DELAY ANALYSIS METHODS IN CONSTRUCTION PROJECTS

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ABSTRACT

DELAY ANALYSIS METHODS IN CONSTRUCTION PROJECTS

Construction industry is recognised to be one of the leading contributors to the economic development. But this industry has a very poor reputation globally associated with coping with delays. Construction projects commonly suffer from schedule delays due to varying reasons, which may cause unresolved debates till end of the project and even costly disputes between different stakeholders of the project. Thus, delay analysis becomes an essential instrument to address problems resulting from delay in a construction project. This research primarily targets to determine in what extent existing delay analysis methods are able to cope with general problematic issues in delay analysis applications. Within this purpose, firstly main causes of delay in construction projects were identified by investigating early studies in the literature. Then the delay in construction projects was identified and categorized based on liabilities of parties in a project through an extensive literature survey. Since most of the studies in the literature - so far as to compare delay analysis methods or how to select one of them or to present opinion regarding their features are concerned – have based on fictional scenarios rather than actual project records. Therefore, a case study approach based on a real project has been adopted. Time slice analysis method was selected as the most appropriate delay analysis technique for the case project and it was carried out to measure delay in the project and allocate liabilities. Moreover, the other retrospective delay analysis methods were also performed to compare results of different techniques. Capabilities of each technique when dealing with problematic issues and application procedure of each technique were presented as findings of this study in light of application of each method on the case study. Time slice analysis method and as-planned vs as-built window analysis were found to be most capable techniques in identification occurrence/period of influence, cause and extent of critical delay to that critical path. Time slice analysis method requires reliable series of updated programmes, on the other hand as-planned vs as-built window analysis requires reliable project record to create the actual critical path in absence of reliable series of updated programmes. Finally, this study targets to be an example for practitioners and academics regarding applications of retrospective delay analysis methods on a real project.

ÖZET

İNŞAAT PROJELERİNDE GECİKME ANALİZİ YÖNTEMLERİ

İnşaat sektörü, ekonomik kalkınmaya en çok katkıda bulunan sektörlerden biri olarak kabul edilmektedir. Ancak bu sektör, küresel olarak gecikmelerle başa çıkma konusunda çok kötü bir üne sahiptir. İnşaat projeleri genellikle çeşitli nedenlerden dolayı iş programındaki gecikmelere maruz kalırlar, bu da projenin sonuna kadar çözülemeyen tartışmalara ve hatta projenin farklı paydaşları arasında meydana gelen maliyetli anlaşmazlıklara neden olabilir. Bu nedenle, gecikme analizi, bir inşaat projesindeki gecikmelerden kaynaklanan sorunları ele almak için önemli bir araç haline gelir. Bu araştırma öncelikli olarak, gecikme analizi uygulamalarında mevcut gecikme analizi yöntemlerinin genel sorunlu konularla ne ölçüde başa çıkabildiğini belirlemeyi hedeflemektedir. Bu amaçla öncelikle literatürdeki öncül çalışmalar incelenerek inşaat projelerindeki gecikmenin ana nedenleri tespit edilmiştir. Daha sonra inşaat projelerindeki gecikme, kapsamlı bir literatür araştırması yoluyla bir projedeki tarafların sorumluluklarına göre belirlenmiş ve kategorize edilmiştir. Literatürdeki çalışmaların çoğu - gecikme analizi yöntemlerinin karşılaştırılması veya bunlardan birinin nasıl seçileceği ya da özellikleriyle ilgili görüş sunulması söz konusu olduğu için - gerçek proje kayıtlarından ziyade kurgusal senaryolara dayanmaktadır. Bu nedenle, gerçek bir projeye dayalı bir vaka çalışması yaklaşımı benimsenmiştir. Vaka çalışması için en uygun gecikme analizi tekniği olarak zaman dilimi analizi yöntemi seçilmiş ve projedeki gecikmelerin ölçülmesi ve yükümlülüklerin tahsisi için gerçekleştirilmiştir. Ayrıca, farklı tekniklerin sonuçlarını karşılaştırmak için diğer geriye dönük gecikme analizi yöntemleri de uygulandı. Metotların proje için uygulanması ışığında, her tekniğin sorunlu konularla nasıl başa çıktığı ve uygulama prosedürleri bulgu olarak sunulmuştur. Zaman dilimi analizi yöntemi ve planlanlanan vs. gerceklesen pencere analizi, olay / etki süresi, bu kritik yol için kritik gecikmenin nedeni ve kapsamının belirlenmesinde en etkili teknikler olarak bulundu. Zaman dilimi analizi yöntemi için bir dizi güvenilir güncellenmiş iş programı gerektirirken, plananlanan vs. gerçekleşen pencere analizi, güncellenmiş programı olmadığı durumlarda, güvenilir proje kayıtlarına ihtiyaç duyar. Son olarak, bu çalışma, geçmişe dönük gecikme analizi yöntemlerinin gerçek bir proje üzerinde uygulanması konusunda uygulayıcılara ve akademisyenlere örnek olmayı hedeflemektedir.

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LIST OF ACRONYMS/ABBREVIATIONS

AACEI RP	AACEI Recommended Practice
AACEI	Association for the Advancement of Cost Engineering International
APAB	As-Planned versus As-Built
ASCE	American Society of Civil Engineers
CA	Contract Administrator
CAB	Collapsed As-Built
CIOB	The Chartered Institute of Building
CPM	Critical Path Method
DAM	Delay Analysis Method
EOT	Extension of Time
FF	Finish to Start
FIDIC	International Federation of Consulting Engineers
FS	Finish to Start
IAP	Impacted As-Planned
JCT	Joint Contracts Tribunal
NEC	New Engineering Contract
PDM	Precedence Diagramming Method
PERT	Programme Evaluation and Review Technique
PM	Project Manager
PMI	Project Management Institute
RLPA	Retrospective Longest Path Analysis
SCL	Society of Construction Law
SF	Start to Finish
SS	Start to Start
TF	Total Float
TIA	Time Impact Analysis
TSAM	Time Slice Analysis Method
WBS	Work Breakdown Structure

1. INTRODUCTION

The introduction part of the study clarifies following areas; the background of the research, related studies, aim and objectives of the study, methodology, scope and limitations, and organization of the thesis.

1.1. Background of the Study

Industry of construction is recognised to be a significant contributor to the economic development. Construction facilitates hundreds of thousands of employments directly and moreover it had established a wide range of associated businesses – such as construction equipment, construction materials, white appliances, engineering and architecture – as key sub-sectors of local and export trade of countries.

Construction industry has become a crucial player in Turkey's economy as well, accounting for approximately 8-9% of GDP and employing nearly 2 million people, furthermore the portion of the construction industry in the Turkish economy extents 30% with the direct and indirect effects on other industries (Turkish Contractors Association, 2020).

Construction projects characteristically involve risk that can be managed such as avoidance, mitigation, transfer, or acceptance, but cannot be ignored (Project Management Institute, 2017). Delays are often unavoidable in construction projects and modern construction projects frequently suffer from delays (Braimah, 2013). Delay in construction has been recognised as one of the most frequent and widespread complications (Gündüz *et al.*, 2013). Delays in construction can result in various changes in a project i.e. late completion, productivity loss, higher expenses, acceleration, pacing, re-sequencing, disputes, and even contract termination.

Contractors have tendency to perceive most of the delays as the liability of the owner or third parties., whilst owners typically are prone to put the blame on the contractor. Hence, the identification, documentation, quantification and evaluation of delays become vital for a successful execution project. Measuring the delay impact is sometimes an argumentative subject. Numerous delay analysis techniques exist however, no method is globally preferred over others in all scenarios (Arditi and Pattanakitchamroon, 2006).

In this thesis, main reasons and effects of delay in construction are investigated. Furthermore, the aim of this study is to provide an insight into different delay analysis methods via assessing delays in a real construction project where the most appropriate technique is selected and applied based on the particular dynamics and contract provisions of the examined project.

1.2. Related Studies

In the literature, the main topics of the academic studies associated with delay in construction projects can be categorized into following groups;

- to identify and rank main causes of construction delays;
- to classify problematic issues in delay analysis methodologies;
- to propose a new delay analysis technique or a new protocol to deal with shortcomings of existing methods; and
- to determine selection criteria of delay analysis methods in disputes.

It is observed that in the literature, main emphasis has been given to identification, categorization and ranking of aspects impacting delays in construction. Some of those studies produced a critical examination on the reasons of delays encountered in the literature (Scott et al., 2004; Hamzah et al., 2011; Fallahnejad, 2013). Some research are confined to particular geographical regions which affected the causation greatly (Sweis, 2008; Doloi et al., 2012; da Silva, 2016; Hossain et al., 2019). Some studies solely focused on delay factors for particular type of an industry such as oil and gas (Gomarn and Pongpeng, 2018; Kazemi et al., 2018), residential projects (McCord et al., 2015; Durdyev et al., 2017), or road projects (Mahamid et al., 2012). There are studies which have focused on to categorization and quantification of delay causes by adopting relative importance index (Sambasivan and Soon, 2007; Aziz, 2013; Gündüz et al., 2013).

In the literature, a great effort also has been given to describe and classify common problematic issues which may hinder success of performed delay analysis technique. One of the most cited-problematic issue observed in the literature is identification of a concurrent delay (Scott et al., 2004; Ndekugri et al., 2008; Arif and Morad, 2014; Bailey, 2014). There are a lot of different approaches to deal with concurrency (Furst and Ramsey, 2001; Gibson, 2008; Baldwin and Bordoli, 2014; Keane and Caletka, 2015). Another unclear area in delay analysis applications is to detect pacing delays and compromise different perspectives of owners and contractors (Zack, 2000; Mohan and Al-Gahtani, 2006; Burr, 2016). Ownership, and utilization of total float is still another subjective area for opposing parties in construction industry where a large number of studies have dedicated to proposed new models to cope with this issue (Householder and Rutland, 1990; de la Garza et al., 1991; Finke, 2000; Nguyen and Ibbs, 2008; Yang, 2017). Mitigation and acceleration in construction projects are another turbulent field for academics and practitioners, several research attempted to differentiate such issues (Bailey, 2014; Baldwin and Bordoli, 2014; Keane and Caletka, 2015).

There are a lot of studies which proposed new techniques or new protocols to overcome problematic issues, to measure delay, and to determine delay impact as follow; Construction Delay Computation Method (Shi et al., 2001), Modified But-For Method for Delay Analysis (Mbabazi et al., 2005), FLORA New Forensic Schedule Analysis Technique (Nguyen and Ibbs, 2008), Isolated Collapsed But-For Delay Analysis Methodology (Yang and Yin, 2009), Computerizing Isolated Collapsed But-For Delay Analysis Methodology (Yang and Tsai, 2011), Modified Isolated Delay Type Technique (Golanaraghi and Alkass, 2012), Integrated Approach to Overcome Shortcomings in Current Delay Analysis Practice (Birgonul et al., 2015), Total Float Management: Computerized Technique for Construction Delay Analysis (Al-Gahtani et al., 2016), Decision-Making Model for Selecting the Optimum Method (Perera et al., 2016), and A Hybrid System Dynamics Decision Making Trial and Evaluation Laboratory (Parchamijalal and Shoar, 2017).

None of the recognised delay analysis practises can be globally adopted in each case (Arditi and Pattanakitchamroon, 2006), hence a wide range of studies have been carried out to determine selection criteria of delay analysis methods in disputes. Some studies employed case study approaches to demonstrate outcomes of different delay analyses (Bubshait and

Cunningham, 1998). Another study analysed fifty-eight time-based claim cases to identify numerous issues on the selection of a delay measurement technique (Arditi and Pattanakitchamroon, 2008). In a study, window based delay analysis models on simulated cases were compared (Kao and Yang, 2009). Muhamad conducted a study based on a questionnaire survey in order to obtain opinions of contractors' and clients' consultants' organizations regarding commonly used methodologies for assessing time-based claims (Muhamad *et al.*, 2016). Abdelhadi conducted interview with experts from five projects in UAE to comprehend how in practice decisions are made to select the most suitable delay analysis method for a construction project (Abdelhadi *et al.*, 2019). Braimah performed five different delay analysis methods based on a simple logic linked scenario to evaluate the important issues not addressed by the methods (Braimah, 2013).

1.3. Aim and Objectives of the Thesis

The core objective of this study is to answer the following question 'What are the most and least effective aspects of delay analysis methods to measure delays when dealing with current problematic issues in delay analysis applications?'. The following steps are taken in order to achieve this objective;

- To study and understand construction programme and scheduling techniques.
- To understand contract requirements for development of a construction programme and procedure for extension of time from point of different standard forms of construction contracts.
- To define the delay and categorize them in relation to responsibilities and liabilities of each party in a project.
- To find main sources of delay through early studies in literature.
- To classify features of delay analysis to comprehend basic notions.
- To reveal advantages and disadvantages of most-commented delay analysis techniques in the literature by investigating international protocols.
- To carry out the most suitable retrospective or prospective delay measurement technique on a real project to measure impact of delays and allocate liabilities of each party.

- To apply alternative methods for comparing the results obtained from the first applied delay analysis method.
- To compare critical delay factors which were identified in case studies, to those which were obtained through literature review.
- To analyse the most and least effective aspects of applied techniques when dealing with current problematic issues in delay analysis applications identified through a literature survey.
- To set an example of delay analysis applications under different dynamics and during different phases of projects for practitioners and academics.

1.4. Methodology

As stated earlier, this thesis is intended to apply the most appropriate delay analysis method, a comprehensive literature survey was performed. Standard form of contracts such as FIDIC, JCT, NEC4 type of contracts were investigated in order to find out different approaches regarding requirements of a construction programme, procedures for entitlement of extension of time application. Later on, to understand identification, categorization, main causes, and potential impacts of construction delays, an extensive literature review was carried on academic papers, associated books and conference proceedings.

Subsequently academic papers, conference papers and articles conducted by practitioners and international protocols such as Society of Construction Law Delay and Disruption and Association for the Advancement of Cost Engineering – Recommended Practices for Forensic Schedule Analysis are studied in order to comprehend different delay analysis methods and existing shortcomings of those methods.

Then a case study approach is adopted to find out the most appropriate retrospective or prospective delay analysis technique on a real project to measure impact of delays and allocate liabilities of each party. Furthermore, other convenient delay analyses are applied to demonstrate how procedures and requirement differ and compare results of each technique. Finally, the most and least effective aspects of applied techniques when dealing with current problematic issues in delay analysis applications are discussed.

1.5. Scope and Limitations

The purpose of this research is not to show one or other method is wrong. The main objective of this study is to propound a inclusive investigation about what construction delays are, how to cope with construction delay issues, and also to provide a comparison between most cited schedule delay analysis techniques. Within this objective, records of an international project used as a case study s to illustrate delay analysis processes by employing the most appropriate delay analysis method for delay impact determination.

Within the context of this research, it is limited to timing aspect of delay analysis, it does not aim to present an opinion regarding cost perspective of delays and cost-based methods. Another limitation is that most of the procedural requirements for delay analysis methods are adopted from SCL Delay and Disruption Protocol, since this protocol is one of the most globally accepted guidance and there is a lack of guidance in Turkish construction sector.

1.6. Organization of Thesis

The first chapter covers background of the research, related studies, aim and objectives of the study, methodology, scope and limits, organization of thesis.

The second section presents literature review associated with planning and project management, scheduling techniques, programme requirements, definition, categorization and main causes of construction delays, problematic issues in delay analysis. Delay analysis methods, selection criteria of those methods and statement of research question and gap in literature are also explained under this chapter.

The third chapter includes the general information about examined the case study whose delays are identified, quantified and liabilities of those delays are allocated or proportioned to responsible parties. Moreover, the areas associated with research methodology such as collection of information and data, initial identification of risk events and their liabilities, and how to select the most appropriate schedule delay analysis method step by step for the case study are presented under this chapter.

The forth chapter comprises application of the most appropriate delay analysis technique which is time slice analysis method for the case study shown. Moreover, since the project required a retrospective method to be implemented, the other retrospective methods were also performed to show the differences of those techniques.

The fifth chapter presents comparison of research finding regarding application of different techniques and the discussion part regarding such findings.

The sixth and the last chapter involves major findings, the conclusion of the study, contributions to literature, limitation of the study, and recommendations for future studies.

2. LITERATURE REVIEW

2.1. Planning and Project Management

2.1.1. Project

A project is a temporary endeavour undertaken for generating a unique product, service, or result (Project Management Institute, 2017). Repetitive components may be found in some project outputs, activities or objectives however this does not change the fundamental nature of a project which is being unique in key characteristics. (i.e. stakeholders, location, methodology or timing etc.).

According to Mubarak, the crucial words in the definition of a project are "temporary" and "unique": any project must have a beginning and an end, and it must have a deliverable product, service, or result that is unique (Mubarak, 2015). Another description for a project is being any series of activities and tasks that: (i) have a definite goal to be accomplished within particular specifications, (ii) have specified starting and finishing periods, (iii) have funding limits (if applicable), (iv) consume human, machinery and capital resources, and (v) are multifunctional (i.e., cut across several functional lines) (Harold, 2002).

2.1.2. Project Management

Project management is the discipline of planning, organizing, and managing resources to bring about the successful completion of specific project goals and objectives. Project management is intended to manage and/or control resources of a company on a given activity within schedule, within budget, and within pre-determined levels of performance/ quality. Therefore, time, cost, and performance are the three constraints for a project. Moreover, if the project is being executed for an customer outside the company, then the project has one more constraint which is good customer relations (Harold, 2002).

2.1.3. Planning and Scheduling

Planning and scheduling are two different terms that are often supposed as synonymous. However, they are not. Scheduling is only one part of the execution of planning. It is not an appropriate approach to think of planning as the creation of a time schedule, nonetheless this is only one feature of effective project planning. The planning concept is used in many different ways and numerous environments thus it should be considered in a wider context.

Planning of a project is not limited to consideration of time but also it includes consideration of cost, quality, health and safety and other characteristics such as design and production (Baldwin and Bordoli, 2014). Project planning is a multidisciplinary execution, composed of construction management team, design department, procurement professionals, cost control team, and project planner in producing the project development strategy. It necessitates experience, terminology, common language and imagination and, at its highest level, delivers the recipe for the logistic strategy for the project construction. (CIOB, 2011).

PMI defines Planning Process Group as the combination of processes which establish the scope of work, identify project objectives and define the course of action taken in order to achieve those objectives (Project Management Institute, 2017). Further, PMI depicts the project schedule as an output of project information (e.g., WBS, activities, resources, durations, constraints, etc.), scheduling method (e.g., CPM, PERT, bar chart, etc.) and scheduling tool. Mubarak (2015) states that project planning answers following questions: ‘What is going to be done? How? How much? Where? By whom? When?’. As project planning is multi-disciplinary concept, and scheduling is the component of project planning which answers the question of ‘When?’ as demonstrated. In light of PMI (2017) and Mubarak (2015), Figure 2.1 was created to portray the project planning components and scheduling as one part of those components and project schedule as an output of the scheduling process.

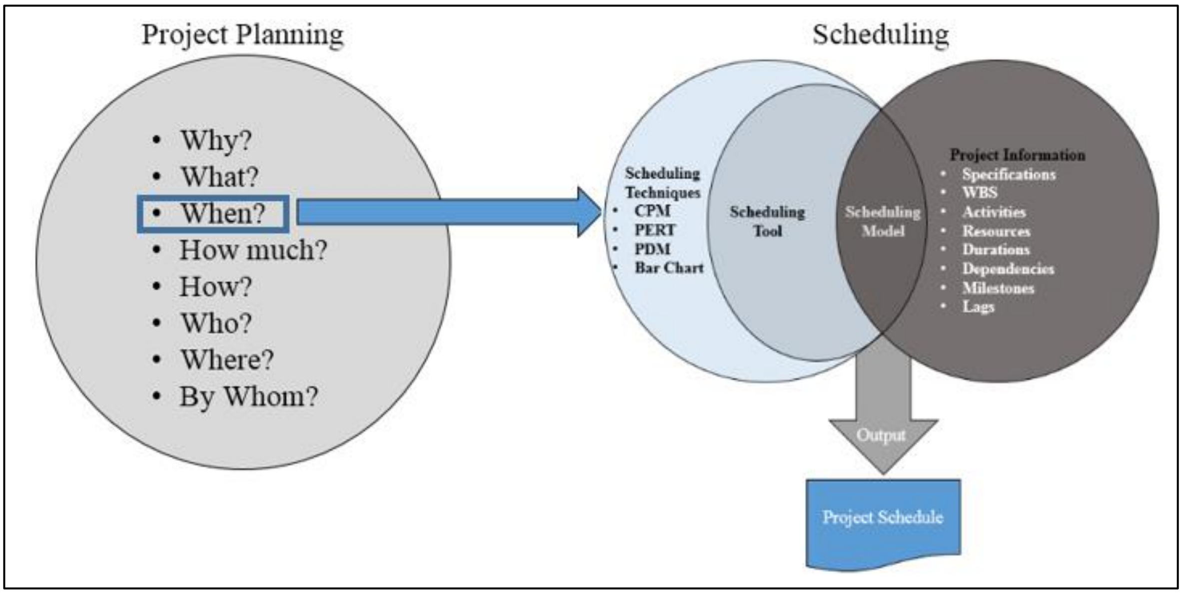


Figure 2.1 Project planning and scheduling relationship.

Keane and Caletka (2015) identified seven key elements which ought to be addressed prior, or during the planning stage for a project to be capable of being planned, programmed and controlled. These elements are (i) a precise description of a project, (ii) an adequate staff level and experience, (iii) appropriately pre-evaluated cost and time, (iv) assigned risk contingency, (v) phases to be broken into controllable tasks, (vi) an official change procedure to be established, and (vii) explicit completion criteria to be agreed.

2.1.4. Why Schedule Project?

Project scheduling delivers a comprehensive plan which demonstrates how and when the project will provide the goods, services, and predetermined outcomes in the contract. The project schedule is a useful instrument to communicate, manage stakeholder requirements, and report existing performance (Project Management Institute, 2017).

Scheduling is a combination of art and science, comprising the prediction of the results of project planning to determine, amongst other details i.e. start and finish dates of tasks logic networks and sequence of activities. Scheduling is typically executed by assist of a software that enables a quick and effective management of the project data in order to estimate dynamics of time and risk management. Hence, the schedule becomes an allocation for the contractor’s time, a management tool for the owner’s risk and a calculator for the contract administrator (CIOB, 2011).

Scheduling is also defined as a method to assign the timing and sequence of actions in a project and their combination to predict the overall completion time. As mentioned earlier, scheduling concentrates on one part of the planning concept (Mubarak, 2015). Trauner (2009) defines the schedule as a written or graphical demonstration of the contractor’s strategy to complete a construction project that highlights the fundamentals of time and sequence. The plan typically identifies the main work tasks (activities) and represent the sequence (logic) in which these tasks will be assembled to complete the project.

Table 2.1 Why schedules needed from different aspects (Mubarak, 2015).

Contractors need project scheduling to:	Owners and developers need project scheduling to:
Calculate the project completion date Calculate the start or end of a specific activity Coordinate among trades and subcontractors, and expose and adjust conflicts Predict and calculate the cash flow Improve work efficiency Serve as an effective project control tool Evaluate the effect of changes Prove delay claims	Get an idea of a project’s expected finish date Ensure contractor’s proper planning for timely finish Predict and calculate the cash flow Serve as an effective project monitoring tool Evaluate the effect of changes Verify delay claims

Though authors defined project schedule in various ways, there are numerous parties involved in any project called stakeholders who need and utilize project schedules from different perspectives. Table 2.1 shows the reasons why project schedules are needed, from two different perspectives: contractors and owners (Mubarak, 2015).

2.1.5. Scheduling Techniques

A contractor can perform a number of different schedules to represent its strategy. The choice of the most suitable scheduling method depends on the scope and complexity of the project (Trauner, 2009). The critical path method is mostly accepted by design and construction professionals as the most dominant scheduling technique in management of complex construction projects. CPM scheduling method is required by many important construction contracts to manage and monitor project performance. However, there are other techniques and methodologies available to be adopted to manage and control construction projects as shown in the table below.

Table 2.2 Planning tools and techniques (Keane and Caletka, 2015).

Arrow diagrams	Programme Evaluation and Review Technique (PERT)	Precedence Diagramming Method (PDM)
Bar chart, or Gantt charts	Linear or time-chainage	Scatter diagrams
Critical Chain Method (CCM)	Mass haul diagrams	Theory of constraints
Cascade diagrams	Milestone charts	Histograms
Critical Path Method (CPM)	Network analysis	

1. Bar Charts, or Gantt Charts was developed by Henry L. Gantt in 1900s. The technique is widely used by construction industry due to being simple to prepare, read, interpret, and comprehend by all project parties. It is a graphical presentation of schedule figures. In the typical bar chart, schedule activities or WBS items are listed on the vertical axis on the left side of the chart, dates are shown across the top, and activity durations are shown as date-placed horizontal bars (Project Management Institute, 2017).
2. Programme Evaluation and Review Technique (PERT) is an event-oriented network analysis method which is used to compute duration of a project when estimation of specific activity duration is very unclear (Mubarak, 2015). The technique was developed by the US Navy in the 1950s to arrange, analyse and control activities of the Polaris submarine missile programme. Though PERT is a probabilistic, or stochastic, method, it utilises logic networks to estimate the completion date of a project or the date of any other event in a schedule as used in deterministic approaches such as CPM. Development of a PERT diagram necessitates a duration frequency distribution for each activity. Firstly, ‘most likely duration’ is assumed by utilizing the industry norms. Then duration calculations are done to assign ‘optimistic durations’ and ‘pessimistic’ values, respectively. All three durations become foundation for a ‘three-point estimate’ for each task in order to obtain an optimistic, most likely and pessimistic completion date of the project. Due to uncertain nature of the technique in calculating activity durations with high accuracy, many

practitioners insist on addition of probability variable to the equation. When the additional variables applied in conjunction with PERT, it is called ‘probabilistic critical path management’ technique.

3. Precedence Diagramming Method (PDM) was initially developed by Johan Fondhal in Stanford University in the early 1960s. The method is an advanced networking system of activity-on-node diagramming with additional precedent relationships. Essentials of PDM can be listed as; capability to show the relationship of the task to each other; available to indicate critical tasks, noncritical tasks, and float time; to allow four logical relationships between activities: FS, FF, SS, SF; to define early and late dates, duration, activity names (Wiest, 1981; Mubarak, 2015).
4. Critical Path Method (CPM) is used to calculate the minimum project duration and observe the flexibility of schedule on the logical network paths. This technique computes the early start, late start, early finish, and late finish dates for all tasks in the schedule regardless of any resource restrictions by using a forward and backward pass analysis through the schedule network. The longest path of the final schedule becomes the “critical path” which is composed of activities that, if delayed, will prolong the project completion date.

2.1.6. Approval or Acceptance of Construction Programme

NEC4 requires an “Accepted Programme”, clause 31.3 requires the project manager to respond to submission of a programme within two weeks. The PM must either approve the programme or give reasons for not accepting it. The reasons stated in clause 31.3 for not approving the programme are; the plans and strategies in the programme are not practicable; information required by the contract is not presented; the contractor’s intentions are not rationally demonstrated; and the contractor’s plans or the programme do not comply with the scope (Eggleston, 2019). The clause 31.3 of NEC4 Engineering and Construction Contract also states the followings;

- If the PM does not respond within the time allowed, then the contractor may notify the PM regarding that failure; and
- If the failure remains for a further one week after the contractor’s notification, it is treated as acceptance by the PM of the programme.

The updated FIDIC (2017) contracts embraced similar methodology to those found in NEC4 type of contracts. Under the FIDIC form sub clause 1.1.67 the contractor submits the proposed programme for the approval of the engineer. Unless the engineer issues a notice of no-objection, the programme is seen as approved. There are some time constraints for this notice: the engineer/employer must issue it (a) within 21 days after receipt of the initial programme or (b) within 14 days after receipt of a revised programme. If he fails to issue the notice within the allowed period, submitted programme will be considered to be the contract programme. The contractor is then to continue in conformity with the programme, subject to his other responsibilities under the contract, and the employer's personnel are entitled to count on the programme when planning their activities (Godwin, 2020).

Under the JCT family of contract forms, approval of the programme is not a prerequisite, also there is not an imposed constraint on how the contractor expresses its programme (Keane and Caletka, 2015). The contract neither necessitates nor authorises the architect/CA to provide any comments regarding the contractor's programme, much less to approve it. If the architect/CA, on receiving the programme, realizes any problematic area that may cause concern, it is sensible to express this concern to the contractor, but then again it cannot be done in the form of an instruction (Chappell, 2014).

2.2. Delay in Construction Projects

Construction delays are not uncommon in construction sector and may cause main concerns associated with the project performance. Although completing the project within the stated duration in the agreement is a legal duty for a contractor, project timing can be influenced by unforeseen events through the course of the project. The project would be impacted from more disruption if the any party failed to come up with an mutual agreement on the problems as relationships and collaboration level may be impacted (Sambasivan and Soon, 2007).

Construction delays can be source of a lot of changes in a project i.e. delay in completion date, loss of productivity, higher costs, acceleration, and even contract termination. The party suffered from delay requires to be able to identify the delays and the parties liable for delays in order to recover time and cost (Arditi and Pattanakitchamroon, 2006).

2.2.1. Causes of Delay in Construction Projects

23 studies which were conducted in last two decades, in various countries and from different construction industries were examined in order to have a broader understanding of contributing factors to delay in construction industry.

Table 2.3 shows the details of the academic studies from literature regarding causes of delay in construction projects. 49 different causes of delay were identified from the literature review. These causes were obtained based on their ranking, occurrence and resulted significance in each study, and then those were classified under 6 groups as delays in relation to owners, contractors, consultants, labour/ material and equipment, external factors, and the project and contractual factors. Literature research reveals that various countries experience different causes of delays and importance of these causes are different regarding project types.

Faridi *et al.* (2006) carried out a detailed questionnaire in order to obtain different opinions of construction professionals regarding reasons of delay in UAE construction projects and they reported the dominant causes of delay as preparation and approval of drawings, inadequate early planning of the project, slowness of the owner's decision-making process, shortage of manpower and poor supervision and poor site management.

Lo *et al.* (2006) categorised 30 identified construction delays into 7 factors as delays related to project, resources, external factors contractor, consultant and client, and as the seventh factor they defined human behaviour related delay causes. They hypothesized causes of human behaviour related delays as adversarial/ confrontational/ controversial culture, delays in the response of project teams in potential dispute resolution, lack of communication, and personality clash between contractor agent and resident engineer. However, each survey result from each group (collected from contractors, consultants and clients) shows that human behaviour related causes have the least importance among other categories.

Table 2.3 Studies on causes of delay in construction in literature.

No.	Authors	Year	Country of Study	Project Type	Methodology
1	Faridi et al.	2006	UAE	General	Survey
2	Lo et al.	2006	Hong Kong	General	Survey
3	Sambasivan and Soon	2007	Malaysia	General	Survey
4	Sweiss et al.	2008	Jordan	Residential	Survey& interviews
5	Al-Kharashi and Skitmore	2009	Saudi Arabia	General	Survey
6	Hamzah et al.	2011	Malaysia	General	Literature Review
7	Kazaz et al.	2012	Turkey	General	Survey
8	Doloi et al.	2012	India	General	Survey& interviews
9	Fallahnejad	2013	Iran	Gas Pipeline Projects	Survey& interviews
10	Aziz	2013	Egypt	General	Interviews& Case Study
11	Gündüz et al.	2013	Turkey	General	Interviews& Case Study
12	Mazrouk and El-Rasas	2014	Egypt	General	Survey& Case Study
13	Ruqaishi and Bashir	2015	Oman	Oil and Gas Industry	Survey
14	McCord et al.	2015	Northern Ireland	Residential	Survey
15	Da Silva	2016	Portugal	General	Survey
16	Durdyev et al.	2017	Cambodia	Residential	Survey
17	Agyekum-Mensah and Knight	2017	United Kingdom	General	Case Study& Interviews
18	Gomarn and Pongpeng	2018	Thailand	Oil and Gas Industries	Survey
19	Shahsavand et al.	2018	Iran	General	Survey& interviews
20	Hossain et al.	2019	Kazakhstan	Industrial, Residential, Commercial, Infrastructural	Survey& interviews
21	Zhang et al.	2020	China	Subway Tunnel	Survey
22	Din et al.	2020	Pakistan	Residential	Survey& interviews
23	Rivera et al.	2020	South Korea	Road Projects	Literature Review

Sambasivan and Soon (2007) carried out a survey research on sources and impacts of delays in construction projects in Malaysia itself, they employed an integrated methodology for reasons and impacts of construction delays. Out of 28 listed sources, they identified 10 significant causes and 6 major impacts of construction delays by using RII (relative importance index) and Spearman rank correlation.

Sweis (2008) identified and ranked delay causes in the Jordanian residential construction industry. Most of the participant in the survey arranged that, monetary problems of the contractor and a great number of change orders by the employer are the most critical sources of construction delay in Jordan. Unexpected weather conditions and variations in government policies and laws classified as the least significant reasons.

Main causes of delays that produce the greatest effects to extension of time in construction projects in Saudi Arabia were identified by Al-Kharashi and Skitmore (2009) by performing a questionnaire survey administered to contractors, consultants and employers to understand their individual opinion on the delay events. The results showed differences of opinion between the contractors and consultants - which have tendency to blame the other to some extent. However, there is a consensus over some reasons of construction delays which are lack of skilled manpower in the industry.

Hamza (2011) collected causes of delay from the previous international journal papers in order to constitute a theoretical framework which demonstrates the delays that occurred during two different construction project in Malaysia. The framework grouped causes of delay under three categories as by owner/consultant, by third parties and act of God, and by contractor.

Kazaz *et al.* (2012) prepared a questionnaire survey which is composed of 34 factors which affects project duration and these factors were grouped under 7 categories. The survey was applied to 71 construction companies after then relative importance index techniques was employed in order rank delay factors. The results indicate that design and material changes, delay of payments and cash flow problems are the most leading causes of delays.

In India, Doloi et al. (2012) acknowledged the important reasons causing delays in construction schedules in Indian construction industry by adopting factor analysis and regression modelling in order to inspect the importance of the delaying elements.

Fallahnejad (2013) used a survey method to detect and rank the reasons of delay in gas pipeline projects in Iran. According to responses from 23 specialists in performances of oil/gas pipeline projects, it was concluded as the 5 most vital causes of project delay (out of 44 factors) were related to imported materials, impractical project duration, materials under client’s responsibility, plot expropriation, and change orders.

Aziz (2013) listed 99 factors, grouped these factors into 9 main categories, and applied a questionnaire survey in order to rank these factors according to their importance level on delay especially after Egyptian revolution. The data were analysed using Relative Importance Index (RII). Delay in progress payments, different tactics patterns for bribes, and inadequate contractor experience were found to be the most leading causes of delays in Egypt.

Gündüz *et al.* (2013) carried out a survey study to classify the relative importance of 83 different causes of delay in Turkish construction business. These causes of delay were classified causes of construction delays into seven categories as (i) contractor-related, (ii) owner-related, (iii) consultant-related, (iv) labour-related, (v) design-related, (vi) material-related, (v) equipment-related, (vii) project related, and (viii) external-related.

Mazrouk and El-Rasas (2014) adopted a questionnaire survey which was distributed to thirty-three construction experts in order to study and analyse causes of construction delays in Egypt. Frequency Index, Severity Index, and Importance Index were calculated and according to the highest values of them, delay causes of construction projects in Egypt are evaluated.

Ruqaishi and Bashir (2015) investigated reasons that cause delay in construction projects in oil and gas processing facilities in Oman, that also served as a case study for the Gulf GCC countries. Outcome of the research indicate that most significant causes of construction delays are poor Site Management and Supervision by contractors, problems with subcontractors and Inadequate Planning and Scheduling of Project by Contractors.

McCord *et al.* (2015) performed a study regarding causes of delays within the housing construction industry in Northern Ireland and results indicated the key findings that can be attributed to shortages in site management, ineffective communication policies and a lack of coordination between key stakeholders involved in the construction process.

Da Silva (2016) conducted a national survey in Portugal in order to identify the most vital causes of delay, the frequency of the effects and the correlation between them. RII was used to classify the relative importance of the reasons and the frequency of the impacts. The outcome of the research was that the dominant causes of delay were slow decision making by owner, change orders, unrealistic contract in contract, and financial constraints of contractor.

Durdyev *et al.* (2017) targeted to identify challenging factors which lead to delays in construction projects in Cambodia. A questionnaire survey method was used to collect data and Relative Importance Index (RII) was used to analyse the collected data. Results showed that delays is mainly caused by shortage of materials on site, followed by unrealistic project scheduling, late delivery of material, shortage of skilled labour, complexity of project.

Agyekum-Mensah and Knight (2017) identified 32 themes, which were categorised into 15 categories of causes of delay in construction projects in the UK by undertaking a total 41 of interviews which comprised 26 interviews within 4 project cases and 26 general interviews with experienced professionals. They reported that insufficient planning, poor project management, unclear initial project objectives, communication and inappropriate resource management are consistent with other studies and universal problems are the most leading problems regarding construction delays.

Research of Gomarn and Pongpeng (2018) aimed to detect the main reasons of delays in construction projects caused by contractors and suppliers in Thailand's oil and gas industries and relationships of these delays. The main causes of delays from contractors in construction projects were poor site management and supervision and lack of safety rules and regulations on the other side the delays caused by suppliers were the supply of unqualified and unskilled personnel and late delivery of materials and equipment.

Shahsavand *et al.* (2018) determined the major causes of delays in construction projects in Iran (according to their significance levels based on RII analysis of collected data from survey) as change orders, underestimation of time to complete, underestimation of project cost, delivery of site by the owner, and effects of subsurface conditions.

Hossain *et al.* (2019) investigated 55 main sources of delays in different type of construction projects executed in Kazakhstan. They contacted with different project parties (client, contractor and consultant) in order to acknowledge diverse opinions on the delay causes through a survey. Research revealed that most leading causes of delays in Kazakhstan's construction industry are incomplete design/improper design, delay in materials' delivery, financial difficulties of the client and slow decision making-process.

Zhang *et al*. (2020) conducted a study in order to identify causes of delay in tunnel construction projects based the questionnaire surveys of 176 companies among which were tunnel consultants and contractors. In light of this study, complicated geological conditions, national policy for subway tunnel construction, progressing payments delay by the owner, award the project to lowest bid price, shortage in construction material, lack of equipment efficiency, low productivity of labours, postponement of the project by the owner, delay in providing construction materials, late land handover to the contractor by the owner and ineffective scheduling of the project by the contractor were found to be the most dominant causes of delay in tunnel construction out of a total of 49 delay sources recognised in this study.

Din *et al.* (2020) surveyed employers, consultants, and contractors of twenty residential projects in Pakistan to comprehend the reasons of construction delays. The result of the study showed that the main causes of delay in residential projects in Pakistan were inefficient decision-making process, interference from the client, unsafe work environments, change orders, lack of qualified subcontractors, inadequate finance management, error in designs, errors in construction, and ineffective communication.

Rivera *et al.* (2020) purposed to identify top ten prevailing causes of delay in road construction projects in 25 developing countries in globe. After having determined the top 10 frequent causes of delay in road construction, their intensity and then their importance were evaluated. According to the results, lack of an experienced construction manager, inadequate planning/scheduling, influence on people’s land along with the road construction project, poor communication between construction parties, frequent changes in design, and shortage of equipment were determined as the most important causes of delay in road construction projects.

Table 2.4 shows most influential factors resulting delay related to employers are variation orders/ too many changes of scope by owner during construction, finance and payments of completed work by employer, and slowness in decision making. No payment of contractor’s claim and selecting inappropriate contractors are the least ranked factors resulting delay from owners’ side.

Table 2.4 Factors causing delays related to owners.

No.	Factors	Rate	Authors
1	Variation orders/ too many changes of scope by owner during construction	14	(Lo *et al.*, 2006), (Sweis, 2008), (Hamzah *et al.*, 2011), (Fallahnejad, 2013), (Aziz, 2013), (Gündüz *et al.*, 2013), (da Silva, 2016), (Marzouk and El-rasas, 2014), (Ruqaishi and Bashir, 2015), (McCord *et al.*, 2015), (Agyekum-Mensah and Knight, 2017), (Shahsavand *et al.*, 2018), (Din *et al.*, 2020), (Rivera *et al.*, 2020).
2	Finance and payments of completed work by owner	12	(Sambasivan and Soon, 2007), (Al-Kharashi and Skitmore, 2009), (Kazaz *et al.*, 2012), (Fallahnejad, 2013), (Aziz, 2013), (Gündüz *et al.*, 2013), (Marzouk and El-rasas, 2014), (McCord *et al.*, 2015), (Durdyev *et al.*, 2017), (Agyekum-Mensah and Knight, 2017), (Hossain *et al.*, 2019), (Zhang *et al.*, 2020), (Rivera *et al.*, 2020).
3	Slowness in decision making	10	(Faridi *et al.*, 2006), (Hamzah *et al.*, 2011), (Aziz, 2013), (Gündüz *et al.*, 2013), (da Silva, 2016), (Ruqaishi and Bashir, 2015), (McCord *et al.*, 2015), (Shahsavand *et al.*, 2018), (Hossain *et al.*, 2019), (Din *et al.*, 2020).
4	Design changes	6	(Sweis, 2008), (Kazaz *et al.*, 2012), (Gündüz *et al.*, 2013), (da Silva, 2016), (Durdyev *et al.*, 2017), (Rivera *et al.*, 2020).
5	Delay in site delivery	5	(Al-Kharashi and Skitmore, 2009), (Hamzah *et al.*, 2011), (Gündüz *et al.*, 2013), (Shahsavand *et al.*, 2018), (Zhang *et al.*, 2020).
6	Client interfaces	4	(Al-Kharashi and Skitmore, 2009), (da Silva, 2016), (Ruqaishi and Bashir, 2015), (Din *et al.*, 2020).
7	Conflicts between joint-ownership	3	(Al-Kharashi and Skitmore, 2009), (Hamzah *et al.*, 2011), (Aziz, 2013).
8	No payment of contractor’s claim	1	(Al-Kharashi and Skitmore, 2009).
9	Selecting inappropriate contractors	1	(Aziz, 2013).
10	Delay in delivering construction materials	1	(Zhang *et al.*, 2020).
11	Postponement of the project	1	(Zhang *et al.*, 2020).

Table 2.5 portrays the main causes of delay in construction industry arisen from factors which are under contractor’s responsibility. Ineffective project planning and scheduling by contractor is encountered in 18 out of 20 studies and found as most influential cause of delay in many studies as well. The following most dominant causes are poor site management and supervision, and difficulties in financing project by contractor are the dominant causes of delay related to contractor, on the other hand inappropriate construction methods, lack of feasibility studies, underestimating project cost, and mistakes during construction are found as less influential factors.

Table 2.5 Factors causing delays related to contractors.

