAll, Operation:=xlNone, SkipBlanks:= _
False, Transpose:=True

'Copying the output of the SAW model
Range("Y30").Select
Application.CutCopyMode = False
    Selection.Copy

'Pasting the output next to the randomly generated case's inputs
Cells(i, 53).Select
Selection.PasteSpecial Paste:=xlPasteValues, Operation:=xlNone, SkipBlanks _
:=False, Transpose:=False

're-iterate until outputs have been calculated for all cases.
Next i

End Sub
```

Figure 7: VBA Code to Calculate Random Cases' Outputs

7. Develop criteria to rule out cases with invalid outputs.
    - Some of the criteria presented in five of the factors can prevent the usage of some DATs. Thus, a rule-based matrix, Error Matrix, was developed to rule out any case with conflicting input(s) and output.
    - Out of the 29,741 cases, 7,568 invalid cases were removed. 22,173 were deemed valid for building the ANN model.
8. Represent the generated data reflecting percentage of occurrence for each variable.
    - Developed analysis dashboard
9. Use the generated data to train the ANN model.
10. Test the ANN model developed from the synthetic data.
    - Obtained 142 actual case studies from the experts.
    - Compared the results collected from the experts to those predicted by the ANN model to ensure that the ANN developed through the proposed model can successfully match the selection of the experts.
11. Validate the ANN model.
    - Validated the ANN model by comparing its results to those of the case study of Perera et al. (2016).

As shown in Table 12 the Error Matrix was established by studying the effects of different factors on the application of the DATs. It was established for the purpose of ruling out invalid cases. The values in bold in the highlighted cells represent criteria that cannot be used for the corresponding DAT. For instance, factor 3 "Baseline Program Availability, criterion 2 "Not Available" prevents the application of all the DATs except for CAB (Perera et al., 2016). Thus, all the generated cases that had such inputs and recommended a DAT other than the CAB are considered invalid and removed.

Table 12: Error Matrix to Rule Out Invalid Cases

Factors / DATs	F1	F2	F3	F4	F5	F6	F7	F8 to F14	F15	F16 to F19
IAP	C2		C2		C2					
CAB	C3		-		-					
APvAB	C3	N/A	C2	N/A	-	N/A	Refer to Tables 13-14	N/A	Refer to Tables 13-14	N/A
TIA	-		C2		C2					
WA	C3		C2		C2					

The purpose of the Error Matrix is to rule out invalid cases by examining the applicability of the output DAT given the corresponding criteria, shaded values in selected in the factors 1, 3, 5, 7 and 15.

Table 13 focuses on factors 7 and 15 which are concerned mostly with analyzing whether a delay is occurring retrospectively or prospectively. For instance, if the user inputs criteria 2 in factor 15 and criteria 1 in factor 7 that indicates that the analysis will be carried prospectively. All the cases with such inputs and recommend a retrospective DAT such as WA are considered invalid and removed from the data set.

Table 13: Error Scenarios Depending on DATs Cateogries

F15: Delay Occurrence	F7: Analysis Occurrence	Outcome
C1: Preconstruction Phase - i.e., Design	C1: Preconstruction Phase - i.e., Design	Either
C1: Preconstruction Phase - i.e., Design	C2: Amid of Construction Phase	Retrospective
C1: Preconstruction Phase - i.e., Design	C3: Close-Out Phase (i.e., Testing)	Retrospective
C2: Amid of Construction Phase	C1: Preconstruction Phase - i.e., Design	Prospective
C2: Amid of Construction Phase	C2: Amid of Construction Phase	Either
C2: Amid of Construction Phase	C3: Close-Out Phase (i.e., Testing)	Retrospective
C3: Close-Out Phase (i.e., Testing)	C1: Preconstruction Phase - i.e., Design	Prospective
C3: Close-Out Phase (i.e., Testing)	C2: Amid of Construction Phase	Prospective
C3: Close-Out Phase (i.e., Testing)	C3: Close-Out Phase (i.e., Testing)	Either

Table 14 shows that out of the 9 possible combinations between factor 15 and factor 7, only three would be valid for a prospective technique such as IAP and three would be valid for a retrospective technique such as CAB, APvAB, or WA. There are three scenarios that would be valid for either prospective or retrospective techniques.

Table 14: Possible Outcomes for Each DAT

DATs	Usage	Possible Outcomes
IAP	Prospective	6
CAB	Retrospective	6
APvAB	Retrospective	6
TIA	Either	9
WA	Retrospective	6

After applying the Error Matrix, the number of cases was cut down to 22,173 cases from the remaining 29,741 cases by eliminating 7,568 cases identified in the process to have an adverse effect on the accuracy of training.

The model predicts the most suitable DAT; yet the most suitable DAT isn't necessarily the most suitable for each factor independently but rather for the given 19 factors altogether. Similar to the Error Matrix shown above, Advice Matrix was created to be included in the support module of the model. Table 15 shows the Advice Matrix which was developed to automatically spot cases in which no DAT meets all criteria selected. The model will recommend to user the most suitable DAT while giving recommendations on what can be improved or changed to make the recommended DAT more suitable and applicable.

Table 15: Advice Matrix Based on Criteria

Factors / DATs	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12	F13	F14	F15	F16	F17	F18	F19
IAP						C2			C2		C3	C3				C3	C1	C3	
CAB		C3				C1				C1	C1	C1	C2			C1		C1	C2
APvAB						C2					C3	C3				C3		C3	
TIA				C1		C1				C1	C1	C1	C2			C1		C1	C2
WA				C1		C1				C1	C1	C1	C2			C1		C1	C2

The Advice Matrix works when any of the user input criteria matches the criteria in the Advice Matrix corresponding to the predicted DAT. For instance, factor 16 "Amount in dispute", criterion 1 "Small" indicates that there may not be a need to perform a complex DAT since the amount in dispute is of small value and thus using a less sophisticated, costly and time demanding DAT would be recommended. Figure 8 shows that the total number of the originally generated cases, 29741 cases, after removing duplicate cases, was reduced to 22,173 cases after removing invalid cases.

Figure 8: Total Number of Valid and Invalid Cases

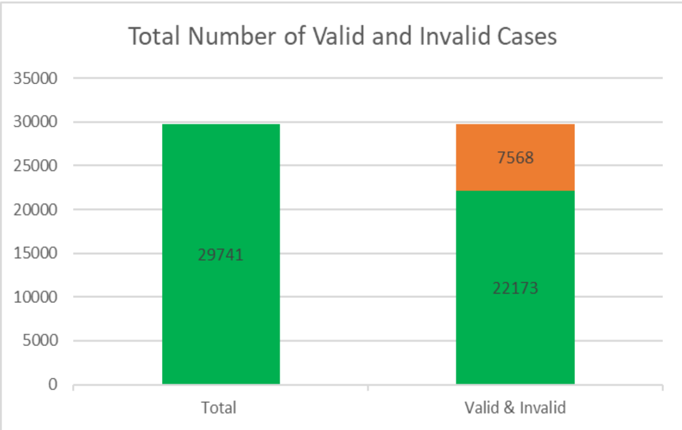


Figure 9 shows the total number of cases generated for each DAT. Figure 10 shows the numbers and percentages of valid and invalid cases for each DAT. The ranking of recommended DATs after removing invalid cases remains the same as the ranking prior to removing invalid cases; however, the gap between the number of cases recommending IAP and TIA widens while the gap between APvAB and CAB shrinks. This can indicate that analyzing more cases may shift the ranking possibly resulting in CAB achieving a lower rank.