No.	Factors	Rate	Authors
1	Ineffective project planning and scheduling	20	(Faridi *et al.*, 2006), (Sambasivan and Soon, 2007), (Sweis, 2008), (Al-Kharashi and Skitmore, 2009), (Hamzah *et al.*, 2011), (Doloi *et al.*, 2012), (Fallahnejad, 2013), (Aziz, 2013), (Gündüz *et al.*, 2013), (da Silva, 2016), (Marzouk and El-rasas, 2014), (Ruqaishi and Bashir, 2015), (McCord *et al.*, 2015), (Durdyev *et al.*, 2017), (Agyekum-Mensah and Knight, 2017), (Gomarn and Pongpeng, 2018), (Shahsavand *et al.*, 2018), (Hossain *et al.*, 2019), (Zhang *et al.*, 2020), (Rivera *et al.*, 2020).
2	Poor site management and supervision	14	(Faridi *et al.*, 2006), (Lo *et al.*, 2006), (Sambasivan and Soon, 2007), (Sweis, 2008), (Al-Kharashi and Skitmore, 2009), (Hamzah *et al.*, 2011), (Doloi *et al.*, 2012), (Aziz, 2013), (Marzouk and El-rasas, 2014), (Ruqaishi and Bashir, 2015), (McCord *et al.*, 2015), (Durdyev *et al.*, 2017), (Agyekum-Mensah and Knight, 2017), (Gomarn and Pongpeng, 2018).
3	Difficulties in financing project by contractor	12	(Faridi *et al.*, 2006), (Lo *et al.*, 2006), (Sweis, 2008), (Al-Kharashi and Skitmore, 2009), (Hamzah *et al.*, 2011), (Kazaz *et al.*, 2012), (da Silva, 2016), (Marzouk and El-rasas, 2014), (Ruqaishi and Bashir, 2015), (McCord *et al.*, 2015), (Agyekum-Mensah and Knight, 2017), (Din *et al.*, 2020).
4	Inadequate experience of contractor	9	(Lo *et al.*, 2006), (Sambasivan and Soon, 2007), (Al-Kharashi and Skitmore, 2009), (Aziz, 2013), (Gündüz *et al.*, 2013), (da Silva, 2016), (Ruqaishi and Bashir, 2015), (Gomarn and Pongpeng, 2018), (Rivera *et al.*, 2020).
5	Problems with subcontractors	7	(Sambasivan and Soon, 2007), (Hamzah *et al.*, 2011), (Fallahnejad, 2013), (Gündüz *et al.*, 2013), (Ruqaishi and Bashir, 2015), (Durdyev *et al.*, 2017), (Din *et al.*, 2020).
6	Rework due to errors during construction	6	(Hamzah *et al.*, 2011), (Kazaz *et al.*, 2012), (Aziz, 2013), (Ruqaishi and Bashir, 2015), (Durdyev *et al.*, 2017), (Gomarn and Pongpeng, 2018).
7	Inappropriate construction methods	3	(Aziz, 2013), (Ruqaishi and Bashir, 2015), (Gomarn and Pongpeng, 2018).
8	Lack of feasibility studies	3	(Sweis, 2008), (Kazaz *et al.*, 2012), (Shahsavand *et al.*, 2018).
9	Underestimating project cost	3	(Sweis, 2008), (Kazaz *et al.*, 2012), (Shahsavand *et al.*, 2018).
10	Mistakes during construction	3	(Shahsavand *et al.*, 2018), (Hossain *et al.*, 2019), (Din *et al.*, 2020).

Table 2.6 indicates that most dominant factor to delay in construction related to consultants is delay in revising and approving design documents which was encountered more than half of the investigated studies. All the other factors related to the consultant are found to have lesser importance relatively.

Table 2.6 Factors causing delays related to consultants.

No.	Factors	Rate	Authors
1	Delay in revising and approving design documents	11	(Faridi *et al.*, 2006), (Al-Kharashi and Skitmore, 2009), (Hamzah *et al.*, 2011), (Fallahnejad, 2013), (Aziz, 2013), (Gündüz *et al.*, 2013), (da Silva, 2016), (Marzouk and El-rasas, 2014), (Ruqaishi and Bashir, 2015), (McCord *et al.*, 2015), (Durdyev *et al.*, 2017),
2	Mistakes and discrepancies in drawings & incomplete/improper design	5	(Hamzah *et al.*, 2011), (da Silva, 2016), (Agyekum-Mensah and Knight, 2017), (Hossain *et al.*, 2019), (Din *et al.*, 2020).
3	Delay in performing inspection and testing	3	(Hamzah *et al.*, 2011), (Aziz, 2013), (Gündüz *et al.*, 2013)
4	Conflicts between consultant and design engineer	2	(Hamzah *et al.*, 2011), (Aziz, 2013).
5	Inflexibility of consultant	2	(Hamzah *et al.*, 2011), (Doloi *et al.*, 2012).

Table 2.7 lists the ranking of delay causes in construction industry with respect to external factors, and obtaining permits from governmental organizations (i.e., municipalities, ministries, public institutions, etc.) was found to be the top rated one among others. Slow land expropriation due to resistance from occupants was found only in one study, thus it can be interpreted as a country specific problem.

Table 2.7 Factors causing delay related to external factors.

No.	Factors	Rate	Authors
1	Obtaining permits from governmental organizations	8	(Faridi *et al.*, 2006), (Lo *et al.*, 2006), (Al-Kharashi and Skitmore, 2009), (Fallahnejad, 2013), (da Silva, 2016), (McCord *et al.*, 2015), (Durdyev *et al.*, 2017), (Shahsavand *et al.*, 2018).
2	Price fluctuations, changes in market conditions	7	(Kazaz *et al.*, 2012), (Fallahnejad, 2013), (Aziz, 2013), (Marzouk and El-rasas, 2014), (Ruqaishi and Bashir, 2015), (Durdyev *et al.*, 2017), (Gomarn and Pongpeng, 2018).
3	Unfavourable weather conditions	4	(Hamzah *et al.*, 2011), (Aziz, 2013), (McCord *et al.*, 2015), (Durdyev *et al.*, 2017).
4	Labour Dispute and Strike	4	(Hamzah *et al.*, 2011), (Fallahnejad, 2013), (Aziz, 2013), (Marzouk and El-rasas, 2014).
5	Slow land expropriation due to resistance from occupants	2	(Fallahnejad, 2013), (Rivera *et al.*, 2020).
6	National policy for the particular type of project	1	(Zhang *et al.*, 2020).

According to Table 2.8, shortage of materials is found to be leading factor to delay. Unqualified workforce, shortage of labour, and late delivery of material are subsequent factors by having equal ranks in Labour/ Material and equipment related ranking. Unbalanced number of workers is observed as the least ranked agent under this group.

Table 2.8 Factors causing delay related to labour/ material and equipment.

No.	Factors	Rate	Authors
1	Shortage of materials	10	(Sambasivan and Soon, 2007), (Al-Kharashi and Skitmore, 2009), (Fallahnejad, 2013), (da Silva, 2016), (Marzouk and El-rasas, 2014), (Durdyev *et al.*, 2017), (Gomarn and Pongpeng, 2018), (Hossain *et al.*, 2019), (Zhang *et al.*, 2020), (Rivera *et al.*, 2020).
2	Unqualified workforce	7	(Faridi *et al.*, 2006), (Sweis, 2008), (Gündüz *et al.*, 2013), (Marzouk and El-rasas, 2014), (Durdyev *et al.*, 2017), (Gomarn and Pongpeng, 2018), (Shahsavand *et al.*, 2018).
3	Shortage of labour	7	(Faridi *et al.*, 2006), (Sambasivan and Soon, 2007), (Aziz, 2013), (Ruqaishi and Bashir, 2015), (Durdyev *et al.*, 2017), (Agyekum-Mensah and Knight, 2017),(Gomarn and Pongpeng, 2018), (Hossain *et al.*, 2019).
4	Late delivery of material	7	(Faridi *et al.*, 2006), (Gündüz *et al.*, 2013), (da Silva, 2016), (Ruqaishi and Bashir, 2015), (Durdyev *et al.*, 2017), (Agyekum-Mensah and Knight, 2017), (Hossain *et al.*, 2019).
5	Poor labour productivity	6	(Faridi *et al.*, 2006), (Kazaz *et al.*, 2012), (Marzouk and El-rasas, 2014), (Durdyev *et al.*, 2017), (Hossain *et al.*, 2019), (Zhang *et al.*, 2020).
6	Shortage of equipment	6	(Sambasivan and Soon, 2007), (Aziz, 2013), (Ruqaishi and Bashir, 2015), (Hossain *et al.*, 2019), (Zhang *et al.*, 2020), (Rivera *et al.*, 2020).
7	Frequent breakdowns of construction plant and equipment	3	(Sambasivan and Soon, 2007), (Durdyev *et al.*, 2017), (Gomarn and Pongpeng, 2018).
8	Low ability of contractor to provide imported material	3	(Fallahnejad, 2013), (Durdyev *et al.*, 2017), (Hossain *et al.*, 2019).
9	Unbalanced number of workers	1	(Kazaz *et al.*, 2012).

Table 2.9 Factors causing delay related to project and contractual factors.

No.	Factors	Rate	Authors
1	Lack of communication between parties	14	(Sambasivan and Soon, 2007), (Sweis, 2008), (Al-Kharashi and Skitmore, 2009), (Hamzah *et al.*, 2011), (Doloi *et al.*, 2012), (Gündüz *et al.*, 2013), (da Silva, 2016), (Ruqaishi and Bashir, 2015), (McCord *et al.*, 2015), (Durdyev *et al.*, 2017), (Agyekum-Mensah and Knight, 2017), (Gomarn and Pongpeng, 2018), (Din *et al.*, 2020), (Rivera *et al.*, 2020).
2	Unrealistic time schedule and specifications in the contract	7	(Lo *et al.*, 2006), (Fallahnejad, 2013), (da Silva, 2016), (Ruqaishi and Bashir, 2015), (Durdyev *et al.*, 2017), (Agyekum-Mensah and Knight, 2017), (Shahsavand *et al.*, 2018).
3	Unexpected surface and subsurface conditions (soil, high water table)	7	(Lo *et al.*, 2006), (Sweis, 2008), (Gündüz *et al.*, 2013), (Marzouk and El-rasas, 2014), (Ruqaishi and Bashir, 2015), (Shahsavand *et al.*, 2018), (Zhang *et al.*, 2020).
4	Insufficiency of incentives for ahead of schedule projects or delay penalties	4	(Hamzah *et al.*, 2011), (Doloi *et al.*, 2012), (Fallahnejad, 2013), (Aziz, 2013).
5	Type of project bidding and award	4	(Fallahnejad, 2013), (da Silva, 2016), (Marzouk and El-rasas, 2014), (Zhang *et al.*, 2020).
6	Legal disputes between project participants	3	(Aziz, 2013), (da Silva, 2016), (Ruqaishi and Bashir, 2015).
7	Complexity of project (project type, project scale, etc.)	2	(Aziz, 2013), (Durdyev *et al.*, 2017).
8	Lack of safety rules and regulations	2	(Durdyev *et al.*, 2017), (Gomarn and Pongpeng, 2018), (Din *et al.*, 2020).

Table 2.9 expresses 8 causes of construction delays regarding project and contractual factors, lack of communication between parties is found to be the most common reason of construction delays under this category. Complexity of project (project type, project scale, etc.) and lack of safety rules and regulations have less weightiness compared to other factors.

Table 2.10 Top 10 ranked factors causing construction delay.

No.	Factors	Rate	Delay Group
1	Ineffective project planning and scheduling	20	Contractors
2	Variation orders/ too many changes of scope by owner during construction	14	Owners
3	Poor site management and supervision	14	Contractors
4	Lack of communication between parties	14	Project Related
5	Finance and payments of completed work by owner	12	Owners
6	Difficulties in financing project by contractor	12	Contractors
7	Delay in revising and approving design documents	11	Consultants
8	Shortage of materials	10	Labour/ material and equipment.
9	Slowness in decision making	10	Owners
10	Inadequate experience of contractor	9	Contractors

Table 2.10 summarises the top ranked 10 out of 49 identified causes of construction delay in the reviewed 23 studies. According to the table above, among top 10 delay causes, 4 of those are resulting from actions or inactions of the contractors, 3 factors are under responsibility of the owners and one factor under each of those groups the project itself, consultants and labour/ material and equipment are listed among the most encountered causes of delay. Ineffective project planning and scheduling is found to be the most common cause of delay. Variation orders/ too many changes of scope by owner during construction is the second most encountered type of delay causes according to literature review.

2.2.2. Critical or Non-Critical Delays

Activities which reside on the longest path to the completion are called ‘Critical Activity’. If such activity delayed or extended, it will impact the completion of the project and, generally, if a critical activity is advanced or reduced it will advance or reduce the completion of a project. ‘Critical delay’ is described as a delay to start and/or finish date of any activity on the critical path will, without acceleration or re-sequencing, cause a delay on completion date of the overall project (Gibson, 2008).

When indicating that a delay is both excusable and compensable, the delay must be shown to be critical, by reference to a dependable critical path study (Keane and Caletka, 2015). Delays are categorized into ‘critical’ and ‘non-critical’ delays. The critical delays cause delay to project completion date on the other hand the others affect progress and/or successor activities but not overall completion. Unless contracts dictate otherwise, delay activity must affect the completion date of the project in order for delay to be valid an extension of contract time. This provides the basis for the high importance attached to the use of critical path method (CPM) of scheduling for proving or disproving time related claims such as extension of time and prolongation cost.

In order for a party to be entitled to an extension of contract duration for any delay event (and later to be considered compensable), the delay must reside on the critical path. Before a party is entitled to time-associated compensation for its damages, it must demonstrate that it was actually damaged. Since conventionally a contractor’s delay damages are a function of the overall duration, there must be a rise in the total duration of the project (AACEI, 2011).

2.2.3. Excusable or Non-Excusable Delays

Critical delays are either ‘excusable’ or ‘non-excusable’. Excusable delays are those for which the contractor can be excused due to an act or omission by the owner i.e. issuance of unclear and inadequate details in drawings by the engineer. Non-excusable delays are resulted by the contractor’s actions or inactions i.e. contractor’s continuous reworks due to poor performance due to poor workmanship (Gibson, 2008).

SCL Protocol refers excusable delays as ‘Employer Delay’ whilst it calls ‘Contractor Delay’ in lieu of non-excusable delays. EOT is only to be approved if the Employer Delay delays completion beyond the contract completion date (SCL, 2017). An excusable delay typically is a delay that is as a result of an unpredictable incident beyond the Contractor’s or the Subcontractor’s control (Trauner, 2009).

Excusable delay is a delay for which a contractor will have relief from damages due to prolongation and potential financial entitlement depending on contractual circumstances whereas non-excusable delays are caused by contractor and not warrant an EOT (Keane and Caletka, 2015).

Generally, regarding mutual general contract provisions or specifications, delays stemming from the following events would be treated as excusable:

- Severe weather conditions,
- Acts of God,
- Employer changes,
- Faults and omissions in the plans and specifications,
- Interference by external agencies, and
- Lack of action by government bodies (Trauner, 2009).

Non-excusable delays are circumstances which were under control of the contractor or which are foreseeable prior to its occurrence. Some examples of such delays are noted below:

- Subcontractors’ poor performance,
- Late deliveries,
- Defective workmanship, and
- A labour strike caused by either the contractor’s reluctance to satisfy contractual obligations or by improper labour practices (Trauner, 2009).

2.2.4. Compensable or Non-Compensable Delay

Excusable delays are either compensable or non-compensable. A compensable delay entitles the contractor, to financial compensation for the period of delay through actions or inactions by the employer or his agents whereas non-compensable delays result from neutral events (such as exceptionally inclement weather), third parties, etc.; indeed any event for which under the contract between the parties there is no recompense for loss and expense (Gibson, 2008).

Referring to the excusable and non-excusable delays, only excusable delays can be compensable. An excusable compensable delay is described as a delay that is triggered by actions that are no under the contractor's control however within the owner's control (e.g., owner-directed changes, design revisions). If an excusable compensable delay exists, this will entitle the contractor to an extension of time and financial recovery (Arditi *et al.*, 2017).

SCL Protocol uses “Employer Risk Event” for compensable delays in respect of which the Contractor is entitled to compensation on the other hand Protocol uses “Contractor Risk Event” in lieu of non-compensable delays. A compensable delay is a delay where the contractor is entitled to a time extension and to compensation for prolongation costs. A non-compensable delay means that when excusable days exists but, the contractor is not granted to any compensation for additional costs resulting from the excusable delay (Trauner, 2009; SCL, 2017).

The contractor generally undertakes the risks of expenses and consequences of delay events which are under its control i.e. lack of manpower, late mobilisation, etc. This type of delay is called as "non-excusable and non-compensable" (NN) delay, which could be compensated to the employer in the form of liquidated or actual damages paid by the contractor for late completion (Braimah, 2008). An excusable non-compensable delay is caused by actions for when no party is responsible i.e. the employer and the contractor (e.g., severe weather conditions, labour strikes). In this case, the contractor is entitled to an extension of time only (Keane and Caletka, 2015; Arditi *et al.*, 2017).

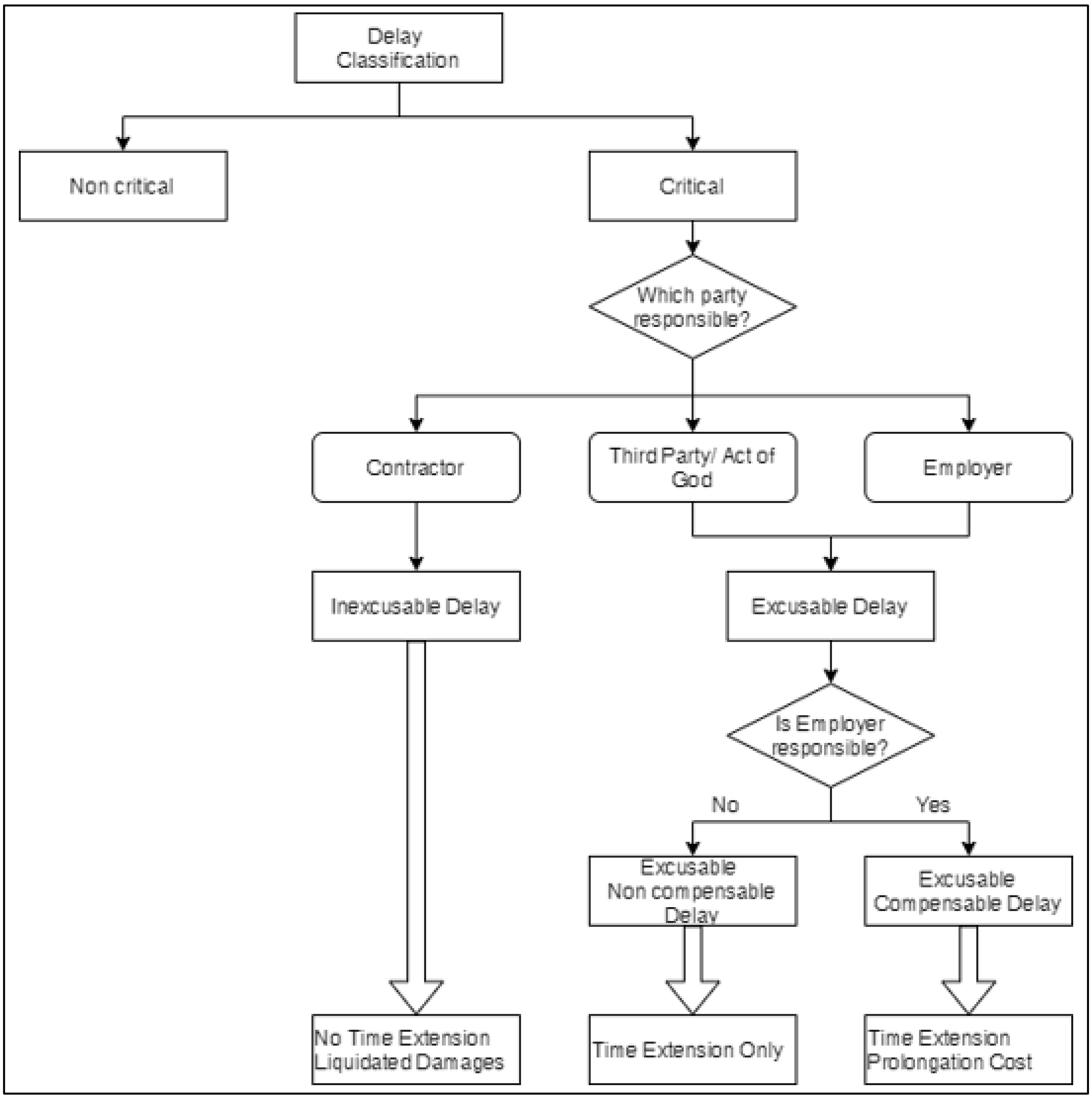


Figure 2.2 Delay classification.

When actions or inactions of the contractor's or one of its subcontractor's cause non-excusable delays, then the contractor becomes accountable. In this case, the contractor is not entitled to an extension of time or compensation for prolongation, also the contractor would be exposed to recover liquidated or actual damages of the employer (Golnaraghi, 2011).

As a summary, Figure 2.2 depicts the classification of different types of delay in construction based on different characteristics i.e. their criticality, liability of the parties and treatment of those delays.

2.2.5. Timing of a Delay

In case of evaluating delay event relative to time, delays can be categorized further three levels as (Besoglu, 2006; Braimah, 2008) (i) independent delays are delays which happens independently, in isolation or without affecting other consecutive or simultaneous delays in a project; (ii) serial delays occur in sequence consecutively and not overlapping with each other on a specific network path; and (iii) concurrent delays occur if the overall delay is triggered by a number of factors, some of which are within the employer's responsibility and others are within the contractor's control.

It is relatively easier to identify and resolve independent and serial delays, to establish its impacts on total project duration, and to assign cost burdens to the associated parties. Hence, the concept of concurrency has been the focus of much disputes and debate among researchers and practitioners. The overlapping nature of the events makes it challenging to distinguish what proportion of the overall delay belongs to which party in the project. Therefore, concurrent delays will be reviewed further.

2.2.6. Association Between EOT and Compensation

A delay claim can be for an extension of time in the contract, monetary compensation, or both. A claim for only financial compensation regularly stems from a change order (Mubarak, 2015). Entitlement to an EOT does not necessarily constitute an entitlement to compensation (and vice versa). In construction industry, it is a common misinterpretation that the contractor who is entitled to an EOT, is also automatically entitled to be compensated (SCL, 2017).

Typical financial claims by a contractor which are reliant on a delay analysis of time are as below (depending on the contract provisions and the particular conditions):

- relief from liquidated damages;
- compensation for time-related costs;
- extended and increased field costs;
- inefficiency or lost productivity costs;
- if the contractor has taken acceleration steps in an endeavour to mitigate the delay, compensation for those steps; and
- other categories of delay damages i.e. non-critical delays, legal and consulting costs, lost profits, lost opportunity costs/bonding impairment, interest, and other impacts (Trauner, 2009).

Under the most of the standard forms of contract, the contractor is almost always obliged to ground its entitlement to an EOT under one provision of the contract and its entitlement to compensation for that prolongation under another provision (Chappell, 2017; Eggleston, 2019; Godwin, 2020).

If a prospective approach is adopted to measure delay impact based on the likely employer delay to completion, and a retrospective method is employed to evaluate time for prolongation depending upon the actually incurred loss and/or costs, then the two analysis of time may generate different conclusions. This is only to be expected, and does not automatically point to faults in either technique (SCL, 2017).

‘Neutral events’ (i.e. force majeure and exceptionally adverse weather) entitle a contractor to extension of time, however not reimbursement for additional incurred costs. A neutral event is a non-compensable and excusable delay (Keane and Caletka, 2015). However, SCL Delay and Disruption Protocol so far as the ‘neutral events’ is concerned states it is misleading due to the fact that those events are solely neutral when that one party carries the time risk and the other party carries the cost risk (SCL, 2017). There is thus no certain linkage between entitlement to an extension of time and the entitlement to compensation for prolongation costs.

2.3. Categories of Delay Analysis

This section provides a comprehensive review of the existing delay analysis methods (DAMs) that are commonly performed in delay analysis process. In literature there are a great number of DAMs which have been developed to analyse the delay in construction projects. However, the DAMs have different ways to determine delay impact and to identify critical path. Moreover, the different DAMs also provides various approaches and analysis types which may produce diverse results. Thus, this section endeavours to provide an insight for categorization of DAMs and examine the widely used DAMs in construction industry.

2.3.1. Delay Impact Determination

Delay analysis methods are either 'prospective' or 'retrospective'. Prospective analyses imply the future, and endeavour determining the possible effect of actual progress or a specific event(s) on project completion. On the other hand, retrospective analyses refer to the past, and typically try to determine the actual impact of events upon progress and completion (Barry, 2009).

The AACEI RP is only concerned with retrospective delay analysis methods (AACEI, 2011). SCL Protocol states that there are two perspectives to evaluate delay impact. Prospective approach endeavours to determine the possible impact of a delay event to the project completion data based on historical data. Retrospective delay analysis examines the delay impact after it occurred (SCL, 2017).

Gibson simplifies the difference as stating that prospective analyses use as-planned programmes and essentially project the likely delay an event will cause on the other hand retrospective analyses use as-built programmes and establish the actual delay an event caused (Gibson, 2008). Each primary delay analysis technique is applied whether prospectively (contemporaneous, forward-looking and predictive modelling) or retrospectively (forensic, after the fact analysis and as-built delay modelling) (Keane and Caletka, 2015).

Whichever methodology is implemented, prospective or retrospective, if the analysis is performed accurately and systematically, they can produce satisfactory results. The dispute as to which approach prevails is usually related the preference of the analyst (Keane and Caletka, 2015). SCL Protocol recommends to use the prospective approach when dealing with a delay however, if an EOT application is assessed after completion of the works, or considerably after the impact of an employer risk event, then the prospective analysis of delay may no longer be appropriate (SCL, 2017).

Both approaches have been accepted by courts many times yet existing differences of these approaches should be taken into account when selecting a delay analysis method. The results of prospective determination might not be similar to the as-built programme since it may not reflect the future performance and intentions of the contractor. For instance, sequence of works may be altered, there might be some mitigation attempts, or the contractor can allocate resources differently. Retrospective approach utilizes updated programmes to identify actual impact of delay event.

2.3.2. Critical Path Determination

Critical path is specified in one of three different angles. Three different approaches can be employed. First approach is purely prospective critical path evaluation which observes the project at the beginning and does not take any progress into consideration. Second way is contemporaneous critical path assessment which adopts a changing and developing perspective as nature of the project during course of the works. It utilizes historical data, considers changes in managerial strategies and trends for future works in order to predict a critical path for rest of the project. The third practice is retrospective critical path assessment which analyse the critical path at the end of the project (SCL, 2017).

Whaley defines these 3 ways as (i) prospective determination is a forward looking critical path, based on the strategy for outstanding works; (ii) contemporaneous determination is the real critical path dominant in the inspected period and taking into consideration current progress and plan for the works (determined progressively through time); and retrospective determination is the critical path designated relying on as-built durations plus sequence alone so it may vary from the contemporaneous critical path (Whaley, 2018).

The "contemporaneous understanding of criticality" is assumed to be very significant since it theoretically sets light to the actions or inactions of the project management team during course of execution of project work. Advocates of this approach assert that only with a true reflection of the motivations of project members can a true understanding of criticality be realized (Levin *et al.*, 2016).

2.3.3. Observational Methods

Certain delay analysis methods begin to identify critical delay (an effect) and afterwards seek to appoint what might have caused that delay – these kind of analyses are called 'effect & cause' type which are commonly considered to be more forensically dependable since they detect any and all likely causes of the delay incurred. Effect & cause analyses are generally employed where an EOT application is evaluated after completion of the works, or very distant from the effect of the delay event (SCL, 2017). Effect & cause type methods rely to examination of documents and project information to discover delays not dependent on electronic programmes. They primarily determine the critical path and critical delays, and then identify the causes of delay (Whaley, 2018).

Figure 2.3 depicts delay analysis approaches based on different methods to be followed. The observational method comprises analysis of the schedule by inspecting a schedule and comparing with another while investigating project records, without making any modification in the schedule to model any particular scenario (AACEI, 2011). The process of reasoning from comparing schedules is necessary when employing observational techniques (Keane and Caletka, 2015). There are two ways (see Figure 2.3) to analyse a schedule observationally;

- Static logic observations compare one set of network logic to either their as-planned, updated or as-built states, as long as those programmes composed of the same set of activities and logic, unaltered between each state (AACEI, 2011). Retrospective longest path analysis and as-planned vs as-built are examples of this particular method (Whaley, 2018); and

- Dynamic logic observations involve the analysis of likely varying logic between each update, in contrast to the static logic observations. This method quantifies the effect of the logic change before evaluating the impact of delay events (Keane and Caletka, 2015). Time slice analysis method is an example of dynamic logic observations. (AACEI, 2011).

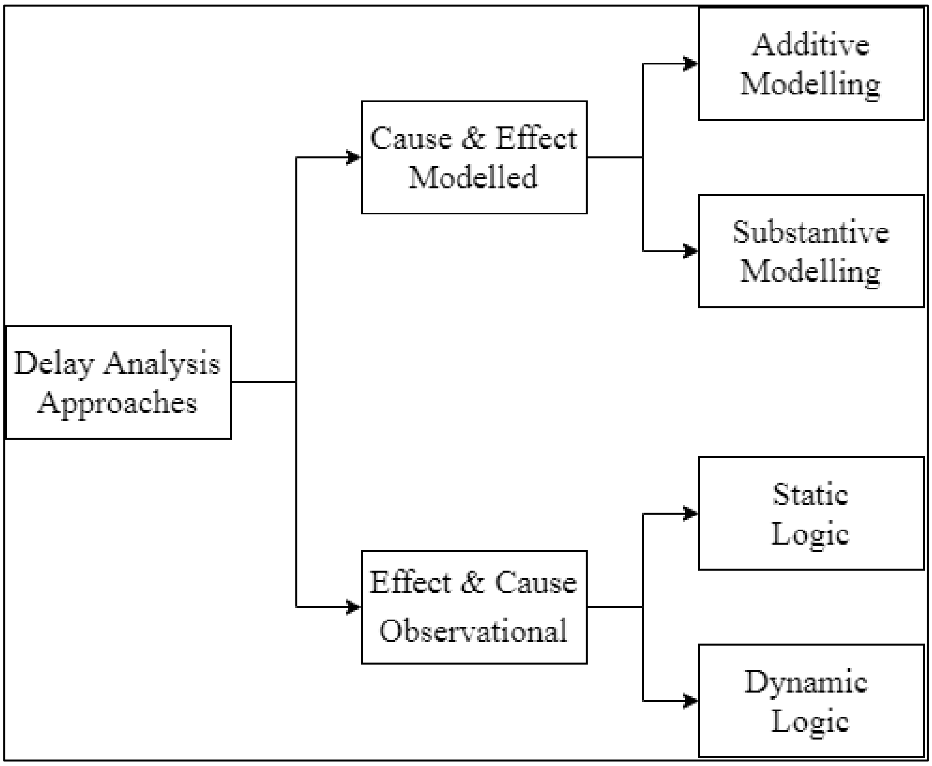


Figure 2.3 Delay analysis approaches.

Static observation is more reliant on facts, hence its conclusions readily can be defended by available contemporaneous records (Keane and Caletka, 2015). Observational methods are generally more realistic however they can be criticized for being impressionistic. Consequently, special attention to be paid in order to ensure results align with common sense and correspond with the wider matrix of fact (Whaley, 2018).

2.3.4. Modelled Methods

Particular delay analysis methods begin to initially identify and describe an event (a cause) and subsequently search to find its impact (the effect) – these kind of analyses are called 'cause & effect' type which are mostly employed, when the EOT application is being conducted contemporaneously (SCL, 2017). Cause & effect type methods fundamentally includes operation of a software programme to determine 'impacts' of a discrete delay event (Whaley, 2018).

Opposite to the observational method, the modelled method requires the analyst to intervene (some would say manipulate by another name) the schedule by means of inserting or extracting activities into or from a CPM network regarding delay events in order for analyst to arrive at 'before' and 'after' situations using 'what if' programme simulations when quantifying the effect of delays (Keane and Caletka, 2015). There are two perspectives (see Figure 2.3) under the modelled method to simulate a CPM network;

- Additive modelling enables a comparison of a base schedule with a recalculated schedule which analyst has established by additional activities, constraints or logic representing a delay event in order to model a particular situation. Impacted as-planned analysis and time impact analysis are classified under the additive modelling; and
- Subtractive modelling involves removals of delay event from an as-built schedule in to simulate a particular situation in order to find out when completion would otherwise have happened 'but for' that event. CAP method is one example that is classified under the subtractive modelling (AACEI, 2011).

When a project is completed, a great number of different as-built records become available which provide advantage of hindsight, and thus the number of applicable analysis methods increases. Moreover, if as-built records is accessible, the best evidence rule demands that all factual investigations utilize the as-built as the prime basis of analysis.

Modelling methods are more reliant on computer simulation and considerable energy devoted into operating software instead of examining facts (AACEI, 2011). Additive and subtractive modelling methods produce 'what if' simulations of the possible effect of delay events, and thus, by their nature, they are somewhat theoretical and might be detached from reality (Keane and Caletka, 2015). Therefore, if possible, many practitioners prefer to employ observational methods (Whaley, 2018).

2.4. Problematic Issues

There are a number of problematic issues that can turn a potential straightforward delay analysis into something complicated which requires much more attention. The main issues such as concurrency, pacing delays, float ownership, mitigation and acceleration, and contractor's right to early completion are examined further in order to have a broader understanding regarding identifications and remedies of such issues from perspectives of SCL Delay and Disruption Protocol and different sources.

2.4.1. Identification of Concurrent Delays

A concurrent delay is considered to be one of the most significant concepts to be evaluated and resolved during performing a delay analysis in construction industry as it relates to delay and compensation for prolongation. There is no globally accepted definition of 'concurrent delay' (Scott *et al.*, 2004). The ambiguity in identifying and managing concurrency causes difficulties for contract administrators while their assessment of extension of time and compensation events during execution of a project. Moreover, this uncertainty results in challenges for identification of causative events, and their effect and also difficulties in allocating responsibility and trying to isolate the costs that were experienced as a direct result of contribution of one party, or the other, to the overall delay.

SCL Delay and Disruption Protocol requires the following conditions to define a 'true concurrent delay';

- two or more delay events should occur simultaneously, one an employer risk event (employer delay), the other a contractor risk event (contractor delay);
- their effects should be felt at the same time; and
- both owner delay and contractor delay should affect the critical path – cause a delay to completion (SCL, 2017).

Whilst the SCL Protocol's description for true concurrency sounds to be precise and consistent, this occurrence is exceptionally rare in practice as time is infinitely divisible (Braimah, 2008). Moreover there is casual reference to concurrency when the effects of two or more delaying events are appeared simultaneously even if the actual causes of the delay or delay events happen at different times (Baldwin and Bordoli, 2014).

Mubarak described the concurrent delay as a combination of two or more independent causes of delay happening during the same period of time. Often the concurrent delays are excusable and non-excusable delays (Mubarak, 2015). Farrow divided concurrency into two; first one is concurrency of events which is defined as two delay event occurring at the same time, and secondly concurrency of delays which is defined as two delay events imposed at different times but causing delay at the same time (Farrow, 2001).

AACEI Forensic Schedule Impact Analysis 29R-03 necessitates two functional requirements for concurrency as; (i) delays must occur during or effect the same time analysis frame; and (ii) each event must independently delay the critical path. Moreover, four pre-requisite factors that must exist to evaluate concurrent delays;

- two or more delays that are independent and unrelated, and would have delayed the project even if the other delay did not occur;
- two or more delays that are the contractual responsibility of different parties, but one may be a force majeure event;
- a delay must be involuntary otherwise it is typically recognized as pacing; and
- a delayed work must be substantial and not easily curable (AACEI, 2011).

There are many different perspectives regarding concurrent delays among various practitioners, especially contractors, contract administrators, and claims consultants.

2.4.2. Dealing with Concurrent Delays

The SCL Protocol’s solution for the concurrent delay is that the contractor should be entitled to an EOT for the owner’s delay to the completion date, moreover contractor caused concurrent delay should not decrease duration of an extension of time (SCL, 2017). The protocol’s current position about concurrent delay is impressed by the ‘prevention principle’ under English law. Hence, in terms of concurrent delay this would imply that an owner would not be able to exploit from the non-fulfilment of a situation where the owner has itself prevented the contractor (Keen and Farr, 2017). With regard to money, the Protocol raises a number of points as follows:

- Entitlement to EOT does not mean an equal entitlement to compensation;
- When concurrent delays exist, a contractor is usually granted time but not money; and
- There are diverse tests for time and money.

Figure 2.4 demonstrates a project composed of 4 activities, and contains an as-planned schedule and four different scenarios which experienced 4-days of delay which are caused by both contractor and owner independently. In Scenario 1, 2 and 3, both contractor and owner delays occurred at the same time, and also their effects are felt during the same time frame, therefore the conditions in these scenarios align with the definition of a true concurrency from point of SCL's view. Each scenario is examined further to understand perspective of each party and allocate liability of each party.

In scenario 1, the contractor might take a position to claim for a 4-days EOT and 4-days of prolongation costs. On the other hand, the owner might refute either entitlement to an extension of time or any prolongation costs. Hence the Protocol recommends entitlement for 4-days EOT, no prolongation costs, but imbursement of costs resulting directly as a result of the owner's delay if any.

In scenario 2, the contractor's delay is 2-days more than the owner's delay. The contractor might claim for a 2-days extension of time and reimbursement for cost incurred during prolonged 2-days duration. On the other hand, the owner might refute either entitlement to an extension of time or any prolongation costs. The SCL Protocol recommends entitlement for 2-days EOT, no prolongation costs, liquidated damages for 2-days, and imbursement of costs resulting directly as a result of the owner's delay if any.

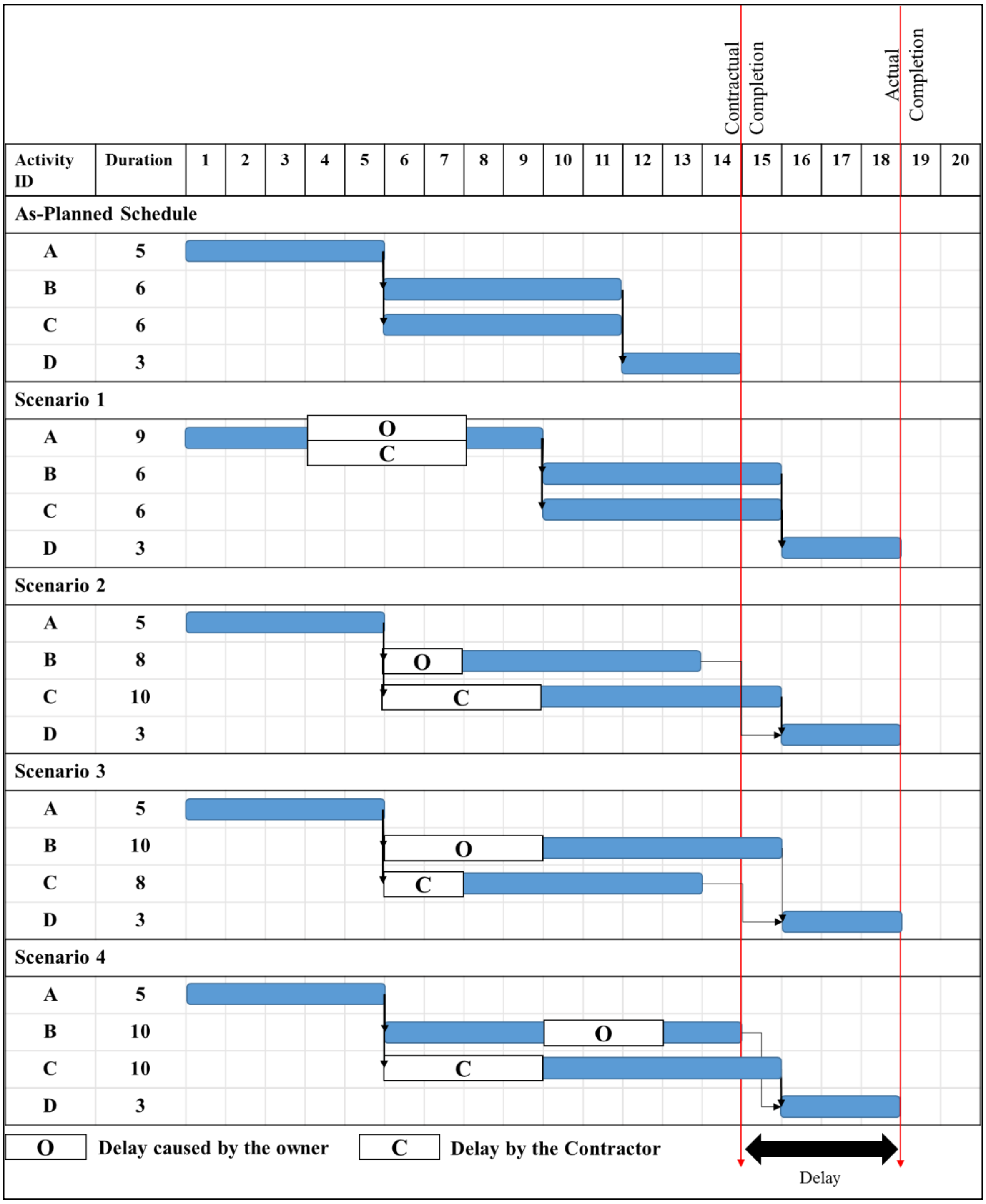


Figure 2.4 Bar chart in relation to possible scenarios for true concurrency.

Scenario 3 reverses the position with the owner's delay event being 2-days greater than the contractor's delay. The contractor might claim for a 4-days extension of time and reimbursement for cost incurred during prolonged 2-days duration. In return, the owner might concede some of the liability. The SCL Protocol recommends entitlement for 4-days

EOT, 2-days of prolongation costs, and imbursement of costs resulting directly as a result of the owner's delay if any.

Scenario 4 indicates the owner delay which is less than the contractor delay, and start after the contractor delay event finishes so owner delay should be seen as not causing a delay to the completion. Due to such reasons, according to SCL Protocol it is not possible to define this situation as true concurrency which arise where owner delay is shown to have caused delay to completion by other words critical delay to completion or, in other words, caused critical delay (i.e. it is on the longest path) to completion.

The concept of concurrency is often misinterpreted when two or more delaying events occur at different periods whilst their effects are felt at the same time. There are some other ways to identify effect of concurrency rather than SCL approach as follows;

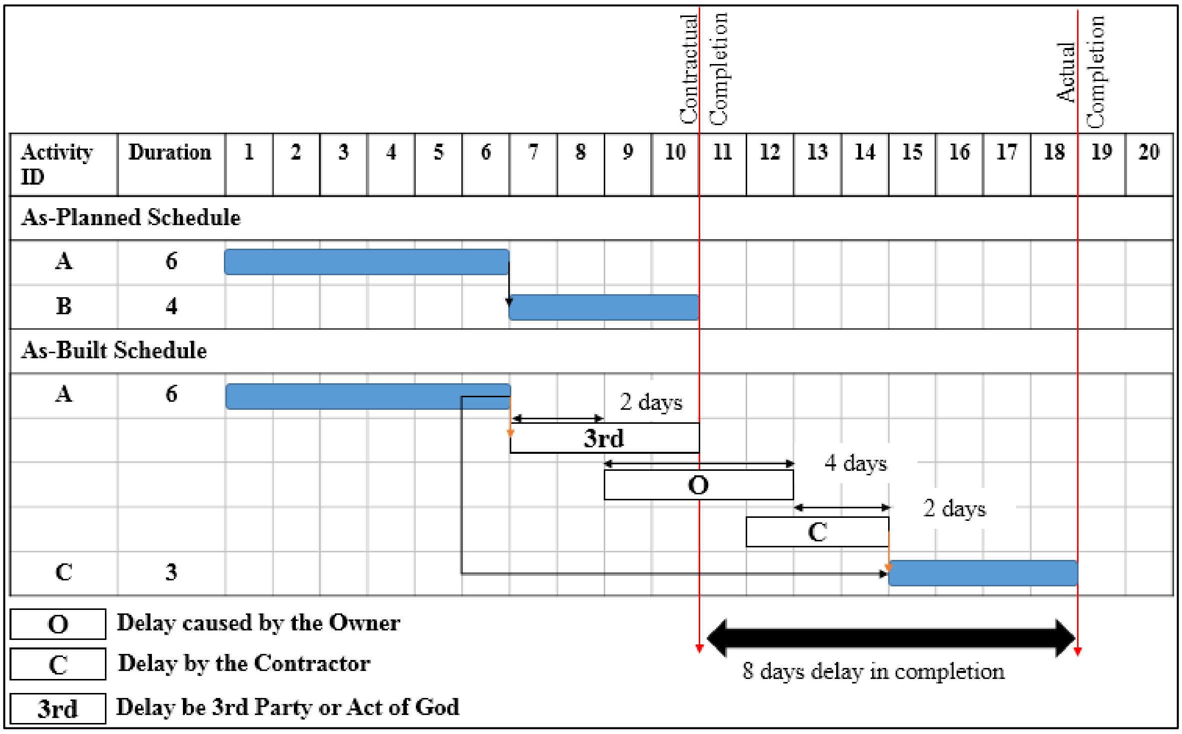


Figure 2.5 Bar chart in relation to dominant cause approach.