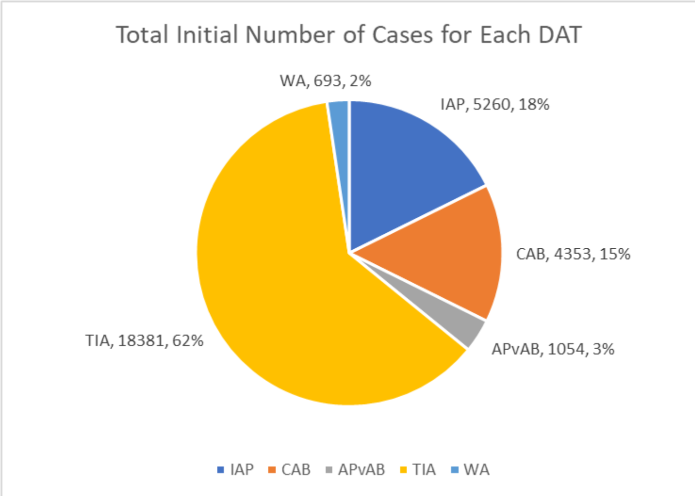


Figure 9: Number of Cases in each DAT

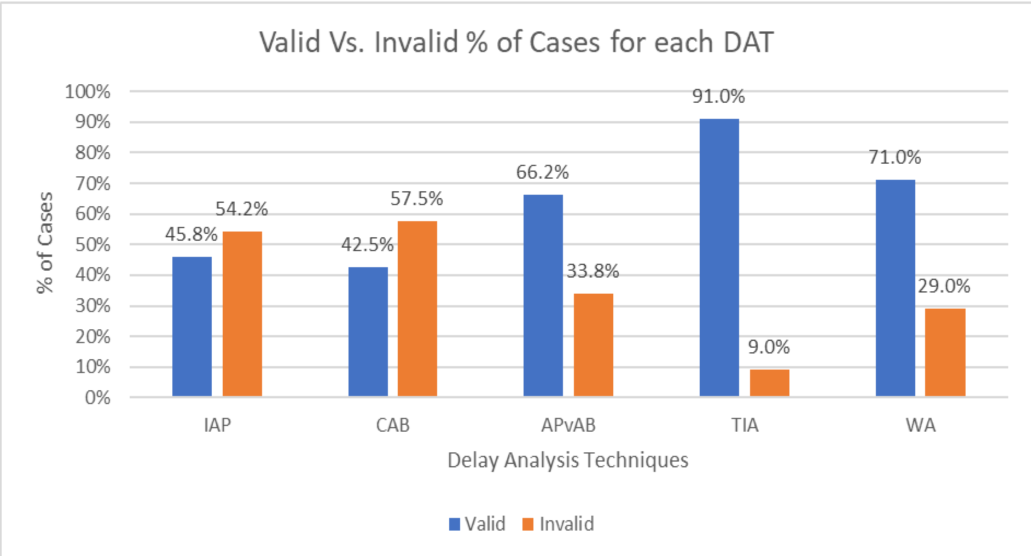
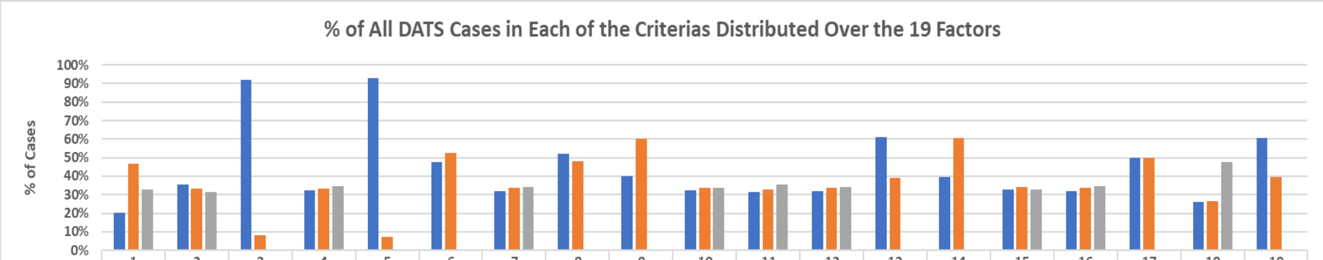


Figure 10: Valid Vs. Invalid % of Cases for each DAT

It is reasonable to assume that TIA being used either retrospectively or prospectively is a reason behind resulting in more cases recommending TIA in the training data set of the model. It would be recommended for future research to consider establishing prospective TIA independently of retrospective TIA. Figure 11 shows the percentage of all cases distributed over the criteria of the 19 factors. Although the cases that were used to build the model were generated randomly based on the scoring model built on the weights and sub weights obtained from the first and second survey, we can deduce that in factors 2, 4, 6, 7, 8, 10, 11, 12, 15, 16, and 17 there the cases had an almost even distribution among the criteria set for each factor. For factors 1, 9, 13, 14, 18, and 19, one of the criteria was a little more represented in the generated cases more than the other(s). For instance, factor 19, Cost of

Using the Technique, has a representation of 61% that for criterion 1, cost is not a constraint, while 39% of the cases had criterion 2 which is that cost is limited.



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Criteria 1	20%	35%	92%	32%	93%	48%	32%	52%	40%	33%	32%	32%	61%	40%	33%	32%	50%	26%	61%
Criteria 2	47%	33%	8%	33%	7%	52%	34%	48%	60%	34%	33%	34%	39%	60%	34%	34%	50%	26%	39%
Criteria 3	33%	31%		35%			34%			34%	35%	34%			33%	34%		48%	

Figure *11*: % of each of the criteria in each factor

For factors 3 and 5, the representation was uneven with one criterion excessively represented more than the other. In factor 3, Baseline Programme Availability, 92% of the cases had criterion 1 which is that baseline program is available, while only 8% of the cases had criterion 2 which is that baseline program is not available. This uneven ratio was not obtained by chance, but rather the generation of cases was directed towards reaching this uneven distribution because it is believed that having a baseline program is a common requirement in most of the construction projects nowadays. For instance, in the FIDIC general conditions, the contractor have to submit a baseline schedule for the project (Wael et al., 2020). Also, almost all the DATs require a CPM schedule to provide reliable results. Similarly, more cases for criterion 1, CPM schedule, in factor 5, Nature of Baseline Program, were generated.

Figure 12 shows the percentage of all the cases that had IAP as the predicted DAT distributed over the criteria of the 19 factors. For factor 1, the DAT was not predicted even once when factor 1, Contract Conditions, criterion 2, contract specifies a retrospective technique, was among the inputs of the case. This aligns with the fact that IAP is a prospective technique. For factor 3, Baseline Program Availability, it can be noted that IAP was never predicted when the factor 3 had criterion 2 which is that no baseline program is available.

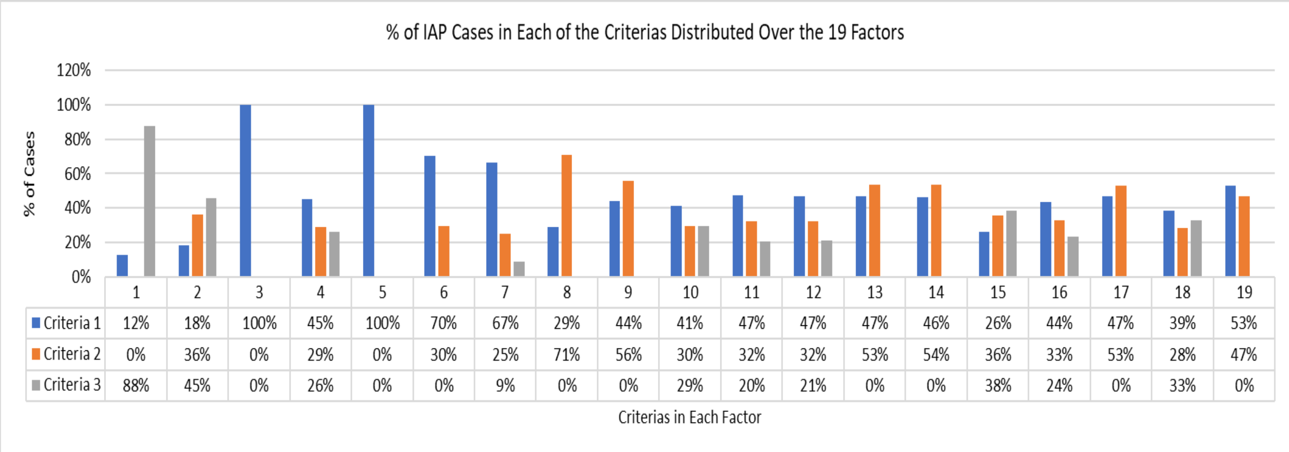


Figure 12: % of each of the criteria in each factor resulting in IAP

Figure 13 shows that almost all the cases which had CAB as the DAT recommended had criteria 2, contract specifies a retrospective technique selected in factor 1. Similarly, criteria 2 in factor 3 was in 99% of the cases in which CAB was recommended. Factor 5, Nature of Baseline Program, has almost close values in each of the two criterions as CAB can be used without a CPM schedule as indicated by Perera et al. (2016). All the remaining factors' criteria are evenly represented in the cases.

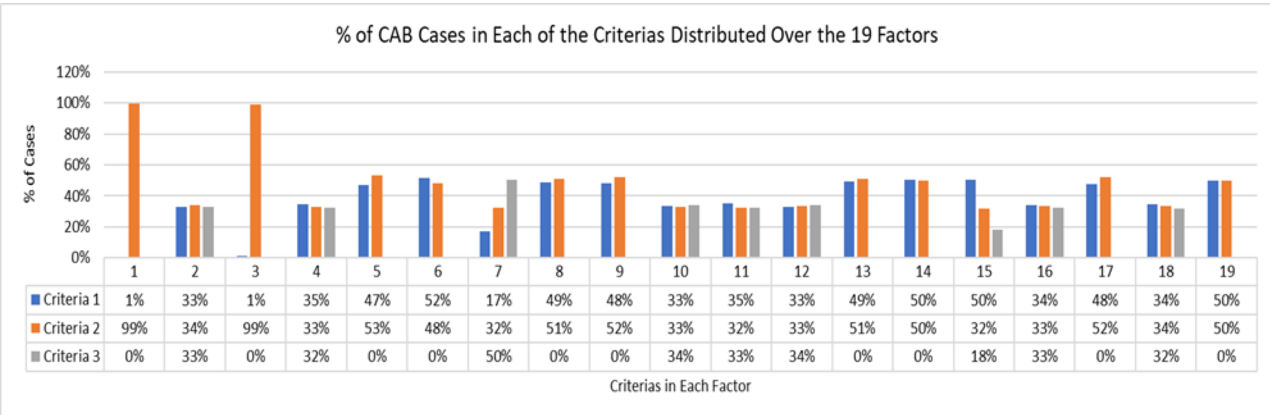


Figure 13: % of each of the criteria in each factor resulting in CAB

From Figure 14, it can be noted how 94% of the cases in which the APvAB was the predicted DAT had Factor 5, Nature of Baseline Programme, criterion 2, Non-CPM which aligns with the work of Parry (2015) and Perera et al. (2016). Also, 100% of the cases in which APvAB was the predicted DAT had factor 1, Contract Conditions, criterion 2, contract specifies a retrospective technique.