1. The Dominant Cause Approach asserts that if there are two or more sources of delay, the effective, dominant cause will be the deciding factor. The contract administrator must establish as a matter of fact which is the dominant cause of the delay, and this

takes precedent over the other causes of delay (Gibson, 2008; Baldwin and Bordoli, 2014). Figure 2.5 demonstrates a basic network comprising three delay events and application of dominant cause approach.

Table 2.11 Liability allocation - dominant cause approach.

	Extension of time	Compensation	Liquidated damages
Excusable and Compensable delay (owner caused)	4	4	
Excusable and Non Compensable delay (3rd party or Act of God)	2		
Non excusable delay (contractor caused)			2
Total	6 days	4 days	2 days

Table 2.11 shows the allocation of liabilities based on dominant cause approach.

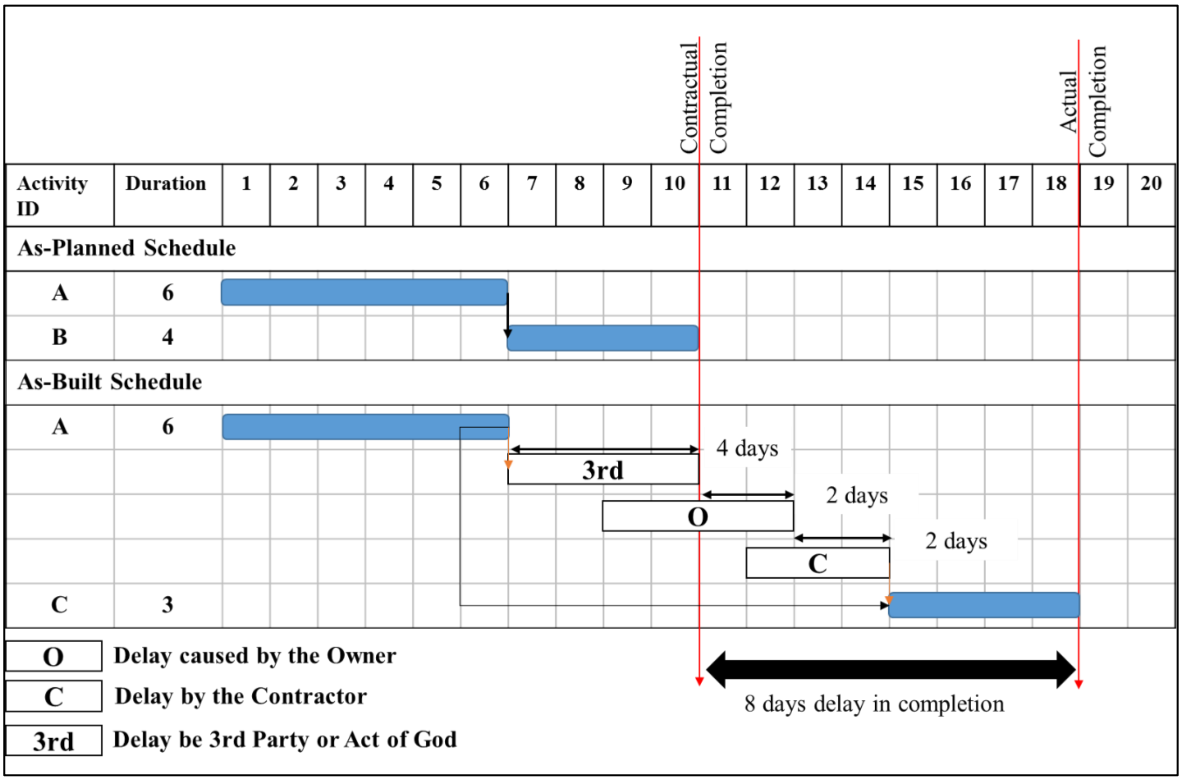


Figure 2.6 Bar chart in relation to first in line approach.

2. First in line approach treats each delay event chronologically with the first to happen taking precedence and the next delaying event not taking impact till the previous

delay has finishes (Baldwin and Bordoli, 2014; Keane and Caletka, 2015). Figure 2.6 demonstrates a basic network comprising three delay events and application of first in line approach.

Table 2.12 shows the allocation of liabilities based on first in line approach.

Table 2.12 Liability allocation – first in line approach.

	Extension of time	Compensation	Liquidated damages
Excusable and Compensable delay (owner caused)	2	2	
Excusable and Non Compensable delay (3rd party or Act of God)	4		
Non excusable delay (contractor caused)			2
Total	6 days	2 days	2 days

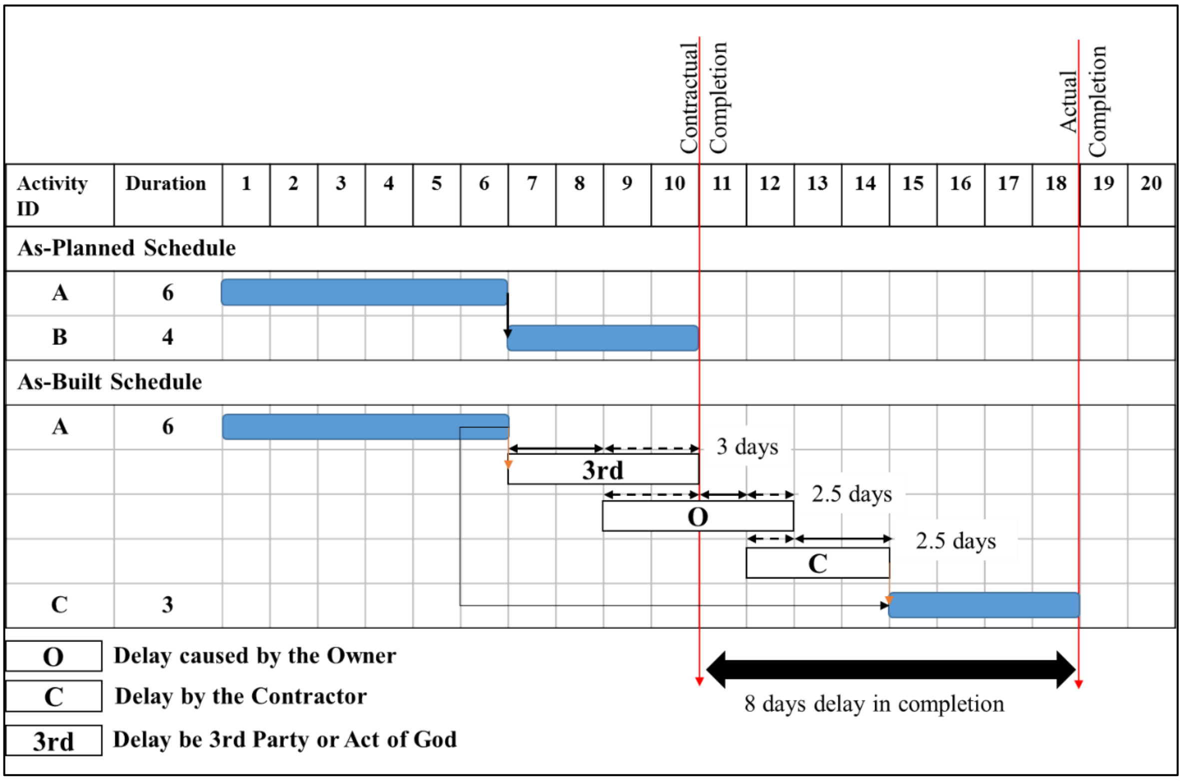


Figure 2.7 Bar chart in relation to apportionment approach.

3. Apportionment method distributes the responsibility for the delays between causes, commonly on a 50:50 basis (if there are two concurrent causes) (Baldwin and

Bordoli, 2014; Keane and Caletka, 2015). Figure 2.7 demonstrates a basic network comprising three delay events and application of apportionment approach.

Table 2.13 shows the allocation of liabilities based on apportionment approach.

Table 2.13 Liability allocation – apportionment approach.

	Extension of time	Compensation	Liquidated damages
Excusable and Compensable delay (owner caused)	2.5	2.5	
Excusable and Non Compensable delay (3rd party or Act of God)	3		
Non excusable delay (contractor caused)			2.5
Total	5.5 days	2.5 days	2.5 days

4. The Devlin Approach asserts that if there are two causes occurring at the same time and one is a breach of contract, then the party is responsible for the breach will be liable for the loss (Furst and Ramsey, 2001; Gibson, 2008).
5. The Burden of Proof Approach, this contends that if there are two delays occurring together and the claimant is in breach of contract, it is for the claimant to show that the loss was caused otherwise than by his breach (Furst and Ramsey, 2001; Gibson, 2008).

As in all matters, the particular provision of the contract and the jurisdictions will directly influence the way concurrent delays are analysed. The project parties should implement a practical and disciplined method for reasonably allocating concurrent delay damages to avoid any disputes and/or further escalations and to enable the procedure of delay analysis.

2.4.3. Pacing Delay

Concurrent delays occur due to two independent action or inaction while pacing arises from a deliberate choice by one of the parties to decrease the pace of its work in order to maintain pace with the pace of the other party. In other words, pacing occurs when a party decides to take up the float caused by a delay by the other party (Burr, 2016).

By other words, a pacing delay can defined as slowing down the execution of the project work by one party to the contract, due to a delay to the end date of the project caused by the other party, thus in order to keep a stable progress with the revised overall project programme (Zack, 2000; Mohan and Al-Gahtani, 2006). For instance, a critical delay to the project completion is caused by an owner, then the contractor decides to decelerate some other activities of the project. The contractor can take advantage from the pacing delay caused by the owner by claiming compensation for any damages in the project duration, whereas also reducing costs by decompressing certain non-critical activities In case of that decelerated activities are on the critical path of the project along with those caused by the owner or resided on parallel critical paths, it is obvious that pacing delay causes concurrent delay (Zack, 2000).

Delay pacing approach is a relatively new defence strategy frequently debated by both owners and contractors to prove that their delay was not the dominant delay. Although each party has the right for pacing delays, resolving the argument is tense with problems similar to those of concurrent delays and float ownership issue. For example, who owns the float question will determine if a specific contractor-caused delay could be a potential employer's protection of concurrent delay or otherwise (Braimah, 2013).

SCL Protocol recommends for Contractor who anticipates to pace the activities that are not on the critical path, they ought to inform the Employer and the Contract Administrator about pacing intention in this regard, along with its reasons for doing so (SCL, 2017). Usually, several types of construction agreements allow contractors to perform the project by selection of different methods, with the least cost, in order to maximize profits (Zack, 2000). However, Mohan and Al-Gahtani argued that this right is not evidently practical due to the fact that some of the following issues in delay analysis have not yet been resolved to the satisfaction of all parties (Mohan and Al-Gahtani, 2006);

- Who possesses the total float in the initial as-planned schedule?
- As a result of changing the initial total float, who has the right to get a credit or discredit for changing the total float?

- How to solve the issue of pacing delay that falls within concurrent delay?

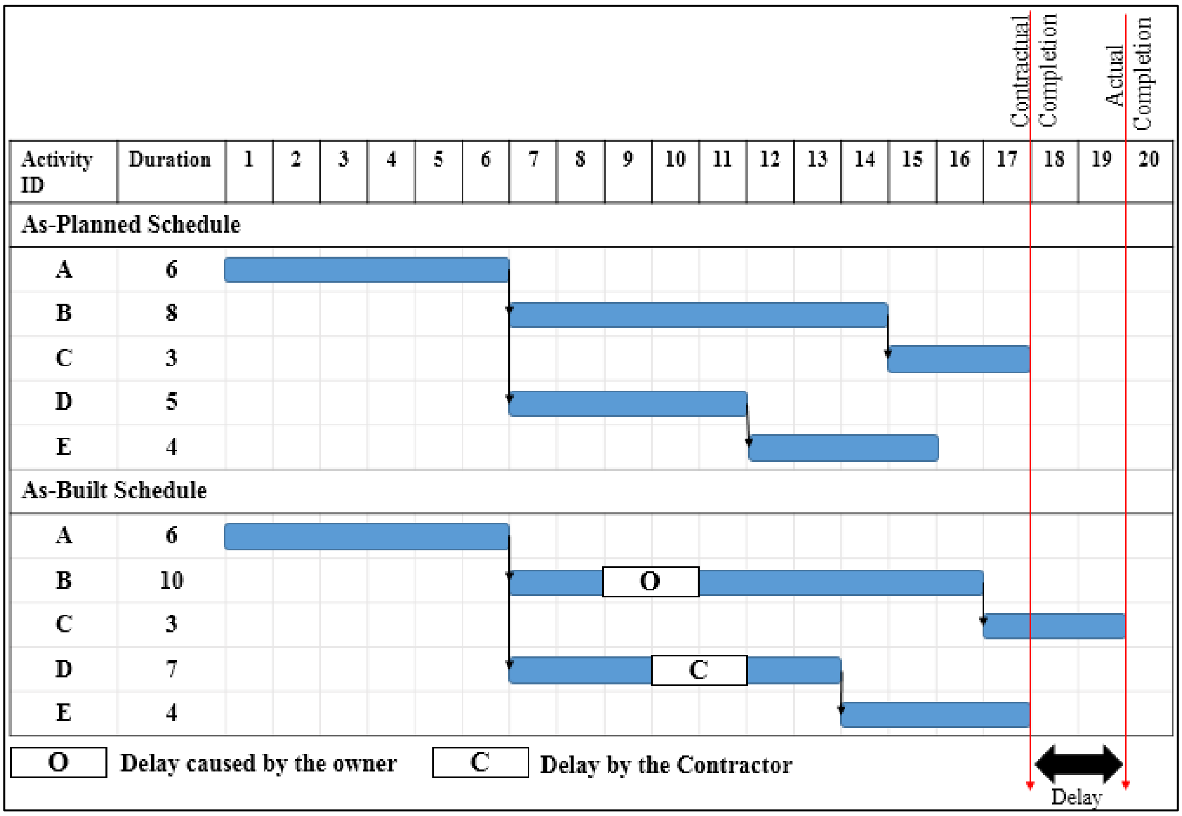


Figure 2.8 Bar chart in relation to pacing delay.

Al-Gahtani and Mohan addressed the pacing issue by exemplifying a situation which is illustrated in Figure 2.8 by putting factual details together. The owner causes 2 days of delay in activity B which affects the critical path and resulting a raise in the total floats of the non-critical path activities (Activity D and E). If the contractor consumes this increased total float by slowing down his work along with the parallel path, (delay in activity D), the contractor will get two types of cost savings;

- To claim compensation for any damages that are occurred due to delaying the project time; and
- To get advantages of decompressing some of the non-critical activities (Al-Gahtani and Mohan, 2007).

Pacing debates are generally happened at the end of a project, when an as-built programme analysis is available to enable parties to find out activities which were not impacted by any owner actions or other excusable events appear to have been delayed. When pacing is disputed with hindsight, it should be approached with both attention and scepticism, particularly if the claim is not supported by contemporaneous records (Keane and Caletka, 2015).

2.4.4. Float; Ownership and Utilization

An activity having total float is by definition a non-critical and therefore does not affect the critical path or the project duration. Nevertheless, if activity float is consumed totally then the critical path will change and initial non-critical activities will reside on critical path. If any delay occurs which prevents non-critical activities from starting at the earliest then float will be used up. This decreases a contractor's contingency time cushion and escalates the possibility of critical delay to the project completion (Keane and Caletka, 2015).

Float is the amount of time by which an activity or group of activities may be shifted in time without causing Delay to Completion (SCL, 2017). Float is a useful tool which assists parties perceive which activities more critical than other and which activities to be tracked carefully and kept under control throughout the project. Float can be both negative and positive value. Positive float indicates the duration for an activity to be delayed without impacting the project completion date. On the other hand, negative float shows the position of an activity how far behind program in terms of time.

Total float (TF) is the amount of time that the start or finish of an activity can be delayed without delaying the project's overall duration. In the critical path method, total float or slack is defined as the total amount of time that an activity can be delayed without delaying the project's completion date (Nguyen and Ibbs, 2008; Birgonul *et al.*, 2015). Because float is a valuable resource for both parties in a project and thus the question of who owns float has increasingly concerned contractual parties.

Float is a valuable timing asset in construction projects for both parties who may have different perspectives regarding consumption of it. Contractors can see float as a reason to be more flexible while arranging, sequencing, preparing and executing non-critical activities or as an allowance for risk work items. In such an approach, any subsequent contractor-caused delays to these non-critical activities will turn out them to become critical activities which may cause possible delay to completion date of the project. In such case, the contractor is not likely to be entitled with an extension of time but rather would be liable to liquidated damages. From owner's perspective, they can typically utilize float period to neutralize the possible impacts of change orders or decisions taken in longer periods since these actions can be accommodated during float timing. Such attitudes can easily deteriorate the situation where an owner's changes or slow decisions result in a delay such that most of float on a specific activity is consumed converting it to a critical or a near critical activity.

In case of identifying the ownership of float in the contract, both parties can have better understanding thus foresee the potential consequences of their actions or inactions accordingly (Arditi and Pattanakitchamroon, 2006). The different perspective of float ownership would most likely cause particular disputes during course of delay analysis; hence it is crucial that float ownership should be explicitly defined in the contract in order to avoid any disputes in delay-related claims. Several studies have proposed various alternatives for total float ownership, sharing, and/or management:

1. "Project owns the float". In other words, the first-come first-served principle should rule the use of float. This approach is widely accepted in the United States and also supported by SCL Protocol of the United Kingdom (Keane and Caletka, 2015). If the contract does not state an explicit clause about ownership of float, float is not time for the exclusive use or benefit of either the Employer or the Contractor (SCL, 2017). In the absence of opposing contractual language, float is a shared resource between the owner and the contractor. In such conditions float is to be shared in the favour of the project rather than to the sole favour of one of the parties (AACEI, 2011). To exemplify this approach, if an owner-caused delay happens first and consumes the total float, a contractor becomes accountable for subsequent contractor-caused delays which affect the project completion date. In case of a contractor delay which occurs first and consumes all the float at the initial phase of the project, the owner may find himself responsible for all delays caused by owner-caused delays i.e. change orders, such situation could have been prevented if the contractor had not used up the total float (Arditi and Pattanakitchamroon, 2006).
2. "Owner owns float". This concept the entitle owners to a right to appropriate the total float of activities along non-critical path. The foundation for this claim is that, as the owner pays the costs related with the project thus he has the right to possess the

project floats (Prateapusanond, 2003). Such an entitlement cannot be defensible, since the more significant concentration is the potential for increasing the overall risk in the project of which cost is only one among several factors (Al-Gahtani, 2009). Moreover, consumption of float controlled only by the owner may have a destructive effect on execution of works i.e. working conditions, stacking of trades, work area congestion, resource diversion, skill dilution, and dilution of supervision (Finke, 2000).

3. "Contractor owns float". Many practitioners and researchers agree that the contactor should possess float of the project. Supporting ideas of this approach are (i) contractor to be able to re-sequence activities to enable maximize benefits, minimize costs, and (ii) contractor has right to full control over to manage the project work, the equipment, and the cash flow to achieve the project completion and so on. (de la Garza *et al.*, 1991; Scott *et al.*, 2004; Al-Gahtani, 2009)
4. "Total float traded as commodity". This approach supports that the contractor owns float and gives full control of float to the contract. Moreover, it perceives total float as a time contingency for both the owner and the contractor, and also discourages contractors to usage of float suppression techniques but encourages them to complete project earlier. The approach allows contractor to sell float as commodity to the owner based on defined pre-agreement selling prices in the contract (de la Garza *et al.*, 1991).
5. "Equal Allocation 50/50 approach". The proposed concept comprises allocating total float of activities on the same non-critical equally to the owner and the contractor. The float is assigned equally to the owner and the contractor, and the float consumption of each party should be recorded appropriately (Prateapusanond, 2003). However, this approach alone is impractical when used in delay analysis. Since it cannot detect the shifting nature of activity paths throughout the project such as changes in critical paths and in logical sequences (Nguyen and Ibbs, 2008).
6. "Risk bearer owns float". Householder and Rutland addressed the issue by recommending that float should be owned by the party which is under more risk depending on contract type. The use of float as a time asset should be allocated for the party who loses or gains as a consequence of fluctuation in the project cost. If the contract is a cost-plus agreement, the additional costs are generally absorbed by the owner, and thus owner should be allowed to possess and utilize float in such contract.

On the other hand if the contract type is lump-sum where contractor has ultimate risk or benefit, the contractor should control usage of float (Householder and Rutland, 1990).

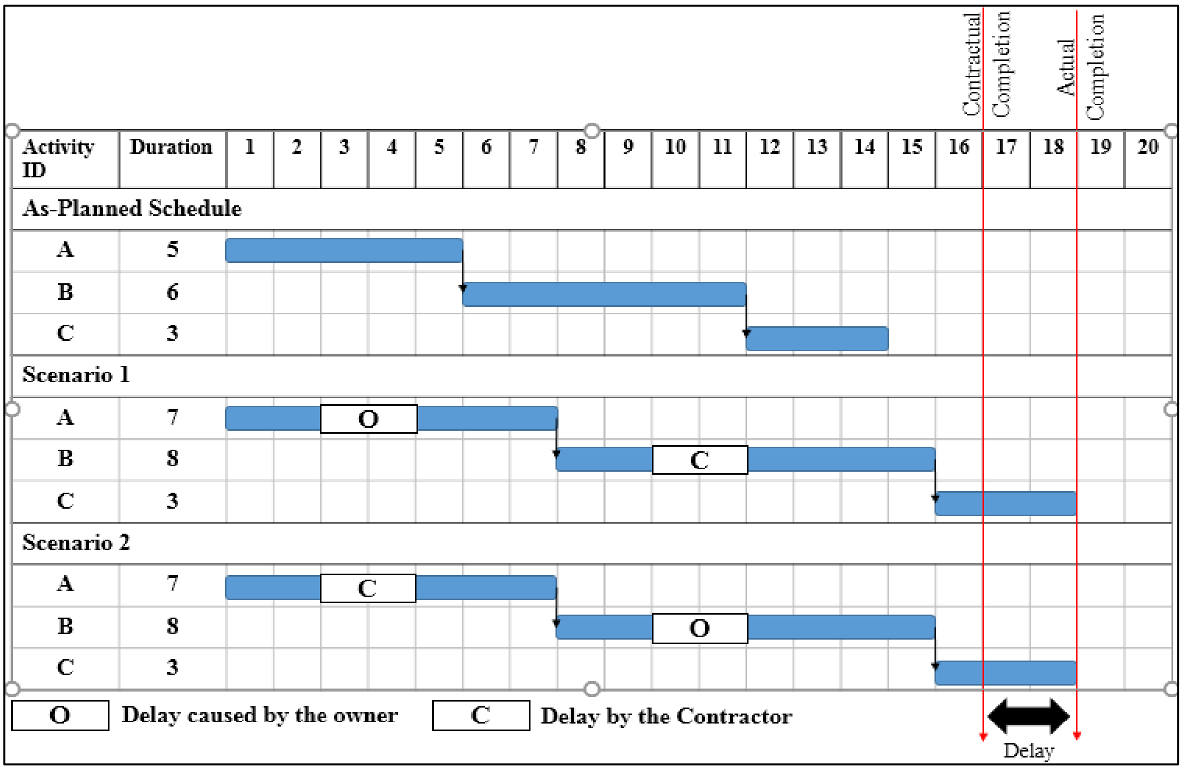


Figure 2.9 Bar chart in relation to float ownership issue.

Figure 2.9 illustrates two basic delay scenarios involving both contractor and owner delays to the schedule. As-planned schedule is composed of three activities and it has two days of float in the beginning. Both scenarios experience subsequent delays caused by both the owner and the contractor and thus experience two days of delay at the end of the project. In Scenario 1, the owner delays Activity-A and uses up all the float and the contractor causes another delay on Activity-B and finally accumulated delay becomes two days. Scenario 2 demonstrates the same network and with same amount of delay but caused by both parties in reverse order.

Table 2.14 shows results from different approaches for float ownership consequences regarding the contractor's entitlement to extension of time and liquidated damages assessed by the owner.

Table 2.14 Different approaches for float ownership.

	Scenario 1		Scenario 2	
Float ownership approach	EOT entitled to contractor in days	LD assessed to contractor in days	EOT entitled to contractor in days	LD assessed to contractor in days
Project owns the float	-	2	2	-
Owner owns float	-	2	-	2
Contractor owns float	2	-	2	-

2.4.5. Mitigation and Acceleration

Mitigation and acceleration are two concepts which can become challenging to differentiate while performing a forensic delay analysis during course of a project or after completion of it. There are many misapprehensions regarding what these actions are, also how and when they happen.

A guidance about requirements to mitigate delay is provided by SCL Protocol. The contractor has a general responsibility to mitigate the actual or potential effect on its works resulting from Employer Risk Events. Such a mitigation duty usually does not require the contractor to put additional resources or to work beyond its planned working hours, though this is subject to express contract wording or agreement to the contrary. The contractor's duty to mitigate its loss has two sides; first, the contractor must take rational precautions to decrease its loss; and at the same time secondly, the contractor must not take irrational steps which increase its loss (SCL, 2017).

Mitigation act, likewise pacing, does not occur by a coincidence; it requires an appropriate planning beforehand. If any mitigation steps are taken, evidence which is composed of planned actions to mitigate loss, and anticipated results of such actions must be documented in project records. Unless an appropriate mitigation planning exists, any shortening of critical or non-critical path is resulted from good luck or improper scheduling (Baldwin and Bordoli, 2014).

The differentiation between practices to minimise the loss arising from the disrupted works and the performing acceleration activities to reduce the delay impact of disrupted works must be identified carefully. A contractor is not obliged to incur additional costs for mitigation unless it prefer to do i.e. to recover culpable delay (Keane and Caletka, 2015).

Whilst mitigation is a general duty of the contractor, acceleration is a subdivision of mitigation, and typically imply the condition of incurred additional costs in order to provide ways to cope with delay or disruption all together or partially (i.e., to guarantee that the contract completion date is met). In case of the employer’s responsibility for delay or disruption, the contractor may claim its costs incurred to acceleration from the employer. (SCL, 2017). Acceleration in this regard is as a consequence of an employer’s instruction for the contractor to increase productivity above which envisaged in the as-planned schedule (Baldwin and Bordoli, 2014).

If particular provisions exist in the contract regarding the acceleration, payment for accelerative actions should be done accordingly. If the contract does not comprise such provisions, and the contractor and the employer still agree for measures to be undertaken for acceleration, then monetary terms should be agreed before commencement of the accelerative actions (SCL, 2017). Keane and Caletka put emphasis on potential challenges regarding quantification and recovery of acceleration costs. They stated that it is undoubtedly imprudent for contractors to embark on a variety of expensive accelerative actions if they do not have a pre-agreed methodology of reimbursement (Keane and Caletka, 2015).

Typical measures which are undertaken to attain acceleration are to prolong working hours, to add extra manpower, to alter shifts and to provide additional plant. Thus, acceleration measures in themselves, mainly increases in labour strength or working hours can give rise to loss of productivity (Keane and Caletka, 2015). Acceleration can actually disrupt execution of works due to overlapping discipline at a time, congestion on site, lowered productivity and an increase in defective installations. Consequently, detailed plans and strategies should be developed to secure that the projected acceleration measures are reasonable and achievable accompanied by added supervision, plant, testing, inspections and other resources regarding higher manpower (Baldwin and Bordoli, 2014).

One significant aspect is to agree regarding how records to be kept during acceleration steps are taken. If the acceleration is instructed and/or agreed, the contractor is not entitled to claim prolongation compensation for the period of employer delay avoided by the acceleration measures (SCL, 2017).

2.4.6. Contractor's Intention to Early Completion

Another thorny area of concern for contractors and owners is when a contractor suggests a programme which indicates an objective to complete a project earlier than the agreed contractual deadline. Actually, contractor is not prevented from planning to complete the project work in a shorter duration than pre-determined, and also not prohibited from inserting a period of float as a contingency between the intended early complete date and the contractual completion date. However, doing such a practise does not unilaterally change contractual rights or obligations (Keane and Caletka, 2015).

The construction projects do not have to be completed at the last minute of the final day of the agreement or be programmed in such a way. However, many standard forms of the contract only require contractors to complete the works on, or before the completion date (Burr, 2016). The core benefits of finishing a project prior to agreed contractual date, to a contractor are:

- to make savings on time-related overhead costs;
- to plan to avoid working under a bad seasonal weather;
- to reduce costs related to materials, temporary works, direct and indirect labour, supervision, site expenses, head office overheads, bonds, insurance and finance (Keane and Caletka, 2015).

Contractors should not be discouraged from drawing up a strategy to accomplish an early completion, due to the fact that the owner can also take advantage of the price benefit of early completion (SCL, 2017). However, early completion is not always very convenient for the owner due to following reasons;

Original contract with tenants or end-users may require to take over after the contract completion date;

- Early completion can give the owner the early responsibilities of heating, maintenance and insurance during absence of tenants or end-users;

- An early completion normally requires accelerated cash flow and intensive performance of the owner's consultants; and
- An early completion can constitute a basis for a claim from the contractor for damages associated with delays (Burr, 2016).

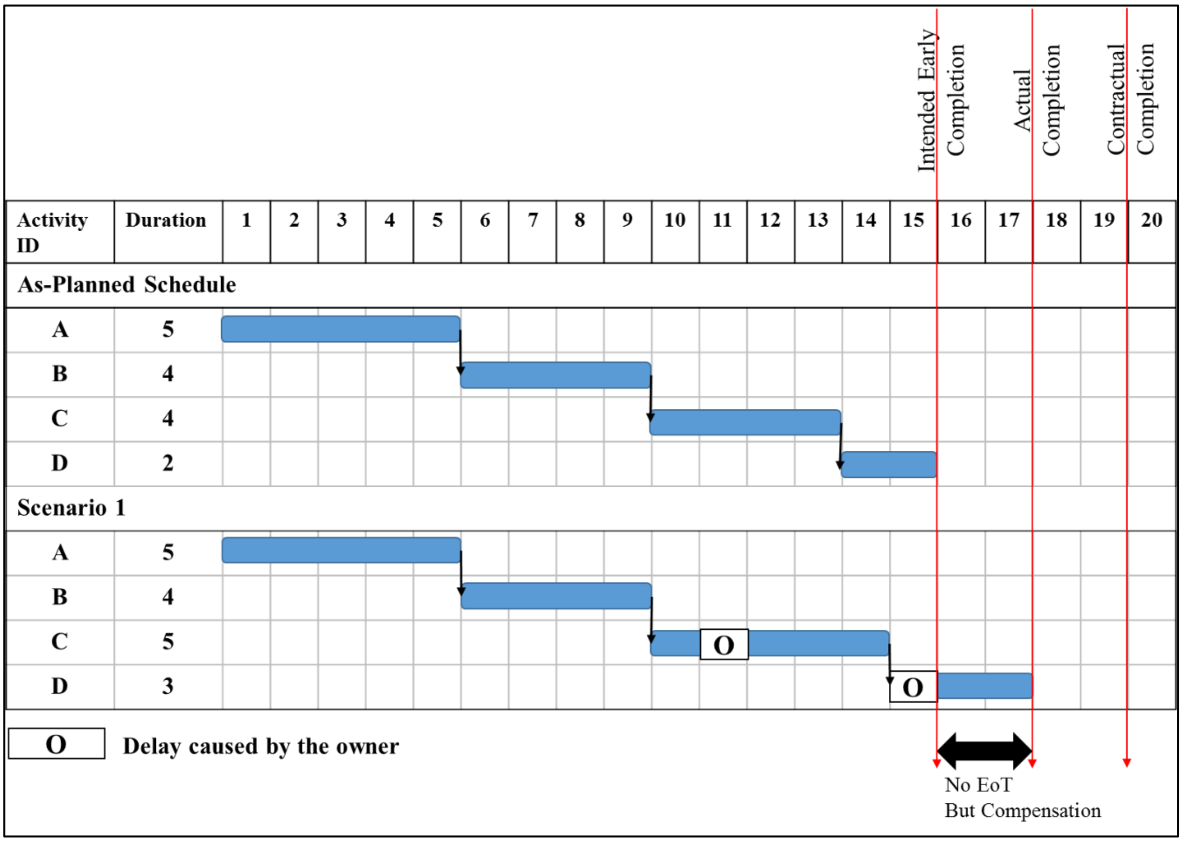


Figure 2.10 Bar chart in relation to contractor's intention to early completion.

In the United States, when a contractor plans to execute the project works in a way to obtain an early completion programme, there are two different practices:

- If the owner agrees with the programme and the early completion date, the provisions for liquidated damages could be modified to align with the earlier completion date. Hence, prolongation costs become recoverable in case of compensable delays which hinder agreed early completion. This should have done by an agreement, and through an explicit change to the contract conditions.
- If the owner accepts solely the programme and sustains the contract completion date same, this distinction naturally will create float to all activities equal to the period of time between the early completion date and the contract completion date. If the contract does not include any provisions regarding float ownership, any delays to the

early completion will basically absorb float, and consequently the traditional debates regarding 'float ownership' will be made by both contracting parties (Keane and Caletka, 2015).

If early completion the project is envisaged by the contractor, the early completion date should be indicated on the official project schedule, and thus multiple schedules should always be avoided (Trauner, 2009). Figure 2.10 shows the position taken by SCL Delay and Disruption Protocol. The protocol states that a delay from the owner should not give rise to an EOT unless the delay event causes a delay to the longest path to contractual completion date. When it comes to compensation, unless the contract stipulates otherwise, the contractor should be entitled to compensation for the delay (SCL, 2017). This approach is also supported by the interview conducted with practitioners in the UK (Scott *et al.*, 2004).

The Protocol also urges that contracting parties explicitly address this issue in their contract. In absence of addressing this issue in the contract, for the contractor to have a fair claim, the owner must have been aware of the contractor's plan to finish project works earlier than the contract completion date, at the time the contract is entered into. If not, it is not allowable for the contractor to remark that it plans to complete early, and claim additional costs for being hindered from doing so (SCL, 2017). Therefore, this issues should be addressed in the contract in order to avoid any conflicts regarding this matter (Braimah and Ndekugri, 2008).

2.4.7. Force Majeure Delays

Construction delays which are the fault of neither the owner (including its agents) nor the contractor (including its agents) are termed force majeure events. Additionally, contract conditions regarding this subject are very significant, since they allocate risk to which party to carry. Force majeure delays contain such event, delays caused by acts of God, adverse weather conditions, acts of war, acts of terrorism, extraordinary economic disruptions, strikes, and other events not foreseeable at the time of contract.

Force majeure delays are sometimes referred as 'neutral events' which typically entitle a contractor to extension of time, however not reimbursement for additional incurred costs.

A neutral event is a non-compensable and excusable delay (Keane and Caletka, 2015). Yet, the concept of 'neutral events' can be misleading resulting from the fact that those events are only neutral when that one party owns the time risk and the other party owns the cost risk (SCL, 2017).

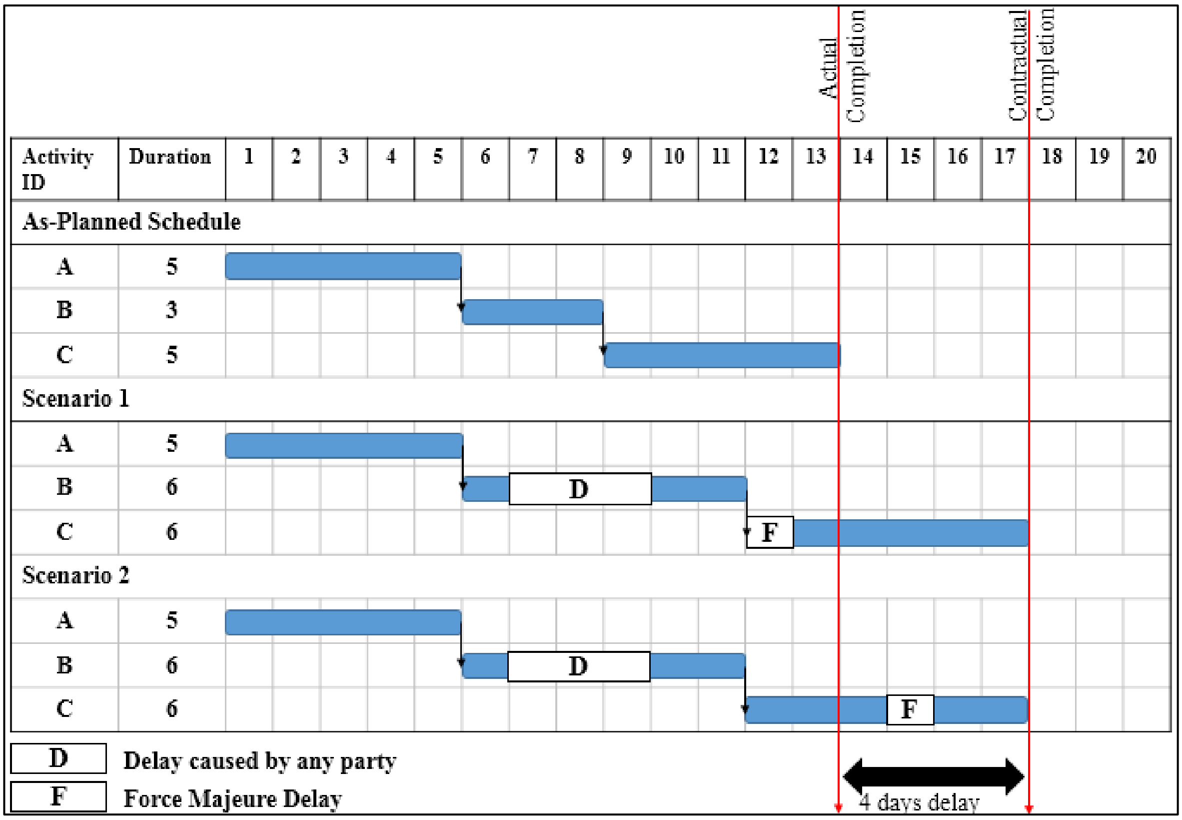


Figure 2.11 Bar chart in relation to force majeure delay
(adopted from Alshammari et al. 2017)

If such force majeure delay is on the critical path, the contractor is entitled to an extension of time however does not obtain an further compensation for the incurred damages resulting from delay even if a concurrent delay exist (AACEI, 2011). However, some suggest that a potential exemption to this statement may exist when a force majeure event occurs within an extended contract period which caused by an owner delay. In such a case, the lost time may be treated compensable because of owner-caused controlling delay (Levin *et al.*, 2016).

In scenario 1, the force majeure delay happened in day 12 which is within original contract duration, by other words with or without the previous delay event, the force majeure delay would still affect project. Hence, this type of delay is called 'unavoidable force majeure delay' (Alshammari *et al.*, 2017). Scenario 2 illustrates a totally different case than the first one because prior delays affect the project completion date and the following force majeure delay happened in day 15 after completion date of the project. The affected party may deem that the force majeure delay would not have occurred if the prior delay did not happen. According to the same research, such delays are called 'preventable force majeure delays' which the innocent party suffering damages have the right to claim monetary compensation to recover its damages (Alshammari et al., 2017).

2.4.8. Poor Contractor's Programme

The capability of scheduling expert to implement an appropriate analysis highly depends on quality of attainable project documentation such as frequent progress report submissions, notices, correspondences, and site photos etc. Additionally, availability and features of baseline programme, updated and revised programmes are the key factors which may determine which type of delay analysis technique to be implemented.

Schedule delay analysis for both simple and complex projects may become extremely difficult in absence of a detailed CPM network, a reasonable original as-planned schedule, and an accurate as-built schedule, and outcome of disputed claims in those projects often end up in litigation (Levin et al., 2016).

There are cases when contemporaneous project programmes are not sufficient to be used to assess delay in a construction project. In such cases, the project programmes either were not produced and updated frequently or the analyst might find out that the contemporaneous programmes did not accurately illustrate the intentions to build the project and thus would not be dependable to measure delay (Levin et al., 2016).

Limitations of insufficient baseline programmes that often make them invalid or unreliable tools for this purpose include the following; programmes prepared in a format other than CPM; incomplete programmes; insufficient details provided for the programme activities; unreasonable logic or relationships between activities; insufficient provisions for constraints likely to be encountered; unrealistic planned resource allocations; and unrealistic durations of major activities (Braimah, 2008).

When no programme exists for a project, the analyst may be intended to generate an "after the fact" schedule, reasoning that it will allow the analysis to be more precise. It is best not to generate such a schedule. When a contemporaneous programme is not obtainable to quantify critical delays in the project, the analyst should adopt an as-built methodology to detect the critical delay, this methodology is based on an 'as-built diagram' which use following documents if they are available; project daily reports, project diaries, meeting minutes, pay requests/estimates, inspection reports by the designer, owner, lending institution, and so on correspondence, memos to the file, dated project photos (Trauner, 2009).

The analyst should document every day that work is logged for each activity in the production of an as-built diagram. It is not adequate to record only the start date and then the finish date of an activity. Whilst the start and finish dates are very significant, to determine whether the work was continuous or interrupted may also be vital to have an appropriate result (Trauner, 2009).

2.5. Delay Analysis Methodologies (DAMs)

Delay analysis methods and techniques are frequently recognized by different names. Each technique can be performed in numerous ways and the popular delay analysis methods are subject to many misuse. Even though a number of existing DAMs are available in the field of delay claims, there are no standardized delay analysis methods accepted by the courts (Arditi and Pattanakitchamroon, 2006). The application of the same method by two opposing practitioners often may assert variable and inconsistent results (Keane and Caletka, 2015).

The AACEI RP features 15 specific retrospective analysis techniques under 9 fundamental groups (AACEI, 2011). All of the frequently applied forensic delay analysis procedures mostly conform to one of the following main groups: As-planned vs. as-built, impacted as-planned, CAB and time impact analysis (SCL, 2002; Keane and Caletka, 2015). SCL Protocol additionally suggested the Time Slice Analysis Method (TSAM) and the Retrospective Longest Path Analysis (RLPA) as common and acceptable delay analysis methods in construction industry and also the Protocol modified the APAB analysis technique to APAB windows analysis technique (SCL, 2017).

The results of delay analysis may be impacted by the selected technique, and thus the selection of an appropriate DAM is vital for a successful assessment in delay analysis to all concerned parties (Mohan and Al-Gahtani, 2006). The thoughts of academics and practitioners on the performance and efficiency of these methods vary (Arditi and Pattanakitchamroon, 2008).

Table 2.15 Existing delay analysis methods in the literature

	Global impact	Net impact	Bar chart	CPM update review	As-built adjusted	As-planned But for	Impacted as-planned	Time impact analysis	Collapsed as-built	Snapshot/windows/ time slice analysis	As-planned vs as-built analysis method	As-planned vs as-built windows analysis	Retrospective longest path analysis	Isolated Delay Type (IDT) Technique	Total float management
(Alkass et al., 1996)	✓	✓			✓			✓	✓	✓					
(Farrow, 2001)	✓	✓				✓	✓		✓	✓	✓				
(Zack, 2001)	✓		✓	✓			✓		✓	✓	✓				
(SCL, 2002)							✓	✓	✓		✓				
(Arditi and Pattanakitchamroon, 2006)							✓	✓	✓		✓				
(Mohan and Al-Gahtani, 2006)	✓					✓	✓	✓	✓	✓	✓			✓	✓
(Al-Gahtani and Mohan, 2007)															✓
(Gibson, 2008)	✓	✓	✓		✓		✓	✓	✓	✓					
(Barry, 2009)							✓	✓	✓	✓		✓			
(Braimah and Ndekugri, 2009)							✓	✓	✓	✓	✓				
(Trauner, 2009)							✓		✓	✓	✓				
(Yang and Kao, 2009)	✓	✓	✓	✓			✓		✓	✓	✓			✓	✓
(AACEI, 2011)					✓	✓	✓	✓	✓	✓	✓	✓	✓		
(Braimah, 2013)						✓	✓	✓	✓	✓	✓				
(Yusuwan and Adnan, 2013)							✓	✓	✓	✓	✓				
(Baldwin and Bordoli, 2014)	✓						✓	✓	✓	✓	✓				
(Keane and Caletka, 2015)	✓						✓	✓	✓	✓	✓	✓			
(SCL, 2017)							✓	✓	✓	✓		✓	✓		
(Whaley, 2018)							✓	✓	✓	✓		✓	✓		

Table 2.15 depicts a great number of existing delay analysis methods available in the literature and the top cited delay analysis methods in the literature are;

- Collapsed As-Built (CAB);
- Impacted As-Planned (IAP);

- Time Impact Analysis (TIA);
- Snapshot/windows/ Time Slice Analysis; and
- As-Planned versus As-Built Analysis Method (APAB).

Hence, these most cited techniques are examined further. Moreover, the Retrospective Longest Path Analysis (RLPA) and the As-Planned versus As-Built Windows Analysis Method are also investigated further as SCL Delay Disruption Protocol recommended, (SCL, 2017) and the strengths and weaknesses of those methods are discussed further below.

2.5.1. Impacted As-Planned Method (IAP)

IAP method is the most basic form of dynamic modelled analysis – that is, it relies on critical path analysis (Baldwin and Bordoli, 2014). It is a ‘dynamic’ technique, and thus needs a networked schedule (Barry, 2009). This practise inserts identified delays to the as-planned schedule to exhibit why the project delayed later than originally envisaged (Zack, 2000). The variance between the completion date before and after the delay impact is used to designate the liability of each party (Mohan and Al-Gahtani, 2006).

IAP requires a logic linked baseline programme and insertion of delay event into the baseline programme in order to remodel the programme to identify prospective impact of the delay event on the project completion date. Critical path in this context is determined prospectively. The method is easy to perform and to be understood (SCL, 2017). The AACEI RP describes the method as Modelled/ Additive/ Single Base - MIP 3.6 (AACEI, 2011).

Some analysts prefer the IAP technique as it is simple and “clean,” however it does not take the dynamic nature of construction projects or the critical path into consideration. This method “freezes” the original critical path at the beginning of the project, and, therefore, the actual changes in the critical path will not be recognized (Trauner, 2009). Though as-built information is not essential to operate this approach, it has key weaknesses such as failure to assess any changes in the critical path and the assumption that the originally intended construction sequence remains unchanged (Braimah and Ndekugri, 2008). Additionally, it is broadly accepted that the IAP analysis method is deficient in balance and equality since it typically comprises solely one party's delay events, while simultaneously supposing flawlessness from the other party (Barry, 2009).

IAP method is the least preferred one among the six methods detailed in this study because of its theoretical flaws. Many courts have not recognized this method since the 1990s due to the primary fact that the method depends solely on an as-planned schedule to assign the impact of delay.(Arditi and Pattanakitchamroon, 2006). Trauner exemplified a forensic case where impacted as-planned technique was used to determine impacts of delay, the judge criticized the result of an impacted as-planned analysis, since it disregards everything but the as-planned schedule and the delay the analyst is assessing, was predetermined (Trauner, 2009).

Table 2.16 Strengths and weaknesses of the IAP analysis method.

Strengths	Weaknesses
• Easy to comprehend • Inexpensive to prepare • As-built information is not required	• Not able to detect true concurrency • Changes in logic and re-sequences are not taken into account • The impact of as-built progress not taken into account • Solely rely on original as-planned schedule • Many courts have not accepted this method • Highly theoretical results

The strengths and weaknesses of the collapsed as-built method are summarised in Table 2.16. The IAP method is easy to perform, comprehend and interpret, however, it may produce poor results due to explained reasons. If the contract does not stipulate to adopt this method, it is not preferred for EOT assessments (Barry, 2009; SCL, 2017)

2.5.2. Time Impact Analysis (TIA)

Similar to the IAP method which was discussed above this approach is both a 'prospective' and 'dynamic' method. Moreover, the TIA is an evolution of the IAP method, TIA copes with some of the crucial drawbacks of the IAP method, insofar as possible TIA pays attention to the effect of actual progress and the timing of delay events on the works

(Barry, 2009). The analyst focuses on a particular delay or delaying event not on time periods containing delays or delaying events (Alkass *et al.*, 1996).

Time impact analysis method requires insertion of delay events and assigning necessary links in the updated programme. For each newly inserted delay event, the baseline schedule is updated (if not available) with actual achievements and assigned a data date just prior to the delaying event occurring. If the updated programme shows any delay in completion date of the project, it is to be recorded. The delay event is inserted into to newly updated baseline schedule in order to identify the likely impact of the delay event to the completion date of the project. This application provides the status of works at the time of delaying event occurring. This process is repeated on a daily basis or whenever a delay event occurs, or the schedule is updated. The effect of separate delay events are accumulated and used to explain remedies (Arditi and Pattanakitchamroon, 2008). In the closing time period, there will be a fully impacted schedule comprising all delay events and takin account of all as built data.

The AACEI RP describes the method as Modelled/ Additive/ Multiple Base - MIP 3.7 (AACEI, 2011). The TIA technique is an additive and 'modelled' methodology since it relies on 'what if' simulations of several CPM baseline programmes. The TIA practise is different from the IAP technique as it utilizes multiple baselines, rather than the original as-planned baseline, to compute the possible effect of delay events (Keane and Caletka, 2015).

Thus, the programme is remodelled in order to prospectively evaluate the likely impact of the delay event on the project completion date. SCL Protocol recommends to perform this method to resolve complex disputes unless the EOT application is evaluated after completion of the works, or significantly after the effect of an delay event (SCL, 2017).

The time impact analysis method incorporates both party delays into the analysis, hence it is distinguished from the IAP and the CAB analyses. The excusable compensable, excusable non-compensable, and non-excusable delays can be discretely recognized (Arditi and Pattanakitchamroon, 2006). Whether applied retrospectively (after the impact of the delay event has occurred) or prospectively (during the life of the project, before the full impact of the event is known) the most recent contemporaneous programme should be relied on (Keane and Caletka, 2015). When performed appropriately, the TIA methodology can be an extremely convincing method to illustrate the effects of delay on a contractor's programme.

One of the major drawbacks of this technique is that it is a time-consuming procedure and expensive to operate, especially in conditions where high number of delaying events are involved hence it may not be an appropriate method when allowed time and resources are limited (Arditi and Pattanakitchamroon, 2006; Ndekugri et al., 2008; Baldwin and Bordoli, 2014). The reasons behind this drawback are that TIA requires a robust as-planned networked schedule and detailed progress, examination of periodic updates, and verification of as-built records and as it models delaying events individually, so it takes a long time to perform.

Table 2.17 Strengths and weaknesses of TIA analysis method.

Strengths	Weaknesses
• Effect of as-built progress and the timing of delay events are taken into consideration • Cope with dynamic nature of critical path • Different type of delays can be identified • Both contractor and owner delays inserted to the schedule • Reliable results • Recognized by Courts	• Consumes more time and resources • Requires a large amount of information • Technically complicated • Requires periodically updated schedules • Cannot identify true concurrency • Accurate progress information • Can ignore future progress/sequence

Delaying events should be introduced once and the recently generated activities should comply with the original baseline programme requirements (Keane and Caletka, 2015). Unless the contract of a project stipulates strict administrative procedures and/or updated schedules, this project is not suitable candidate for this technique (Arditi and Pattanakitchamroon, 2006).

Another limitation of the method which could reduce the power of the technique is that the TIA technique requires a large amount of data (Baldwin and Bordoli, 2014; SCL, 2017). The data required to perform a basic time impact analysis are;

- A logic linked baseline schedule;

- A selection of the delaying events (listed and categorised);
- Periodically updated schedules;
- Progress records with which to update the baseline programme; and
- As-built details for the project.

To sum up, if TIA methodology is implemented properly, it is a highly persuasive technique to show the effects of delay on a contractor's programme. Moreover, the method is highly accepted by practitioners in the construction industry and also recommended by the SCL Protocol but not when the case of analysis is distant from the events. However it has many drawbacks as summarised in Table 2.17.

2.5.3. Collapsed As-Built or 'But for' Analysis Method (CAB)

CAB method does not require an as-planned programme but it needs a detailed and accurate as-built programme. In this method, predominant delay event and related path are extracted from the as-built programme in order to find out second critical path or closest near critical path retrospectively. The method demonstrates what would have happened if the predominant delay event had not occurred (SCL, 2017). The AACEI RP classifies this method as Modelled/ Subtractive/ Single Simulation - MIP 3.8 and Modelled/ Subtractive/ Multiple Base- MIP 3.9 (AACEI, 2011).

Zack states that the method constructs an as-built schedule, detects actual delays initiated by one of the parties, take out those delays from the as-built schedule, and collapses the schedule in order to find out when the project would have been completed if the other party's delay had not occurred (Zack, 2000). In fact, the CAB is the opposite of the IAP method. Instead of adding delays to the schedule, the analyst subtracts the delays from the schedule.

CAB method is generally applied when analyst cannot obtain consistent schedules from project records or the project does not have sufficient scheduling material. If an as-planned schedule is not available or not updated, an as-built schedule can be formed by utilizing contemporaneous information available such as daily reports or monthly reports (Arditi and Pattanakitchamroon, 2006). According to Baldwin and Bordoli, the technique is actually only appropriate for simple projects, where the most of relationships are sequential and the delay events and impacts are apparent and readily isolated (Baldwin and Bordoli, 2014). Thus, the analyst should undertake a practical common sense and intensive review of the hypothetical conclusion (Barry, 2009).

Table 2.18 Strengths and weaknesses of CAB analysis method.

Strengths	Weaknesses
• Does not require as a baseline schedule • Suitable when baseline and updates are defective • Simple to understand • Accepted in many courts and boards • Depends on actual data only i.e. durations, sequence, start & finish dates etc. • Satisfactory results in smaller programmes or projects composed of linear sequence of work	• Not able to differentiate concurrent delays and pacing delays • Very subjective when retrospectively creating as-built logic between activities • Conclusion is a hypothesis and not a fact • Not able to identify as-built contemporaneous critical path • Poor performance in complicated programmes • Results based on accuracy of as-built and logic links

The main difficulty of the CAB is in constructing logical relationships between as-built activities retrospectively. This task is very challenging most of the time, especially for large-scale complicated projects (Barry, 2009). When reconstructing network logic, each assumption may become a risk factor which can put the entire analysis into doubtful situation if any of these assumptions found to be incorrect. Consequently, it would result that as-built critical path activities will deteriorate the outcomes of the whole analysis. Such factors can be exemplified as non-driving dependent activities which reside on the as-built critical path, or as-built critical activities which are not in line with common sense or contemporaneous progress reports. (Keane and Caletka, 2015). In fact, an as-built schedule does not depend on the logic of the original network but on actual dates of activity progress. This procedure is highly subjective and subject to manipulation since the records, including logical sequences, lag times, etc., can be subjectively interpreted (Arditi and Pattanakitchamroon, 2006).

CAB technique does not take the dynamic nature of the critical path method into consideration. In fact, it supposes that the as-built schedule makes use originally envisaged intentions of the contractor to execute the project, using the same sequence of activities and the same productivities. Accordingly, the events that cause delay during course of the project may not be discovered (Zack, 2001). Barry emphasized that the CAB method favours a defensive perspective, due to the fact that a great number of activities and sequences finishes when project gets closer to the completion, thus the collapsing of a specific path or sequence, will hardly result with important enhancements in the completion date. The next near-critical path shown up will prevent any considerable collapsing. Therefore, this technique is frequently utilized, to show to a contractor that it would have been evidently late in any event (Barry, 2009). In case of delay analyses which are subject to many overlapping delaying events, acceleration, mitigation, pacing and concurrency, it is questionable that a CAB will be able to reveal the causes and liability for the delays (Baldwin and Bordoli, 2014).

The strengths and weaknesses of the collapsed as-built method are briefed in Table 2.18. To sum up, CAB analysis method is a useful tool when dealing with projects which requires delay analysis within limited time and with insufficient resources for analysis(Arditi and Pattanakitchamroon, 2006). It mostly produces satisfactory results in very discrete conditions such as where the dominant delay is being addressed when it is very close to the project completion (Barry, 2009). This methodology is stronger where programmes are smaller, easily to be managed and composed of linear sequence of work, hence the results are more likely to comply with common sense and intuition (Keane and Caletka, 2015).

2.5.4. As-planned versus As-Built (APAB) Analysis Method

APAB is simply the comparison of a baseline or an as-planned schedule with the final or an as-built schedule. The method is composed of identifying the as-built critical path, comparing the as-built critical activities to the as-planned schedule, and considering the causes of actual delay events and activity sequences to deduce the impact of delay on project completion (Zack, 2001; Arditi and Pattanakitchamroon, 2008; Yang and Kao, 2009; Keane and Caletka, 2015).

Different versions of this method are also known as the net impact method (Baram, 1994), the total time method (Stumpf, 2000; Keane and Caletka, 2015), and the critical path method (CPM) update review (Zack, 2001). There are many methodologies which can be used when measuring the impact of delay events when depending on as-built data. The AACEI RP defines As-Planned versus As-Built analysis method under either of two listed observational protocols (MIPs):

- Observational/Static/Gross (MIP 3.1),
- Observational/Static/Periodic (MIP 3.2) (AACEI, 2011).

Whilst The SCL Protocol solely referred to the as-built analysis, it did not make any distinction between the gross periodic or options (SCL, 2002). However, 2nd Edition of Delay and Disruption Protocol updated the APAB analysis technique to APAB windows analysis technique in 2017. Moreover the Protocol additionally recommended the Time Slice Analysis Method (TSAM) and the Retrospective Longest Path Analysis (RLPA) as common and acceptable delay analysis methods in construction delay analysis applications (SCL, 2017). Yusuwan and Adnan stated that this method is the most preferred one among the other delay analysis methods since it basically compares the activities on the as-planned schedule with the as-built schedule for detailed evaluation of the delay (Yusuwan and Adnan, 2013).

Table 2.19 Strengths and weaknesses of the APAB analysis method.

Strengths	Weaknesses
• One of the cheapest and simplest forms of delay analysis methods	• Inabilities to identify concurrency, re-sequencing, mitigation and acceleration • Very subjective when identifying as-built critical path • Not suitable for complex projects with large number of activities

This method is ideal for the projects where the identification of major delay cause is easy and suitable for analysis for relatively small programmes (Farrow, 2001; Zack, 2001). The method can be used as a starting point prior to more complex delay analysis methods in order to have an initial understanding (SCL, 2002). However, this characterization was disapproved by the practitioners from the United States due to the fact that the APAB method is recognised to be more reliant when it is compared to the IAP and the CAB (Lowe *et al.*, 2006).

APAB method can be employed to identify delays to progress, but its performance is highly depended on the level of accuracy of as-built information. Moreover, it has some major drawback as demonstrated by Table 2.19, which limits the usage of this method such as inabilities to identify concurrency, re-sequencing, mitigation and acceleration (Alkass *et al.*, 1996; SCL, 2002; Ndekugri *et al.*, 2008; Muhamad *et al.*, 2016).

2.5.5. As-Planned versus As-Built (APAB) Windows Analysis Method

In the APABW method, the analyst divides the project duration into windows. The method principally targets to discover and locate the contemporaneous or actual critical path of the project in each window by applying common sense and practical analysis of available facts. Then after the analyst investigates the project records to deduce the causes of identified critical path (SCL, 2017).

In this method, before seeking to discern the actual critical path, the analyst is required to be experienced and obtain great understanding of project scope, the schedule, construction methodology, actual data and contemporaneous records including photographs, correspondence, reports, minutes etc. (Barry, 2009). APABW is another analytical approach and referred by the AACEI RP as Observational/ Static/ Periodic - MIP 3.2 (AACEI, 2011).

As the names resemble, APABW method is an upgraded version of APAB. SCL Delay and Disruption Protocol upgraded the APAB analysis method to APAB windows analysis method. They are very similar delay analysis techniques in principle. The main distinctions of upgraded version from the original version are;

- the capability to separate and examine periods while the contractor altered its intentions/ strategies at some time after the preparation of an as-planned schedule; and
- it can describe the effect of delaying or disrupting factors in each windows period (Keane and Caletka, 2015).

The as-planned versus as-built windows analysis method is one of the two 'windows' analysis methods described in the SCL Delay and Disruption Protocol. Moreover, it has primary similarities with the time slice analysis method such as determining the delay impact retrospectively whilst deducing the critical path contemporaneously, as shown in Table 2.21. On the other hand, the main differences of APAB windows analysis method from TSAM are;

- It is less software dependent;
- Applied when there are concerns over validity of baseline programme and/or contemporaneously updated programmes; and
- Applied where there is lack of updated programmes (SCL, 2017).

Table 2.20 Strengths and weaknesses of the APAB window analysis method.

Strengths	Weaknesses
• Does not require frequently updated progress schedules • Suitable when baseline or updates are defective • Less software reliant • Conclusions based primarily on facts • Can identify and quantify mitigation and acceleration	• Can be time consuming • Tends to be impressionistic unless results are supported by robust analysis • Requires detailed contemporaneous project records • Requires high expertise in planning and project management

The analyst should have expertise in construction sequencing, delay analysis and forensic investigation, since the method can be challenging to execute, and thus it can be time consuming since it requires validation and detailed examination of all relevant records. This methodology may tend to be impressionistic unless results are supported by robust analysis. (Whaley, 2018). The effectiveness of this method is reduced when;

- Consistent /frequent programme updates are readily available;
- The period of the windows lasts too long;
- The contract scope excessively; and
- The contractor failed to follow the as-planned sequence or made too many changes in actual sequence of works (Keane and Caletka, 2015).

APABW method accumulates critical delay incurred and/or the mitigation achieved and/or acceleration taken in each window in order to identify critical delay to the completion date. Thus establishing an accurate actual critical path is the key to the success in this method (Barry, 2009; SCL, 2017).

To sum up, the method has many common grounds in principle with APAB and TSAM, similarities and dissimilarities are enlightened and the strengths and weaknesses of the collapsed as-built method are summarised in Table 2.20.

2.5.6. The Time Slice Analysis Method (TSAM)

TSAM is the second of two 'windows' analysis methods according to SCL Protocol. It is adopted when there are available series of reliable contemporaneous baseline updates which demonstrates accurate status of the project at a particular point in time. The analyst investigates delay impact and contemporaneous critical path from each time frame (SCL, 2017). As shown in Table 2.21, the method investigates the delay impact retrospectively while determining critical path contemporaneously.

Table 2.21 Features of delay analysis methods (DAMs) adapted from SCL (2017).

Method of Analysis	Analysis Type	Approach	Critical Path Determined	Delay Impact Determined
Impacted as-planned analysis	Cause & Effect	Modelled/ Additive	Prospectively	Prospectively
Time impact analysis	Cause & Effect	Modelled/ Additive	Contemporaneously	Prospectively
Collapsed as- built analysis	Cause & Effect	Modelled/ Subtractive	Retrospectively	Retrospectively
As-Planned vs As-Built analysis	Effect & Cause	Observational/ Static	Contemporaneously	Retrospectively
As-Planned vs As-Built windows analysis	Effect & Cause	Observational/ Static	Contemporaneously	Retrospectively
Time slice analysis method	Effect & Cause	Observational/ Dynamic	Contemporaneously	Retrospectively
Retrospective longest path analysis	Effect & Cause	Observational/ Static	Retrospectively	Retrospectively

The AACEI RP categorizes this technique as Observational/ Dynamic/ Contemporaneous Updates - MIP 3.4. This technique is an observational one as it does not involve the addition or elimination of delays, nonetheless it relies on observing the behaviour of the programme from update to update and calculating schedule differences regarding essentially unaltered, existing schedule logic. Furthermore, it is regarded as a dynamic logic methodology, as the method utilises schedule updates whose logic may have altered from the baseline even from the preceding updates (AACEI, 2011).

The key criteria that ensure consistency of this technique to produce an accurate assessment;

1. Each time slice should be developed from correct and comprehensive as-built data, otherwise it would cause skewed results, particularly not able to comprehend the actual critical path; and
2. Analyst should not completely rely on initial sequencing and logic of the original base schedule, for the reason that the future elements of each time slice should accurately and reasonably show the status of the works in point of analysis time (Barry, 2009).

Table 2.22 Strengths and weaknesses of the TSAM analysis method.

Strengths	Weaknesses
• Allows for easier identification of schedule slippage • Delays or mitigations in time can be assigned to specific activities • Data preparation process may be quicker than other methods • Considers the dynamic nature of the critical path • Can identify and quantify mitigation and acceleration	• Cannot be carried out if contemporaneous programme updates do not exist • Logic linked baseline programme is essential. • Accurate, detailed as-built data required • Can be time consuming

According to Zack, performing such windows analysis techniques can take longer time due to the necessity to validate all scheduling elements used in the analysis. Hence this may not be an appropriate method where time and budget constraints are dominant (Zack, 2001). Whaley warns that TSAM can produce theoretical results unless the analyst implements the analysis appropriately and is guided by common sense (Whaley, 2018).

Table 2.22 shows the requirements of the time slice analysis method as appropriate and frequent updated schedules to be performed and also it can improve credibility of the analysis if it can be demonstrated that the project participants used the contemporaneous schedules in supervision and execution of the project.

2.5.7. The Retrospective Longest Path Analysis Method (RLPA)

The retrospective longest path analysis is introduced by SCL Protocol in 2017. The method adopts a static approach while other retrospective methods are being dynamic. The method determines both the critical path and delay impact retrospectively. In this technique, the analyst should primarily develop or verify the as-built programme, then the analyst starts tracing critical path backwards starting from completion date in order to identify the retrospective as-built critical path which is different from the contemporaneous or actual critical path used in the windows methods above. Then the as-built dates are compared with as-planned dates from the baseline programme in light of investigating project documents in order to deduce what might have caused the detected critical delay (SCL, 2017).

Table 2.23 Strengths and weaknesses of the RLPA method.

Strengths	Weaknesses
• Easy to implement and understand • Does not need complete schedule updates	• Cannot identify switches in the critical path • Cannot identify concurrent delays and pacing issue • Ignores mitigation and sequence changes • it typically produces theoretical results • Requires an as-built programme or data to create one

The AACEI RP classifies this method as Observational/ Static/ Gross - MIP 3.1. It adopts a static logic method since it principally is reliant on the single set of critical path method. The method is performed on the whole project against a sole baseline or other planned schedule rather than in periodic sections, and thus the method is classified as gross (AACEI, 2011).

Table 2.23 summarizes strengths and weakness of the retrospective longest path analysis method above.

2.6. Selecting the Most Appropriate Method

As explained previously, there is a great number of delay analysis methods cited in the literature and accepted by the practitioners in the industry. Even though a large number of analysts support a specific type of analysis, there is not a straightforward procedure which matches the suitable method to the particular type of project or dispute since each project is unique and involving particular dynamics.

Table 2.24 Factors influencing choice of delay analysis methods.

SN	Factors	(Arditi and Pattanakitchamroon, 2006)	(Braimah and Ndekugri, 2008)	(AACEI, 2011)	(Baldwin and Bordoli, 2014)	(SCL, 2017)
1	Contract requirements or form of contract		✓	✓	✓	✓
2	Purposes of analysis or reasons for delay analysis		✓	✓		
3	The nature and complexity of the causative events		✓			✓
4	Features of the project i.e. type, size, duration and complexity		✓			✓
5	The availability and reliability of project records	✓		✓	✓	✓
6	The nature, extent and quality of existing programmes		✓			✓
7	Value, amount and size of the dispute		✓	✓	✓	✓
8	The nature and complexity of the dispute and claims		✓	✓		
9	Time of analysis	✓				✓
10	Time and budget allowed for delay analysis	✓	✓	✓	✓	✓
11	Expertise of the delay analyst and familiarity with techniques		✓	✓	✓	
12	Forum to assess and resolve the dispute		✓	✓		✓
13	Legal or procedural requirements, applicable legislation		✓	✓		
14	Custom and usage of methods on the project or the case			✓		
15	Agreement of technique				✓	
16	Capabilities of the methodology	✓				

There are a number of factors that may directly affect the selection of which way delay impact are assessed. Different perceptions regarding such factors are shown in Table 2.24. However, this thesis adopts the selection criteria guided by Society of Construction Law since it is a very comprehensive framework and widely recognized by the practitioners in the industry. Therefore, the following factors will be taken into consideration (if they are applicable) when selecting which delay analysis method to be carried on for the case study to prove entitlement to an extension of time or time related compensation:

1. The relevant conditions of contract: The selection of a particular technique will be based primarily on the contract conditions. Firstly, the relevant conditions of contract will be review. If the contract stipulates a specific delay analysis technique, the specified technique will be carried out in order to comply with such provisions, since contract compliance is the prevailing element. Otherwise, any reasonable method which satisfies other affecting factors in choice of DAMs can be preferred. Next thing to do is to investigate other contract conditions associated with planning and programming in order to understand the obligations of the owner and the contractor preparation and submission requirements of baseline and updated programmes, concurrent delays, pacing delays, procedure for EOT application etc. in order to comprehend legal requirements of the project.
2. The nature and complexity of the causative events: When the contract does not dictate any particular method, certain subjects (i.e. concurrent delays, pacing delays, delay mitigation, acceleration, etc.) which might have caused concurrent delay should be investigated. If such issues are encountered, some advanced techniques such as times impact analysis and time slice windows analysis which are able to identify and cope with those issues analysis will be adopted. On the other hand, if discrete events exist such as the failure by the owner to provide access to the contractor or the failure of a key supplier to deliver a long lead item as planned will not require complex analysis.
3. The nature of the project: It is expected that the complexity of the project has been proportioned to the programme. A typical delay analysis requires identification of the critical path(s) to the completion date. If the critical path or near critical paths are sensed changing through the project, and those paths are composed of sequence or chain of activities from different trades, then a more robust method (i.e. TIA, TSAM or APAB windows) will be required to reveal overcome such matters. However, on some projects the critical path that is driving or determining the end date can continue through a sequence of typical work activities (such as a tunnel project or underground

piping project). In such cases a simpler method will be sufficient to measure delays in the project.

4. The value of the project or dispute: Another significant factor to be considered is the size of the dispute or amount of time or money in controversy. If the size of dispute is high, then the price of the delay analysis will not be an essential consideration in comparison. The cost of carrying out a delay analysis is mostly associated with the time/cost of ancillary staff including that of the contractor/owner. If the amount of dispute is high, a more advanced technique will be required. Otherwise a simplistic method will be preferential. Therefore, the most optimum method will be chosen to be both cost effective and suitable for the size of the dispute.
5. The time available: The more sophisticated delay analysis methods (i.e., TIA, TSAM, CAB or APAB windows) may consume much more time and may incur higher costs. The most time and resource consuming methods of delay analysis are probably to be time impact analysis and as-planned vs as-built window analysis, and the latter one likely being the most time consuming because of the volume of work involved to validate all scheduling elements used in the analysis network. Comparatively, less time and resource consuming methods are IAP and simple APAB. Yet, recognition of impacted as-planned methods are very limited in limited conditions and simple as-planned vs as-built methods can produce subjective results. Therefore, such facts constitute a trade-off between a cheap but less accurate technique or an expensive and more accurate technique.
6. The nature, extent and quality of the records available: Availability of reliant and reasonable data is one of the dominant factors that affect decision of which method to be implemented. The more enhanced techniques of analysis can only be performed if detailed project documentation and records have been prepared in the right way during the project. Available contemporaneous project records i.e. frequent progress report, site photos, correspondences, letters will be reviewed to understand dynamics of the project, comprehend the reasons behind the dispute, and verify the validity of updated programmes. If there is solely as-built data available, then only technique that can be applied is the APAB window analysis method as shown in Table 2.25. In absence of reliable update programmes, properly recorded project documentation becomes very important in updating the baseline programme which to be used in application of time impact analysis and time slice windows analysis.

7. The nature, extent and quality of the programme information available: Availability and validation of baseline and updated programmes are very important processes in selection of a delay analysis method. For instance, if a logic-linked baseline programme is not available, then it not possible to carry out IAP, TIA and TSAM methods. If an as-built programme is not obtainable, it is not possible to implement RLPA and CAB methods. The impacted as-planned method as being the simplest technique only relies on the baseline programme. Methods such as – time impact analysis and time slice windows analysis – need consistent update programmes or adequate information with which to update the baseline programme (Table 2.25).
8. Timing of analysis: If assessment for extension of time and measurement of delay events will be done during course of the project, the preferential method will be time impact analysis which determines critical path contemporaneously and delay impact determined on a prospective basis by modelling incremental impact of the delay event on the future. If an EOT application is assessed after completion of the works, or considerably after the impact of a delay event, then the most appropriate retrospective approach will be implemented based on other determining dynamics of the project/dispute.

Table 2.25 Required information for delay analysis methods adapted from SCL (2017).

Method of Analysis	Baseline programme	Logic linked baseline programme	As-built programme	As-built data	Up to date programmes/ progress data	Delay events to model
Impacted as-planned analysis		✓				✓
Time impact analysis		✓			✓	✓
Collapsed as- built analysis			✓			✓
As-Planned vs As-Built windows analysis	✓			✓		
Time slice analysis method		✓			✓	
Retrospective longest path analysis	✓		✓			

2.7. Gap in Literature and Statement of Research Question

In the literature, the main topics of the academic studies associated with delay in construction projects can be categorized into following groups;

1. to recognise and rank main causes of construction delays;
2. to classify problematic issues in delay analysis methodologies;
3. to propose a new delay analysis technique or a new protocol to deal with shortcomings of existing methods; and
4. to determine selection criteria of delay analysis methods in the entitlement to extension of time and compensation of prolongation costs.

It is observed that in the literature, the main emphasis has been given to identification, categorization and ranking of factors affecting delays in construction projects. Hence in this study, a large number of studies have been reviewed in order to comprehend the dynamic of a various factors behind construction delays in the industry. Some of those studies produced a critical review on the causes of delays encountered in the literature (Scott et al., 2004; Hamzah et al., 2011; Fallahnejad, 2013). Some research are confined to particular geographical regions which affected the causation greatly (Lo et al., 2006; Sweis, 2008; Doloi et al., 2012; da Silva, 2016; Hossain et al., 2019). Some studies solely focused on delay factors for particular type of an industry such as oil and gas (Gomarn and Pongpeng, 2018; Kazemi et al., 2018), residential projects (McCord et al., 2015; Durdyev et al., 2017), road projects (Mahamid *et al.*, 2012; Rivera *et al.*, 2020). There are studies which have focused on to categorization and quantification of delay factors by adopting relative importance index (Sambasivan and Soon, 2007; Aziz, 2013; Gündüz et al., 2013). Some authors concentrated on conducting a review of relevant literatures from conference articles and journals in order to provide recommendations to achieve timely delivery of projects (Hamzah et al., 2011; Mbala et al., 2019).

In the literature, a great effort has been given to describe and classify common problematic issues which may hinder success of performed delay analysis technique. One of the most cited-problematic issue observed in the literature is identification of a concurrent delay (Scott et al., 2004; Ndekugri et al., 2008; Arif and Morad, 2014; Bailey, 2014). There are a lot of different approaches to deal with concurrency (Furst and Ramsey, 2001; Gibson, 2008; Baldwin and Bordoli, 2014; Keane and Caletka, 2015). Another unclear area in delay analysis applications is to detect pacing delays and compromise different perspectives of owners and contractors. (Zack, 2000; Mohan and Al-Gahtani, 2006; Burr, 2016). Ownership, and utilization of total float is still another subjective area for opposing parties in construction industry where a large number of studies have dedicated to proposed new models to cope with this issue (Householder and Rutland, 1990; de la Garza et al., 1991; Finke, 2000; Nguyen and Ibbs, 2008; Yang, 2017). Mitigation and acceleration in construction projects are another turbulent field for academics and practitioners, several research attempted to differentiate such issues (Bailey, 2014; Baldwin and Bordoli, 2014; Keane and Caletka, 2015).

Analysing construction delays has become an integral part of the project's lifecycle. However as stated earlier, there are a number of shortcomings of existing delay analysis methods. Hence, following new techniques or new protocols have been conducted to overcome problematic issues, to measure delay, and to determine delay impact;

- Construction Delay Computation Method (Shi *et al.*, 2001),
- Modified But-For Method for Delay Analysis (Mbabazi *et al.*, 2005),
- FLORA New Forensic Schedule Analysis Technique (Nguyen and Ibbs, 2008),
- Isolated Collapsed But-For Delay Analysis Methodology (Yang and Yin, 2009),
- Computerizing Isolated Collapsed But-For Delay Analysis Methodology (Yang and Tsai, 2011),
- Modified Isolated Delay Type Technique (Golanaraghi and Alkass, 2012),
- Integrated Approach to Overcome Shortcomings in Current Delay Analysis Practice (Birgonul *et al.*, 2015),
- Total Float Management: Computerized Technique for Construction Delay Analysis (Al-Gahtani *et al.*, 2016),
- Decision-Making Model for Selecting the Optimum Method (Perera *et al.*, 2016), and
- A Hybrid System Dynamics Decision Making Trial and Evaluation Laboratory (Parchamijalal and Shoar, 2017).

However, practical implementations of proposed new techniques and models in the industry are limited due to the fact that fundamental principles which are recognized by professional associations like Society of Construction Law (SCL), Association for the Advancement of Cost Engineering International (AACEI) and American Society of Civil Engineers (ASCE) are mostly preferred by the industry on this subject.

None of the identified delay analysis methodologies can be universally used in all situations (Arditi and Pattanakitchamroon, 2006), hence a wide range of studies have been conducted to determine selection criteria of delay analysis methods in the entitlement to extension of time and compensation of prolongation costs. Some studies employed case study approaches to demonstrate outcomes of different delay analyses (Bubshait and Cunningham, 1998). Another study analysed fifty-eight time-based claim cases to identify various factors on the selection of a delay analysis method (Arditi and Pattanakitchamroon, 2008). Kao and Yang compared window based delay analysis models on simulated cases (Kao and Yang, 2009). Muhamad conducted a study based on a questionnaire survey in order to obtain opinions of contractors' and clients' consultants' organizations regarding commonly used methodologies for assessing time-based claims (Muhamad *et al.*, 2016). Abdelhadi conducted interview with experts from five projects in UAE to understand how in practice decisions are made to select the most appropriate delay analysis method for a construction project.(Abdelhadi *et al.*, 2019). Braimah performed five different delay analysis methods based on a simple logic linked scenario to assess main problems not addressed by the delay measurement methods (Braimah, 2013).

Since most of the studies in the literature - so far as to compare delay analysis methods or how to select one of them or to present opinion regarding their features are concerned – have based on fictional scenarios rather than actual project records. Therefore, a case study approach based on a real project has been adopted to illustrate;

- to elect the most suitable delay analysis method;
- to measure impact of delays;
- to perform the selected technique;
- to allocate liabilities to each responsible party; and
- to carry out alternative methods for comparison purpose.

Furthermore, this research aims to discuss and compare the results associated with the applied delay analysis techniques and lastly this study targets to be an example for practitioners and academics regarding applications of delay analysis methods under different dynamics and during different phases of projects.

Finally, the research attempts to response to the questions: What are the most and least effective aspects of delay analysis methods which were performed to measure delays of the case study when dealing with problematic issues in delay analysis applications identified through a literature survey?

3. RESEARCH METHODOLOGY

This research aims to demonstrate fundamental features of different delay analysis methods. The research methodology of this study can be summarized as main steps as given below;

1. An extensive literature review was carried to understand identification, categorization, main causes, and potential impacts of construction delays.
2. Standard form of contracts such as FIDIC, JCT, NEC4 type of contracts were investigated in order to find out different approaches regarding requirements of a construction programme, procedures for entitlement of extension of time application.
3. SCL Delay and Disruption and AACEI Recommended Practice for Forensic Schedule Analysis are studied in order to comprehend different delay analysis methods and existing shortcomings of those methods.
4. A case study approach is selected to find out the most appropriate retrospective or prospective delay analysis technique for a particular project to measure extent, incidence and impact of delays and to allocate liabilities of each party.
5. Delay analyses were performed by utilizing project records, contemporaneous reports, schedules which were analysed via Primavera P6 Professional R8.3. Four different retrospective delay analysis techniques were carried out in order to demonstrate differences regarding their procedures, requirements and performances.

3.1. Case Study

A case study approach was adopted to specify and compare fundamental characteristics of different delay analysis methods. The case project, which is based on the actual facts, is the construction of a central utility complex.

A joint venture consortium was contracted to carry out construction of a project which was designed to house;

- a chilled water plant which comprises water-cooled chillers, cooling towers, chilled water distribution network, hydronic pumps, and ancillaries; and

- an electrical power supply system which involves construction of substations, switchgears, transformers, ring main units, generators and medium voltage power distribution cabling.

The value of the contract was 165 million US$. The contract was under FIDIC Red Book (1999) form of contract for construction. The date for commencement of the project was April 16, 2016, with a date for completion of August 30, 2018. In fact, the project was completed on November 30, 2018. The agreed contract duration for the project was 867 days, however this was overrun by 92 days. By other words, the project duration was extended 10% due to a number of events initiated by the employer, the contractor and third parties. The organizational hierarchy in the project is shown in Figure 3.1.

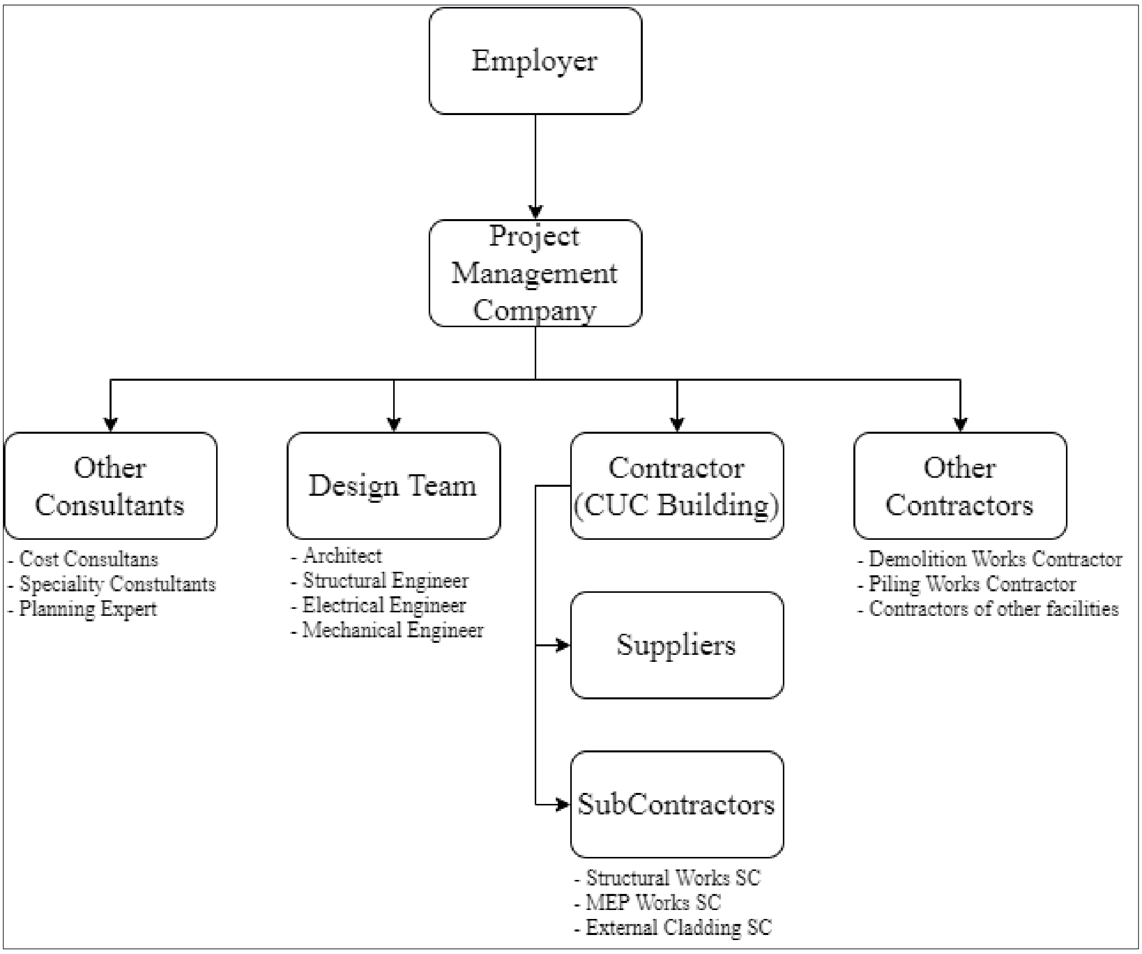


Figure 3.1: Organizational hierarchy in the project.

The employer has submitted a statement of his claims for liquidated damages because the contractor finished the project 92 days after its contractual completion. Whilst the contractor claimed an EOT of 110 days and for the associated prolongation costs due to several employer delays such as late site hand over, late progress in piling works (by piling contractor), and change in chiller design (a detailed list provided in Table 3.1).

The contractor prepared his claims for EOT by employing IAP method, then submitted couple of weeks after each delay event finished, in contrast to the contractual requirement to notify the employer of such claims prior.

The planning expert of the employer asserted that the contractor could not have proved his argument since he failed to address appropriately establishing causal links from the risk events to his losses that were being claimed. Moreover, other comments that were asserted:

- The contractor would have delayed the project in any case, due to delays resulted from slow rate of structural works, formwork failure of water tank walls, late appointment of cladding subcontractor and late delivery of long lead items which were not varied or delayed in any way by the employer.
- IAP technique was not adequate tool to measure delays and reveal the effects on the completion date for such a complex project.
- The claim submissions of the contractor were not compliant to the relevant contract provision because he should have notified the employer in time of delay event happened.
- The contractor has shown only delays caused by the employer and the external factors, though he has not elaborated any of his own delay events in his submission.

At the end of the project, parties agreed on 92 days of EOT but no compensation for additional costs incurred.

3.2. Available Project Information

A great number of project documents, contemporaneous records and information were gathered and reviewed in order to have a broader understanding about the project, programmes and delays for the purpose of delay analysis.

3.2.1. The Contract

The contract was under FIDIC Red Book (1999) form of contract for construction. The particular contract provisions were examined to understand the obligations of both parties from a programming perspective;

- Sub-Clause 8.3 Programme;
- Sub-Clause 8.4 Extension of Time for Completion;
- Sub-Clause 8.5 Delays Caused by Authorities;
- Sub-Clause 8.7 Delay Damages;
- Sub-Clause 10.1 Taking Over of the Works and Sections;
- Sub-Clause 13.3 Variation Procedure; and
- Sub-Clause 20.1 Contractor's Claims.

3.2.2. Baseline Programme

The contractor submitted and obtained approval for the baseline programme. Thus, the approved baseline programme was determined as the as-planned programme in order to establish the basis for analysis. The baseline programme was developed in Primavera P6 Professional R8.3 and consisted of considerable volume of construction work with scope of over 2000 activities including design, procurement, construction, testing & commissioning and final hand over works.

Some sanitary checks were carried out to verify reasonableness of the as-planned programme such as;

- to verify the programme is compliant to the contract;

- to examine that modelled programme to have at least one continuous chain of activities from commencement to completion;
- to control all activities having at least one predecessor, and one successor activity;
- to check no activities having excessive positive or negative lags to hide float;
- the verify the date constraints utilized in the programme are reasonable;
- to verify the programme is free from any actual progress data and have a data date which is on or before the commencement date of the project;
- to confirm all third-party interfaces (i.e. local/regulatory authorities, direct contractors of the Owner, etc.) are represented; and
- to check proper calendars had been assigned along with proper public holidays and seasonal working hour requirements;

3.2.3. Monthly Programme Updates

The contractor produced contemporaneously monthly programme updates regularly and submitted them but none of which were ever accepted or rejected by the employer. However, in fact, the contractor’s contemporaneous updates were used as management tools for carrying out the project works, to measure progress or any delay and to facilitate communication among project participants. The reliability in as-built dates in the updates were reviewed. Therefore, it was concluded that contemporaneous programme updates could be utilized in delay analysis if there were appropriately prepared and demonstrating the in light of further verifications.

3.2.4. Regular Progress Reports

A full set of daily, weekly and monthly progress reports which has been submitted to the employer throughout the project has been provided. Such records were utilized to verify accuracy of the features of the updated programmes such as;

- as-built dates - inaccurate actual dates were rectified;
- change in programming logic and sequence of works at site – if there is an incorrect logic relationship or a missing links exist, they were corrected;
- reasonableness of critical path in each programme update;

- no actual dates beyond the data date of the updated programme;
- submission and approval process of shop drawing, material and any other technical submittals; and
- durations of main procurement items and construction activities along critical, and near critical paths.

3.2.5. Correspondences and Meeting Minutes

A full set of monthly progress meeting minutes and correspondences including change orders from the employer, notices and EOT claims from the contractor side were obtained and such records were used time to time;

- to understand causes and timing of risk events;
- to comprehend requirements and intentions of the employer regarding risk events;
- to understand the reasons behind the employer's rejection; and
- to understand intended strategy of the contractor during course of the project.