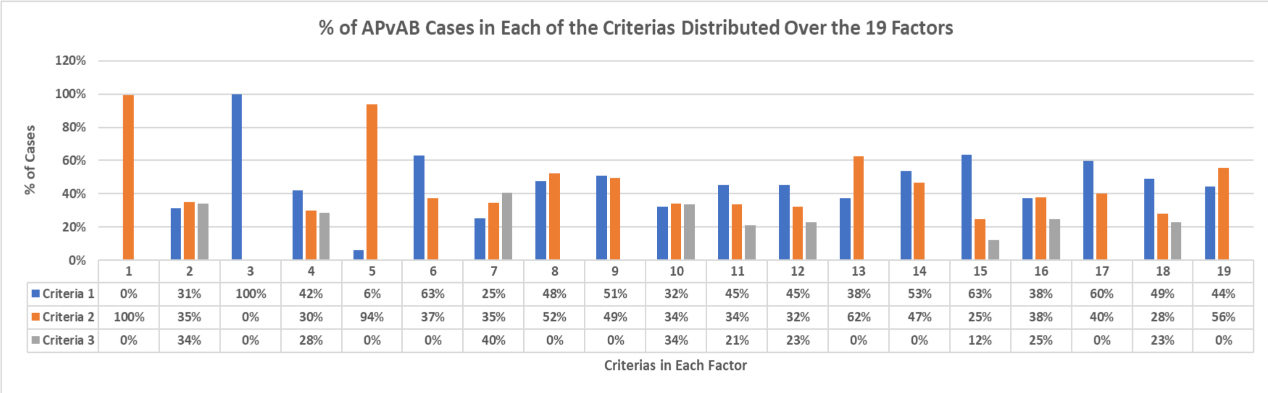


Figure 14: % of each of the criteria in each factor resulting in APvAB

Figure 15 shows how the all the cases in which TIA is the recommended DAT include that a CPM baseline schedule should be available as indicated by criteria 1 in both factors 3 and 5. The distribution of cases over the three criteria in factor 1 is slightly uneven showing that TIA is the recommended DAT in more cases when the contract specifies a retrospective technique rather than when the contract specifies a prospective technique or doesn't include conditions regarding DAT selection.

Factor 13 and 19, related to time and cost limitations, show that more cases in which TIA is recommended have time and cost unconstrained. Factor 18 shows that more than 50% of the cases that recommended TIA had large project size.

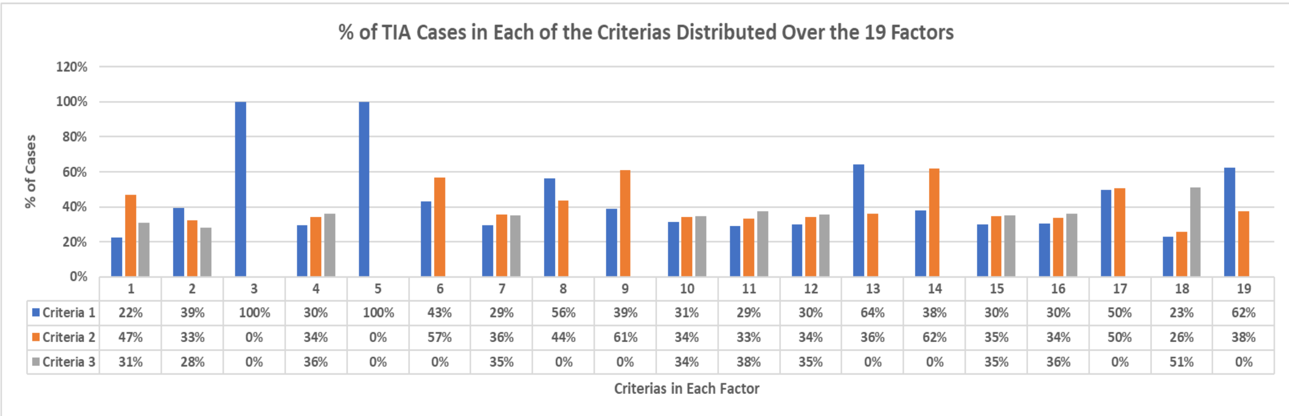


Figure 15: % of each of the criteria in each factor resulting in TIA

Figure 16 shows that, similar to TIA cases, cases in which WA was recommended include that a CPM baseline schedule should be available as indicated by criteria 1 in both factors 3 and 5. For factor 7, Status (Stage at which Delay Analysis Takes Place), most of the cases show that WA is recommended when the analysis takes place towards the end of the project which is similar to the conclusion of Abouorban et al. (2018).

Factor 9 shows that 100% of the WA cases had criteria 2, DAB/ Arbitration/ Court, selected in factor 9 which indicates that WA, similar to TIA, may be more favored in court proceedings (Perera et al., 2016; Arditi, 2006).

WA majority of cases show that in order to implement WA an analyst with advanced skills is needed. Another conclusion can be drawn from factor 12 is that WA, similar to TIA, is recommended in cases when there are many delay events. Factor 13 and 19, related to time and cost limitations, show that more cases in which WA is recommended have time and cost unconstrained. From factor 18, it can be noted that WA cases were recommended only when the project's size was classified "large".

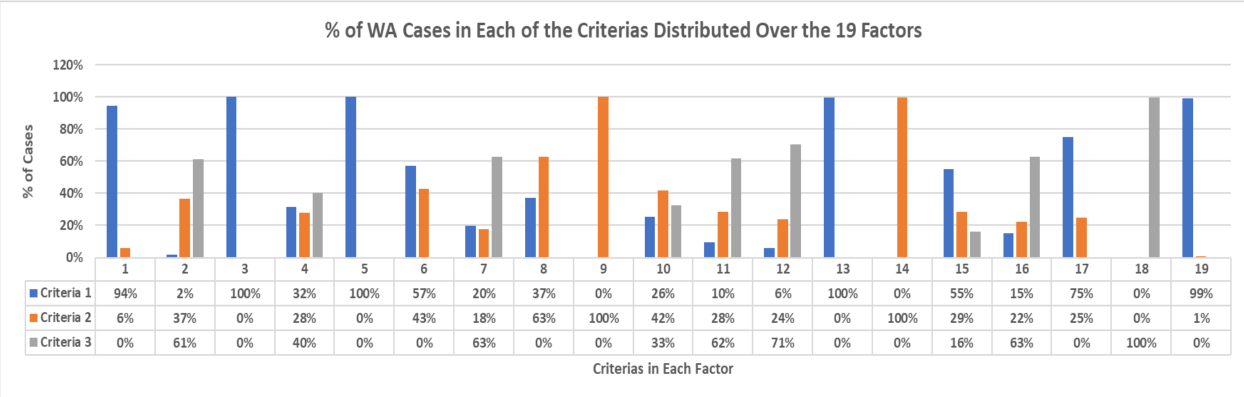


Figure 16: % of each of the criteria in each factor resulting in WA

Figure 11 to Figure 16 provide a swift way to analyze and validate the cases upon which the model was built as they show the distribution of cases of each DAT over the criteria, allowing the user to point out any anomalies.

Activation Function

Activation function introduces non-linearity to the ANN model by deciding on which neurons to be activated. This decision is based on adding bias to calculated weighted sum. (Sharma, 2020). A drawback of using NeuralTools is that the activation function is neither set by the user nor shared with the user. However, it is important to note that, generally, sigmoid functions are suited for classification problems since they return values more than zero and less than one and thus can represent existence probabilities of a data point with a specific set; however, a SoftMax function, which resembles a combination of sigmoid functions is more suited for multiclassification problems such as the one in this research. Probability of a datapoint matching to each specific set is the focus in multiclassification problems. (Analytics Vidhya, 2020).

3.2.4 Model Interface and application steps

Figure 17 to Figure 21 show the application steps for the model. The model is saved on an excel file that is macro enabled. Upon opening the file, the user shall start the model by clicking the “Start” button. The user selects a criterion for each of the factors then the model integrates with the NeuralTools ANN to recommend the most suitable DAT. The model provides support for the user in the form of referenced advantages and disadvantages, advice on factors that are not optimum with the predicted DAT and detailed application steps. The application steps are extracted from the work of Keane and Caletka (2009), so that a user who is not familiar with the DAT can find some guidance on how to apply it.

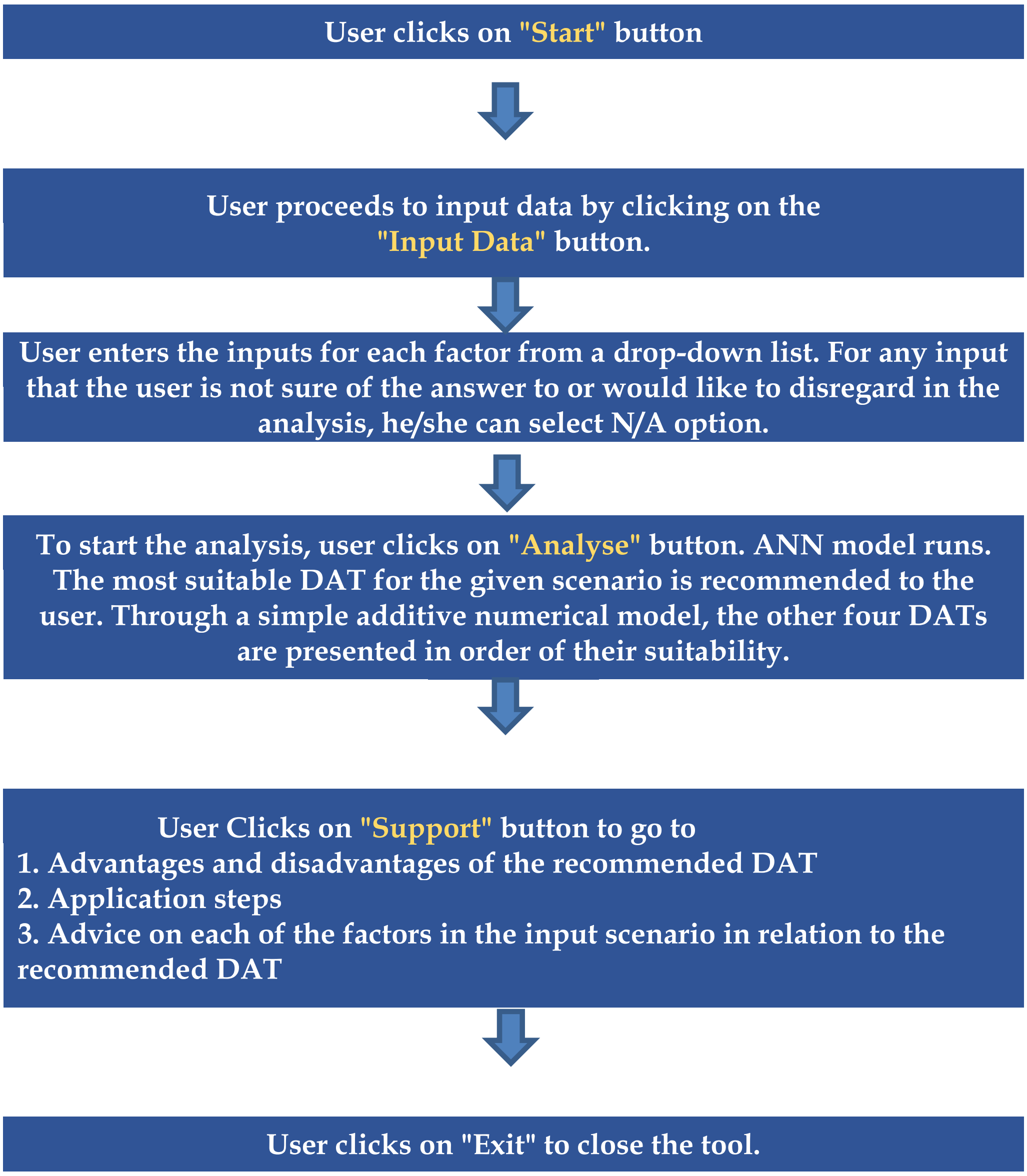


Figure 17: User Interface Application Steps

Figure 18 shows the welcome screen in which a brief introduction about the topic is provided.

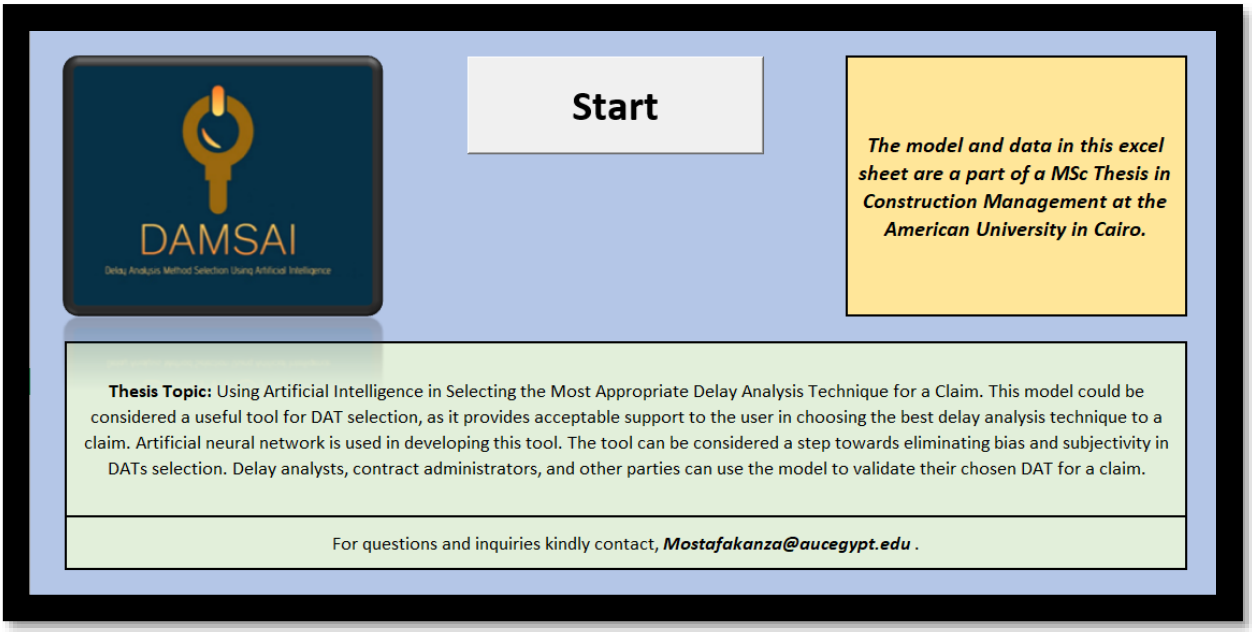


Figure 18: Welcome Screen Upon Opening the Excel File

Figure 19 shows the input user form in which user selects a criterion for each factor to start running the model.

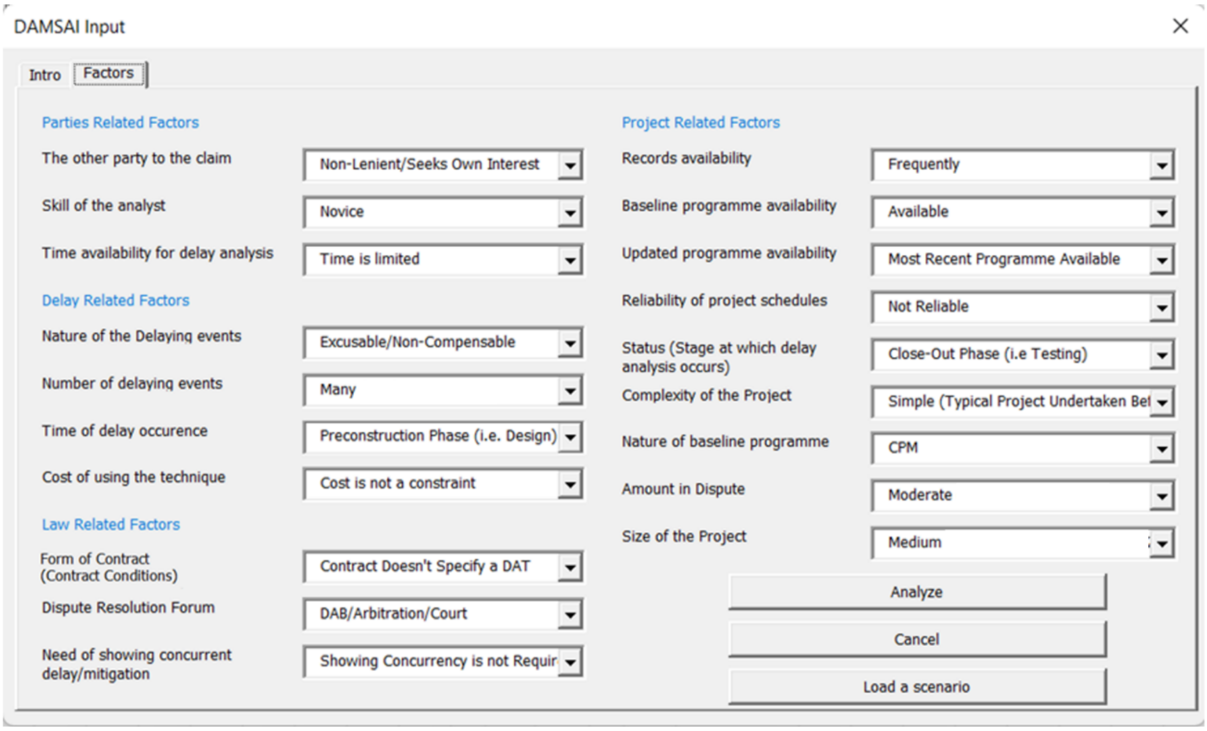
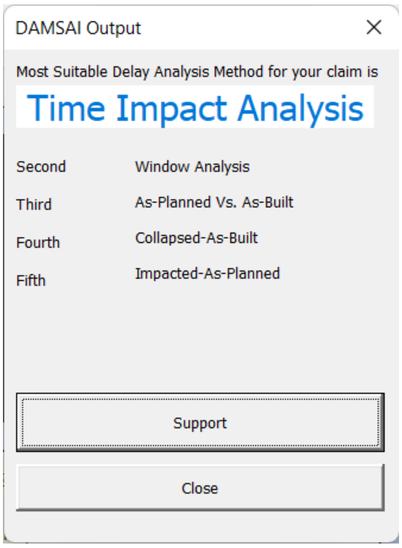


Figure 19: Input Data User Form

Figure 20 shows the interface for the output of the prediction of the most suitable DAT according to the ANN model. The model only predicts the most suitable DAT; however, the



remaining DATs are ranked according to the scoring model which is based on the weights obtained from the experts in the first and second surveys.