3.2.6. Progress Photos

Thousands of progress photos which were categorized based on the date and the related areas were obtained. Such records were utilized as evidence of;

- site conditions and progress;
- area handovers between the contractor and the employer (the others); and
- impact of alleged risk event if any lack of progress existed for a particular area between certain periods.

3.3. Identification of Risk Events and Liabilities

As explained earlier, risk events have been identified based on initial investigation on available as-built programme and project records. Identified events were determined by examining the regular reports of the contractor, official correspondences between employer and contractor, EOT claims and notices of the contractor, variation orders from the employer during the course of the project. In light of such examination, 20 risk events have been found among which 8 resulting from the employer's actions or inactions,10 under responsibility of the contractor, and 2 resulting from external factors or 3rd parties. Initially identified risk events are shown in Table 3.1.

Table 3.1 Initially identified risk events

SN	RISK EVENTS
1	Late Access
2	Completion of Piling Works (By piling works contractor)
3	Changes to Design of Chillers
4	Changes in Ring Main Unit Specs
5	Changing Motor of Hydronic Pumps
6	Late Approval of Medium-Voltage Circuit Breaker Switchgears
7	Revised Water Supply Schematic Layout
8	Change in Louver Size and Connections
9	Slow Rate of Pile Head Treatment
10	Formwork Failure of Water Tank Wall
11	Late Appointment of External Wall Cladding Subcontractor
12	Slow Rate of Super-Structural Works
13	Late Material Submission of VAVs
14	Late Material Submission of Bus Bars
15	Late Material Submission of Cooling Towers
16	Late Technical Submission of Floor Tiles
17	Area Readiness for 1st Fix MEP Works (Blockwork, Cutting and Chasing)
18	Lack of Manpower for Piping Works
19	Inclement Weather Conditions – Flood due to Heavy Rain
20	Late Approval of Permanent Power Supply

The extent, incidence, criticality and effect on the project completion date for identified risk events were determined by performed delay analysis methods.

3.4. Selection of Delay Analysis Method

After validating reliability of the project records and programmes, potential causative events of delays to the completion of the project were identified. The most appropriate delay analysis method was chosen by utilizing selection criteria which are listed under Chapter 2.6. Therefore, steps were undertaken by examining the following criteria:

- The Relevant Conditions of Contract: Since the contract compliance is the prevailing factor, relevant clauses of the contract were reviewed to assure if the contract stipulates a certain delay analysis technique to be used when measuring delay impact. However, the contract provisions are quiet on which schedule delay analysis technique is to be adopted. Therefore, it is free to use any method which is able to reveal events behind late project completion and satisfy all project participants.

- The Nature and Complexity of the Causative Events: The delay events to the completion date of the project were definable and limited to initially found risk events. However, some risk events caused by the employer, contractor and external factors were occurred parallelly during the same period of time, so concurrency might have been a dominant issue to be examined. Furthermore, through investigation of correspondences, the contractor noticed the employer that he’s paced down some project work due to continuous delays resulted by employer risk events. Moreover, it was observed that the longest path and near critical paths have changed over different time periods, in light of initial investigation of updated programmes. As a result, RLPA and CAB methods were not found adequate candidates because such methods are not capable of identifying shifts in the critical path.

- The Nature of the Project: Mechanical and electrical works formed the majority of the scope of work in the project. The project is composed of various participants (shown in Figure 3.1) including different contractors, the employer, many consultants and designers. New requirements of different stakeholders caused changes in scope of the original contract. It was deduced that causative events triggered changes in construction sequence and reallocation of crews to different areas/zones than it was planned originally. As the contractor asserted such changes might have caused loss of productivity and ineffectiveness for those activities which have not impacted by the employer risk events directly. Therefore, the technique to be adopted should be capable of demonstrating such problems. Furthermore, some improvements on the planned completion date of the project among updated programmes were observed so the method to be selected should reveal successful mitigation measures, if any.

- The Value of the Project or Dispute: If the amount of dispute is high, a more advanced technique will be required. Otherwise a simplistic method will be preferential. The project duration was extended 10%. The employer claimed 2,5 million US$ for the liquidated damages resulting from extended duration while the contractor claimed 2 million US$ as financial compensation due to prolongation expenses and loss of productivity. In fact, the disputed monetary amount and extended duration are not very high comparatively, so a very advanced technique might not be required. But it should not be forgotten that one of the reasons why the employer rejected the claims of the contractor was the simple method used in assessment. Hence, any other method different than simple as-planned vs as-built and impacted as-planned and impacted as-planned methods could be adopted.

- The Time Available: The more sophisticated delay analysis methods may consume more time. In many cases, the decision for forensic delay analysis is not made early enough to allow sufficient flexibility in the choice of the most appropriate methodology. In the case study, the delay analysis was being done after the project but the contract did not contain a fast track arbitration clause which might have limited the duration of analysis process. Therefore, it was assumed that there was not a time constraint for the analysis.

- The Nature, Extent and Quality of the Records Available: As shown in Table 2.25 required information for analysis methods were checked. The project documentation was reviewed and found sufficient for the purpose of the delay analysis from point of reliability of the logic linked baseline programme and necessary information for delay events to be modelled. Moreover, as-built records and up to date progress data were available and adequate, so existence of such records did not limit selection of delay analysis technique.

- The Nature, Extent and Quality of the Programme Information: Baseline programme was approved by the employer, moreover sanitary checks, identified in Chapter 3.2.2

were carried out, thus validity of the baseline programme was verified. The contractor produced contemporaneously monthly programme updates regularly and submitted them but none of which were ever accepted or rejected by the employer. However, in essence, the contractor's contemporaneous updates were used actively as management tools for carrying out the project works, to measure progress or any delay and to facilitate communication among project participants. Furthermore, contemporaneous updates were controlled through available project records, thus necessary minor abnormalities were altered. From point of programme availability, the sources are adequate to carry out any preferred technique.

- Timing of Analysis: Since the EOT assessment is being done after completion of the works, by other words significantly after the impact of risk events, then the prospective delay analysis methods i.e. TIA and IAP are no longer be appropriate. Therefore, one of the retrospective delay analysis methods should be used in order to measure impacts of risk.

As a result of the steps undertaken, it was concluded that one of the retrospective approaches would be used for the purpose of delay analysis, and thus IAP and TIA methods were not suitable candidates anymore due to being prospective approaches. Simple APAB method was not a preferential approach due to precedent rejection of the employer. Moreover, it was thought that the project might have contained potential concurrent delays, pacing delays, and mitigation steps, therefore CAB and RLPA were found not to be very suitable methods due to their lack of competence regarding such issues. Since allowed time and financial resources for schedule analysis were assumed not to be constraints, it could be concluded that both TSAM and APAB windows analysis method and could be selected.

3.5. Methodology

Both TSAM and APAB windows analysis method were considered to be suitable candidates for the purpose of schedule delay analysis. A valid as-planned programme and reliable series of monthly updated programmes were available, and thus TSAM could be appropriately carried out. Moreover, this method has not been discussed in detail and applications of this method on a real case scenario in previous studies were not encountered through the literature survey, therefore TSAM has been chosen to provide a better understanding. After the process of time slice analysis method was completed, the other retrospective methods were carried out in order to test capabilities of TSAM technique against APABW, RLPA and CAB.

4. ANALYSES

4.1. Schedule Delay Analysis with TSAM

To perform Time Slice Analysis Method, 31 consecutive programmes were considered as base windows including baseline programme (as-planned programme), monthly updated programmes (contemporaneous programmes), and latest updated programme (as-built programme). Available programmes with relevant data dates and projected completion dates are listed Table 4.1.

Table 4.1 Available programmes for delay analysis purpose.

Programme SN	Data Date	Completion Date	Total Float
As-Planned	16-Apr-16	30-Aug-18	0
1	30-Jun-16	16-Sep-18	-17
2	31-Jul-16	15-Sep-18	-16
3	31-Aug-16	01-Oct-18	-32
4	30-Sep-16	25-Sep-18	-26
5	31-Oct-16	30-Sep-18	-31
6	30-Nov-16	30-Oct-18	-61
7	31-Dec-16	20-Oct-18	-51
8	31-Jan-17	16-Oct-18	-47
9	28-Feb-17	14-Oct-18	-45
10	31-Mar-17	23-Oct-18	-54
11	30-Apr-17	28-Oct-18	-59
12	31-May-17	25-Nov-18	-87
13	30-Jun-17	22-Nov-18	-84
14	31-Jul-17	07-Nov-18	-69
15	31-Aug-17	14-Nov-18	-76
16	30-Sep-17	12-Nov-18	-74
17	31-Oct-17	03-Dec-18	-95
18	30-Nov-17	22-Dec-18	-114
19	31-Dec-17	25-Dec-18	-117
20	31-Jan-18	09-Dec-18	-101
21	28-Feb-18	06-Dec-18	-98
22	31-Mar-18	28-Nov-18	-90
23	30-Apr-18	03-Dec-18	-95
24	31-May-18	15-Nov-18	-77
25	30-Jun-18	28-Nov-18	-90
26	31-Jul-18	13-Nov-18	-97
27	31-Aug-18	10-Dec-18	-102
28	30-Sep-18	29-Nov-18	-91
29	31-Oct-18	02-Dec-18	-94
30	12-Nov-18	30-Nov-18	-92

Underground utilities were mostly completed on or before planned completion dates, and thus they were not taken into account for assessing delay. As explained in Chapter 2.4.8, updated programmes were reviewed, sanitary checks were carried out, and some abnormalities were rectified in each updated programme such as;

- the actual dates after the data date were corrected;
- unnecessary constraints including hard logic removed to reflect true logic;
- the longest path and near critical paths were reviewed in order not to have inappropriate chains of activities;
- dates of owner related activities were controlled based on official submittals; and
- irrational remaining durations i.e. excessive or zero were rectified in order to have realistic prediction for the remaining project work.

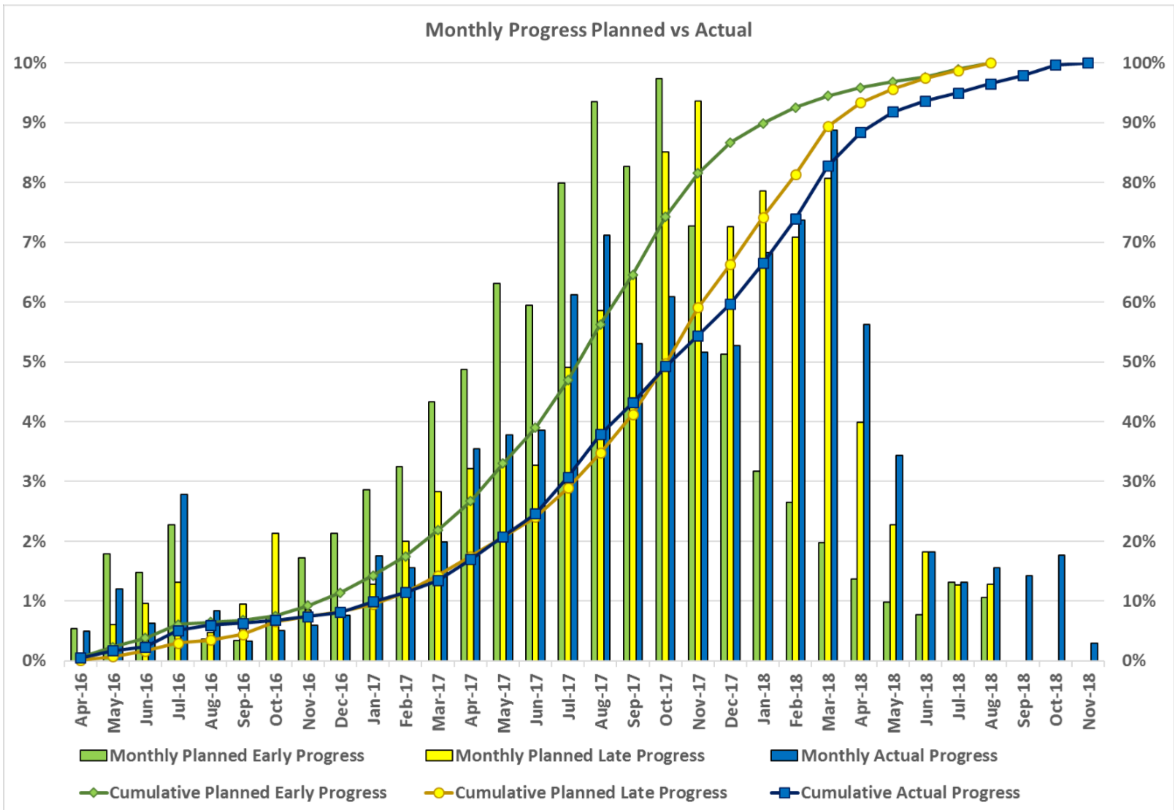


Figure 4.1 Monthly progress curve.

A monthly physical progress curve was generated based on assigned man-hours to the as-built programme with data date 30-Nov-18, in order to review and analyse the actual progress of the works. Figure 4.1 provides a comparison between curves of the early and late planned progress percent figures against actual progress achieved at site. As it can be seen, the actual progress fell behind the early planned progress since the beginning of the project. However, actual progress accomplished at site followed almost the same trend with the late planned progress figures until the October 2017, from this date on the planned progress could not be kept up.

The progress curve in Figure 4.1 does not show a lack of progress till the updated programme as of 31-October-2017, on the other hand the same programme (Window #17) also projected 97 days of delay in the project completion date shown in Table 4.1. This circumstance indicates that even though the actual progress at site was aligned with the late planned progress curve during the same period, the contractor did not or could not carry out the project work on the critical path which had delayed 92 days in the original completion date.

Contemporaneous programmes were analysed to understand how much float deterioration was experienced contemporaneously area-wise. Float deterioration chart (Figure 4.2) was developed to specify how far behind schedule each particular area slipped from month to month. The main areas which have completed beyond contractual completion date were depicted in the figure to understand competing areas for dominance throughout the project.

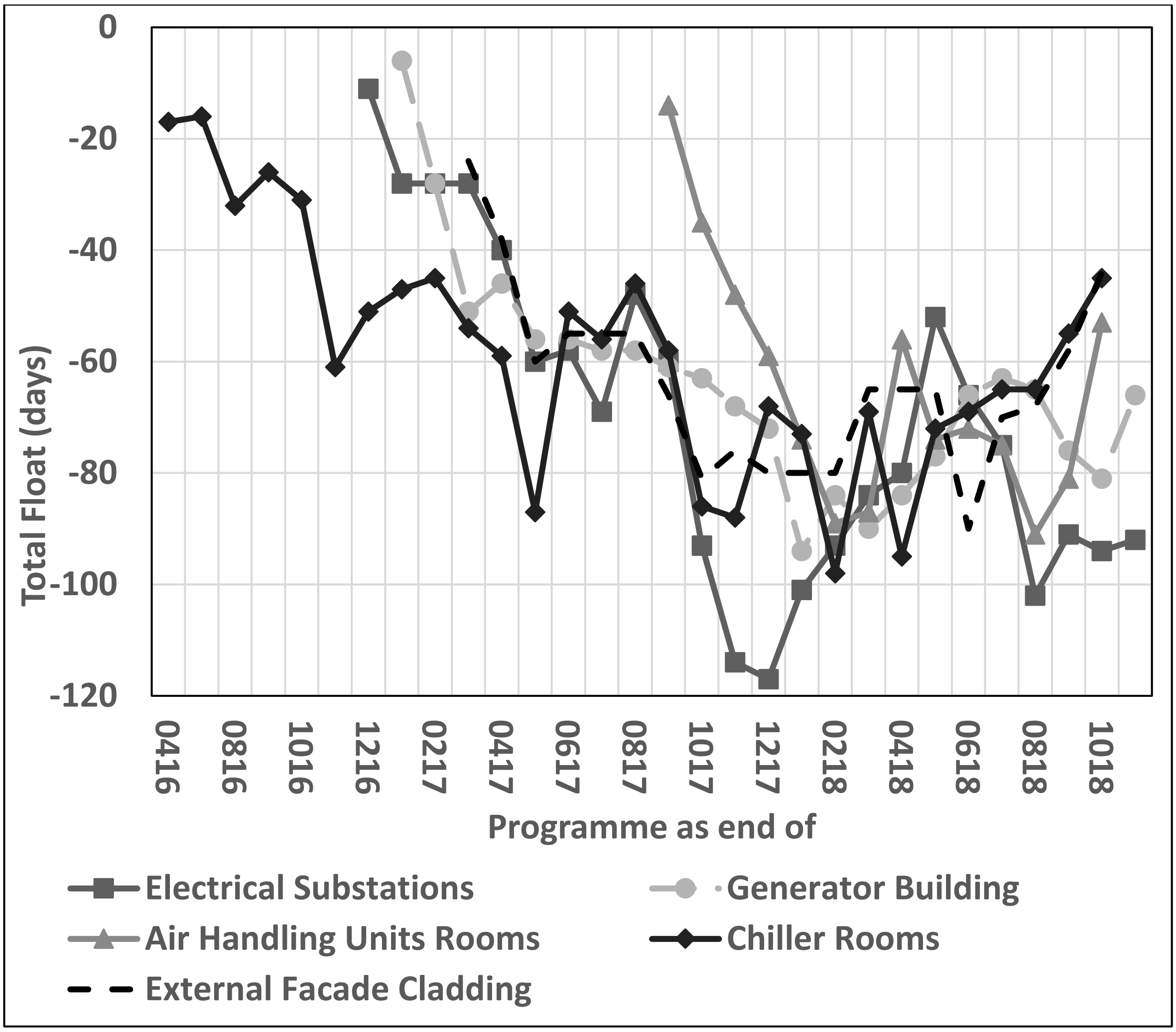


Figure 4.2 Float deterioration curves.

Longest path and near critical paths which are composed of chain of activities with the least amount of float in each time frame were determined contemporaneous programme, and thus the competing critical paths and near critical paths were extracted from each updated programme. To provide better understanding about this examination, following programmes were attached at the end of this study;

- The Longest Path in Window #2 as of 31-Jul-16 (Appendix A)
- 2nd Near Critical Path in Window #17 as of 31-Oct-17 (Appendix B)
- The Longest Path in Window #28 as of 30-Sep-18(Appendix C)

It is very important to comprehend critical path which might change through monthly updates or even in a daily basis in order to able to deduce what might have caused critical delay to the completion. Therefore, contemporaneous programme updates were examined carefully to find out all of the activities satisfying the following two conditions to determine the ‘driving’ activities within each window:

- to reside on the ‘longest path’ to completion date of the project.
- to be “in progress” or planned to commence within the concerned period (until the cut-off date of the subsequent update).

All activities which had satisfied above conditions and their details were sorted chronologically in a timetable to form the Contemporaneous Critical Path (refer Appendix D) which depicts Activity IDs, Activity Names and amount of total floats in each programme update. Only the float values which belonged to activities which were on the longest path within the specific update period and were planned to start during that update were highlighted with dark colour. All activities were classified according to their particular discipline or area in order to understand shifts in the longest path.

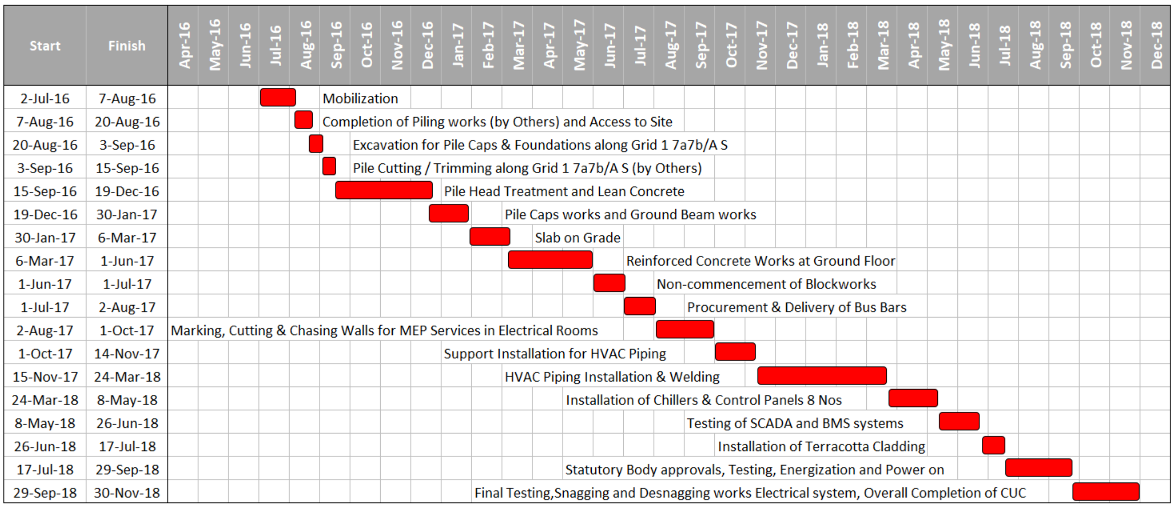


Figure 4.3 Summary Contemporaneous Critical Path

Figure 4.3 demonstrates the contemporaneous critical activities and switches on the critical path throughout the project based on review of subsequent updates. After having set contemporaneous critical path, a reference critical activity was selected in each programme to measure the critical delay incurred against late dates from baseline programme.

Table 4.2 Summary of risk events and liabilities.

SN	CODE	RISK EVENTS	CATEGORY OF DELAY FACTOR	LIABLE PARTY	TYPE OF DELAY
1	ERE-01	Late Access	Delay in site delivery	Employer Related	Excusable Compensable
2	ERE-02	Completion of Piling Works (By piling works contractor)	Delay in site delivery		
3	ERE-03	Changes to Design of Chillers	Design changes		
4	ERE-04	Changes in Ring Main Unit Specs	Design changes		
5	ERE-05	Changing Motor of Hydronic Pumps	Design changes		
6	ERE-06	Late Approval of Medium-Voltage Circuit Breaker Switchgears	Slowness in decision making		
7	ERE-07	Revised Water Supply Schematic Layout	Delay in revising and approving design documents	Consultant Related	
8	ERE-08	Change in Louver Size and Connections			
9	CRE-01	Slow Rate of Pile Head Treatment	Poor site management and supervision	Contractor Related	Non Excusable Non Compensable
10	CRE-02	Formwork Failure of Water Tank Wall	Rework due to errors during construction		
11	CRE-03	Late Appointment of External Wall Cladding Subcontractor	Underestimating project cost		
12	CRE-04	Slow Rate of Super-Structural Works	Shortage of materials/ Shortage of labour		
13	CRE-05	Late Material Submission of VAVs	Problems with subcontractors		
14	CRE-06	Late Material Submission of Bus Bars	Problems with subcontractors		
15	CRE-07	Late Material Submission of Cooling Towers	Difficulties in financing project by contractor		
16	CRE-08	Late Technical Submission of Floor Tiles	Ineffective project planning and scheduling		
17	CRE-09	Area Readiness for 1st Fix MEP Works (Blockwork, Cutting and Chasing)	Poor site management and supervision		
18	CRE-10	Lack of Manpower for Piping Works	Shortage of labour		
19	XRE-01	Inclement Weather Conditions – Flood due to Heavy Rain	Unfavourable weather conditions	External Factors	Excusable Non Compensable
20	XRE-02	Late Approval of Permanent Power Supply	Obtaining permits from governmental organizations		

In order to understand causative events behind the measured delays, the next step is to identify the dominant risk events for the driving activities in each longest path. The initially identified risk events are and the liable parties, categorization and type of the identified 20 risk events are summarized in Table 4.2. Those risk events were gathered by examining the official correspondences between employer and contractor, issued EOT claims and notices of the contractor early warnings, minutes of meeting and the updated programmes and variation orders from the employer during the course of the project. Risk events were categorized based on the literature survey which was conducted under Chapter 2.2.1.

On 30 June 2016, the Employer handed over the site to the Contractor. Contractor's early mobilization activities were delayed due to XRE-01 'Late access (by the Employer)' even though the contractor had readily available resources to carry out mobilization work. However, when critical mobilization activities compared against baseline late dates, it was concluded that there was no critical delay incurred during the 1st update.

On 7 August 2016, the critical path was switched from mobilization works to the piling works which was carried out by another contractor. was agreed as 16 April 2016 during pre-contract award meetings. Those piles were handed over to the Contractor on 20 August 2016. It was 126 days late than the agreed hand over date, but only 27 days after the late finish date. Therefore, ERE-02-Completion of Piling Works (By the Piling Contractor) caused 27 days of critical delay during this period.

On 20 August 2016, the Contractor commenced excavation works after taking over the piles. On 3 September 2016 the Contractor completed substantial amount of excavation works which enabled the Piling Contractor to commence pile cutting activities in the same area 1 day earlier than planned. By other words, when the critical path had switched to pile cutting works, the Contractor mitigated 1 day of the critical delays.

On 15 September 2016, the Contractor commenced the pile treatment works when pile cutting works were sufficiently handed over the Contractor. Thus, critical path switched into pile treatment works. However, the Contractor was able to commence such works 4 days later than plan, due to ERE-02-Completion of Piling Works (By the Piling Contractor).

Critical path run through pile head treatment and lean concrete from 15 September 2016 to 19 December 2016. By end of November 2016, 30 days of critical delay incurred due to confluence of slower than planned progress in pile head treatment works and heavy rains. The project had suffered a flood to the heavy rains. During inclement weather conditions (XRE-01) from 14 November to 22 November 2016, the Contractor claimed that the project site was not accessible for substructure works, furthermore some rework activities were performed due to this risk event. Destructive impacts of the risk event were validated with site photos. Thus, remaining critical delay of 22 days were attributable CRE-01 Slow Rate of Pile Head Treatment. On 19 December 2016, after having completed sufficient amount of pile treatment, lean concrete and other civil works, the Contractor was in a position to commence reinforced concrete works and thus the critical path shifted to foundation works. The Contractor commenced excavation works 12 days ahead of the plan, therefore 12 days of critical delay was mitigated by end of this period.

On 30 January 2017, after having completed enough pile caps and ground beams, the Contractor was in a position to commence related works for slab on grade and thus the critical path shifted to those works. The Contractor commenced slab on grade works 1 day ahead of the plan, therefore 1 days of critical delay was mitigated by end of this period.

On 6 March 2017, the Contractor was in a position to commence construction of columns and walls in Zone 2, 6 days ahead of the its relative planned commencement date. Hence, 6 days of critical delay were mitigated by this date. has become critical. But, in fact, the construction of columns and walls in Zone 2 was commenced 18 March 2017. After investigating the project records, it was concluded that 12 days of critical delay resulted from ERE-03 Changes to Design of Chillers. The contemporaneous critical path proceeded though reinforced concrete works at ground floor until 1 June 2017. By end of this period, there were 17 days of critical delay occurred in structural works which was assumed to be related to the CRE-04 Slow Rate of Super-Structural Works. It’s deduced that the contractor had not generated sufficient rate of progress regarding super structural works in Zone 2B. The contractor claimed that he’s paced down his progress due to continuous delays initiated by the employer and he did not have any liabilities for such a risk event. When contemporaneous daily and weekly reports were reviewed, it was deduced the contractor decreased number of carpenters and steel fixers and he noticed the employer. However, as works progressed, higher number of workers were required to catch up the scheduled tasks. In case of this necessity, the contractor could not able react satisfactorily, and thus the risk event CRE-04 (Slow Rate of Super-Structural Works) jeopardized carrying out project work as per plan and eventually became one of the causative critical events to the completion of project work. It’s concluded that why this critical delay impacted the project completion did not only result from pacing intention but also from shortage of labour and late delivery of cut and bent reinforcements.

On 1 June 2017, the majority of ground floor was ready for the Contractor to commence blockwork installation, thus the critical path was shifted from the structural works to blockworks. However, the Contractor did not commence blockworks until 1 July 2017. The revised water supply schematic layout (ERE-07) occurred at the same time when the contractor planned to start blockwork activities after completion of structural works in Zone 2. Thus, the Contractor claimed that he was not able to start blockwork and following activities and he had suffered loss of productivity. Daily reports were examined, it was concluded that the contractor was ready to commence and progress blockwork regarding number of employed masons, therefore there was no concurrent delay happened from the Contractor side. The Employer issued revised mechanical and architectural drawings to the Contractor to prepare and submit shop drawings in due course. There was 4 days of critical delay occurred in this activity. After submission of revised shop drawings of the Contractor, the Employer approved the 2 days earlier than planned, therefore in total, the revised water supply schematic layout (ERE-07) caused 2 days of critical delay by 1 July 2017.

From 1 July 2017 to 2 August 2017, procurement and delivery of bus bars had become critical due to late technical submission of those materials. When start date manufacturing of those materials were compared to the late baseline dates the total delay was measured as 70 days which was 2 days less than the delay as 1 July 2017. Thus, even though the critical path had shifted, 2 days of mitigation were measured likely because of the faster than planned progress in blockworks.

On 24 August 2017, the critical path was started to run through area readiness for MEP services until 1 October 2017 when the Contractor completed marking, cutting & chasing walls for MEP activities. When measured against baseline late dates, it was concluded that 79 days of critical delay occurred, by other words, 9 additional days of critical delay occurred by 1 October 2017. It was assumed that this resulted from confluence of lack of coordination between different teams at site and slower than planned progress of blockworks. However, both causes are attributable to the Contractor, therefore they were grouped under CRE-09 Area Readiness for 1st Fİx MEP Works.

On 1 October 2017, the Contractor commenced 1st fix installation for heating, cooling and ventilating piping in technical rooms. The critical path proceeded through HVAC pipe installation, welding, insulation and flushing until 24 March 2018. The activities along critical path were periodically measured against planned dates, there were loss and gains throughout the period. As a result, delay in piping works eventually affected installation of chiller units and air handling units. Moreover, following project work including testing and commissioning of those HVAC equipment, and final finishing works in those mechanical rooms had delayed beyond original project completion date. By end of the window, the chilled water piping was in a delay of 104 days in total. In the beginning of the windows, total delay was measured as 79 days, therefore total critical delay incurred during this period was concluded as 25 days which was resulting from slower than planned progress of piping works. When reviewing the contemporaneous records, there were few notices issued by the Employer concerning about the lack of manpower for piping and welding. Thus, 25 days of critical delay was attributable to CRE-10 Lack of Manpower for Piping Works.

On 24 March 2018, the Contractor commenced installation the first chiller unit, and thus the critical path was switched to the installation of chillers and control panels. When it was measured against the planned date, there was 14 days of mitigation achieved in this period.

By 8 May 2018, the Contractor was in a position to commence testing of SCADA and BMS systems, since most of the electrical systems and installation of panel were complete. When start of this activity was measured against the planned date, it was found that this activity had started 6 ahead of its relative planned dates, hence 6 days of mitigation achieved in this period. On 26 June 2018, external cladding works became critical when testing of SCADA and BMS systems was 90% complete which to be achieved as of 11 September 2017 according to the plan. Thus, the difference from the baseline date was 77 days while total delay as of 8 May 2018 was 84 days. Therefore, 7 days of mitigation achieved by 26 June 2018 due to faster than planned in testing of electrical systems.

The terracotta cladding commenced on 30 June 2018 which was 12 days later than the planned date. On 17 July 2018, the critical path was switched from external cladding into testing, energization and powering activities. When delay was measured by that time, it was found that there was additional 5 days of critical delay occurred due to CRE-03 Late Appointment of Cladding Subcontractor.

From 17 July 2018 to 29 September 2018, critical path proceeded through the process of obtaining statutory body approvals, testing with permanent power, energization and power on. The Contractor became able to start testing with permeant power on 4 September 2019 which is 19 days later than the planned when measured against baseline programme. This delay is attributable to XRE-02 Late Approval of Permanent Power Supply. By 4 September 2018, the total critical delay incurred in the project was 113 days.

On 30 November 2018, the Contractor obtained certificate of substantial completion which is assumed as the cut-off date of this study. The total critical delay occurred in this project is assumed as 92 days due to the variance from contract completion date 30 August 2018 to 30 November. Thus, the Contractor had mitigated 21 days of critical delay as at 30 November 2018.

Table 4.3 summarises schedule differences in critical activities in each window that were compared in order to comprehend gains and losses in between each window. Further, Table 4.3 shows month to month changes which were obtained through the time slice analysis method by determining causes of monthly changes in contemporaneous critical path (Appendix D). The table simplifies the results for the understanding of the analysis. Liabilities of delay events were allocated to the responsible parties. Under ‘Δ Impact’, net change between each consecutive programme classified as critical delay incurred or mitigated delays in the period. Moreover, delays were allocated to liable parties. Furthermore, resulting delay in each period was assigned to the causative events of the employer, the contractor and external factor separately. The cumulative data under “∑ Impact” demonstrates the cumulative liabilities of each party from the beginning of the project till end of analysis period.

Table 4.3 Liabilities - time slice analysis method

Window SN	Window As Of	Δ Impact					Δ ERE				Δ XRE		Δ CRE								∑ Impact			
		Variance	Delay			Mitigation	ERE-01	ERE-02	ERE-03	ERE-07	XRE-01	XRE-02	CRE-01	CRE-03	CRE-04	CRE-06	CRE-09	CRE-10	CRE-11	Mitigation	Variance	Variance		
			EC	EN	NN																	EC	EN	NN
As-Planned	16-Apr-16																							
1	30-Jun-16																				0	0	0	0
2	31-Jul-16	14		14				14													14	14	0	0
3	31-Aug-16	13		13				13													27	27	0	0
4	30-Sep-16	3		4		-1		4												-1	30	31	0	-1
5	31-Oct-16	0																			30	31	0	-1
6	30-Nov-16	30		8	22						8		22								60	31	8	21
7	31-Dec-16	-12				-12														-12	48	31	8	9
8	31-Jan-17	-1				-1														-1	47	31	8	8
9	28-Feb-17	-6				-6														-6	41	31	8	2
10	31-Mar-17	12	12						12												53	43	8	2
11	30-Apr-17	3			3										3						56	43	8	5
12	31-May-17	14			14										14						70	43	8	19
13	30-Jun-17	2	2							2											72	45	8	19
14	31-Jul-17	-2				-2														-2	70	45	8	17
15	31-Aug-17	14			14												14				84	45	8	31
16	30-Sep-17	-4																		-4	80	45	8	27
17	31-Oct-17	-1																		-1	79	45	8	26
18	30-Nov-17	25																25			104	45	8	51
19	31-Dec-17	11																11			115	45	8	62
20	31-Jan-18	-24				-24														-24	91	45	8	38
21	28-Feb-18	5			5													5			96	45	8	43
22	31-Mar-18	8			8												8				104	45	8	51
23	30-Apr-18	-14				-14														-14	90	45	8	37
24	31-May-18	-6				-6														-6	84	45	8	31
25	30-Jun-18	5												12						-7	89	45	8	36
26	31-Jul-18	5												5							94	45	8	41
27	31-Aug-18	19			19							19									113	45	27	41
28	30-Sep-18	-20				-20														-20	93	45	27	21
29	31-Oct-18	1			1														1		94	45	27	22
30	30-Nov-18	-2				-2														-2	92	45	27	20
Overall	**16-Apr-16**	**92**	**14**	**39**	**86**	**-88**	**-**	**31**	**12**	**2**	**8**	**19**	**22**	**17**	**17**	**-**	**22**	**41**	**1**	**-100**	**92**	**45**	**27**	**20**
							45				**27**		**20**											

45 days of critical delay resulted from the employer's actions or inactions, 27 days of critical delay occurred due to external factors, and 120 days of delay was attributable to the contractor. The contractor recovered 100 days out 192 days of delay which the project could have experienced. Monthly recovered amount of delays were shown under gain mitigation in Table 4.3, if any. Therefore, the project was completed 92 days behind the original programme. According to results of time slice analysis method;

- 45 days were found to be excusable and compensable as being attributable to the employer;
- none of the parties were responsible for 27 days of delay which were excusable and non-compensable;
- the contractor was liable for remaining 20 days of delay which were non excusable and non-compensable and;
- 100 days of recovery accomplished during course of the project.

4.2. Schedule Delay Analysis with APAB Windows

The first retrospective method to test capabilities of TSAM is APABW method. It was aimed to understand the dynamic nature of the longest path which might change through windows and recognise reasons of critical delay.

As being main difference from TSAM, APABW method mostly relies on the factual data rather than solely depending on the programme information. The available contemporaneous project records have reviewed, and the chronology of the events were compiled. In order to measure the delay in the project, firstly the critical path was to be developed by examining project records.

In the period from the Commencement Date on 16 April 2016 to 30 June 2016, the actual critical path proceeded through the site hand over by the Client to the contractor. Since the all subsequent activities are dependent on the availability of the construction site and thus the critical path is considered as running through site hand over process.

Having taken over the site by Contractor, there were two pre-requisite activities to commence excavation works i.e. piling works to be completed by the Piling Contractor and mobilization works to be carried out by the Contractor. Piles were handed over the Contractor on 20 August 2016. Even though the as-built programme shows that the Contractor finished all mobilization activities on 26 September 2016, the Contractor was in a position to start excavation works on 20 August 2016 since substantial portion of the contractor’s mobilization was complete according to site photos and daily reports e.g. site offices, main construction equipment and temporary site facilities. Therefore, the critical path is running through piling works by the Piling Contractor in the 2nd window from 30 June 2016 until 20 August 2016.

In the period from the pile hand over to the Contractor on 20 August 2016 to 30 November 2016 when substantial amount of pile treatment was complete by the Contractor which enabled the Contractor to proceed with subsequent foundation works on. Thus, after taking over the piles, the consecutive activities; (a) excavation works by the Contractor, (b) pile cutting works by the Piling Contractor, (c) pile head treatment and (d) pouring lean concrete by the Contractor were needed to take place to proceed subsequent reinforced concrete foundation works. Therefore, the 3rd window takes a picture of the transition period from early earthworks to the foundation works.

In the circa 4-month period from 30 November 216 to 17 March 2017, the actual critical path proceeded through the waterproofing works, reinforced bar installation and concrete foundation works, structural design of ground floor columns and construction of those vertical members. By 17 March 2017, the Contractor was in a position to commence construction of those columns at ground floor.

In the period from 17 March 2017 to 01 July 2017 when the contractor commenced blockwork installation at ground floor, the actual critical path proceeded through reinforced concrete works and availability of shop drawings which enabled the contractor to commence blockworks. Then, the critical path has switched into blockworks from the structural works.

In the period from 1 July 2017 to 24 March 2018 the critical path proceeded through blockworks, marking, cutting & chasing walls for MEP services, piping support and installation and welding of HVAC pipes. On 24 March 2018, the Contractor commenced installation of chiller units and its panels, and thus critical path switched into MEP equipment installation and testing of those systems.

In the period from 24 March 2018 to 17 July 2018, actual critical path proceeded through the chillers' installation, testing and pre-commissioning works, external cladding and completion of finishes to receive permanent power. Thus, the actual critical path switched into obtaining permanent power and testing and commissioning with permanent power.

In the period from 17 July 2018 to 4 September 2018, the actual critical path proceeded through obtaining permanent power and testing and commissioning with permanent power.

In the last period from 4 September 2018 to 30 November 2018, when the substantial completion certificate issued, the actual critical path proceeded through testing and commissioning with permanent power and final closing up activities.

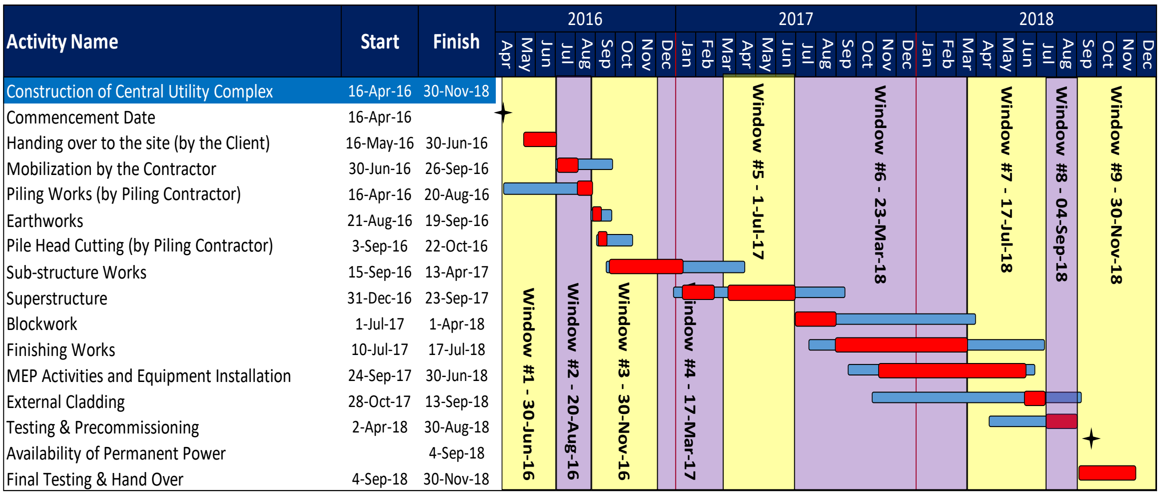


Figure 4.4 Actual critical path according to APABW.

Figure 4.4 depicts the critical activities resided along the actual critical path outlined above. Having set the contemporaneous critical path through the project, the next step is to determine the occurrence/period of influence, cause and extent of critical delay to that critical path by measuring the critical activities against the baseline programme, within each of the previously identified windows.

"Set-up Site Access & Temporary Roads" which is along the critical path during Window 2, selected to be compared against its baseline late dates to measure critical delay by 30 June 2016;

- At the beginning of this windows as at 16 April 2016, there were no delays;

- At the end of this windows as at 30-Jun-16, no critical delay incurred in the concerned mobilization activity; and
- Therefore, no critical delay incurred by end of the 1st Window.

“Completion of Piling works (by Others) and Access to Site” which is along the critical path during Window 2, selected to be compared against its baseline late dates to measure critical delay by 20 August 2016;

- At the beginning of this windows as at 30-Jun-16, there were no delays;
- At the end of this windows as at 20 August 2016, the pile hand over activity was delayed by 27 days; and
- Therefore, 27 days of additional critical delay incurred by end of the 2nd Window.

“Pile Head Treatment in Zone 1D” which is along the critical path during Window 3, selected to be compared against its baseline late dates to measure critical delay by 30 November 2016;

- At the beginning of this windows as at 20 August 2016, there were 27 days of critical delays;
- At the end of this windows as at 30 November 2016, the pile head treatment works in Zone 1D delayed by 60 days; and
- Therefore, 33 days of additional critical delay incurred in the 3rd Window.

“Construction of Verticals in Zone 2” which is along the critical path during Window 4, selected to be compared against its baseline late dates to measure critical delay by 17 March 2017;

- At the beginning of this windows as at 30 November 2016, there were 60 days of critical delays;
- At the end of this windows as at 17 March 2017, the commencement date of column and shear walls at ground floor in Zone 2 delayed by 53 days; and
- Therefore, 7 days critical delay mitigated in the 4th Window.

"Review and Approval of Architectural Layout/ Shop drawings for Level 0" which is along the critical path during Window 5, selected to be compared against its baseline late dates to measure critical delay by 1 July 2017;

- At the beginning of this windows as at 17 March 2017, there were 53 days of critical delays;
- At the end of this windows as at 1 July 2017, availability of shop drawings to commence blockwork at ground floor delayed by 72 days; and
- Therefore, 19 days of additional critical delay incurred in the 5th Window.

"Installation of Chiller Units 8 Nos" which is along the critical path during Window 6, selected to be compared against its baseline late dates to measure critical delay by 24 March 2018;

- At the beginning of this windows as at 1 July 2017, there were 72 days of critical delays;
- At the end of this windows as at 24 March 2018, commencement of installation of chiller units delayed by 90 days; and
- Therefore, 12 days of additional critical delay incurred in the 6th Window.

"Installation of Terracotta Cladding" which is along the critical path during Window 7, selected to be compared against its baseline late dates to measure critical delay by 17 July 2018;

- At the beginning of this windows as at 24 March 2018, there were 90 days of critical delays;
- At the end of this windows as at 17 July 2018, completion of envelope works delayed by 94 days; and
- Therefore, 4 days of additional critical delay incurred in the 7th Window.