Figure 20: Output Data User Form

Figure 21 shows the interface for the model's support module from which the user can explore the advantages and disadvantages of the recommended DAT as well as its application steps. Also, the model provides recommendations regarding the inputs that the user has provided.

Figure 21: Support Decision Making User Form

Figure 22 shows the interface for the advantages and disadvantages of the predicted DAT. The advantages and disadvantages are referenced and provided as part of the model to provide a robust way for the user to evaluate the DAT and be aware of possible points that he can use to support his choice or possible weakness points that the selection can be challenged on.

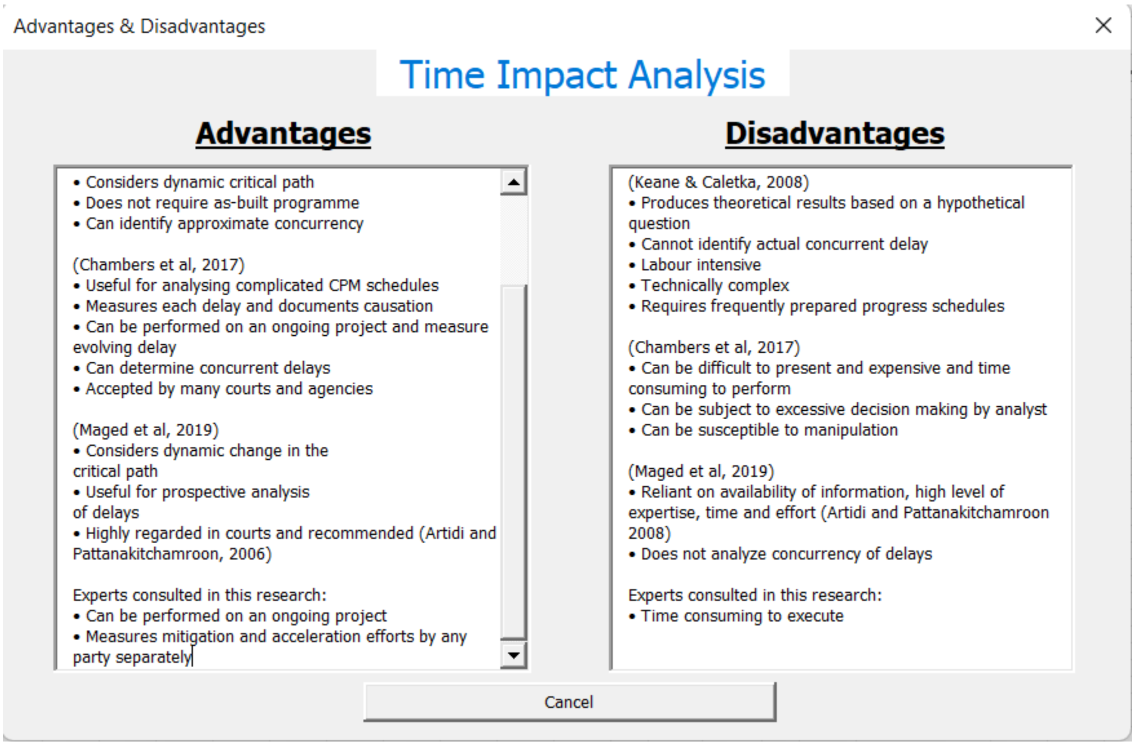


Figure 22: Advantages and Disadvantages of the Recommended DAT

Figure 23 shows the interface for the application steps provided for the recommended DAT. The purpose of these steps is to guide user, especially inexperienced ones, on how to apply DATs. These detailed steps were prepared following Keane and Caletka (2009). Users are also encouraged to consult guidelines such as SCL delay and disruption protocol (SCL, 2017).

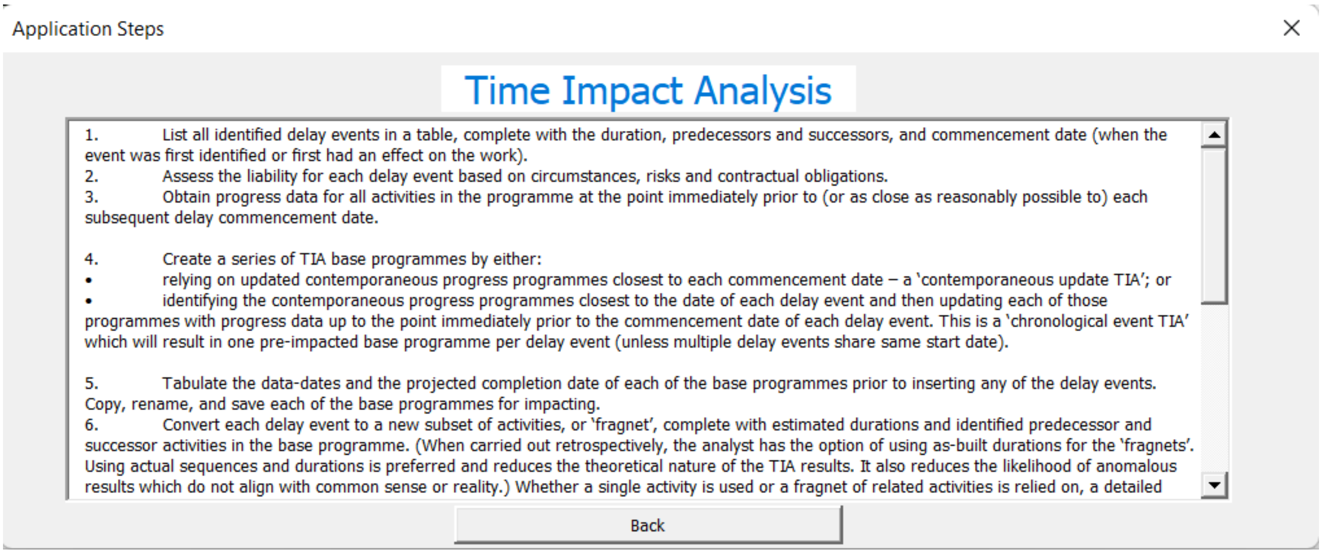


Figure 23: Application Steps of the Recommended DAT

Since the input criteria for each factor would not equally favor all DATs, the weights assigned through the ANN would determine which factors are more important and thus which DAT is the most suitable. Still through added-in logical framework, the model is able to point out to the user the factors with inputs that doesn't favour the selected DAT the most. There may be a case in which an input to one factor clearly contradicts with the needs of the selected DAT.

For example, Figure 24 shows the interface for the "Advice on Factors" tab for the predicted DAT. The most suitable DAT predicted is TIA; however, the user indicated in the inputs that the analyst who will carry out the analysis doesn't have much expertise. Thus, the advice presented by the model is to have a third party with more expertise conduct the analysis.

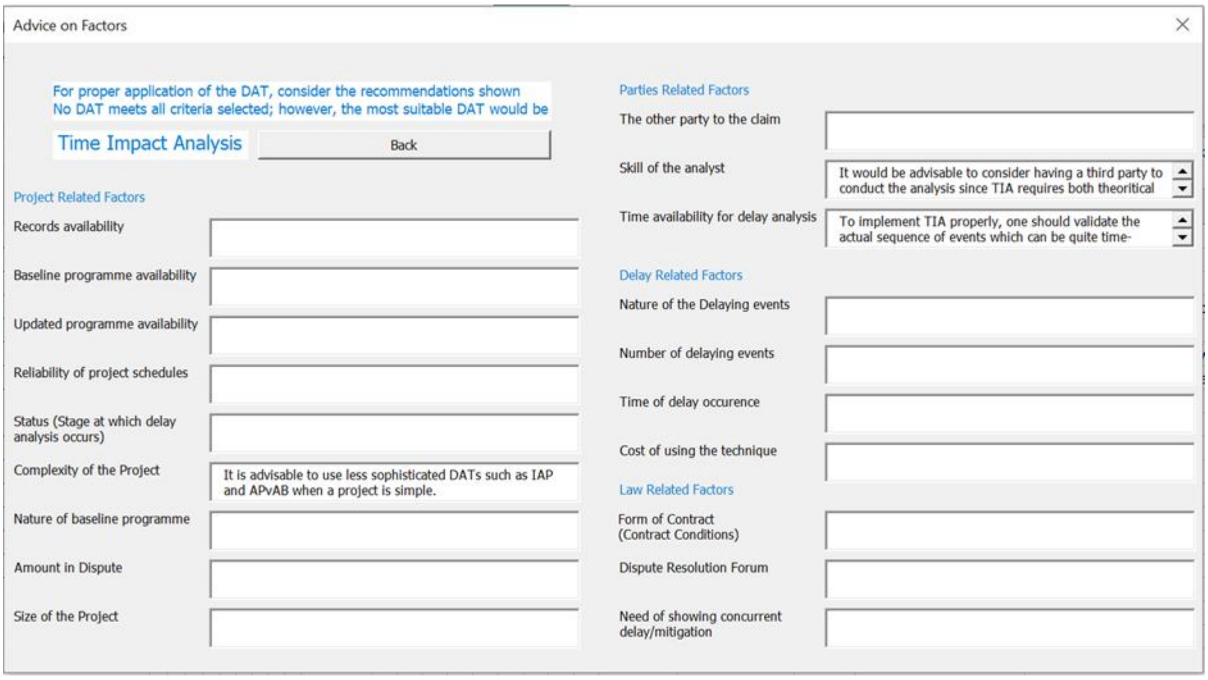


Figure 24: Advice on Factors for the Recommended DAT

Chapter 4

Model Application and Validation

4.1 ANN Model

A set of 142 cases was obtained from the experts and used to test the ANN model developed through the synthetically generated data. The DAT of choice by the experts and the DAT which scored the highest in the SAW model were compared to the one predicted through the ANN model.

Figure 25 shows the distribution of the 142 cases over the different DATS. This distribution shows close values in the numbers each DAT was selected through the three approaches, which indicate that the SAW model as well as the ANN model were able to reflect the DAT selection of the experts.

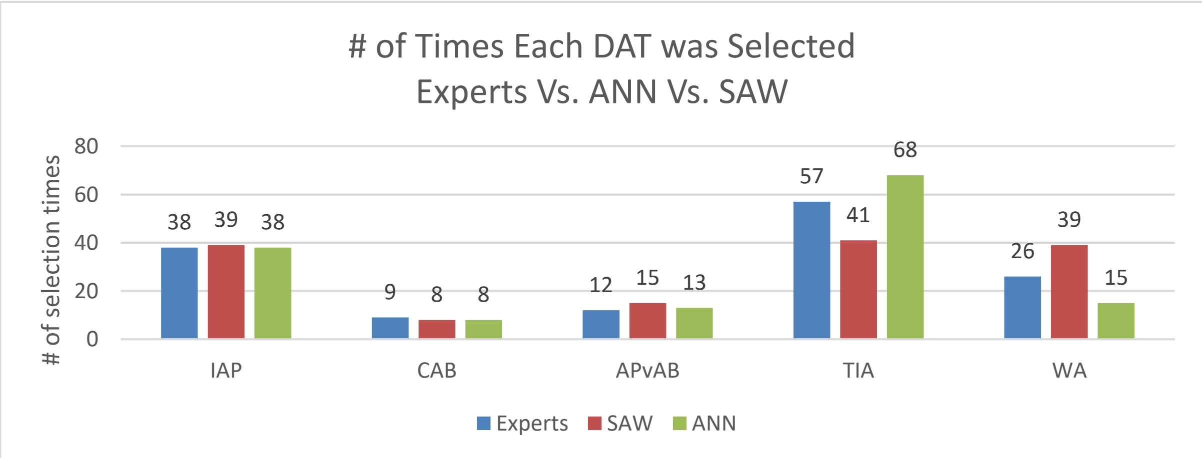


Figure 25: Outputs of 142 Testing Cases

Table 16 shows that the three approaches resulted in identical rankings of the DATs based on the number each DAT was selected. Similar to Abouorban et al. (2018), TIA is the most widely used DAT and CAB is the least used DAT. Abouorban et al. (2018) concluded that IAP is the most used DAT by contractors supports IAP being the second highest used DAT.

Table 16: DATs Most Commonly Selected Across Different Approaches

DATs	Ranking		
	Experts	SAW	ANN
IAP	2	2	2
CAB	5	5	5
APvAB	4	4	4
TIA	1	1	1
WA	3	2	3

Table 17 shows that the ANN model achieved a higher conformity with experts selections than did the SAW model. The ANN model matched the experts' selections in 121 out of 142 cases, while the SAW model matched the experts' selections in 109 out of 142 cases.

Table 17: Level of Conformity Among Different Approaches

	Experts	SAW	ANN
Experts	100%	76.8%	85.2%
SAW		100%	72.5%
ANN			100%

Comparing SAW model to ANN model, it was found that 39 cases had different DAT selection resulting in a 72.5% conformity. However, as shown in Figure 26, in 87% of the cases, 34 out of the 39 cases, the selected DAT from ANN was amongst the two highest ranking DATs in SAW.

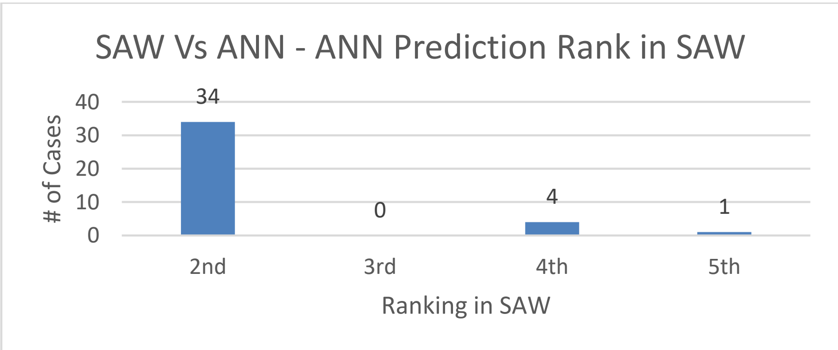


Figure 26: ANN Predictions' Ranks in SAW

Table 18 shows sample of the cases which didn't have identical DAT selection through the three approaches. Cases 1 to 7 had either WA or TIA in the selection. It is reasonable to relate this to the similarity between TIA and WA which reflected on close values for the weights assigned to each of them which in turn challenges the model as well as the experts in choosing between them.

Cases 8 to 12 had either APvAB or CAB in the selection. Both DATs are applied retrospectively and can be used for Non-CPM programs (Perera et al., 2016). According to

Abouorban et al. (2018), both APvAB and CAB are equally favorable to use towards the end of the project. In case 13, the experts' DAT of choice matched that of the ANN model as TIA. SAW model highest ranking DAT was IAP. Both techniques can be applied prospectively and more favorable to be used at the beginning of the project (Abouorban et al., 2018).

Table 18: Sample cases with different outputs across models.

Cases / Factors	1	2	3	4	5	6	7	8	9	10	11	12	13
Form of contract (Contract Conditions)	C1	C1	C1	C1	C1	C1	C1	C2	C1	C1	C1	C1	C3
Records Availability	C1	C1	C1	C1	C3	C3	C2	C2	C2	C2	C3	C3	C2
Baseline Program Availability	C1	C1	C1	C1	C1	C1	C1	C1	C1	C1	C1	C1	C1
Updated Programme Availability	C3	C3	C3	C3	C1	C2	C1	C2	C1	C2	C2	C2	C1
Nature of Baseline Program	C1	C1	C1	C1	C1	C1	C1	C2	C2	C2	C2	C2	C1
Complexity of the project	C1	C1	C1	C1	C2	C2	C2	C1	C1	C1	C1	C1	C1
Status (Stage of delay analysis)	C3	C3	C3	C3	C3	C2	C3	C3	C2	C2	C3	C3	C1
Reliability of project schedules	C1	C1	C1	C2	C1	C1	C1	C1	C1	C1	C2	C2	C2
Dispute Resolution Forum	C2	C2	C2	C2	C2	C2	C2	C2	C1	C1	C1	C1	C2
Nature of Delaying Events	C2	C2	C2	C2	C2	C2	C3	C1	C1	C3	C3	C3	C2
Skills of the analyst	C3	C3	C3	C3	C3	C3	C3	C3	C2	C2	C3	C3	C1
Number of Delaying Events	C3	C3	C3	C3	C3	C3	C2	C3	C1	C2	C3	C2	C2
Time availability for delay analysis	C1	C1	C1	C1	C1	C1	C1	C1	C2	C2	C2	C2	C1
The Other Party to the Claim	C2	C2	C2	C2	C2	C2	C2	C2	C1	C1	C1	C1	C2
Time of the delay occurrence	C1	C2	C3	C1	C2	C2	C3	C3	C2	C3	C3	C3	C2
Amount in Dispute	C3	C3	C3	C3	C2	C2	C3	C2	C2	C1	C2	C1	C2
Need of showing concurrent delay	C1	C1	C1	C1	C2	C1	C1	C1	C2	C2	C2	C2	C1
Size of Project	C3	C3	C3	C3	C3	C3	C3	C1	C1	C2	C1	C2	C3
Cost of using the technique	C1	C1	C1	C1	C1	C1	C1	C1	C2	C2	C2	C2	C1
Experts DAT of Choice	WA	WA	WA	TIA	WA	WA	WA	APvAB	CAB	APvAB	CAB	CAB	TIA
SAW Highest Ranking DAT	WA	WA	WA	WA	TIA	WA	WA	CAB	APvAB	APvAB	APvAB	APvAB	IAP
ANN Predicted DAT	TIA	TIA	TIA	TIA	TIA	TIA	TIA	APvAB	CAB	CAB	CAB	APvAB	TIA

Table 19 shows that the ANN model trained on the synthetically generated dataset has successfully learned the interdependencies of the SAW model as it produced results comparable to those of the experts. Similar to the conclusion of Horvath et al. (2021), this research proposes that synthetically generated data are promising for ANN modelling in selection of DATs.