"Testing, Energization and Power on" which is along the critical path during Window 8, selected to be compared against its baseline late dates to measure critical delay by 4 September 2018;

- At the beginning of this windows as at 17 July 2018, there were 94 days of critical delays;

- At the end of this windows as at 4 September 2018, receiving permanent power delayed by 113 days; and
- Therefore, 19 days of additional critical delay incurred in the 8th Window.

Table 4.4 Delay analysis summary for APAB window analysis.

Delay event	**Period of influence**	**Cause of critical delay**	**Extent of critical delay**	**Critical delay (cumulative)**
Window 1 - From 16 April 2016 to 30 June 2016				
1.1	16 April 2016 to 30 June 2016	27 days due to slower than planned progress of piling works.	27	27
Window 2 - From 30 June 2016 - 20 August 2016				
2.1	30 June 2016 to 20 August 2016	No delay was incurred in the period.	-	27
Window 3 - From 20 August 2016 to 30 November 2016				
3.1	20 August 2016 to 14 November 2016	14 days due to slower than planned progress of pile head treatment works.	17	44
3.2	14 November to 2016 22 November 2016	8 days due to Increment weather conditions	8	52
3.3	22 November 2016 to 30 November 2016	8 days due to slower than planned progress of pile head treatment works.	8	60
Window 4 - From 30 November 2016 to 17 March 2017				
4.1	30 November to 2016 5 March 2017	19 days of mitigation due to faster than planned progress in substructure works	-19	41
4.2	5 March to 2017 17 March 2017	12 day to day delay due to non-commencement of columns due to change in chiller design	12	53
Window 5 - From 17 March 2017 to 1 July 2017				
5.1	17 March 2017 to 23 May 2017	17 days due to slower than planned progress of superstructure works.	17	70
5.2	23 May 2017 to 20 June 2017	4 days due to revised water supply scheme by the engineer	4	74
5.3	20 June 2017 to 1 July 2017	-2 days due to faster than planned progress in approval process of shop drawings by engineer.	-2	72
Window 6 - From 1 July 2017 to 23 March 2018				
6.1	1 July 2017 to 23 March 2018	32 days due to confluence of the following; • slower than planned progress of area readiness for MEP services; and • slower than planned progress of HVAC piping.	32	104
Window 7 - From 23 March 2018 to 17 July 2018				
7.1	23 March 2018 30 June 2018	-27 days to faster than planned progress in equipment installation and pre-commissioning works	-27	77
7.2	30 June 2018 17 July 2018	17 days due to slower than planned progress in external cladding works	17	94
Window 8 - From 17 July 2018 to 4 September 2018				
8.1	17 July 2018 to 4 September 2018	19 days due to obtaining statutory body approval to receive permeant power from the external entities.	19	113
Window 9 - From 4 September 2018 to 30 November 2018				
9.1	4 September 2018 to 30 November 2018	-21 days due to faster than planned progress in testing and commissioning and issuance final closing up documentation.	-21	92

"Overall Completion of CUC" which is along the critical path during Window 9, selected to be compared against its baseline late dates to measure critical delay by 30 November 2018;

- At the beginning of this windows as at 4 September 2018, there were 113 days of critical delays;
- At the end of this windows as at 30 November 2018, obtaining certificate of substantial completion of works delayed by 92 days; and
- Therefore, 21 days of critical delay mitigated in the 9th Window.

Table 4.4 summarizes occurrence/period of influence, cause and extent of critical delay to that critical path by measuring the critical activities against the baseline programme, within each of the previously identified windows. 45 days of critical delay resulted from the employer's actions or inactions, 20 days of critical delay occurred due to external factors, and the contractor was responsible for 27 days of critical delay.

4.3. Schedule Delay Analysis with CAB

The collapsed as-built method models a what if scenario, as explained earlier. The analysis relies on a critical path which is based on as-built sequences of activities with actual durations, start and finish dates, therefore existence of a baseline programme is not essential to carry out this method. The method involves extraction of a particular delay event from the as-built programme to provide a model which answers the question of 'what the project completion date would be if the delay event did not occur?'.

The routine checks before performing the CAB method, following sources for the analysis need to be reviewed, validated and corrected if necessary;

- Availability of detailed as-built programme;
- Accuracy of actual start and finish dates of activities;
- Actual duration of activities; and
- If the actual logical relationships between activities reflect sequence at site.

The collapsed as-built method can be carried based on a single base as-built programme (entire project) or performed in windows which were collapsed using the final as-built programme.

In this study, the CAB analysis was performed in 10 main windows (including last as-built programme) by forming 30 base schedules for CAB models in order to provide more comprehensive and precise results regarding potential impact of all identified 20 risk events, even though not all risk events impacted the project completion date. Risk events were grouped according to their occurrence period. Then, windows were framed just before commencement of the impact of the dominant risk event in each window to determine the amount of delay caused by the risk event.

The retrospective creation of the underlying as-built logic is the single most subjective step in the process (Keane and Caletka, 2015). Process of creating each base schedule for CAB model, was done cautiously, in order to not to affect as-built logic. Following steps were repeated to generate base schedules appropriately;

- As-built start and finish dates belonged to the as-built programme used for collapsing were identically reflected on the CAB base schedule.
- The as-built schedule which is used to create the base schedule for collapsing was assigned as a baseline in the software to ease replication of as-built dates same as before resetting data date.
- Assigning new constraints with hard logic to the activities for freezing dates were avoided in order to provide appropriate programme calculation since the ‘as-built’ dates were actually calculated by the selected programme data date.
- The replicated start and finish dates of each activity had only relied on appropriate remaining duration and one of four types of logical relationships as FS, SS, FF and SF used in CPM networks.
- After all dates, durations and logic links were appropriately established, the data date was reset to generate the base schedule for CAB back in time to a point at the beginning of the time frame being studied. If there is a variance between two schedules, it was recorded.

- The logic relationships from the risk event to its successor activities were dissolved, then the programme was scheduled without the impact of the extracted risk event to show if the risk event actually cause a delay to the completion date of the project.

If the collapsed model has calculated an earlier completion date, the variance was recorded meaning that risk event was an actual cause to the critical delay to the project completion. In case of more than one risk event exist in the same window, they were extracted chronologically in reverse order and the process was repeated for the following risk event. If there was no movement in the project completion date after collapsing the next risk event in the same window, all operations were undone and repeated from the beginning for that risk event in order to identify if there was any pacing or concurrent delay occurred or not in the same window.

Firstly, the base schedule was generated from the as-built programme with data date of 30-Nov-18. Relationships and remaining durations were reorganized to replicate as-built dates, and thus the data date was reset to 20-Jun-18 in order to model the programme for the point in time just before incidence of XRE-02 had started. The new generated base schedule for CAB analysis projected a completion date of 10-Dec-18 meaning 10 days recovered between 20-Jun-18 till 30-Nov-18. This is not attributable to the employer since recovery did not happen due to a specific instruction of the employer, and it accumulated to the contractor because this was potentially resulting from resequencing. Then the first extraction was carried out by dissolving logic links from XRE-02 to its successors, and the programme was run one more time with data date of 20-Jun-18, and the variance in completion date become 27 days which was resulting impact of XRE-02.

The next delay studied was CRE-10 which began on January 25, 2018. The data date, progress and logic in the CAB were then reviewed and the data date and progress reset to 24-Jan-18 to identify impact of CRE-10 between 24 January 2018 and 20 June 2018. The base schedule for CAB did not move. After extraction of CRE-10, new calculated completion date become November 7, 2018 which indicates a loss of 6 days which was attributable to the contractor.

The process was repeated to form the base programme for Window #3 in order to analyse impacts of CRE-09 and CRE-08 between 6 August 2017 and 24 January 2018. Completion date of the new base programme was calculated as 9 November 2018 which indicates 2 days of loss which was accumulated to the contractor. After extraction of CRE-09, a loss of 8 days was found and attributable to the contractor. In the same window, CRE-08 was dissolved and programme was run again with the same data date but there was no movement in the completion date of the project.

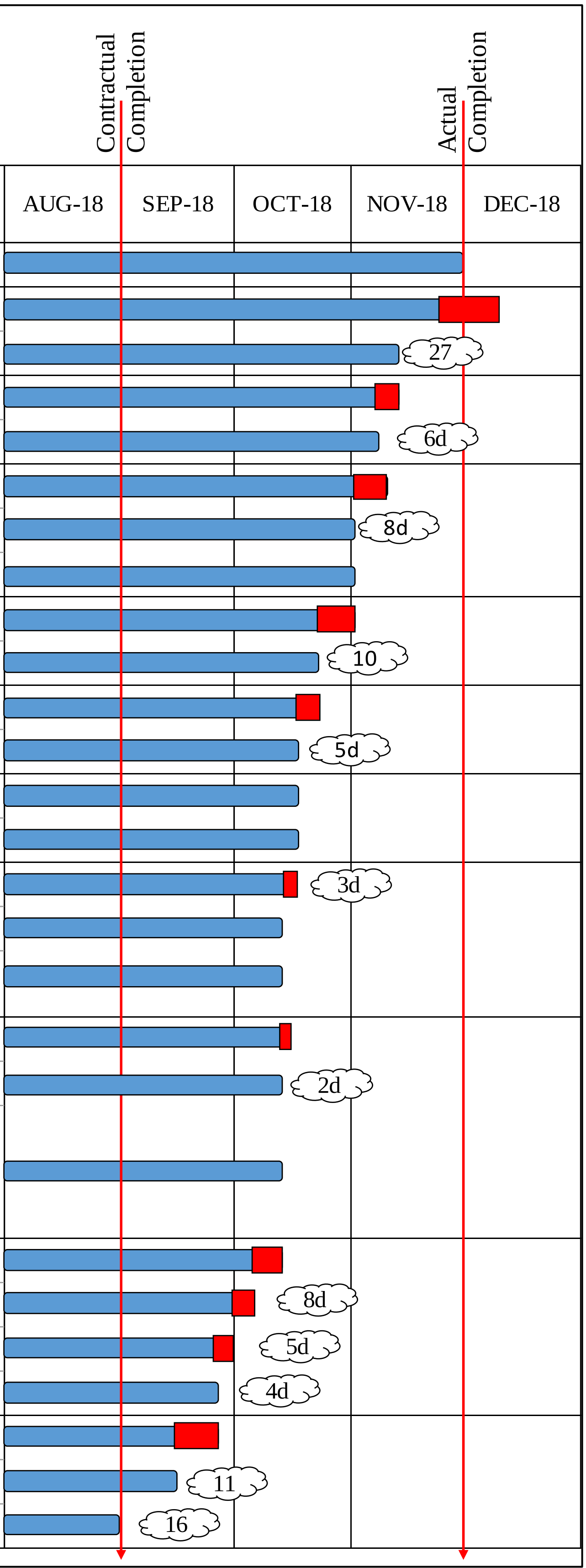
The same process was carried out for the following windows backwards until the very first risk event identified in the project was analysed. Thus, all critical delays were identified, and their liabilities were assigned to the responsible parties. Table 4.5 lists the liabilities of identified critical delays through the explained process above.

Table 4.5 Liabilities - collapsed as-built analysis

Window SN	Risk Event	Actual Start	Actual Finish	Event Duration	CAB Schedule Data Date	Projected Completion Date	Variance from baseline	Variance bwt schedules	ERE	XRE	CRE
					30-Nov-18	30-Nov-18	-92				
1					20-Jun-18	10-Dec-18	-102	-10			-10
2	XRE-02	21-Jun-18	1-Sep-18	72	20-Jun-18	13-Nov-18	-75	27		27	
3					24-Jan-18	13-Nov-18	-75	0			
4	CRE-10	25-Jan-18	31-May-18	126	24-Jan-18	7-Nov-18	-69	6			6
5					6-Aug-17	9-Nov-18	-71	-2			-2
6	CRE-09	7-Aug-17	31-Mar-18	236	6-Aug-17	1-Nov-18	-63	8			8
7	CRE-08	13-Aug-17	30-Sep-17	48	6-Aug-17	1-Nov-18	-63	0			
8					2-Jun-17	1-Nov-18	-63	0			
9	ERE-07	3-Jun-17	14-Jun-17	11	2-Jun-17	22-Oct-18	-53	10	10		
10					10-May-17	22-Oct-18	-53	0			
11	CRE-04	11-May-17	28-Jul-17	78	10-May-17	17-Oct-18	-48	5			5
12					7-Apr-17	17-Oct-18	-48	0			
13	ERE-08	8-Apr-17	31-Jul-17	114	7-Apr-17	17-Oct-18	-48	0			
14					3-Mar-17	17-Oct-18	-48	0			
15	CRE-03	11-Mar-17	13-Jun-17	94	3-Mar-17	14-Oct-18	-45	3			3
16	CRE-02	4-Mar-17	22-Apr-17	49	3-Mar-17	14-Oct-18	-45	0			
17	CRE-07	13-Mar-17	21-Mar-17	8	3-Mar-17	14-Oct-18	-45	0			
18					6-Dec-16	15-Oct-18	-46	-1			-1
19	CRE-06	9-Jan-17	5-Feb-17	27	6-Dec-16	13-Oct-18	-44	2			2
20	ERE-06	22-Feb-17	3-Jun-17	101	6-Dec-16	13-Oct-18	-44	0			
21	CRE-05	15-Feb-17	13-Mar-17	26	6-Dec-16	13-Oct-18	-44	0			
22	ERE-05	18-Dec-16	17-Apr-17	120	6-Dec-16	13-Oct-18	-44	0			
23	ERE-04	7-Dec-16	23-Mar-17	106	6-Dec-16	13-Oct-18	-44	0			
24					7-Oct-16	13-Oct-18	-44	0			
25	XRE-01	14-Nov-16	22-Nov-16	8	7-Oct-16	5-Oct-18	-36	8		8	
26	ERE-03	8-Oct-16	17-Mar-17	160	7-Oct-16	30-Sep-18	-31	5	5		
27	CRE-01	26-Oct-16	29-Nov-16	34	7-Oct-16	26-Sep-18	-27	4			4
28					15-May-16	26-Sep-18	-27	0			
29	ERE-02	16-Jun-16	20-Aug-16	65	15-May-16	15-Sep-18	-16	11	11		
30	ERE-01	16-May-16	30-Jun-16	45	15-May-16	30-Aug-18	0	16	16		
								Overall	**42**	**35**	**15**

The critical delay events to the completion were found according to collapsed as-built method are;

- XRE-02 Late Approval of Permanent Power Supply
- CRE-10 Lack of Manpower for Piping Works
- CRE-09 Area Readiness for 1st Fix MEP Works (Blockwork, Cutting & Chasing)
- ERE-07 Revised Water Supply Schematic Layout
- CRE-04 Slow Rate of Super-Structural Works
- CRE-03 Late Appointment of External Wall Cladding Subcontractor
- CRE-06 Late Material Submission of Bus Bars
- XRE-01 Inclement Weather Conditions
- ERE-03 Changes to Design of Chillers
- CRE-01 Slow Rate of Pile Head Treatment
- ERE-02 Completion of Piling Works (By Piling Contractor)
- ERE-01 Late Access (By the Employer)



Schedule SN	CAB Schedule Data Date	Schedule Collapsed for	Projected Completion Date
1	30-Nov-18		30-Nov-18
2	20-Jun-18		10-Dec-18
		XRE-02	13-Nov-18
3	24-Jan-18		13-Nov-18
		CRE-10	7-Nov-18
4	6-Aug-17		9-Nov-18
		CRE-09	1-Nov-18
		CRE-08	1-Nov-18
5	2-Jun-17		1-Nov-18
		ERE-07	22-Oct-18
6	10-May-17		22-Oct-18
		CRE-04	17-Oct-18
7	7-Apr-17		17-Oct-18
		ERE-08	17-Oct-18
8	3-Mar-17		17-Oct-18
		CRE-03	14-Oct-18
		CRE-02 CRE-07	14-Oct-18
9	6-Dec-16		15-Oct-18
		CRE-06	13-Oct-18
		ERE-06 CRE-05 ERE-05 ERE-04	13-Oct-18
9	7-Oct-16		13-Oct-18
		XRE-01	5-Oct-18
		ERE-01	30-Sep-18
		CRE-01	26-Sep-18
10	16-May-16		26-Sep-18
		ERE-02	15-Sep-18
		ERE-01	30-Aug-16

Figure 4.5 Summary of collapsed as-built schedules

Figure 4.5 comprises 10 base programmes with different data dates belonging each window which were used for collapsing to identify impact of each risk event. Time table shows a smaller portion of the project duration from August 2018 till December 2018 to scale only the delayed period. The figure shows the gross impact of each risk events in clouds. After recovered amount of delay was allocated as shown in Table 4.5, final results have been concluded as follow,

- 42 days were found to be excusable and compensable as being attributable to the employer;
- External factors (3rd parties) were found responsible for 35 days of critical delay which were excusable and non-compensable; and
- the contractor was liable for remaining 15 days of critical delay which were non excusable and non-compensable.

4.4. Schedule Delay Analysis with RLPA

The last retrospective delay analysis method to compare with TSAM was retrospective longest path analysis which adopts a static logic approach since it essentially is reliant on the single set of critical path. It is an observational technique whose fundamental objective is to compare the as-planned programme (baseline) to the as-built programme.

Baseline critical path (refer Appendix G) was examined in order to have a wider understanding about the initial programme. The original baseline critical path of the project run through mobilization activities, substructure works in Zone 1 & Zone 2, super structural works in Zone 2, readiness of transformer room, installation of transformers, statutory body approvals, final testing/commissioning and snagging.

The method primarily requires verification of the as-built programme which was already done during course of TSAM. Moreover, the as-built programme was traced backwards starting from the completion date to the commencement date of the project in order find out the longest chain of activities. Accordingly, the longest continuous chain of activities had been extracted to establish the retrospective critical path which is different from the contemporaneous critical path used in TSAM above. This step potentially is the most subjective part of the RLPA method if the sole reliable source for analysis was the as-built programme. However, monthly programme updates were already accessible and thus generated retrospective longest path was validated with those updates.

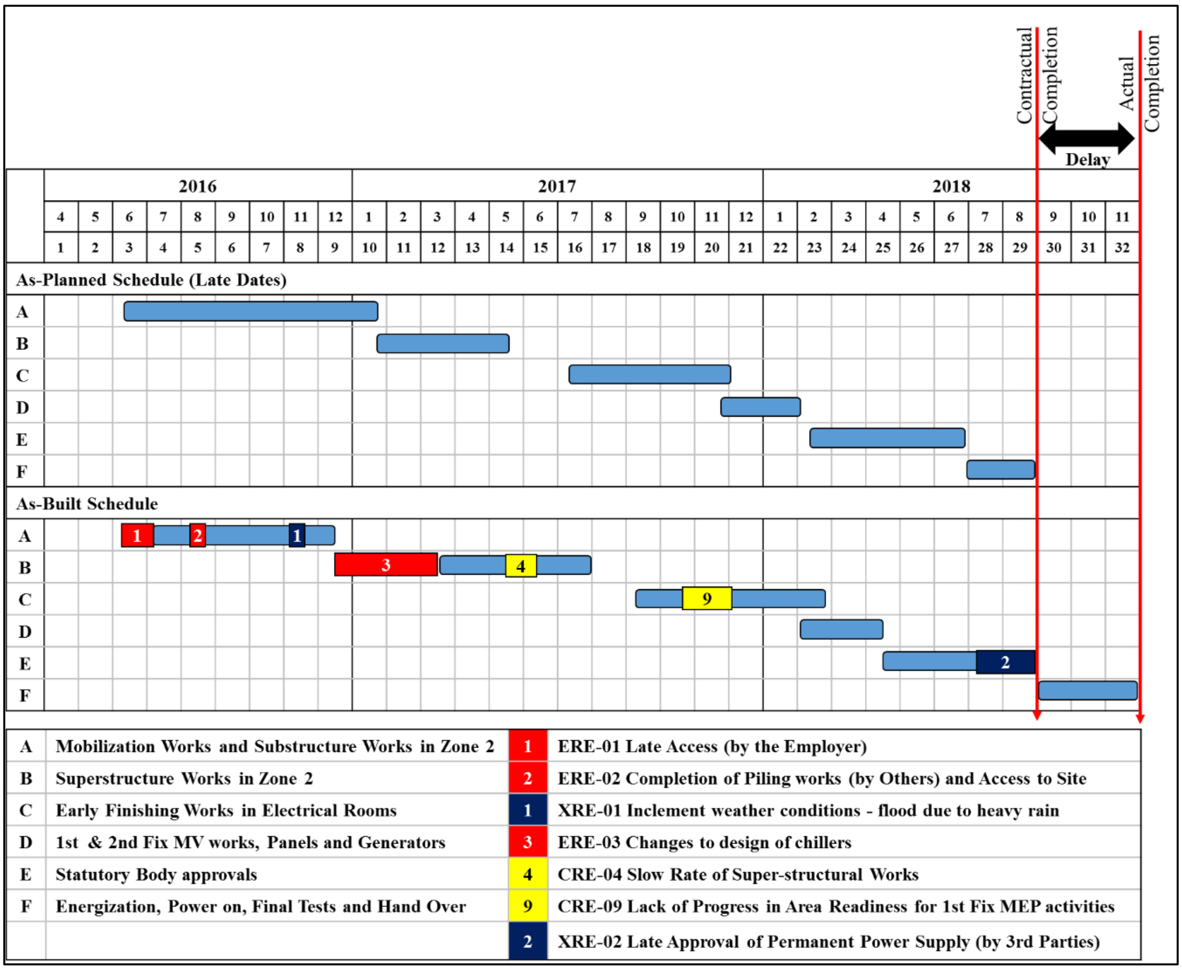


Figure 4.6 Summary as-built retrospective longest path

The delay in the project was analysed by reviewing the overall as-built critical path of the project (refer Appendix H) which had run through piling works and pile cutting/trimming works (by the Piling Contractor), sub structural works in Zone 2, super structural works in Zone 2, early finishing activities, 1st and 2nd fix activities for medium voltage, installation of generators and totalizing panels, statutory body approvals, final testing/commissioning and snagging. Figure 4.6 demonstrates the summary level comparison of baseline late dates versus actual dates of activities which are on the as-built retrospective critical path as shown in Appendix H. The evaluation mainly comprises the risk events triggered by the owner, external factors and the dominant contractor risk events. Remaining delays were though as attributable to the contractor.

Table 4.6 Liabilities – retrospective longest path analysis

Activity Name	Baseline Duration	Baseline Late Start	Baseline Late Finish	Actual Duration	Actual Start	Actual Finish	Δ Start Date	Δ Finish Date	Δ Activity Level		Δ ERE	Δ XRE	Δ CRE
Installation of Site Fencing/Hoarding	37	16-Jun-16	23-Jul-16	35	06-Jul-16	10-Aug-16	20	-2	18	ERE-01	18		
Excavation for Pile Caps & Foundations along Grid 1 7a7b/A S	13	24-Jul-16	06-Aug-16	12	20-Aug-16	01-Sep-16	9	-1	8	ERE-02	8		
Pile Cutting / Trimming along Grid 1 7a7b/A S (by Others)	22	07-Aug-16	29-Aug-16	25	03-Sep-16	28-Sep-16	1	3	4	ERE-02	4		
Pile Cutting / Trimming along Grid 8 2'/A S (by Others)	25	03-Sep-16	28-Sep-16	23	29-Sep-16	22-Oct-16	-4	-2	-6		-6		
Pile Head Treatment	15	08-Oct-16	23-Oct-16	14	22-Oct-16	05-Nov-16	-10	-1	-11		-11		
Blinding, Waterproofing, Block Works and Screed	13	24-Oct-16	06-Nov-16	15	08-Nov-16	23-Nov-16	2	2	4	XRE-01		4	
Pile Caps works and Tunnel works	14	22-Dec-16	05-Jan-17	11	31-Dec-16	11-Jan-17	-8	-3	-11		-11		
Backfilling works	14	26-Dec-16	09-Jan-17	13	02-Jan-17	15-Jan-17	1	-1	0				
Slab on Grade	13	10-Jan-17	23-Jan-17	13	16-Jan-17	29-Jan-17	0	0	0				
Construction of Verticals	15	24-Jan-17	08-Feb-17	10	18-Mar-17	28-Mar-17	47	-5	42	ERE-03	42		
Construction of Beams	16	09-Feb-17	25-Feb-17	15	01-Apr-17	16-Apr-17	3	-1	2				2
Construction of Slab @ Level 01	15	26-Feb-17	13-Mar-17	14	17-Apr-17	01-May-17	0	-1	-1				-1
Construction of Verticals	15	14-Mar-17	29-Mar-17	28	02-May-17	30-May-17	0	13	13	CRE-04			13
Construction of Beams	16	30-Mar-17	15-Apr-17	11	01-Jun-17	12-Jun-17	1	-5	-4				-4
Construction of Roof RCC slab and Hollow Core Slab	16	16-Apr-17	02-May-17	16	13-Jun-17	29-Jun-17	0	0	0				0
Construction of Verticals	16	30-Mar-17	15-Apr-17	18	18-Jun-17	06-Jul-17	22	2	24	CRE-04			24
Construction of Beams	16	16-Apr-17	02-May-17	12	06-Jul-17	18-Jul-17	-1	-4	-5				-5
Construction of Roof RCC slab and Hollow Core Slab	15	03-May-17	18-May-17	12	19-Jul-17	31-Jul-17	0	-3	-3				-3
Block Work	38	12-Sep-17	20-Oct-17	45	13-Nov-17	28-Dec-17	-12	7	-5				-5
Sub Frames Fixing	33	09-Oct-17	11-Nov-17	12	06-Jan-18	18-Jan-18	20	-21	-1				-1
Marking, Cutting & Chasing Walls for MEP Services	23	19-Oct-17	11-Nov-17	23	31-Dec-17	23-Jan-18	5	0	5	CRE-09			5
Floor Screed	6	07-Nov-17	13-Nov-17	10	20-Jan-18	30-Jan-18	1	4	5	CRE-09			5
Plastering Works	20	31-Oct-17	20-Nov-17	19	13-Jan-18	01-Feb-18	-4	-1	-5				-5
Wall Finishes	13	12-Nov-17	25-Nov-17	33	24-Jan-18	26-Feb-18	0	20	20	CRE-09			20
Ceiling Finishes	9	23-Nov-17	02-Dec-17	22	05-Feb-18	27-Feb-18	-19	13	-6				-6
1st Fix Electrical / ELV	13	23-Nov-17	06-Dec-17	13	05-Feb-18	18-Feb-18	-13	0	-13				-13
2nd Fix Electrical / ELV	38	07-Dec-17	14-Jan-18	34	19-Feb-18	25-Mar-18	0	-4	-4				-4
Installation of Totalizaing Panel A & B	23	13-Jan-18	05-Feb-18	24	24-Mar-18	17-Apr-18	0	1	1				1
Installation of Engine Generators and Daily Fuel Tank	23	13-Jan-18	05-Feb-18	29	20-Mar-18	18-Apr-18	-5	6	1				1
Statutory Body approvals	70	04-Mar-18	13-May-18	133	21-Apr-18	01-Sep-18	-24	63	39	XRE-02		39	
Testing, Energization and Power on	45	14-May-18	28-Jun-18	27	02-Sep-18	29-Sep-18	0	-18	-18				-18
Final Testing,Snagging and Desnagging works SCADA and BMS systems	61	30-Jun-18	30-Aug-18	59	02-Oct-18	30-Nov-18	1	-2	-1				-1
								Overall	92		44	43	5

Critical activities were extracted from the retrospective longest path in order to determine activity level variances which is tabulated Table 4.6. Activity level variance analysed differences which are all in calendar days were calculated by reference to start date variances plus finish date variances for the activities identified along the as-built critical path. Activity Level Variance Table includes following attributes of the as-built critical activities to show delay incurred and mitigation achieved in activity level;

- ID and Name;
- Baseline (as-planned);
- Actual (as-built);
- Variance in actual/baseline start dates (not additive to exclude amount of delay resulting from predecessor activities);
- Variance in actual/baseline finish dates; and
- Activity Level Variance indicates the delay (+ sign) or recovery (-sign) occurred at activity level and equals to the summation of variances in start date and those in finish date.

As a result of the investigation through retrospective longest path analysis, ERE-01, ERE-02, ERE-03, XRE-01, XRE-02, CRE-04 and CRE-09 were found to be causative events for critical delay to the completion.

Results obtained from the Table 4.6 as follow:

- ‘Installation of Site Fencing/Hoarding’ was delayed by 20 days in its start date and took 2 days less than its planned duration. The delay was resulted from XRE-01 ‘Late access (by the Employer)’.
- ‘Excavation for Pile Caps & Foundations along Grid 1 7a7b/A S’ started 9 days behind the intended date and total duration was 13 days to be completed which is 1 day less than its planned duration. But, delay in start date was resulted from incomplete access to the site whose causative event was ERE-02 ‘Completion of Piling Works (By the Employer)’, thus variance in start date was shifted to the ERE-02. Since the succeeding pile cutting activities were also under responsibility of the employer, consecutive loss of 4 days and gains of 6 and 11 days were allocated to the employer as well.
- The contractor could not progress with ‘Construction of Verticals’ at ground floor in Zone 2A due to the changes in structural design resulting from ERE-03 ‘Changes to

Design of Chillers', and thus 42 days in delay of this activity was allocated to the employer.

- All other losses and gains through the period between incidences of ERE-03 and XRE-02 were accrued to the contractor. Dominant causes of non-excusable & non-compensable delays were found as CRE-04 'Slow Rate of Super-structural Works' and CRE-09 'Lack of Progress in Area Readiness for 1st Fix MEP activities'.
- 'Statutory Body approvals' started 24 days ahead of its planned but lasted 133 days which was planned to take 70 days as a contractual provision, thus there was a loss of 63 days in finish date. Hence, 39 days of the activity level variance were allocated to the external factors (3rd parties) and the causative risk event was determined as XRE-02 'Late Approval of Permanent Power Supply'.

Results have been concluded as follow,

- 44 days were found to be excusable and compensable as being attributable to the employer;
- External factors (3rd parties) were found responsible for 43 days of critical delay which were excusable and non-compensable;
- the contractor was liable for remaining 5 days of critical delay which were non excusable and non-compensable and;

5. RESULTS AND DISCUSSION

In the literature, the main topics of the academic studies associated with delay in construction projects can be categorized into following groups; to recognise key reasons of construction delays; to classify problematic issues in delay analysis methodologies; to propose a new delay analysis technique or a new protocol to deal with shortcomings of existing methods; and to determine selection criteria of delay analysis methods.

A wide range of researches have been carried out to determine selection criteria of delay analysis methods to be used in disputes. Muhamad conducted a study based on a questionnaire survey in order to obtain opinions of contractors' and clients' consultants' organizations regarding commonly used methodologies for assessing time-based claims (Muhamad et al., 2016). Abdelhadi conducted interview with experts from five projects in UAE to understand how in practice decisions are made to select the most appropriate delay analysis method for a construction project (Abdelhadi et al., 2019). Another study analysed fifty-eight time-based claim cases to identify various factors on the selection of a delay analysis method (Arditi and Pattanakitchamroon, 2008). Some studies employed case study approaches to demonstrate outcomes of different delay analyses (Bubshait and Cunningham, 1998). Kao and Yang compared window based delay analysis models on simulated cases (Kao and Yang, 2009). Braimah performed five different delay analysis methods based on a simple logic linked scenario to evaluate main problems not addressed by the delay measurement methods (Braimah, 2013). Since most of the studies in the literature - so far as to compare delay analysis methods or how to select one of them or to present opinion regarding their features are concerned – have based on fictional scenarios rather than actual project records. Therefore, a case study approach based on a real project has been adopted to illustrate; to select the most appropriate delay analysis technique; to measure impact of delays; to perform the selected technique; to allocate liabilities to each responsible party; and to carry out alternative methods for comparison purpose.

In this chapter, the major findings of different retrospective delay analysis techniques carried out will be presented. Furthermore, results of applied techniques are compared and consistency of these findings with the prior literature are discussed and evaluated.

5.1. Availability of Project Records

Since the project data i.e. contemporaneous progress data, logic linked baseline and updated programmes was obtainable and found as reliable for the purpose of delay analysis in the case study, the availability of project records was not a limitation to select a DAM. However, performing different delay analysis techniques has shown that, TSAM requires comprehensive as-built data to validate actual/ finish dates and activity status between each time slice and to provide accurate as-built sequencing and logic as Barry stated (Barry, 2009). In case of nonexistence of required project records, results of TSAM might become very doubtful which states as a major drawback of this method. CAB method requires as-built programme and contemporaneous records to validate as-built dates and activities status. Moreover, since the CAB method was performed in windows to allocate liabilities to particular activities, updated programmes were also utilized. To perform retrospective longest path analysis, the as-built programme and as-planned programmes were used.

5.2. Critical Path Analysis

Understanding dynamic nature of the project by examining critical path through life cycle of the project is very important to identify concurrency, pacing, resequencing and deduce what might have caused critical delay to the completion.

Collapsed as-built method required to intervene the programme by extracting risk events to remodel a what if scenario whereas other retrospective techniques were observational methods. Even though, the CAB produced parallel results with TSAM in the case study, the resulting as-built critical path from the CAB might not be consistent with common sense. Thus, reconstructed logic included too many assumptions in terms of logic link changes for instance;

- the programme would have been progressed in precisely the same way even without the causative event;
- the logic between all activities can be assigned accurately from the project records or actual dates from programme updates.

Hence, the critical path was generated through manipulation rather than through calculation (Zack, 2001). Therefore, CAB method has found to be only useful for linear projects which do not include excessive number of activities with complicated relationships in the programme.

As a result of retrospective longest path analysis, a retrospective as-built critical path were produced to compare as-built dates to as-planned dates. However, as being the biggest weakness of this method, it not likely to trace switches and changes in activities on the critical path through the project by examining the retrospective as-built critical path.

As being different from other two methods, TSAM and APABW method examine critical path contemporaneously. Moreover, as illustrated in the case study, TSAM and APABW are more improved techniques in terms of calculation of the critical path rather than deduction by the analysis. Besides, selecting appropriate time frames for APABW is an essential step to understand changing critical path of the project. As results of TSAM and APABW, contemporaneous critical paths which allow analyst to comprehend changes in the critical path through windows and picture the state of the project back in time when the programme was analysed were generated. The study shows that TSAM and APABW analyses are able produce the same results only if;

- the same contemporaneous critical path is set for both analyses which heavily rely on the availability of reliable project records for APABW technique, and
- the same critical activities to be selected of the to measure delay for a point in time.

5.3. Identification of Causative Events

As it can be seen in Figure 5.1, contractor related risk factors constitutes the half of the identified risk events. Regarding contractor related risk events, poor site management and problems with subcontractors are the most encountered causes of risk events in this project. Design changes and delay in site delivery are found to be main reasons behind risk events associated with the employer and consultants. However, all listed 20 risk factors had not affected the completion date, moreover their impact and criticality were not same. Such features of the identified risks events such as extent, incidence and criticality were studied for each time slice separately and their liability were allocated or proportioned accordingly.

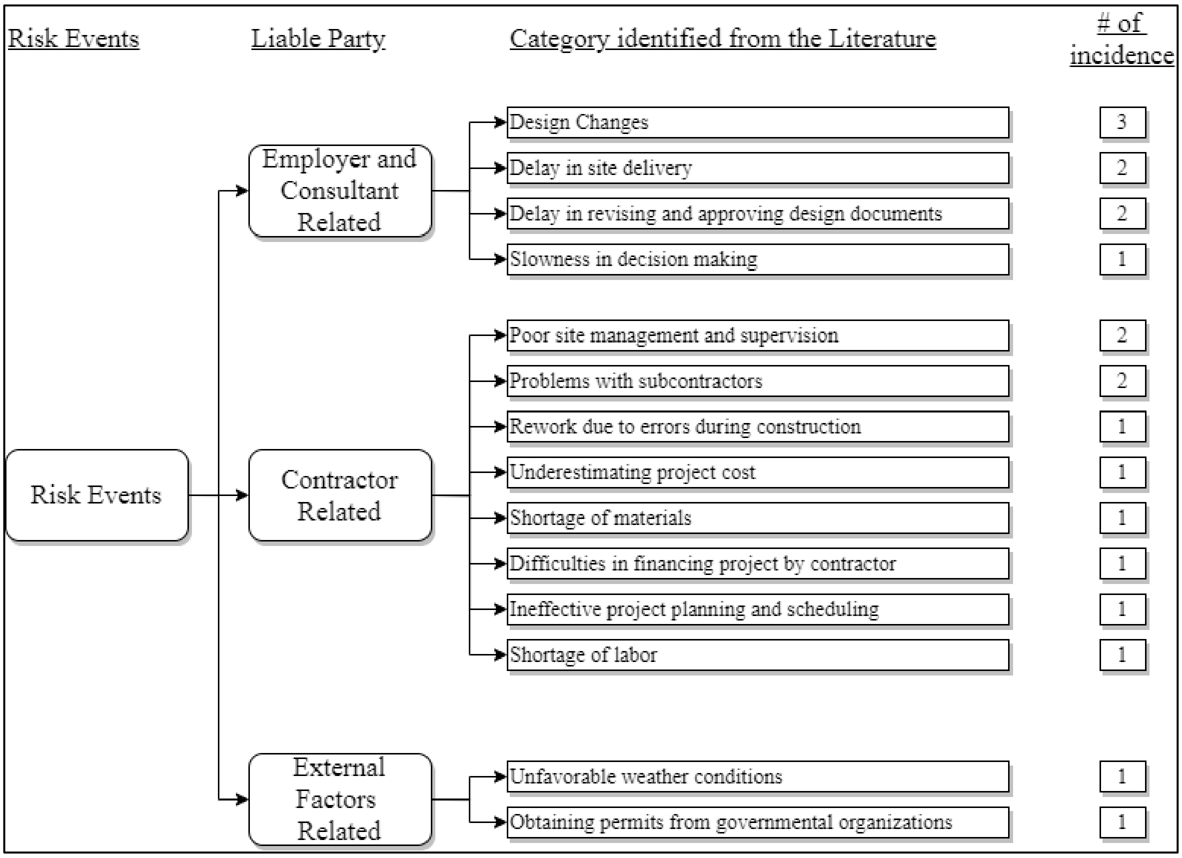


Figure 5.1 Categorization of risk events.

Table 5.1 demonstrates the critical causative events, which were identified through performing each delay analysis technique, among initially identified all risk events. Performing TSAM and APABW analysis lead to the identification of the same causative events since the application process shares the same fundamentals i.e. determining the occurrence/period of influence, cause and extent of critical delay by measuring contemporaneous critical activities against the baseline programme.

Table 5.1 Risk events causing critical delay.

Risk Event ID	Risk Event Name	Time Slice Analysis Method (TSAM)	As-Planned vs. As-Built (APAB) Windows	Collapsed As-Built (CAB) Analysis	Retrospective Longest Path (RLPA)
ERE-01	Access to Site (by Employer)			+	+
ERE-02	Completion of Piling works (by Others) and Access to Site	+	+	+	+
ERE-03	Changes to design of chillers	+	+	+	+
ERE-04	Changes in Ring Main Unit Specs				
ERE-05	Changing Motor of Hydronic Pumps				
ERE-06	Material Approval of MV Circuit Breaker Switchgears				
ERE-07	Revised Water Supply Schematic Layout	+	+	+	
ERE-08	Change in Louver Size and Connections				
CRE-01	Slow rate of pile head treatment	+	+	+	
CRE-02	Formwork failure of water tank wall, demolition and clearing debris				
CRE-03	Late Appoinment of External Wall Cladding Subcontractor	+	+	+	
CRE-04	Slow Rate of Super-structural Works	+	+	+	+
CRE-05	Late Material Submission of VAVs				
CRE-06	Late Material Submission of Bus Bars	+	+	+	
CRE-07	Late Material Submission of Cooling Towers				
CRE-08	Late Technical Submission of Floor Tiles				
CRE-09	Lack of Progress in Area Readiness for 1st Fix MEP activities	+	+	+	+
CRE-10	Lack of Manpower for Piping Works	+	+	+	
XRE-01	Inclement weather conditions - flood due to heavy rain	+	+	+	+
XRE-02	Late Approval of Permanent Power Supply (by 3rd Parties)	+	+	+	+

Capability of delay analysis techniques associated with identification of causative events may differ. Late mobilization resulting from ERE-01 Access to Site (by Employer) was along the critical path according to TSAM and APAB, however, in fact, it didn’t cause a critical delay as a cause of critical delay in RLPA and CAB. The collapsed as-built method differs from other retrospective methods as being cause & effect type rather than being effect & cause. Therefore, each risk event was extracted from the base programme in reverse chronological order in order to test if particular risk event has caused a delay to the completion. Moreover, the analysis was carried out in windows to increase accuracy and precision of the results. Thus, it can be concluded that the collapsed as-built analysis have capacity to identify all causative events to the critical delay to the completion when it's performed in windows. However, it should be noted that the collapsed as-built method would have identified different causative events, if the analysis was carried out in a single schedule rather than performing in windows.

Since the retrospective longest path only compares the actual dates to the planned dates of the critical activities, the method is not capable to identify all causative event. It only identified six out of twelve causative events. This stands as a major drawback for retrospective longest path analysis method.

5.4. Liability Allocation

Table 5.2 shows the summary of liabilities allocated to each party based on each retrospective delay analysis method. They may produce similar results when the overall figures are evaluated. But when the changes and the switches in the critical path were taken into account, the net changes can be easily noticed under '∆ Impact'.

Table 5.2 Summary of liabilities

Method	∆ Impact				∑ Impact		
	Loss			Gain	Loss		
	EC	EN	NN		EC	EN	NN
TSAM	45	27	120	-100	45	20	27
APABW	43	27	91	-69	41	24	27
CAB	42	35	28	-13	42	35	15
RLPA	72	43	71	-94	44	43	5

TSAM allowed to determine the extent of actual critical delay occurred during each time slice. After concluding the critical delay to the completion within each window, the attributable causative events were identified by reviewing project records. As shown in Table 4.3, TSAM allowed to attribute monthly changes in completion date of the project to the particular causative events. Moreover, this method is capable to allocate recoveries/mitigations accomplished within each time slice. According to the analysis, 192 days of critical delay incurred, during the project lifecycle, among which 100 days were recovered.

As-planned vs. as-built window analysis has a closer capacity to TSAM, if the contemporaneous critical path is determined accurately and window periods are selected appropriately i.e. number of windows are increased or time periods are shortened. According to results of APABW analysis, the project suffered 161 days of delay in total among which 69 days were recovered. Such difference obviously results from the fact that TSAM carried out in 30 windows whilst APABW performed in 9 windows. However, the difference in overall liability allocation resulted from 4 days of additional critical delay incurred (due to slower than planned progress in pile cutting works ERE-02) were not identified due to a different delay measurement activity in Window #3. TSAM identified 120 days of mitigation but APABW detected 69 days of mitigation. Most of unidentified mitigation happened in the Window #6 in the period from 1 July 2017 to 23 March 2018. The window was not slipped into shorter frames since all risk events were related to Contractor during this window. Therefore, it can be concluded that the method may not be able to identify mitigations if the periods are too long, also it may produce different analysis outcome due to the different analysis time frames employed.

The collapsed as-built method produced relatively close results with time slice analysis method. Moreover, the method is capable of assigning delays to specific risk events due to extraction was done one by one in windows. But this method is not the most appropriate technique to measure mitigations, because the method begins with the as-built programme which already includes all mitigation measures to the degree that they were actually implemented. Thus, CAB method quantifies only incremental delay to the critical path. Therefore, it can be concluded that the method ignores re-sequencing and mitigation because. It should be noted that the performance of the CAB heavily relies on the detailed as-built schedule depends on detailed and comprehensive as-built records and expertise of the analyst to remodel to logic links.

The retrospective longest path analysis produced the most divergent results in liability allocation. It is not likely to precisely allocate amount of delay to particular activities with RLPA. This method does not take incremental effect of delays into consideration. Moreover, this method ignores re-sequencing and mitigations. Consequently, the method may produce theoretical results compared to outcome of other methods, when applied for complicated projects as done in this case.

5.5. Identification of Concurrent Delays

Thus, true concurrent delay is a rare occurrence (SCL, 2017). In analyses of delay TSAM and APABW, Critical and near critical paths were reviewed in order to identify if a concurrency was the dominant cause of the delay in the concerned period. But there were not concurrent delays. Collapsed as-built model by nature comprises all delays which happened on the modelled paths. After a particular delay was extracted from the base programme, the new programme still has included the impact of those delay events which left in the new model. Thus, ability of collapsed as-built method to identify concurrent impact of stands as one of the major advantages of this method. Retrospective longest path is not able to address concurrency issue regarding identifying concurrent delay and dealing with concurrency issue since the sole focus of the method is to identify the longest continuous path and trace it backwards in order to determine the critical delay causes.