The ANN model can explain the variance of parameters with the outputs; showing how significant each factor is towards the selection of the most suitable DAT. Had there been discrepancies in data provided to the ANN model, the model results would not have aligned with those provided by the experts or scored highest through the SAW model.

4.1.1 Confusion Matrix

Equations 6 to 9 were used by Mahum et al. (2021) to calculate the recall, precision, accuracy and F1 score. The experts' DATs selections were considered as the most suitable DATs which the ANN model should predict. Finally, the indices were calculated for the model as a whole.

$$recall = \frac{True\ Positive\ (TP)}{True\ Positive\ (TP) + False\ Negative\ (FN)} \quad (6)$$

$$precision = \frac{True\ Positive\ (TP)}{True\ Positive\ (TP) + False\ Positive\ (FP)} \quad (7)$$

Accuracy (Conformity to experts)

$$= \frac{True\ Positive\ (TP) + True\ Negative\ (TN)}{True\ Positive + True\ Negative + False\ Positive + False\ Negative} \quad (8)$$

$$F1 - Score = 2 \times \frac{precision \times recall}{precision + recall} \quad (9)$$

Table 19: Confusion Matrix for the Model (Testing Cases)

	True Positive	False Negative	False Positive	True Negative	Recall	Precision	Accuracy	F1-Score
Total	121	21	21	547	85.2%	85.2%	94.1%	85.2%

Table 19 shows the total number of times the model's prediction was in fact the most suitable DAT (True Positive), the number of times the model's prediction was not the most suitable DAT (False Positive), the number of times the model didn't predict the most suitable DAT that should have been predicted (False Negative), and the number of times the model didn't predict a DAT that was not the most suitable (True Negative). Overall, the model was deemed valid as 85.2% of the cases were identical in their choice of the most suitable DAT.

4.1.2 Variable Impact

The variable impact is a key figure as it shows the cause-and-effect relationship between the independent variables and the dependent variable. Accordingly, Figure 27 was developed using NeuralTools to measure the impact of each variable on the selection of the DAT. It shows that the top three factors that affect the prediction results are the Baseline Programme Availability, Nature of Baseline Program, and Contract Conditions while the least three factors are Dispute Resolution Forum, Other Party to the Claim, and Cost of

Using the Technique. The top three factors with the highest relative variable impacts are amongst the top five factors based on the weights obtained through the experts in the first survey.

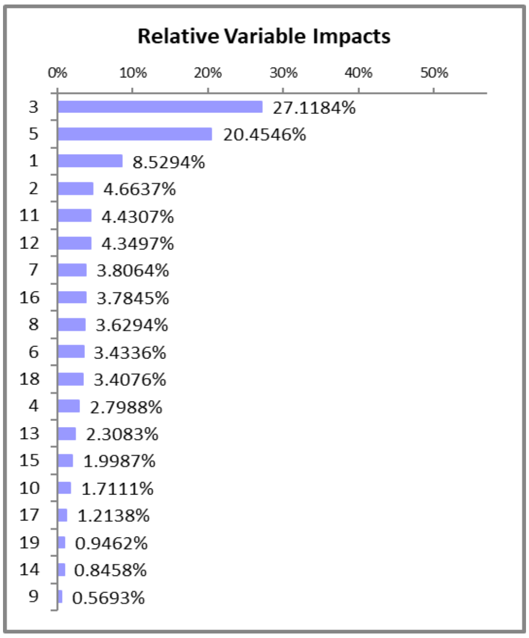


Figure 27: Relative Variable Impacts of Factors on DAT Selection

4.2 Model Validation

The selection of the most suitable DAT is an issue of great debate and the choice of a DAT for the same case may differ according to different perspectives. Figure 28 shows the inputs extracted from the case study applied in Perera et al. (2016) research. The inputs show that the team who will perform the analysis is skilled and thus able to perform DA using any technique. It also shows that time and cost are not constraints and thus the use of more costly techniques is fine. The contract conditions don't specify a DAT to be used. Baseline program, updates of the program as well as other records are available, so this allows any of the DATs to be used. The delay analysis will occur towards the end of the project for delays that occurred amid of the project, thus the analysis is to be carried out retrospectively. The amount in dispute and the size of the project are both sizable as to justify spending money and time in preparing a sound delay analysis. The project is complex and thus it is expected to require a sophisticated DAT.

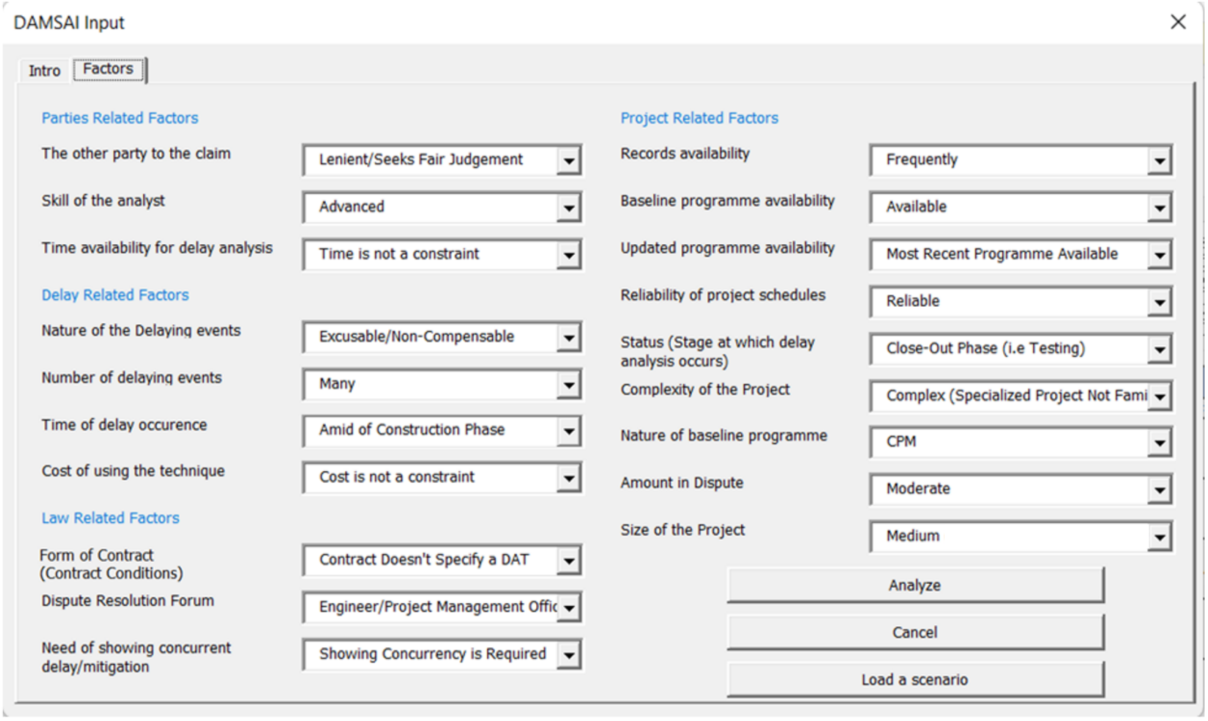


Figure 28: Data Input to ANN Model for Perera et al. (2016) Case Study

Figure 29 shows the model output for the case study. Similar to Perera et al. (2016), TIA is predicted to be the most suitable DAT for a claim based on the case study inputs. This outcome aligns with Abouorban et al. (2018) conclusion that TIA is the DAT suitable throughout and towards the end of the project based on the survey conducted from an Egyptian construction industry perspective.

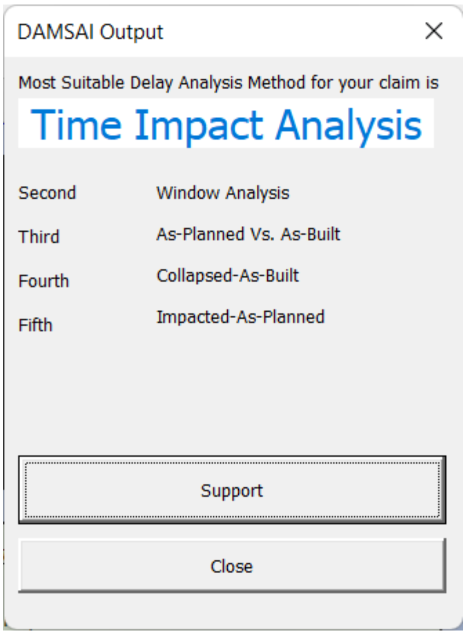


Figure 29: Model Output for Case Study

According to the output of the SAW model shown in Table 20, a close second to the TIA was WA technique which according to many experts is considered a very worthy technique which is applied by many practitioners in the Egyptian construction industry. As suggested by Parry (2015), the choice of methodology is overwhelmingly in support of the WA technique. Parry (2015) proposes that WA is the best technique that should be adopted in any delay analysis.

Different from Perera et al. (2016), APvAB had the third highest score instead of CAB. According to Enshassi (2008), there was a consent that the APvAB is the most common technique in Gaza Strip as the nature of the projects is simple which doesn't dictate the use of more complex techniques. Still the project applied in this research was a complex one and thus the reasoning behind choosing APvAB may not apply; however, it ranked third rather than first or second. CAB ranked fourth and this may be attributed to the high number of delaying events as this would make CAB much more time consuming.

The inputs show that the project is complex, thus the ranking of CAB as fourth aligns with the SCL protocol which implies that the CAB method may only be used for the simplest, intuitive, and linear of projects (Keane & Caletka, 2009). IAP ranked fifth and this is in line with the fact that IAP is a prospective DAT which contradicts with the inputs. It is worth noting that IAP ranking fifth aligns with Arditi and Pattanakitchamroon (2006) conclusion that IAP method is the least favored method as it has theoretical flaws; however, during interviews, experts confirmed Abouorban et al. (2018) conclusion that IAP is a common DAT used in the construction industry despite its major drawbacks.

Table 20: SAW model - Perera et al. (2016) Case Study

Factors	Selected Criterion	Scores				
		IAP	CAB	APvAB	TIA	WA
Form of contract (Contract Conditions)	Contract Doesn't Specify a DAT	0.000	0.000	0.000	0.000	0.000
Records availability	Frequently	0.021	0.005	0.010	0.013	0.014
Baseline programme availability	Available	0.016	0.004	0.015	0.015	0.015
Updated programme availability	Most recent programme available	0.010	0.012	0.010	0.015	0.016
Nature of baseline programme	CPM	0.014	0.009	0.010	0.015	0.014
Complexity of the Project	Complex (specialized project)	0.004	0.014	0.010	0.017	0.016
Status (Stage at which DA occurs)	Close-Out Phase (i.e., Testing)	0.005	0.018	0.009	0.015	0.015
Reliability of project schedules	Reliable	0.010	0.012	0.009	0.015	0.014
Dispute resolution forum	Engineer/Project Management Office	0.009	0.009	0.011	0.014	0.011
Nature of the Delaying events	Excusable/Non-Compensable	0.013	0.005	0.010	0.013	0.013
Skills of the analyst	Advanced	0.004	0.012	0.007	0.015	0.014
Number of delaying events	Many	0.004	0.011	0.006	0.013	0.013
Time availability for delay analysis	Time is not a constraint	0.006	0.010	0.006	0.010	0.010
The other party to the claim	Lenient / seeks fair judgement	0.009	0.007	0.010	0.010	0.007
Time of the delay occurrence	Amid of Construction Phase.	0.007	0.007	0.008	0.010	0.010
Amount in dispute	Moderate	0.009	0.007	0.009	0.009	0.007
Need of showing concurrent delay	Showing concurrency is required	0.003	0.007	0.012	0.010	0.012
Size of project	Medium	0.008	0.006	0.008	0.008	0.007
Cost of using the technique	Cost is not a constraint	0.006	0.010	0.005	0.007	0.010
Total Score		**0.160**	**0.166**	**0.167**	**0.224**	**0.219**
DAT Selected				**TIA**		

Chapter 5

Conclusion and Future Work

In conclusion, this research proposes a classification model for delay analysis techniques selection based on artificial neural network. The aim of this research was to classify the most suitable DAT for a claim. Hence, a list of 40 factors affecting the DAT selection was identified from the literature. After analyzing the 40 factors and conducting three semi structured interviews, 19 factors were selected. The selected factors are Records Availability, Baseline Programme Availability, Nature of Baseline Programme, Updated Programme Availability, Complexity of the Project, Size of Project, Skills of the Analyst, Form of contract (Contract Conditions), Dispute Resolution Forum, Need of Showing Concurrent Delay/Mitigation, Nature of Delaying Events, Time of the Delay Occurrence, Number of Delaying Events, Amount in dispute, Cost of using the Technique, Time availability for Delay Analysis, Other Party to the Claim, Status (prevailing stage of the project), and Reliability of Project Schedules.

Two surveys were conducted and distributed to construction experts. The first survey aimed at weighing the impact of the 19 factors on the DAT selection, and the second survey aimed at weighing the impact of each of those factor's criteria on DAT selection.

The mixed-method approach in collecting data through semi-structured interviews as well as two thorough surveys allowed the research to benefit from the experts' judgements in selection of DATs to develop a tool that conserves this experience and utilizes it in a robust way to support the user in the DAT selection.

The highest three ranking factors that affects DAT selection are Contract Conditions, Records Availability and Baseline Programme Availability. The lowest three ranking factors are Need of Showing Concurrent Delay/Mitigation, Size of the Project and Cost of Using the Technique.

An ANN model has been developed for selection most appropriate DAT to be used. The proposed ANN model was tested on 142 actual case studies, and its results matched 85.2% of the cases.

Conclusions of this research can be summarized in the following points:

- The developed tool can help delay analysts, arbitrators, contract administrators, and other parties choose, support, and validate their DAT selection.
- The tool was applied on the same case study in the work of Perera et al. (2016). The highest scored DAT was TIA in both works.
- According to this research and the one conducted by Abouorban et al. (2018), the most important factor is the contract conditions in regard to the DAT. However, the combined overall ranking of the factors found in the literature provide that records availability, baseline programme availability and updated programme availability factors are the most influential factors in the DAT selection. A question remains: what happens if the contract specifies a DAT that is not suitable for the analysis?
- Works from common law countries highlight that the dispute resolution forum is a factor in selecting the appropriate DAT. A conclusion of this research is that presenting a delay analysis may require a different strategy in front of a judge in litigation than to the engineer/consultant for a claim. Also, how important it can be to survey the previous rulings of a certain country regarding issues as concurrency, float ownership, etc. Further analysis on differences between the factors highlighted in common and civil law works can provide more insight on this aspect.
- Available guidelines on delay analysis selection are mostly developed by entities based in common law systems. It may be beneficial to develop guidelines that discuss delay analysis from civil law perspective.
- No one DAT is fit for all cases or claims as indicated through the discussion with the experts as well as the several research mentioned.
- As the data generated for this research was able to produce a model that matches the experts' selections to a great , use of synthetically generated data can be exploited in conducting research in topics with scarcity of data.

5.1 Research Contribution

The research was able to overcome the lack of data, case law or arbitration cases, that relates the DATs and their selection factors to making a successful claim. A framework was established to generate synthetic data which was used in building an artificial neural network (ANN) to provide decision support in the selection of the DAT. According to Magdy et al. (2019), ANNs have not been employed in DAT selection, which makes the model developed through this research a novel contribution to the body of literature on delay analysis selection factors topic. Also, this research utilized the rankings of previous research to provide a combined overall ranking of the factors found in the literature. Moreover, the research provided commentary on the different DAT selection factors from common and civil law perspectives. Overall, with its simple user interface, the robust tool developed through this research provides different parties in the construction field with support in regard to the selection of the DAT.

5.2 Research Limitations

This research is limited to the five DATs and the 19 factors and their proposed criteria which are used in building the model. Those factors are determined to be the ones that impact the DAT selection the most. Another limitation is the cases generated to develop the model. These cases were generated based on the weights collected through the experts' surveys. As highlighted by Perera et al. (2016), tools such as the one in this research are mainly based on experts' psychological constructs. Thus, further research is recommended to ensure continuous improvement of the tool in its database of experts.

5.3 Recommendations for Future Research

1. It would be recommended to integrate this model with other machine learning algorithms to obtain the benefits of both.
2. Since some of the factors demonstrate a low variable impact, it would be recommended to explore if removing the least three would result in better predictions.
3. For future research, the works found in literature along with the survey conducted in this research can be integrated to provide a weight for each of the DAT selection factors from the perspective of each party separately.
4. Further validation is required through applying more case studies and through having experts examine the model and giving feedback on its results and user experience.
5. The synthetic data generation process should be automated to allow further testing and enhancing of the model under different factors and criteria weights, based on the number of experts included in the SAW model, and under different number of generated scenarios.
6. Adding case law or legal support in the support module of the model.

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