5.6. Pacing Delays

In the case project, the contractor slowed down structural works in Zone 2B due to lack information in structural drawings due to mechanical changes (ERE-03) to progress further. The contractor also noticed the employer regarding pacing down related works, thus number of workers allocated for this area was decreased. From early February 2017 till late April 2017, the risk event was treated as a pacing delay but eventually it had become a causative event (CRE-04) to the critical delay to the completion. TSAM and APABW have found to be the only methods which are capable to identify and trace pacing delays. Because, this method not only concentrate on the longest path but also near critical paths. The other techniques fail to address pacing issue.

Table 5.3 Capabilities of applied delay analysis methods

	Time Slice Analysis Method (TSAM)	As-Planned vs. As-Built (APAB) Windows	Collapsed As-Built (CAB) Analysis	Retrospective Longest Path (RLPA)
Identify all causative events	✓	✓	✓	✗
Identify concurrent delays	✓	✓	✓	✗
Identify mitigation/ recovery	✓	✓	✗	✗
Real time critical path analysis	✓	✓	✗	✗
Tend to produce fact results rather than theoretical results	✓	✓	✗	✗
Identify pacing delays	✓	✓	✗	✗

Table 5.3 summarizes capabilities of retrospective delay analysis methods obtained through application of those methods for the case project.

Time slice analysis method stands as the most capable technique among other retrospective techniques, especially it addresses concurrency issue, mitigation /recovery and pacing delay through real time critical path analysis.

Both TSAM and APABW methods determine and evaluate the critical path contemporaneously, and thus they are accountable for real time critical path analysis. Both methods tend to produce fact-based outcome when results are supported by robust analysis and detailed contemporaneous project records.

CAB is accountable for identification of all causative events and concurrency issues, but it has limited capacity when mitigation/recovery and pacing delays are the main issues in the project.

Retrospective longest path analysis has been found to be the least effective method associated with the examined capabilities of retrospective methods, therefore RLPA is assumed to be suitable for the simple/linear projects which does not comprise such problematic issues.

5.7. Requirements in Applications

As explained earlier, time slice analysis method utilized contemporaneous updated programmes. Existence of properly developed detailed updated programmes can be adequate for the analyst to understand project sufficiently. But the projects which last over couple of years will require establishing too many windows to perform TSAM in order to comprehend critical path and near critical paths throughout project life cycle. That’s why TSAM tends to take longer time and be highly software reliant. The method adopts an observational approach hence it may not require complicated software operations. Therefore, accuracy of the updated programmes particularly the critical path in each period plays a crucial role to obtain satisfactory results. Since the project was evaluated in monthly intervals, comprehension of the changes between time periods is easier than APABW analysis, thus expertise in construction may play relatively less important role for performing this method.

Table 5.4 demonstrates requirements in application of each retrospective delay analysis method rather than documentary requirements. The main requirements which play important role in performing each technique appropriately based on the analyses carried out for the case project in this study are;

- Required time for analysis;
- Project knowledge requirement;
- Expertise requirement in construction & planning;
- Dependency on software; and
- Complexity of software operations.

Table 5.4 Application requirements of delay analysis methods

	Time Slice Analysis Method (TSAM)	As-Planned vs. As-Built (APAB) Windows	Collapsed As-Built (CAB) Analysis	Retrospective Longest Path (RLPA)
Required time for analysis	High	High	High	Low
Project knowledge requirement	Medium	High	Low	Low
Expertise requirement in construction & planning	Medium	High	Low	Low
Dependency on software	High	Medium	High	Low
Complexity of software operations	Medium	Medium	High	Low

APABW requires investigation of the project records (the schedule, construction methodology, actual data and contemporaneous records including photographs, correspondence, reports, minutes) which may be very time consuming in order for the analyst to obtain sufficient knowledge about the project. Because the analyst needs to develop the time frames appropriately in order not to miss any essential information which may play a crucial role in analysis. The method is less software reliant, since fundamental principle behind the method is to observe changes between each time period. Thus, it does not require complicated operations in the software. But, the analyst needs to be highly educated/ experienced in construction and planning to set the contemporaneous critical path accurately, only then comprehend the changes between each time period and the facts behind the critical delay.

CAB requires inserting delays into a base programme and introducing individual logic to found as-built logic in order to regenerate a base programme for extracting delay events and leading logic to measure delay of the particular delay event. Moreover, it also requires additional changes and alterations in the network as explained in Chapter 4.4. Therefore, CAB analysis has found to be the most software reliant method among other techniques which were carried out in this study. Thus, the analysis process may take too long comparatively. Additionally, CAB method requires high level of proficiency in software operations rather than project knowledge and expertise of construction.

To perform retrospective longest path analysis, the process firstly requires a general construction knowledge to determine the retrospective critical path. And secondly, overall knowledge about the project is essential to identify causes to the critical dely. When application requirements are taken into consideration, retrospective longest path analysis has found to be the simplest form among the retrospective methods which are recommended by Society of Construction Law (SCL, 2017).

6. CONCLUSION

Construction projects commonly suffer from schedule delays due to varying reasons, which may cause unresolved debates till end of the project and even costly disputes between different stakeholders of the project. Thus, delay analysis becomes very essential to address problems resulting from delays in construction project.

In the literature, the main topics of the academic studies associated with delay in construction projects can be categorized into following groups; to recognize and rank main reasons of construction delays; to classify problematic issues in delay analysis methodologies; to recommend a new delay analysis method or a new protocol to deal with shortcomings of existing methods; and to determine selection criteria of delay analysis methods to be used in disputes.

Most of the studies in the literature - so far as to compare delay analysis methods or how to select one of them or to present opinion regarding their features are concerned – have based on fictional scenarios rather than actual project records. Therefore, a case study approach based on a real project has been adopted to exemplify; to identify risk events in a real project; to select the most appropriate delay analysis technique; to measure impact of delays; to perform the selected technique; to allocate liabilities to each responsible party; and to carry out alternative methods for comparison purpose.

The most appropriate delay analysis method has been attempted to be selected in light of available records of the case project and selection criteria of delay analysis methods. Since the project was over and analysis to be performed distant from delay effect, one of the retrospective delay analysis methods were to be selected (SCL, 2017). Most of the as-built project records were obtainable, and thus availability of project records was not a constraint to select any of the retrospective methods. Moreover, time slice analysis method as being one of the retrospective methods introduced by Society of Construction Law in 2017, has not been discussed in detail and applications of this method on a real case scenario in previous studies were not encountered through the literature survey. Therefore, time slice analysis method (TSAM) has been chosen to be conducted on a real project to provide a better understanding for delay analysis issues. Moreover, other retrospective delay analysis methods recommended by SCL were carried out in order to demonstrate differences regarding their procedures, requirements and performances.

In the case project examined in this study, the 20 risk events were identified initially. They were categorized based literature survey. Through TSAM analysis, 11 risk events were determined as causes of critical delay to the completion date of the project. Therefore, recommendations for avoidance or at least minimizing delays in construction projects associated with the delay causes identified in the case project are listed below;

- The employer and his representatives should be very careful and act proactively when dealing with several contractors at the same time and put great emphasis on managing their interfaces in order not to interrupt different parties works.
- All design details of the project should be completed before tender stage in order to avoid bombshell changes during course of the project.
- The contractor should provide a list of potential subcontractors to the employer and get approval during tender stage in order to shorten the procurement process of particular work item during course of the project.
- The contractor should understand requirements of contract clauses and specifications in order not to underestimate project cost during tender stage and plan his strategies accordingly.
- Site management personnel of the contractor should work very closely with the project management team in order to allocate resources appropriately to progress on the critical activities rather than working for non-critical activities.
- The employer and the contractor should communicate in a transparent way especially during involvement of 3rd parties.

Liabilities of each party were allocated during course of time slice analysis method. Furthermore, the other retrospective delay analysis methods recommended by SCL i.e. APABW, CAB and RLPA were carried out to demonstrate differences of techniques associated with their procedures, requirements and performances. The analyses indicated the following findings;

- TSAM method is capable of identification all causative events, concurrent delays, mitigation and pacing delays through real time critical path analysis. But it is highly software reliant and it requires a long period to be performed. Moreover, performance of the method is directly correlated with existence and accuracy of the contemporaneously updated programmes. Furthermore, credibility of the analysis is heavily depending on the critical activities which were used to measure delay, therefore reasons of why such activities selected should be convincing.
- APAB windows analysis tends to produce parallel results to TSAM only if;
    - the same contemporaneous critical path is set for both analyses which heavily rely on the availability of reliable project records for APABW technique;
    - windows are selected appropriately; and
    - the same critical activities to be selected of the to measure delay for a point in time.

  Furthermore, the method has shown similar capabilities. The method tends to take long time as well. Moreover, the method requires dependable project records to rely on to understand the chronology of the project and create the as-built critical path accurately in absence of reliable updated programmes. Furthermore, the analyst to have expertise in construction and great knowledge about the project in order to produce satisfactory results.
- CAB analysis is accountable for identification of all causative events and concurrency issues, but it has limited capacity when dealing with mitigation/recovery and pacing delays. The method has found to be the most software reliant one among other retrospective techniques, and thus the analysis process may take too long comparatively. Additionally, the method requires high level of proficiency in software to be able to deal complicated operations rather than project knowledge and expertise of construction.
- RLPA has been found to be the least capable method when dealing with problematic issues in delay analysis matters. The method tends to produce theoretical results and it is assumed to be suitable for the simple/linear projects which does not comprise such problematic issues.

Based on this study, recommendations regarding delay analysis issues in construction project associated with the different methods applied in the case project are presented below;

- Contractor to have an officially approved as-planned (baseline) programme in the beginning of the project and to produce and submit regularly updated programmes.
- Contract should include explicit provisions about which delay analysis method to be employed in case of a claim/dispute. In case of absence of contract language for selecting a delay analysis technique, the steps taken in this study can be followed.
- Contract should have clear guidelines how to allocate the liability for concurrent delays.
- Project records should be kept systematically and officially. Because they become utmost important to identify potential causes of the delay and to validate as-built data/programmes which constitute the basis for delay analysis, further they play a crucial role in establishing the as-built critical path in absence of reliable updated programmes.
- In case of performing as-planned vs. as-built windows analysis; windows should be selected very carefully in order not to miss any essential information which may play a crucial role in analysis; windows to be used should be mutually agreed between both parties before carrying out the analysis; and time periods should not be very long.

This study has some limitations as well. Within the context of this research, it is limited to timing aspect of delay analysis, it does not aim to present an opinion regarding cost perspective of delays, cost-based methods and loss of productivity. Another limitation is that most of the procedural requirements for delay analysis methods are adopted from SCL Delay and Disruption Protocol, since this protocol is one of the most globally accepted guidance and there is lack of guidance in Turkish construction industry. This research targets to be an example for practitioners and academics regarding applications of retrospective delay analysis methods on a real project. In the future studies, projects with variant dynamics i.e. subject to particular problematic issues, different level of complexity of the project and programme, availability of project records etc. can be selected to validate findings of this research. Moreover, not only timing aspect of different delay analyses but also their cost perspective and cost-based methods can be investigated on a real project through in further studies.

REFERENCES

AACEI, 2011, *Forensic Schedule Analysis Recommended Practices No. 29R-03*, AACE International, Morgantown.

Abdelhadi, Y., M. F. Dulaimi and A. Bajracharya, 2019, "Factors influencing the selection of delay analysis methods in construction projects in UAE", *International Journal of Construction Management*, Vol. 19, No. 4, pp.329–340, February.

Agyekum-Mensah, G. and A. D. Knight, 2017, "The professionals perspective on the causes of project delay in the construction industry", *Engineering, Construction and Architectural Management*, Vol. 24, No. 5, pp.828–841, August.

Al-Gahtani, K. S., 2009, "Float allocation using the total risk approach", *Journal of Construction Engineering and Management*, Vol. 135, No. 2, pp.88–95, February.

Al-Gahtani, K. S., I. A. Al-Sulaihi and A. Iqupal, 2016, "Total float management: Computerized technique for construction delay analysis", *Canadian Journal of Civil Engineering*, Vol. 43, No. 5, pp.391–401, March.

Al-Gahtani, K. S. and S. B. Mohan, 2007, "Total float management for delay analysis", *Cost Engineering (Morgantown, West Virginia)*, Vol. 49, No. 2, pp.32–37, February.

Al-Kharashi, A. and M. Skitmore, 2009, "Causes of delays in Saudi Arabian public sector construction projects", *Construction Management and Economics*, Vol. 27, No. 1, pp.3–23, February.

Alkass, S., M. Mazerolle and F. Harris, 1996, "Construction Delay Analysis Techniques", *Construction Management and Economics*, Vol. 14, No. 5, pp.375–394.

Alnaas, K. A. A., A. H. H. Khalil and G. E. Nassar, 2014, "Guideline for preparing comprehensive extension of time (EoT) claim", *HBRC Journal*, Vol. 10, No. 3, pp.308–316, December.

Alshammari, S. *et al.*, 2017, "A systematic method to analyze force majeure in construction claims", *Buildings*, Vol. 7, No. 4, pp.1–22, December.

Arditi, D., S. Nayak and A. Damci, 2017, "Effect of organizational culture on delay in construction", *International Journal of Project Management*, Vol. 35, No. 2, pp.136–147, February.

Arditi, D. and T. Pattanakitchamroon, 2006, "Selecting a delay analysis method in resolving construction claims", Vol. 24, No. 2, pp.145–155, February.

Arditi, D. and T. Pattanakitchamroon, 2008, "Analysis Methods in Time-Based Claims", *J. Constr. Eng. Manage*, Vol. 134, No. 4, pp.242–252, April.

Arif, F. and A. A. Morad, 2014, "Concurrent Delays in Construction: International Legal Perspective", *Journal of Legal Affairs and Dispute Resolution in Engineering and Construction*, Vol. 6, No. 1, pp.1-8, February.

Aziz, R. F., 2013, "Ranking of delay factors in construction projects after Egyptian revolution", *Alexandria Engineering Journal*, Vol. 52, No. 3, pp.387–406, September.

Bailey, J., 2014, "A retrospective analysis", *Proceedings of SCL International Conference on 20th September 2014*, Kuala Lumpur, Malaysia, November 2014, Society of Construction Law, London.

Baldwin, A. and D. Bordoli, 2014, *Handbook for Construction Planning and Scheduling*, Wiley-Blackwell, Oxford.

Baram, G. E., 1994, "Delay analysis - Issues not for granted", *Transactions of AACE International*, pp.DCL5.1–9.

Barry, D., 2009, "Beware the Dark Arts ! Delay Analysis and the Problems With Reliance on Technology", *Proceedings of Society of Construction Law International Conference*, London, 6-7 October 2008, Society of Construction Law, London.

Besoglu, E., 2006, *Reasons of Delays in Steel Construction Projects: An Application of a Delay Analysis*, M.S. Thesis, Middle East Technical University.

Birgonul, M. T., I. Dikmen and S. Bektas, 2015, "Integrated approach to overcome shortcomings in current delay analysis practices", *Journal of Construction Engineering and Management*, Vol. 141, No. 4, pp.1–11, April.

Braimah, N., 2008, *an Investigation Into the Use of Construction Delay and*, PhD Thesis, University of Wolverhampton.

Braimah, N., 2013, "Construction delay analysis techniques-a review of application issues and improvement needs", *Buildings*, Vol. 3, No. 3, pp.506–531, September.

Braimah, N. and I. Ndekugri, 2008, "Factors influencing the selection of delay analysis methodologies", *International Journal of Project Management*, Vol. 26, No. 8, pp.789–799, November.

Braimah, N. and I. Ndekugri, 2009, "Consultants' perceptions on construction delay analysis methodologies", *Journal of Construction Engineering and Management*, Vol. 135, No. 12, pp.1279–1288, December.

Bubshait, B. A. A. and M. J. Cunningham, 1998, "Comparison of Delay Analysis Methodologies", *Journal of Construction Engineering and Management*, Vol. 124, No. 4, pp.315–322, July.

Burr, A., 2016, *Delay and Disruption in Construction Contracts*, 5th Edn, Informa Law from Routledge, New York.

Chappell, D., 2014, *The JCT standard building contract 2011 : An explanation and guide for busy practitioners and students*, Wiley-Blackwell, Chichester, West Sussex.

Chappell, D., 2017, *Understanding JCT Standard Building Contracts*, Tenth Edn, Routledge, London & New York.

The Chartered Institute of Building, 2011, *Guide to Good Practice in the Management of Time in Complex Projects*, John Wiley & Sons, Oxford, UK.

Din, Z. U., A. Raza and M. B. Khan, 2020, "Comparative Analysis of Factors Causing Delay in Residential Construction Projects in Pakistan", *Proceedings of Construction Research Congress 2020*, Tempe, 8-10 March 2020, No. 2006, pp.640–648, ASCE.

Doloi, H. *et al.*, 2012, "Analysing factors affecting delays in Indian construction projects", *International Journal of Project Management*, Vol. 30, No. 4, pp.479–489, May.

Durdyev, S., M. Omarov and S. Ismail, 2017, "Causes of delay in residential construction projects in Cambodia", *Cogent Engineering*, Vol. 134, pp.1–12, February.

Eggleston, B., 2019, *The NEC4 Engineering and Construction Contract A Commentary*, 3rd Edition, Wiley-Blackwell, Chichester.

Fallahnejad, M. H., 2013, "Delay causes in Iran gas pipeline projects", *International Journal of Project Management*, Vol. 31, No. 1, pp.136–146, January.

Faridi, A. S., S. Monir and E. Sayegh, 2006, "Significant factors causing delay in the UAE construction industry Significant factors causing delay in the UAE construction industry", *Construction Management and Economics*, Vol. 24, pp.1167–1176, May.

Farrow, T., 2001, "Delay Analysis – Methodology and Mythology", *Proceedings of Society of Manchester on 6th November 2001*, Manchester, 6 November 2001, Society of Construction Law, London.

Finke, M. R., 2000, "Schedule density as a tool for pricing compensable float consumption", *Cost Engineering*, Vol. 42, No. 6, pp.34–37, June.

Furst, S. and V. Ramsey, 2001, *Keating on Construction Contracts*, 7th Edn, Sweet & Maxwell, London.

Gibson, R., 2008, *Construction Delays Extensions of time and prolongation*, Taylor & Francis, New York.

Godwin, W. Q., 2020, *The 2017 FIDIC Contracts The Second Editions of the Red, Yellow and Silver Books,* Wiley-Blackwell, Oxford, UK.

Golanaraghi, S. and S. Alkass, 2012, "Modified isolated delay type technique", *Proceedings of Construction Research Congress 2012: Construction Challenges in a Flat World*, 21-23 May 2012, pp.90–99, ASCE.

Golnaraghi, S., 2011, *Development of Delays Claims Assessment Model*, MSc Thesis, Concordia University.

Gomarn, P. and J. Pongpeng, 2018, "Causes of construction delay from contractors and suppliers in Thailand ' s oil and gas platform projects", *Proceedings of MATEC Web of Conferences,* Vol. 192, No. 1, pp.8–11, January.

Gündüz, M., Y. Nielsen and M. Özdemir, 2013, "Quantification of delay factors using the relative importance index method for construction projects in Turkey", *Journal of Management in Engineering*, Vol. 29, No. 2, pp.133–139, April.

Hamzah, N. *et al.*, 2011, "Cause of construction delay - Theoretical framework", *Procedia Engineering*, Vol. 20, pp.490–495, December.

Harold, K., 2002, *Project Management Project Management*, 8th Edn, John Wiley & Sons, New Jersey.

Hewitt, A., 2014, *The FIDIC Contracts Obligations of the parties*, Wiley-Blackwell, Oxford, UK.

Hossain, A. *et al.*, 2019, "Delay causes in Kazakhstan's construction projects and remedial measures", *International Journal of Construction Management*, Vol. 0, No. 0, pp.1–19, July.

Householder, J. L. and H. E. Rutland, 1990, "Who owns float?", *Journal of Construction Engineering and Management*, Vol. 116, No. 1, pp.130–133, March.

Kao, C. K. and J. Bin Yang, 2009, "Comparison of windows-based delay analysis methods", *International Journal of Project Management*, Vol. 27, No. 4, pp.408–418, May.

Kazaz, A., S. Ulubeyli and N. A. Tuncbilekli, 2012, "Causes of Delays in Construction Projects in Turkey", *Journal of Civil Engineering and Management*, Vol. 18, No. 3, pp.426-425, September 2013.

Kazemi, A., A. Katebi and M.-H. Kazemi, 2018, "Causes of delay in construction projects: The case of oil and gas projects", *International Journal of Advanced Research in Engineering*, Vol. 4, No. 1, pp.11-16, March.

Keane, P. J. and A. F. Caletka, 2015, *Delay Analysis in Construction Contracts*, 2nd Edn, Wiley-Blackwell, Chichester, UK.

Keen, D. and A. Farr, 2017, *SCL Delay and Disruption Protocol 2nd Edition Review*, https://www.fticonsulting.com/~/media/Files/emea--files/insights/articles/scl-delay-disruption-protocol.pdf

de la Garza, J. M., M. C. Vorster and C. M. Parvin, 1991, "Total float traded as commodity", *Journal of Construction Engineering and Management*, Vol. 117, No. 4, pp.716–727, December.

Levin, P. *et al.*, 2016, *Construction Contract Claims, Changes, and Dispute Resolution*, Third Edn, ASCE Press, Reston, Virginia.

Lo, T. Y., I. W. H. Fung and K. C. F. Tung, 2006, "Construction delays in Hong Kong civil engineering projects", *Journal of Construction Engineering and Management*, Vol. 132, No. 6, pp.636–649, June.

Lowe, R. H., E. M. Barba and G. B. Lare, 2006, "A View from across the pond: An American perspective on the SCL Delay and Disruption Porotocol", *Proceedings of Society of Construction Law London on 8th May 2006*, London, 8 May 2007, Society of Construction Law, London.

Mahamid, I., A. Bruland and N. Dmaidi, 2012, "Causes of delay in road construction projects", *Journal of Management in Engineering*, Vol. 28, No. 3, pp.300–310, July.

Marzouk, M. M. and T. I. El-rasas, 2014, "Analyzing delay causes in Egyptian construction projects", *Journal of Advanced Research*, Vol. 5, No. 1, pp.49–55, January.

Mbabazi, A., T. Hegazy and F. Saccomanno, 2005, "Modified but-for method for delay analysis", *Journal of Construction Engineering and Management*, Vol. 131, No. 10, pp.1142–1144, October.

Mbala, M., C. Aigbavboa and J. Aliu, 2019, "Causes of Delay in Various Construction Projects: A Literature Review", *Advances in Human Factors, Sustainable Urban Planning and Infrastructure*, Vol. 788, pp.489–495, January.

McCord, J. *et al.*, 2015, "Understanding delays in housing construction: evidence from Northern Ireland", *Journal of Financial Management of Property and Construction*, Vol. 20, Issue 3, pp.286 - 319, November.

Mohan, S. B. and K. S. Al-Gahtani, 2006, "Current delay analysis techniques and improvements", *Cost Engineering (Morgantown, West Virginia)*, Vol. 48, No. 9, pp.12–21.

Mubarak, S., 2015, *Construction Project Scheduling and Control*, 3rd Edn, John Wiley & Sons, New Jersey.

Muhamad, N. H. *et al.*, 2016, "Delay Analysis Methodologies (DAMs) in Delivering Quality Projects: Contractors and Consultants' Perceptions", *Procedia - Social and Behavioral Sciences*, Vol. 222, pp.121–131, June.

Ndekugri, I., N. Braimah and R. Gameson, 2008, "Delay analysis within construction contracting organizations", *Journal of Construction Engineering and Management*, Vol. 134, No. 9, pp.692–700, September.

Nguyen, L. D. and W. Ibbs, 2008, "FLORA: New forensic schedule analysis technique", *Journal of Construction Engineering and Management*, Vol. 134, No. 7, pp.483–491, July.

Nguyen, L. duy, 2007, *The dynamics of float, logic, resource allocation, and delay timing in forensic schedule analysis and construction delay claims*, Ph.D. Dissertation, University of California, Berkeley.

Parchamijalal, M. and S. Shoar, 2017, "A Hybrid SD-DEMATEL Approach to Develop a Delay Model for Construction", *Engineering , Construction and Architectural Management*, Vol. 24, No. 4, pp.629-651, July.

Perera, N. A., M. Sutrisna and T. W. Yiu, 2016, "Decision-making model for selecting the optimum method of delay analysis in construction projects", *Journal of Management in Engineering*, Vol. 32, No. 5, pp.1–14, April.

Prateapusanond, A., 2003, *A Comprehensive Practice of Total Float Pre-Allocation and Management for the Application of A CPM-Based Construction Contract*, PhD Thesis, Virginia Polytechnic Institute and State University.

Project Management Institute, 2017, *A Guide to the Project Management Body of Knowledge*, 6th Edn, PMI, Pennsylvania.

Rivera, L., H. Baguec and C. Yeom, 2020, "A Study on Causes of Delay in Road Construction Projects across 25 Developing Countries", *Infrastructures*, Vol. 5, No. 10, pp.84, October.

Ruqaishi, M. and H. A. Bashir, 2015, "Causes of Delay in Construction Projects in the Oil and Gas Industry in the Gulf Cooperation Council Countries : A Case Study", *American Society of Civil Engineers*, Vol. 31, No. 3, pp.1–8, August.

Sambasivan, M. and Y. W. Soon, 2007, "Causes and effects of delays in Malaysian construction industry", *International Journal of Project Management*, Vol. 25, No. 5, pp.517–526, July.

SCL, 2002, *Society of Construction Law Delay and Disruption Protocol*, Oxford.

SCL, 2017, *Society of Construction Law Delay and Disruption Protocol*, 2nd Edn, Leicestershire.

Scott, S., R. A. Harris and D. Greenwood, 2004, "Assessing the new United Kingdom protocol for dealing with delay and disruption", *Journal of Professional Issues in Engineering Education and Practice*, Vol. 130, No. 1, pp.50–59, January.

Shahsavand, P., A. Marefat and M. Parchamijalal, 2018, "Causes of delays in construction industry and comparative delay analysis techniques with SCL protocol", *Engineering, Construction and Architectural Management*, Vol. 25, No. 4, pp.497–533, May.

Shi, J. J., S. O. Cheung and A. Arditi, 2001, "Construction delay computation method", *Journal of Construction Engineering and Management*, Vol. 127, No. 1, pp.60–65, February.

da Silva, P. M. de M. R. F., 2016, "Causes and effects of delay in Portuguese construction industry", *International Research Journal of Engineering and Technology*, Vol. 3, No. 10, pp.564–566, January.

Stumpf, G. R., 2000, "Schedule delay analysis", *Cost Engineering (Morgantown, West Virginia)*, Vol. 42, No. 7, pp.32-32.

Sweis, G., 2008, "Delays in construction projects : The case of Jordan", *International Journal of Project Management*, Vol. 26, No. 6, pp.665–674, August.

Trauner, T. J., 2009, *Construction Delays: Understanding Them Clearly, Analyzing Them Correctly*, 2nd Edn, Elsevier Butterworth–Heinemann, London.

Turkish Contractors Association, 2020, *Turkish Contracting in the International Market*, https://www.tmb.org.tr/duyurular/Turkish_Contracting_in_the_International_Markets_2019_06october2020.pdf.

Whaley, A., 2018, "Forensic Delay Analysis", *Proceedings of The Chartered Institute of Arbitrators East Anglia Branch, London Evening Seminar-'Demystifying Delay Analysis'*, London, 27 November 2018, The Chartered Institute of Arbitrators, London.

Wiest, J. D., 1981, "Precedence diagramming method: Some unusual characteristics and their implications for project managers", *Journal of Operations Management*, Vol. 1, No. 3, pp.121–130, February.

Yang, J.-B., 2017, "Reviewing Construction Schedule Float Management", *The Open Construction* *and Building Technology Journal*, Vol. 11, No. 1, pp.1–13, January.

Yang, J.-B. and C.-K. Kao, 2009, "Review of Delay Analysis Methods: A Process-Based Comparison", *The Open Construction and Building Technology Journal*, Vol. 3, No. 1, pp.81–89, August.

Yang, J. Bin and M. K. Tsai, 2011, "Computerizing ICBF method for schedule delay analysis", *Journal of Construction Engineering and Management*, Vol. 137, No. 8, pp.583–591, August.

Yang, J. Bin and P. C. Yin, 2009, "Isolated collapsed but-for delay analysis methodology", *Journal of Construction Engineering and Management*, Vol. 135, No. 7, pp.570–578, July.

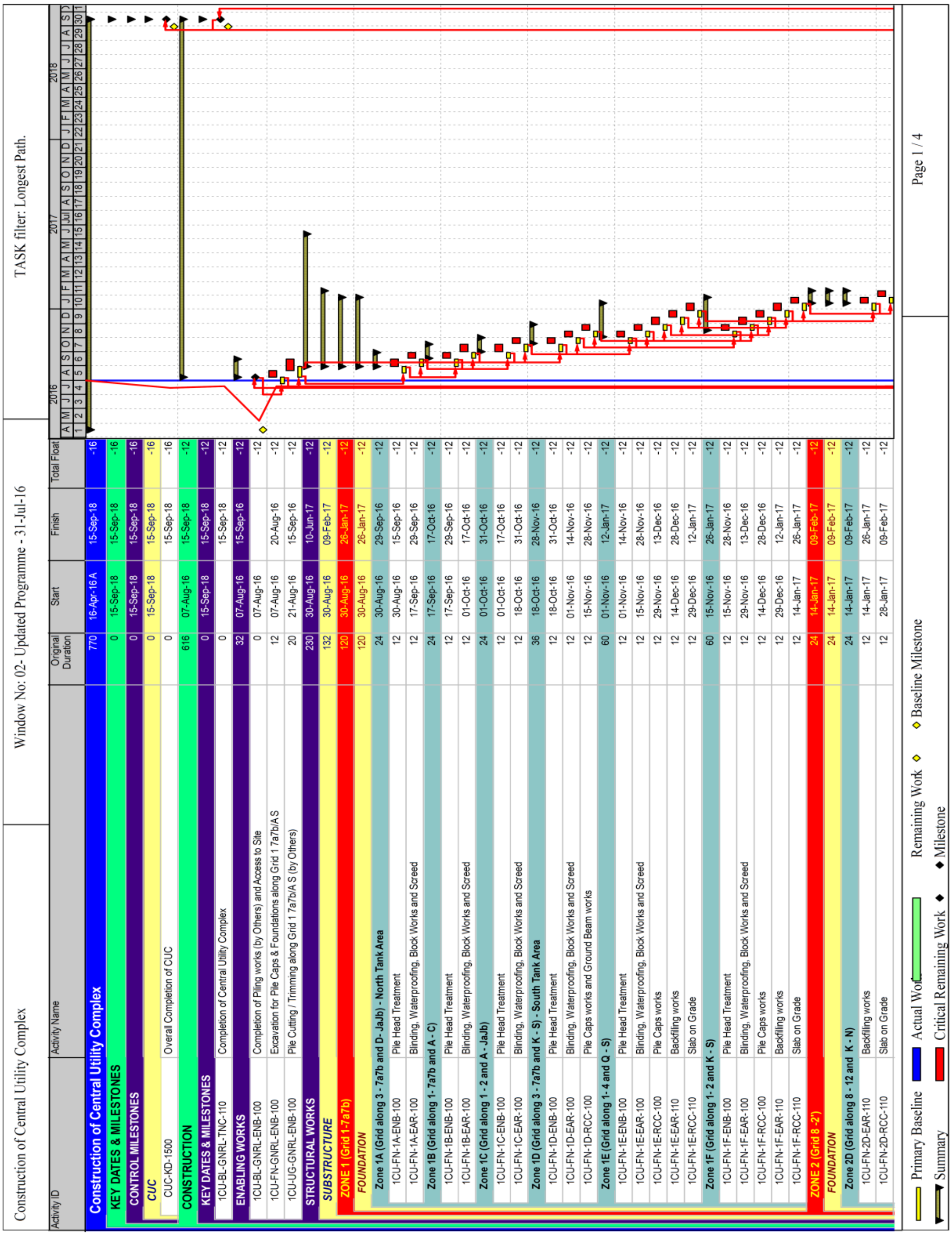
Yusuwan, N. M. and H. Adnan, 2013, "Assessing Extension of Time Application in Malaysian Construction Industry: Views from Professionals", *Procedia - Social and Behavioral Sciences*, Vol. 105, pp.54–63, December.

Zack, J. G., 2000, "Pacing Delays - The Practical Effect", *Journal of Cost Engineering*, Vol. 42, No. 7, pp.23–27, July.

Zack, J. G., 2001, "But-for schedules - Analysis and defense", *Cost Engineering (Morgantown, West Virginia)*, Vol. 43, No. 8, pp.13–17, August.

Zhang, D., H. Zhang and T. Cheng, 2020, "Causes of Delay in the Construction Projects of Subway Tunnel", *Hindawi Advances in Civil Engineering*, Vol. 2020, 14 pages, November.

APPENDIX A: WINDOW #2 AS OF 31-JUL-16 - LONGEST PATH

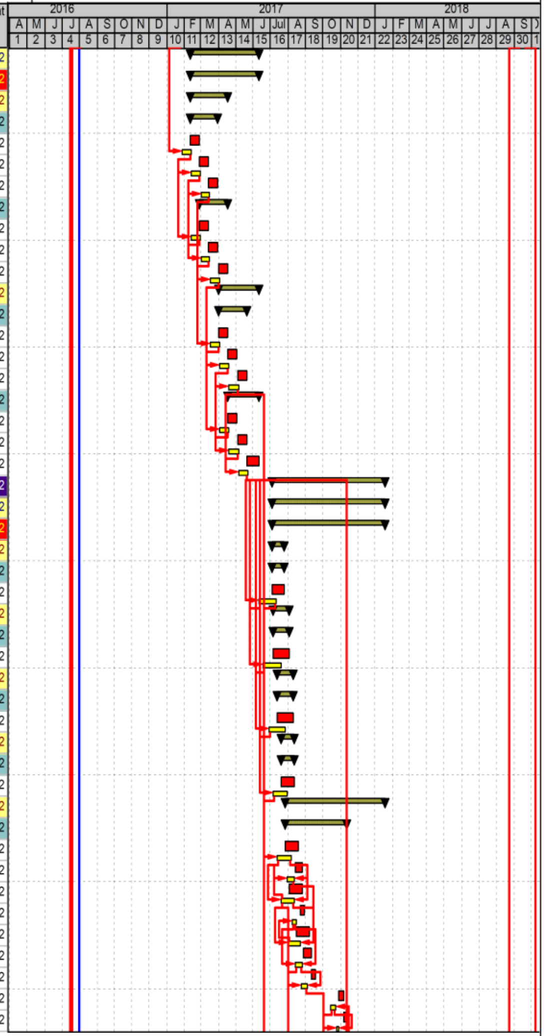


Activity ID	Activity Name	Original Duration	Start	Finish	Total Float
Construction of Central Utility Complex		770	16-Apr-16 A	15-Sep-18	-16
KEY DATES & MILESTONES		0	15-Sep-18	15-Sep-18	-16
CONTROL MILESTONES		0	15-Sep-18	15-Sep-18	-16
CUC		0	15-Sep-18	15-Sep-18	-16
CUC-KD-1500	Overall Completion of CUC	0		15-Sep-18	-16
CONSTRUCTION		616	07-Aug-16	15-Sep-18	-12
KEY DATES & MILESTONES		0	15-Sep-18	15-Sep-18	-12
1CU-BL-GNRL-TNC-110	Completion of Central Utility Complex	0		15-Sep-18	-12
ENABLING WORKS		32	07-Aug-16	15-Sep-16	-12
1CU-BL-GNRL-ENB-100	Completion of Piling works (by Others) and Access to Site	0	07-Aug-16		-12
1CU-FN-GNRL-ENB-100	Excavation for Pile Caps & Foundations along Grid 1 7a7b/A S	12	07-Aug-16	20-Aug-16	-12
1CU-UG-GNRL-ENB-100	Pile Cutting / Trimming along Grid 1 7a7b/A S (by Others)	20	21-Aug-16	15-Sep-16	-12
STRUCTURAL WORKS		230	30-Aug-16	10-Jun-17	-12
SUBSTRUCTURE		132	30-Aug-16	09-Feb-17	-12
ZONE 1 (Grid 1-7a7b)		120	30-Aug-16	26-Jan-17	-12
FOUNDATION		120	30-Aug-16	26-Jan-17	-12
Zone 1A (Grid along 3 - 7a7b and D - JaJb) - North Tank Area		24	30-Aug-16	29-Sep-16	-12
1CU-FN-1A-ENB-100	Pile Head Treatment	12	30-Aug-16	15-Sep-16	-12
1CU-FN-1A-EAR-100	Binding, Waterproofing, Block Works and Screed	12	17-Sep-16	29-Sep-16	-12
Zone 1B (Grid along 1-7a7b and A - C)		24	17-Sep-16	17-Oct-16	-12
1CU-FN-1B-ENB-100	Pile Head Treatment	12	17-Sep-16	29-Sep-16	-12
1CU-FN-1B-EAR-100	Binding, Waterproofing, Block Works and Screed	12	01-Oct-16	17-Oct-16	-12
Zone 1C (Grid along 1 - 2 and A - JaJb)		24	01-Oct-16	31-Oct-16	-12
1CU-FN-1C-ENB-100	Pile Head Treatment	12	01-Oct-16	17-Oct-16	-12
1CU-FN-1C-EAR-100	Binding, Waterproofing, Block Works and Screed	12	18-Oct-16	31-Oct-16	-12
Zone 1D (Grid along 3 - 7a7b and K - S) - South Tank Area		36	18-Oct-16	28-Nov-16	-12
1CU-FN-1D-ENB-100	Pile Head Treatment	12	18-Oct-16	31-Oct-16	-12
1CU-FN-1D-EAR-100	Binding, Waterproofing, Block Works and Screed	12	01-Nov-16	14-Nov-16	-12
1CU-FN-1D-RCC-100	Pile Caps works and Ground Beam works	12	15-Nov-16	28-Nov-16	-12
Zone 1E (Grid along 1-4 and Q - S)		60	01-Nov-16	12-Jan-17	-12
1CU-FN-1E-ENB-100	Pile Head Treatment	12	01-Nov-16	14-Nov-16	-12
1CU-FN-1E-EAR-100	Binding, Waterproofing, Block Works and Screed	12	15-Nov-16	28-Nov-16	-12
1CU-FN-1E-RCC-100	Pile Caps works	12	29-Nov-16	13-Dec-16	-12
1CU-FN-1E-EAR-110	Backfilling works	12	14-Dec-16	28-Dec-16	-12
1CU-FN-1E-RCC-110	Slab on Grade	12	29-Dec-16	12-Jan-17	-12
Zone 1F (Grid along 1-2 and K - S)		60	15-Nov-16	26-Jan-17	-12
1CU-FN-1F-ENB-100	Pile Head Treatment	12	15-Nov-16	28-Nov-16	-12
1CU-FN-1F-EAR-100	Binding, Waterproofing, Block Works and Screed	12	29-Nov-16	13-Dec-16	-12
1CU-FN-1F-RCC-100	Pile Caps works	12	14-Dec-16	28-Dec-16	-12
1CU-FN-1F-EAR-110	Backfilling works	12	29-Dec-16	12-Jan-17	-12
1CU-FN-1F-RCC-110	Slab on Grade	12	14-Jan-17	26-Jan-17	-12
ZONE 2 (Grid 8 -2')		24	14-Jan-17	09-Feb-17	-12
FOUNDATION		24	14-Jan-17	09-Feb-17	-12
Zone 2D (Grid along 8 - 12 and K - N)		24	14-Jan-17	09-Feb-17	-12
1CU-FN-2D-EAR-110	Backfilling works	12	14-Jan-17	26-Jan-17	-12
1CU-FN-2D-RCC-110	Slab on Grade	12	28-Jan-17	09-Feb-17	-12

Figure A.1. Window #2 as of 31 July 2016 - Longest Path.

Construction of Central Utility Complex | Window No: 02- Updated Programme - 31-Jul-16 | TASK filter: Longest Path.

Activity ID	Activity Name	Original Duration	Start	Finish	Total Float
SUPERSTRUCTURE		98	11-Feb-17	10-Jun-17	-12
ZONE 2 (Grid 8 -2')		98	11-Feb-17	10-Jun-17	-12
LEVEL 00		56	11-Feb-17	16-Apr-17	-12
Zone 2D (Grid along 8 - 12 and K - N)		42	11-Feb-17	30-Mar-17	-12
1CU-L0-2D-RCC-100	Construction of Verticals	14	11-Feb-17	26-Feb-17	-12
1CU-L0-2D-RCC-110	Construction of Beams	14	27-Feb-17	14-Mar-17	-12
1CU-L0-2D-RCC-120	Construction of Slab @ Level 01	14	15-Mar-17	30-Mar-17	-12
Zone 2E (Grid along 8 - 12 and O - S)		42	27-Feb-17	16-Apr-17	-12
1CU-L0-2E-RCC-100	Construction of Verticals	14	27-Feb-17	14-Mar-17	-12
1CU-L0-2E-RCC-110	Construction of Beams	14	15-Mar-17	30-Mar-17	-12
1CU-L0-2E-RCC-120	Construction of Slab @ Level 01	14	01-Apr-17	16-Apr-17	-12
LEVEL 01		56	01-Apr-17	10-Jun-17	-12
Zone 2D (Grid along 8 - 12 and K - N)		42	01-Apr-17	20-May-17	-12
1CU-L1-2D-RCC-100	Construction of Verticals	14	01-Apr-17	16-Apr-17	-12
1CU-L1-2D-RCC-110	Construction of Beams	14	17-Apr-17	03-May-17	-12
1CU-L1-2D-RCC-120	Construction of Roof RCC slab and Hollow Core Slab	14	04-May-17	20-May-17	-12
Zone 2E (Grid along 8 - 12 and O - S)		42	17-Apr-17	10-Jun-17	-12
1CU-L1-2E-RCC-100	Construction of Verticals	14	17-Apr-17	03-May-17	-12
1CU-L1-2E-RCC-110	Construction of Beams	14	04-May-17	20-May-17	-12
1CU-L1-2E-RCC-120	Construction of Roof RCC slab and Hollow Core Slab	14	21-May-17	10-Jun-17	-12
INTERNAL FINISHES & MEP		164	03-Jul-17	17-Jan-18	-12
Level 00		164	03-Jul-17	17-Jan-18	-12
MEP/UTILITIES/SERVICE AREA		164	03-Jul-17	17-Jan-18	-12
CHEMICAL DOSING ROOM (GF-21)		20	03-Jul-17	25-Jul-17	-12
FINISHES		20	03-Jul-17	25-Jul-17	-12
1CU-L0-TCRM-BLK-140	Block Work	20	03-Jul-17	25-Jul-17	-12
TECHNICAL GALLERY FOR OUTGOING LOOP (GF-14 & GF-15)		24	06-Jul-17	02-Aug-17	-12
FINISHES		24	06-Jul-17	02-Aug-17	-12
1CU-L0-TCGL-BLK-100	Block Work	24	06-Jul-17	02-Aug-17	-12
MV ROOM 1 & 2 (GF-09 & GF-10)		24	13-Jul-17	09-Aug-17	-12
FINISHES		24	13-Jul-17	09-Aug-17	-12
1CU-L0-MVRM-BLK-100	Block Work	24	13-Jul-17	09-Aug-17	-12
ATS ROOM 1 & 2 (GF-11 & GF-12)		20	20-Jul-17	12-Aug-17	-12
FINISHES		20	20-Jul-17	12-Aug-17	-12
1CU-L0-ELRM-BLK-100	Block Work	20	20-Jul-17	12-Aug-17	-12
STEP DOWN TRANSFORMER ROOM (GF-05,GF-06 & GF-35)		143	27-Jul-17	17-Jan-18	-12
FINISHES		88	27-Jul-17	11-Nov-17	-12
1CU-L0-TRRM-BLK-100	Block Work	20	27-Jul-17	19-Aug-17	-12
1CU-L0-TRRM-BLK-110	Sub Frames Fixing	12	13-Aug-17	26-Aug-17	-12
1CU-L0-TRRM-BLK-120	Marking, Cutting & Chasing Walls for MEP Services	20	03-Aug-17	26-Aug-17	-12
1CU-L0-TRRM-FLR-100	Floor Screed	6	22-Aug-17	28-Aug-17	-12
1CU-L0-TRRM-BLK-130	Plastering Works	18	15-Aug-17	06-Sep-17	-12
1CU-L0-TRRM-WLL-100	Wall Finishes	12	27-Aug-17	11-Sep-17	-12
1CU-L0-TRRM-CEL-100	Ceiling Finishes	8	10-Sep-17	18-Sep-17	-12
1CU-L0-TRRM-FLR-110	Floor Finishes	8	29-Oct-17	06-Nov-17	-12
1CU-L0-TRRM-FFE-100	Door Shuttering & Ironmongery	4	07-Nov-17	11-Nov-17	-12

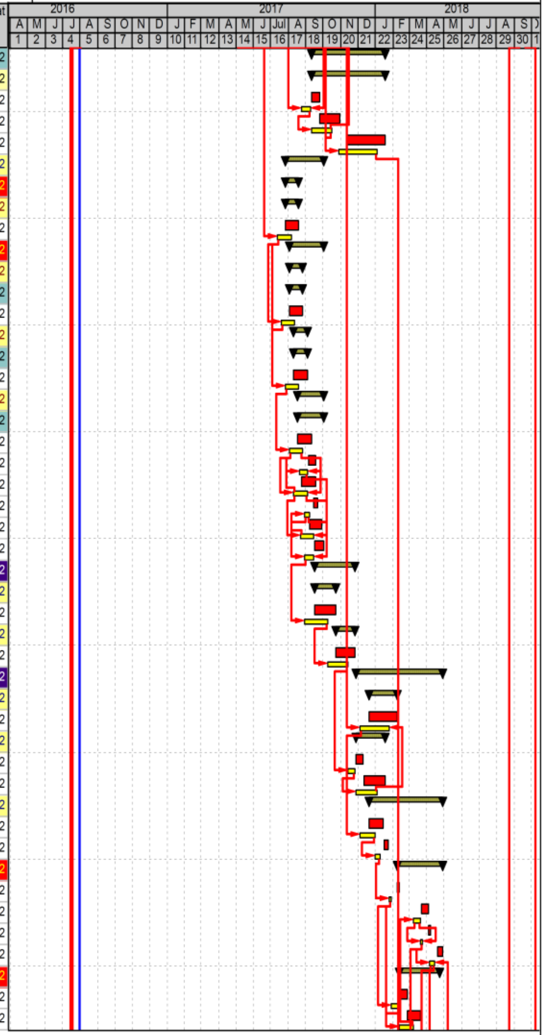


Primary Baseline | Actual Work | Remaining Work | Baseline Milestone
Summary | Critical Remaining Work | Milestone

Figure A.1. Window #2 as of 31 July 2016 - Longest Path (cont.).

Construction of Central Utility Complex	Window No: 02- Updated Programme - 31-Jul-16	TASK filter: Longest Path.

Activity ID	Activity Name	Original Duration	Start	Finish	Total Float
MEP WORKS		107	10-Sep-17	17-Jan-18	-12
ELECTRICAL		107	10-Sep-17	17-Jan-18	-12
1CU-L0-TRRM-ELC-100	1st Fix Electrical / ELV	12	10-Sep-17	24-Sep-17	-12
1CU-L0-TRRM-ELC-110	2nd Fix Electrical / ELV	30	25-Sep-17	30-Oct-17	-12
1CU-L0-TRRM-ELC-120	Installation of Step down Transformer	55	12-Nov-17	17-Jan-18	-12
Level 01		53	27-Jul-17	01-Oct-17	-12
PUBLIC/COMMON AREAS		20	27-Jul-17	19-Aug-17	-12
GENERAL WORKS		20	27-Jul-17	19-Aug-17	-12
1CU-L1-PUBL-BLK-100	Block Work	20	27-Jul-17	19-Aug-17	-12
MEP/UTILITIES/SERVICE AREA		47	03-Aug-17	01-Oct-17	-12
SPARE PARTS AND REFRIGERANT STORAGE (1F-02)		20	03-Aug-17	26-Aug-17	-12
FINISHES		20	03-Aug-17	26-Aug-17	-12
1CU-L1-STRM-BLK-100	Block Work	20	03-Aug-17	26-Aug-17	-12
PUMP ROOM (1F-12)		20	10-Aug-17	04-Sep-17	-12
FINISHES		20	10-Aug-17	04-Sep-17	-12
1CU-L1-PMRM-BLK-100	Block Work	20	10-Aug-17	04-Sep-17	-12
COOLING CHILLER ROOM WITH MOBILE CRANE (1F-05 & 1F-17)		35	17-Aug-17	01-Oct-17	-12
FINISHES		35	17-Aug-17	01-Oct-17	-12
1CU-L1-CHRM-BLK-100	Block Work	20	17-Aug-17	11-Sep-17	-12
1CU-L1-CHRM-BLK-110	Sub Frames Fixing	12	05-Sep-17	18-Sep-17	-12
1CU-L1-CHRM-BLK-120	Marking, Cutting & Chasing Walls for MEP Services	20	24-Aug-17	18-Sep-17	-12
1CU-L1-CHRM-FLR-100	Floor Screed	6	14-Sep-17	20-Sep-17	-12
1CU-L1-CHRM-BLK-130	Plastering Works	18	07-Sep-17	28-Sep-17	-12
1CU-L1-CHRM-WLL-100	Wall Finishes	12	16-Sep-17	01-Oct-17	-12
ENVELOPE FINISHES		60	16-Sep-17	26-Nov-17	-12
NORTH ELEVATION		30	16-Sep-17	22-Oct-17	-12
1CU-EV-NORT-WLL-100	External Plaster and Painting Works	30	16-Sep-17	22-Oct-17	-12
EAST ELEVATION		30	23-Oct-17	26-Nov-17	-12
1CU-EV-EAST-WLL-100	External Plaster and Painting Works	30	23-Oct-17	26-Nov-17	-12
EXTERNAL WORKS		128	27-Nov-17	28-Apr-18	-12
EXTERNAL WORKS & HARD LANDSCAPING		42	20-Dec-17	07-Feb-18	-12
1CU-UG-EXTR-EXT-100	Grading and Sub Base works	42	20-Dec-17	07-Feb-18	-12
UNDERGROUND FUEL TANK		42	27-Nov-17	17-Jan-18	-12
1CU-UG-EXTR-EAR-100	Excavation for Underground Fuel Tank	12	27-Nov-17	10-Dec-17	-12
1CU-UG-EXTR-ELC-110	Installation of Underground Fuel Tank and MEP Works	30	11-Dec-17	17-Jan-18	-12
GUARD ROOM		110	20-Dec-17	28-Apr-18	-12
1CU-FN-EXTR-RCC-110	Foundation works and SOG	21	20-Dec-17	14-Jan-18	-12
1CU-BL-EXTR-RCC-100	Verticals and Slab	8	15-Jan-18	23-Jan-18	-12
FINISHES		69	07-Feb-18	28-Apr-18	-12
1CU-EV-EXTR-BLK-100	Block Work	4	07-Feb-18	11-Feb-18	-12
1CU-EV-EXTR-FLR-110	Floor Finishes	12	22-Mar-18	04-Apr-18	-12
1CU-EV-EXTR-FFE-100	Door Shuttering & Ironmongery	4	03-Apr-18	07-Apr-18	-12
1CU-EV-EXTR-FFE-110	Final Finishes & Cleaning	8	19-Apr-18	28-Apr-18	-12
MEP WORKS		61	12-Feb-18	23-Apr-18	-12
1CU-EV-EXTR-ELC-100	MEP First Fix	12	12-Feb-18	25-Feb-18	-12
1CU-EV-EXTR-ELC-110	MEP Second Fix	21	26-Feb-18	21-Mar-18	-12



Primary Baseline — Actual Work — Remaining Work ◇ Baseline Milestone
Summary — Critical Remaining Work ◆ Milestone

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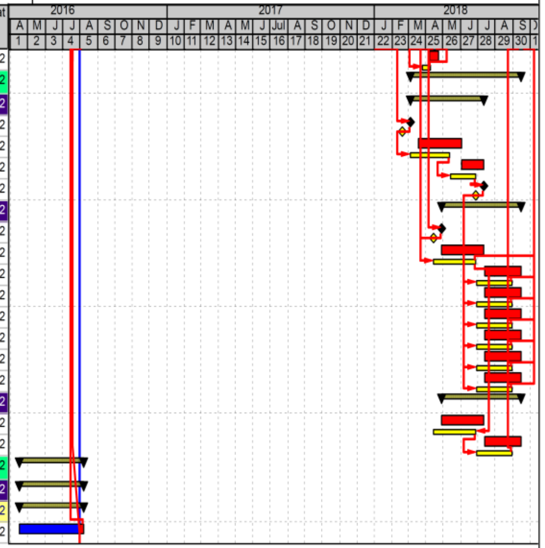
Figure A.1. Window #2 as of 31 July 2016 - Longest Path (cont.).

Construction of Central Utility Complex | Window No: 02- Updated Programme - 31-Jul-16 | TASK filter: Longest Path.

Activity ID	Activity Name	Original Duration	Start	Finish	Total Float
1CU-EV-EXTR-ELC-120	MEP Final Fix	14	08-Apr-18	23-Apr-18	-12
TESTING & COMMISSIONING WORKS		151	04-Mar-18	15-Sep-18	-12
READINESS FOR POWER ON AND WILD AIR		99	04-Mar-18	12-Jul-18	-12
1CU-EV-GNRL-ELC-100	Readiness of Transformer, MV Rooms and ATS Rooms for Power on requirement	0		04-Mar-18	-12
1CU-EV-GNRL-ELC-110	Statutory Body approvals	60	18-Mar-18	02-Jun-18	-12
1CU-EV-GNRL-TNC-100	Testing, Energization and Power on	28	03-Jun-18	12-Jul-18	-12
1CU-EV-GNRL-ELC-130	Availability of Power on	0		12-Jul-18	-12
FINAL TESTING, SNAGGING & DESNAGGING WORKS		104	28-Apr-18	15-Sep-18	-12
1CU-RF-GNRL-FLR-100	Completion of Finishes at Roof	0		28-Apr-18	-12
1CU-BL-GNRL-TNC-190	Final Testing ,Snagging and Desnagging Works Finishes	52	29-Apr-18	12-Jul-18	-12
1CU-BL-GNRL-TNC-170	Final Testing,Snagging and Desnagging works Plumbing system	52	14-Jul-18	15-Sep-18	-12
1CU-BL-GNRL-TNC-160	Final Testing,Snagging and Desnagging works HVAC & Ventilation system	52	14-Jul-18	15-Sep-18	-12
1CU-BL-GNRL-TNC-120	Final Testing,Snagging and Desnagging works Irrigation system	52	14-Jul-18	15-Sep-18	-12
1CU-BL-GNRL-TNC-130	Final Testing,Snagging and Desnagging works Electronic Safety and Security system (Fire A	52	14-Jul-18	15-Sep-18	-12
1CU-BL-GNRL-TNC-140	Final Testing,Snagging and Desnagging works Electrical system	52	14-Jul-18	15-Sep-18	-12
1CU-BL-GNRL-TNC-150	Final Testing,Snagging and Desnagging works SCADA and BMS systems	52	14-Jul-18	15-Sep-18	-12
PROJECT CLOSEOUT DOCUMENTS		104	29-Apr-18	15-Sep-18	-12
1CU-BL-GNRL-DSG-100	Submit Draft Close out Documents	52	29-Apr-18	12-Jul-18	-12
1CU-BL-GNRL-DSG-110	Submit Project Close out Documents	52	14-Jul-18	15-Sep-18	-12
RISK EVENTS		5	16-Apr-16 A	06-Aug-16	-12
EMPLOYER RISK EVENTS		5	16-Apr-16 A	06-Aug-16	-12
ERE-02 COMPLETION OF PILING WORKS (BY OTHERS)		5	16-Apr-16 A	06-Aug-16	-12
1CU-BL-GNRL-DSG-130	Completion of Piling works (by Others) and Access to Site	5	16-Apr-16 A	06-Aug-16	-12



Primary Baseline | Actual Work | Remaining Work | Baseline Milestone | Summary | Critical Remaining Work | Milestone

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Figure A.1. Window #2 as of 31 July 2016 - Longest Path (cont.).

APPENDIX B: WINDOW #17 AS OF 31-OCT-17 - 2ND CRITICAL PATH

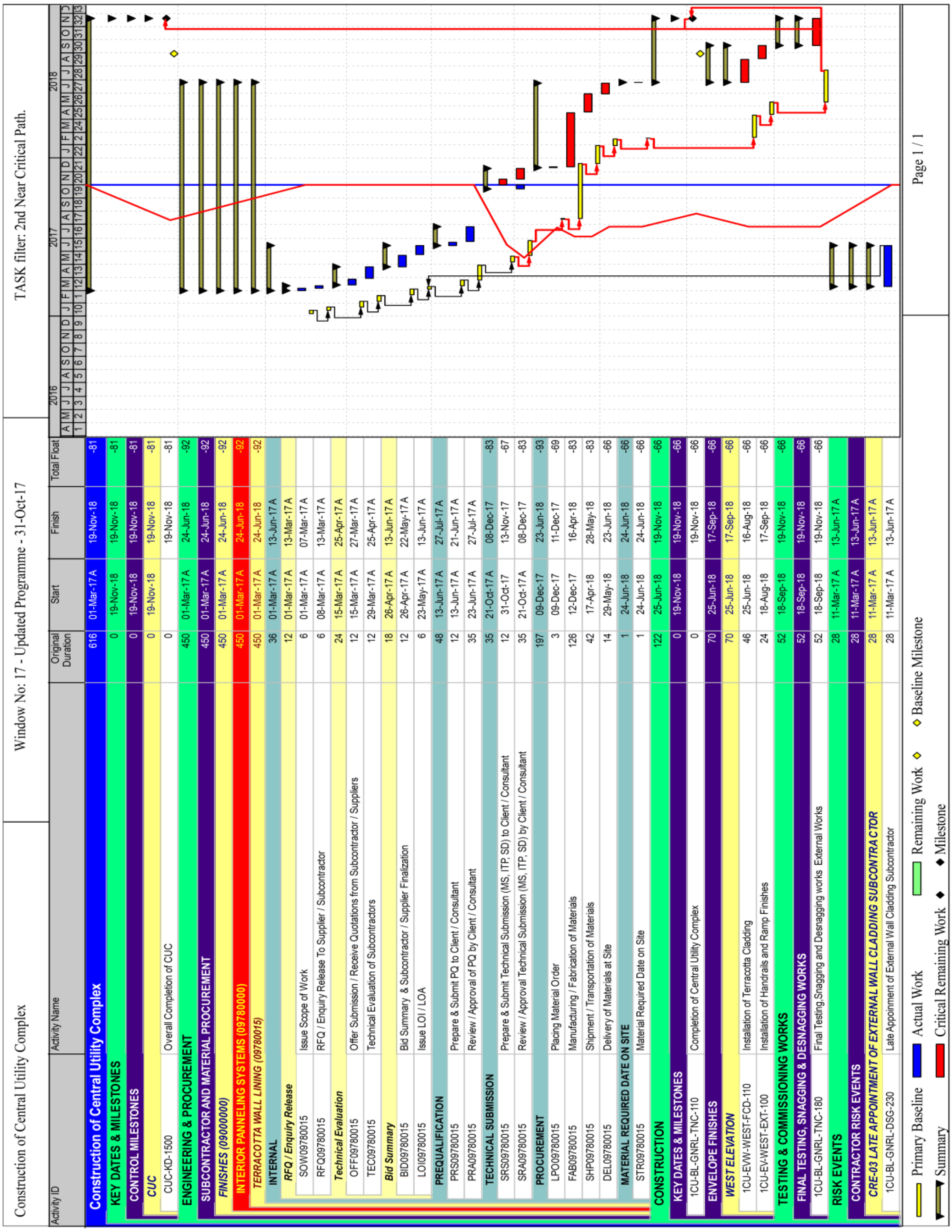


Figure B.1. Window #17 as of 31 October 2017 - 2nd Critical Path.

APPENDIX C: WINDOW #28 AS OF 30-SEP-18 - LONGEST PATH

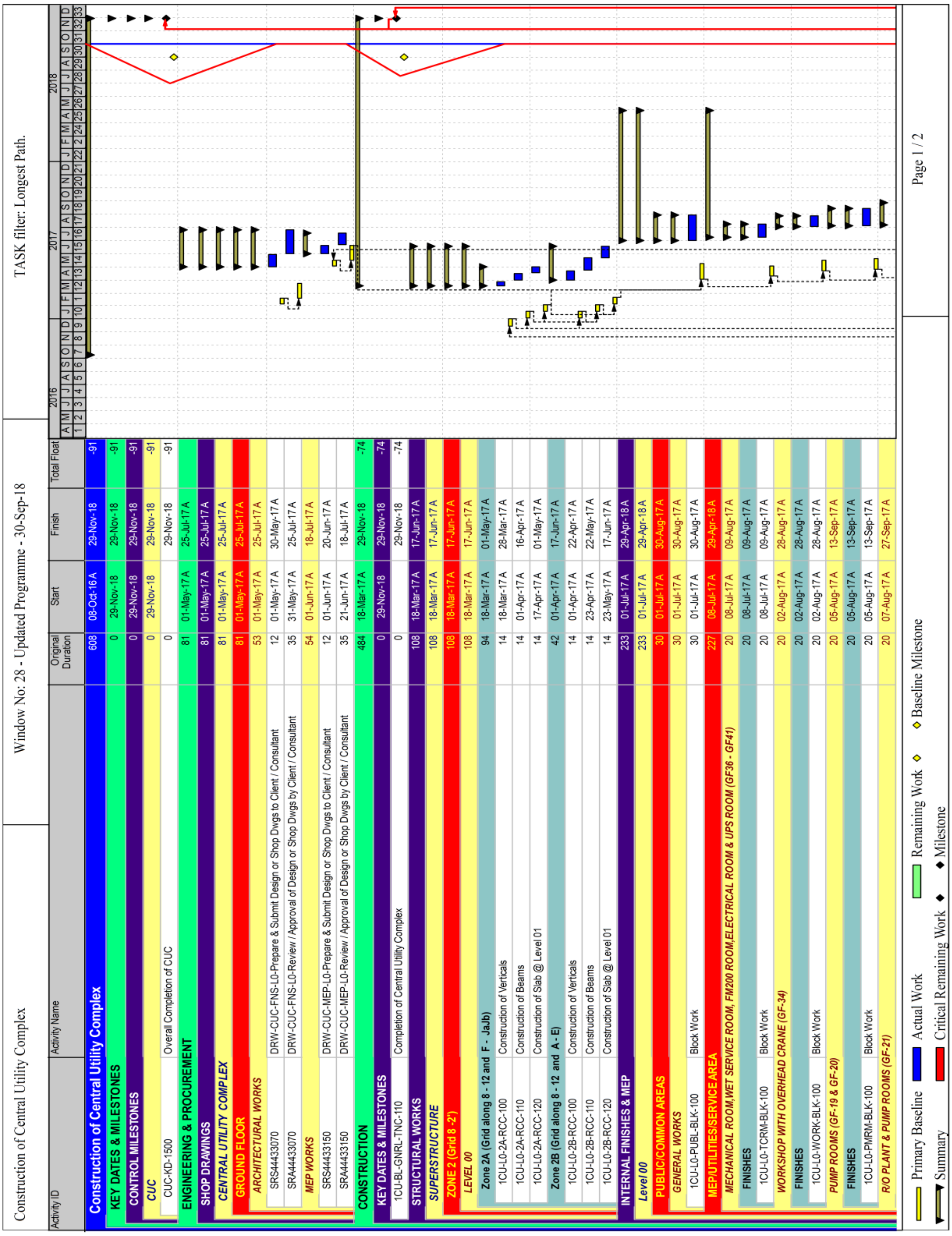
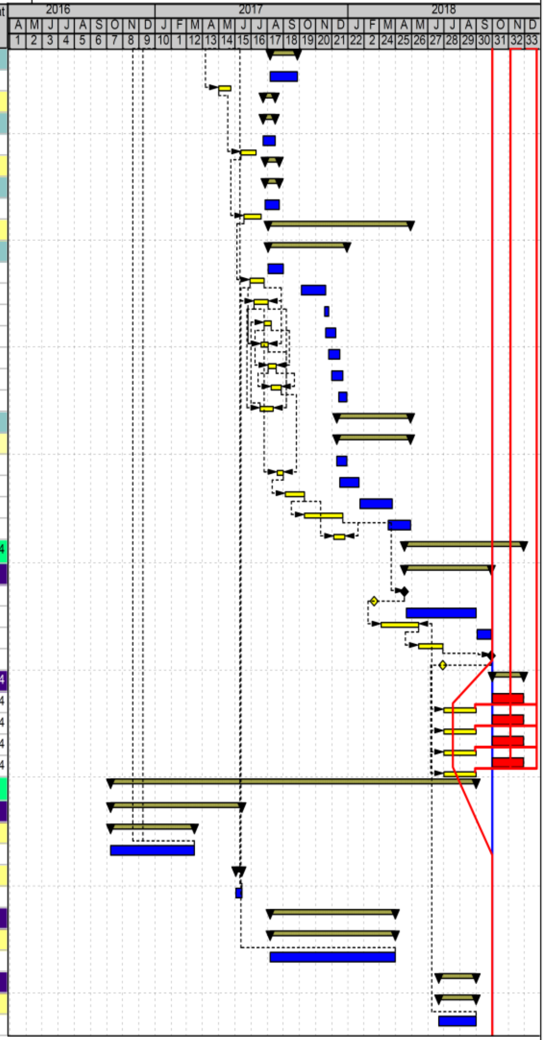


Figure C.1. Window #28 as of 30 September 2018 - Longest Path.

Construction of Central Utility Complex	Window No: 28 - Updated Programme - 30-Sep-18				TASK filter: Longest Path.
Activity ID	**Activity Name**	**Original Duration**	**Start**	**Finish**	**Total Float**
FINISHES		20	07-Aug-17 A	27-Sep-17 A	
1CU-L0-PMRM-BLK-140	Block Work	20	07-Aug-17 A	27-Sep-17 A	
CHEMICAL DOSING ROOM (GF-21)		20	24-Jul-17 A	15-Aug-17 A	
FINISHES		20	24-Jul-17 A	15-Aug-17 A	
1CU-L0-TCRM-BLK-140	Block Work	20	24-Jul-17 A	15-Aug-17 A	
TECHNICAL GALLERY FOR OUTGOING LOOP (GF-14 & GF-15)		24	27-Jul-17 A	23-Aug-17 A	
FINISHES		24	27-Jul-17 A	23-Aug-17 A	
1CU-L0-TCGL-BLK-100	Block Work	24	27-Jul-17 A	23-Aug-17 A	
MV ROOM 1 & 2 (GF-09 & GF-10)		204	03-Aug-17 A	29-Apr-18 A	
FINISHES		122	03-Aug-17 A	30-Dec-17 A	
1CU-L0-MVRM-BLK-100	Block Work	24	03-Aug-17 A	30-Aug-17 A	
1CU-L0-MVRM-BLK-120	Marking, Cutting & Chasing Walls for MEP Services	24	05-Oct-17 A	18-Nov-17 A	
1CU-L0-MVRM-FLR-100	Floor Screed	12	18-Nov-17 A	25-Nov-17 A	
1CU-L0-MVRM-BLK-110	Sub Frames Fixing	12	19-Nov-17 A	09-Dec-17 A	
1CU-L0-MVRM-WLL-100	Wall Finishes	14	26-Nov-17 A	16-Dec-17 A	
1CU-L0-MVRM-CEL-100	Ceiling Finishes	16	02-Dec-17 A	23-Dec-17 A	
1CU-L0-MVRM-BLK-130	Plastering Works	21	14-Dec-17 A	30-Dec-17 A	
MEP WORKS		90	10-Dec-17 A	29-Apr-18 A	
ELECTRICAL		90	10-Dec-17 A	29-Apr-18 A	
1CU-L0-MVRM-ELC-100	1st Fix Electrical / ELV	12	10-Dec-17 A	30-Dec-17 A	
1CU-L0-MVRM-ELC-110	2nd Fix Electrical / ELV	30	17-Dec-17 A	22-Jan-18 A	
1CU-L0-MVRM-ELC-120	Installation of MV Switch Gear Panels A & B and Connections	60	24-Jan-18 A	25-Mar-18 A	
1CU-L0-MVRM-ELC-130	Final Fix Electrical / ELV	18	18-Mar-18 A	29-Apr-18 A	
TESTING & COMMISSIONING WORKS		157	18-Apr-18 A	29-Nov-18	-74
READINESS FOR POWER ON AND WILD AIR		114	18-Apr-18 A	29-Sep-18 A	
1CU-EV-GNRL-ELC-100	Readiness of Transformer, MV Rooms and ATS Rooms for Power on requirement	0		18-Apr-18 A	
1CU-EV-GNRL-ELC-110	Statutory Body approvals	60	21-Apr-18 A	01-Sep-18 A	
1CU-EV-GNRL-TNC-100	Testing, Energization and Power on	28	02-Sep-18 A	29-Sep-18 A	
1CU-EV-GNRL-ELC-130	Availability of Power on	0		29-Sep-18 A	
FINAL TESTING, SNAGGING & DESNAGGING WORKS		52	30-Sep-18	29-Nov-18	-74
1CU-BL-GNRL-TNC-140	Final Testing,Snagging and Desnagging works Electrical system	52	30-Sep-18	29-Nov-18	-74
1CU-BL-GNRL-TNC-150	Final Testing,Snagging and Desnagging works SCADA and BMS systems	52	30-Sep-18	29-Nov-18	-74
1CU-BL-GNRL-TNC-120	Final Testing,Snagging and Desnagging works Irrigation system	52	30-Sep-18	29-Nov-18	-74
1CU-BL-GNRL-TNC-130	Final Testing,Snagging and Desnagging works Electronic Safety and Security system (Fire A	52	30-Sep-18	29-Nov-18	-74
RISK EVENTS		456	08-Oct-16 A	01-Sep-18 A	
EMPLOYER RISK EVENTS		60	08-Oct-16 A	14-Jun-17 A	
ERE-03 CHANGES TO DESIGN OF CHILLERS		60	08-Oct-16 A	17-Mar-17 A	
1CU-BL-GNRL-DSG-180	Changes to design of chillers	60	08-Oct-16 A	17-Mar-17 A	
ERE-07 REVISED WATER SUPPLY SCHEMATIC LAYOUT		7	03-Jun-17 A	14-Jun-17 A	
1CU-BL-GNRL-DSG-240	Revised Water Supply Schematic Layout	7	03-Jun-17 A	14-Jun-17 A	
CONTRACTOR RISK EVENTS		0	07-Aug-17 A	31-Mar-18 A	
CRE-09 AREA READINESS FOR 1ST FIX MEP WORKS (BLOCKWORK, CUTTING AND CHASING)		0	07-Aug-17 A	31-Mar-18 A	
1CU-BL-GNRL-DSG-280	Lack of Progress in Area Readiness for 1st Fix MEP activities	0	07-Aug-17 A	31-Mar-18 A	
EXTERNAL RISK EVENTS		0	21-Jun-18 A	01-Sep-18 A	
XRE-02 LATE APPROVAL OF PERMANENT POWER SUPPLY		0	21-Jun-18 A	01-Sep-18 A	
1CU-BL-GNRL-DSG-300	Late Approval of Permanent Power Supply (by 3rd Parties)	0	21-Jun-18 A	01-Sep-18 A	



Primary Baseline — Actual Work — Remaining Work ◇ Baseline Milestone
Summary — Critical Remaining Work ◆ Milestone

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Figure C.1. Window #28 as of 30 September 2018 - Longest Path (cont.).

APPENDIX D: CONTEMPORANEOUS CRITICAL PATH - TSWA

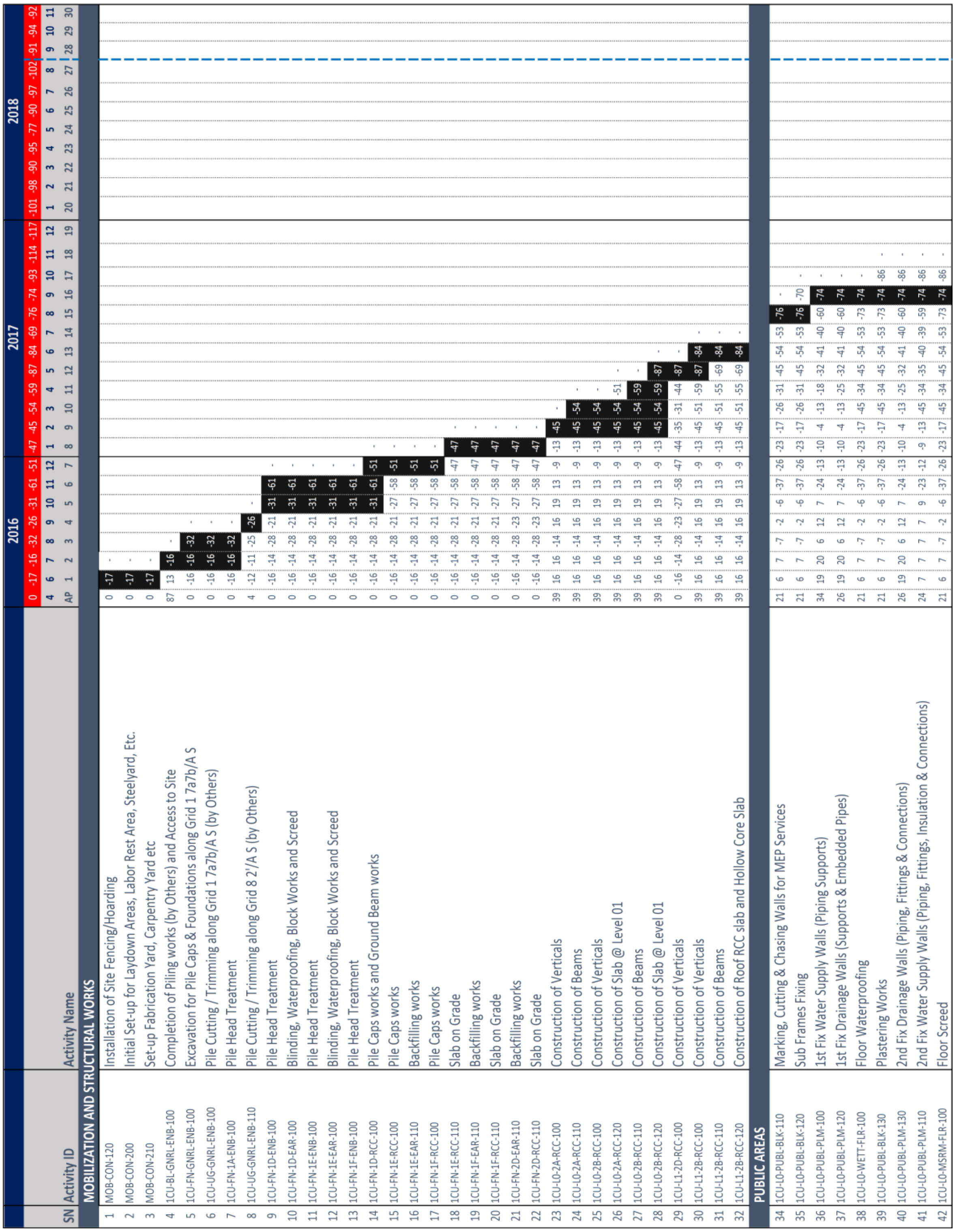


Figure D.1. Contemporaneous Critical Path - TSWA.

			2016								2017												2018										
			0	-17	-16	-32	-26	-31	-61	-51	-47	-45	-54	-59	-87	-84	-69	-76	-74	-93	-114	-117	-101	-98	-90	-95	-77	-90	-97	-102	-91	-94	-92
			4	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11
SN	Activity ID	Activity Name	AP	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
	MOBILIZATION AND STRUCTURAL WORKS																																
1	MOB-CON-120	Installation of Site Fencing/Hoarding	0	-17	-																												
2	MOB-CON-200	Initial Set-up for Laydown Areas, Labor Rest Area, Steelyard, Etc.	0	-17	-																												
3	MOB-CON-210	Set-up Fabrication Yard, Carpentry Yard etc	0	-17	-																												
4	1CU-BL-GNRL-ENB-100	Completion of Piling works (by Others) and Access to Site	87	13	-16	-																											
5	1CU-FN-GNRL-ENB-100	Excavation for Pile Caps & Foundations along Grid 1 7a7b/A S	0	-16	-16	-32	-																										
6	1CU-UG-GNRL-ENB-100	Pile Cutting / Trimming along Grid 1 7a7b/A S (by Others)	0	-16	-16	-32	-																										
7	1CU-FN-1A-ENB-100	Pile Head Treatment	0	-16	-16	-32	-																										
8	1CU-UG-GNRL-ENB-110	Pile Cutting / Trimming along Grid 8 2'/A S (by Others)	4	-12	-11	-25	-26	-																									
9	1CU-FN-1D-ENB-100	Pile Head Treatment	0	-16	-14	-28	-21	-31	-61	-																							
10	1CU-FN-1D-EAR-100	Blinding, Waterproofing, Block Works and Screed	0	-16	-14	-28	-21	-31	-61	-																							
11	1CU-FN-1E-ENB-100	Pile Head Treatment	0	-16	-14	-28	-21	-31	-61	-																							
12	1CU-FN-1E-EAR-100	Blinding, Waterproofing, Block Works and Screed	0	-16	-14	-28	-21	-31	-61	-																							
13	1CU-FN-1F-ENB-100	Pile Head Treatment	0	-16	-14	-28	-21	-31	-61	-																							
14	1CU-FN-1D-RCC-100	Pile Caps works and Ground Beam works	0	-16	-14	-28	-21	-31	-61	-51	-																						
15	1CU-FN-1E-RCC-100	Pile Caps works	0	-16	-14	-28	-21	-27	-58	-51	-																						
16	1CU-FN-1E-EAR-110	Backfilling works	0	-16	-14	-28	-21	-27	-58	-51	-																						
17	1CU-FN-1F-RCC-100	Pile Caps works	0	-16	-14	-28	-21	-27	-58	-51	-																						
18	1CU-FN-1E-RCC-110	Slab on Grade	0	-16	-14	-28	-21	-27	-58	-47	-47	-																					
19	1CU-FN-1F-EAR-110	Backfilling works	0	-16	-14	-28	-21	-27	-58	-47	-47	-																					
20	1CU-FN-1F-RCC-110	Slab on Grade	0	-16	-14	-28	-21	-27	-58	-47	-47	-																					
21	1CU-FN-2D-EAR-110	Backfilling works	0	-16	-14	-28	-23	-27	-58	-47	-47	-																					
22	1CU-FN-2D-RCC-110	Slab on Grade	0	-16	-14	-28	-23	-27	-58	-47	-47	-																					
23	1CU-L0-2A-RCC-100	Construction of Verticals	39	16	16	-14	16	19	13	-9	-13	-45	-																				
24	1CU-L0-2A-RCC-110	Construction of Beams	39	16	16	-14	16	19	13	-9	-13	-45	-54	-																			
25	1CU-L0-2B-RCC-100	Construction of Verticals	39	16	16	-14	16	19	13	-9	-13	-45	-54	-																			
26	1CU-L0-2A-RCC-120	Construction of Slab @ Level 01	39	16	16	-14	16	19	13	-9	-13	-45	-54	-51	-																		
27	1CU-L0-2B-RCC-110	Construction of Beams	39	16	16	-14	16	19	13	-9	-13	-45	-54	-59	-																		
28	1CU-L0-2B-RCC-120	Construction of Slab @ Level 01	39	16	16	-14	16	19	13	-9	-13	-45	-54	-59	-87	-																	
29	1CU-L1-2D-RCC-100	Construction of Verticals	0	-16	-14	-28	-23	-27	-58	-47	-44	-35	-31	-44	-87	-																	
30	1CU-L1-2B-RCC-100	Construction of Verticals	39	16	16	-14	16	19	13	-9	-13	-45	-51	-59	-87	-84	-																
31	1CU-L1-2B-RCC-110	Construction of Beams	39	16	16	-14	16	19	13	-9	-13	-45	-51	-55	-69	-84	-																
32	1CU-L1-2B-RCC-120	Construction of Roof RCC slab and Hollow Core Slab	39	16	16	-14	16	19	13	-9	-13	-45	-51	-55	-69	-84	-																
	PUBLIC AREAS																																
34	1CU-L0-PUBL-BLK-110	Marking, Cutting & Chasing Walls for MEP Services	21	6	7	-7	-2	-6	-37	-26	-23	-17	-26	-31	-45	-54	-53	-76	-														
35	1CU-L0-PUBL-BLK-120	Sub Frames Fixing	21	6	7	-7	-2	-6	-37	-26	-23	-17	-26	-31	-45	-54	-53	-76	-70	-													
36	1CU-L0-PUBL-PLM-100	1st Fix Water Supply Walls (Piping Supports)	34	19	20	6	12	7	-24	-13	-10	-4	-13	-18	-32	-41	-40	-60	-74	-													
37	1CU-L0-PUBL-PLM-120	1st Fix Drainage Walls (Supports & Embedded Pipes)	26	19	20	6	12	7	-24	-13	-10	-4	-13	-25	-32	-41	-40	-60	-74	-													
38	1CU-L0-WETT-FLR-100	Floor Waterproofing	21	6	7	-7	-2	-6	-37	-26	-23	-17	-45	-34	-45	-54	-53	-73	-74	-													
39	1CU-L0-PUBL-BLK-130	Plastering Works	21	6	7	-7	-2	-6	-37	-26	-23	-17	-45	-34	-45	-54	-53	-73	-74	-86	-												
40	1CU-L0-PUBL-PLM-130	2nd Fix Drainage Walls (Piping, Fittings & Connections)	26	19	20	6	12	7	-24	-13	-10	-4	-13	-25	-32	-41	-40	-60	-74	-86	-												
41	1CU-L0-PUBL-PLM-110	2nd Fix Water Supply Walls (Piping, Fittings, Insulation & Connections)	24	7	7	7	7	9	-23	-12	-9	-13	-45	-34	-35	-40	-39	-59	-74	-86	-												
42	1CU-L0-MSRM-FLR-100	Floor Screed	21	6	7	-7	-2	-6	-37	-26	-23	-17	-45	-34	-45	-54	-53	-73	-74	-86	-												

Figure D.1. Contemporaneous Critical Path - TSWA (cont.).

			2016								2017												2018										
			0	-17	-16	-32	-26	-31	-61	-51	-47	-45	-54	-59	-87	-84	-69	-76	-74	-93	-114	-117	-101	-98	-90	-95	-77	-90	-97	-102	-91	-94	-92
			4	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11
SN	Activity ID	Activity Name	AP	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
	CHILLER ROOMS																																
43	1CU-L1-CHRM-FLR-100	Floor Screed	0	-16	-14	-28	-23	-27	-58	-47	-44	-45	-51	-55	-82	-75	-53	-42	-54	-81	-83	-68	-73	-98	-								
44	1CU-L1-CHRM-WLL-100	Wall Finishes	0	-16	-14	-28	-23	-27	-58	-47	-44	-45	-51	-55	-82	-75	-53	-42	-54	-81	-83	-68	-73	-98	-								
45	1CU-L1-CHRM-HVC-100	1st Fix HVAC	79	63	65	51	56	52	21	32	35	35	28	24	-4	7	26	37	25	-6	-37	-68	-73	-98	-								
46	1CU-L1-CHRM-HVC-110	2nd Fix HVAC	79	63	65	51	56	52	21	32	35	35	28	24	-4	7	26	37	25	-6	-37	-68	-73	-98	-								
47	1CU-L1-CHRM-HVC-140	Installation of Chiller Control Panels 8 Nos	79	63	65	51	56	52	21	32	4	-23	-49	-45	-32	-30	-30	-30	-32	-30	-38	-68	-73	-98	-69	-95	-72	-					
	GENERATOR BUILDING																																
48	1CU-L1-LVRM-BLK-100	Block Work	62	47	48	34	40	35	5	16	19	19	12	7	-20	-10	10	20	40	21	-10	-41	-62	-84	-90	-							
49	1CU-L1-LVRM-BLK-120	Marking, Cutting & Chasing Walls for MEP Services	62	47	48	34	40	35	5	16	19	19	12	7	-20	-10	10	20	40	21	-10	-41	-62	-84	-90	-							
50	1CU-L1-LVRM-BLK-130	Plastering Works	62	47	48	34	40	35	5	16	19	19	12	7	-20	-10	10	20	40	21	-10	-41	-62	-84	-90	-84	-						
51	1CU-L1-LVRM-FLR-100	Floor Screed	62	47	48	34	40	35	5	16	19	19	12	7	-20	-10	10	20	40	21	-10	-41	-62	-84	-90	-84	-						
52	1CU-L1-LVRM-WLL-100	Wall Finishes	62	47	48	34	40	35	5	16	19	19	12	7	-20	-10	10	20	40	21	-10	-41	-62	-84	-90	-84	-						
53	1CU-L1-LVRM-HVC-110	2nd Fix HVAC	82	67	68	54	60	55	25	35	39	39	32	27	0	11	30	40	60	41	11	-20	-42	-69	-90	-84	-67	-					
54	1CU-L0-GNRL-TNC-120	Testing of SCADA and BMS systems	35	20	21	7	13	9	-23	-12	-9	11	-16	-35	-47	-37	-34	-34	-35	-55	-72	-91	-94	-75	-72	-80	-77	-					
	EXTERNAL FACADE CLADDING																																
55	1CU-EVN-NORT-FCD-110	Installation of Terracotta Cladding	41	41	41	41	41	41	41	41	14	-16	-16	-30	-62	-47	-47	-47	-58	-73	-68	-76	-76	-76	-60	-34	-30	-90	-				
56	1CU-EVE-EAST-FCD-110	Installation of Terracotta Cladding	41	41	41	41	41	41	41	41	14	-16	-16	-30	-62	-47	-47	-47	-58	-73	-68	-76	-76	-76	-60	-34	-60	-90	-70	-			
57	1CU-EVS-SOUT-FCD-110	Installation of Terracotta Cladding	41	41	41	41	41	41	37	41	14	-16	-16	-30	-62	-47	-47	-47	-58	-73	-68	-76	-76	-76	-60	-34	-60	-90	-70	-			
58	1CU-EVW-WEST-FCD-110	Installation of Terracotta Cladding	37	32	33	19	25	20	-11	0	4	-20	-20	-34	-67	-52	-52	-52	-62	-77	-73	-80	-80	-80	-65	-40	-65	-90	-70	-68	-		
	ELECTRICAL SUBSTATIONS																																
59	FAB26250000	Manufacturing / Fabrication of Materials	42	42	42	42	42	42	18	-13	-28	-28	-28	-41	-73	-58	-69	-															
60	1CU-L0-MVRM-BLK-120	Marking, Cutting & Chasing Walls for MEP Services	12	-4	-3	-17	-11	-16	-46	-35	-32	-36	-39	-44	-70	-60	-41	-45	-74	-93	-												
61	1CU-L0-MVRM-FLR-100	Floor Screed	12	-4	-3	-17	-11	-16	-46	-35	-32	-35	-39	-44	-70	-60	-41	-45	-74	-93	-												
62	1CU-L0-MVRM-BLK-130	Plastering Works	12	-4	-3	-17	-11	-16	-46	-35	-32	-35	-39	-44	-70	-60	-41	-45	-74	-93	-114	-											
63	1CU-L0-MVRM-WLL-100	Wall Finishes	12	-4	-3	-17	-11	-16	-46	-35	-32	-35	-39	-44	-70	-60	-41	-45	-74	-93	-114	-											
64	1CU-L0-MVRM-CEL-100	Ceiling Finishes	12	-4	-3	-17	-11	-16	-46	-35	-32	-35	-39	-44	-70	-60	-41	-45	-70	-93	-114	-											
65	1CU-L0-MVRM-ELC-100	1st Fix Electrical / ELV	12	-4	-3	-17	-11	-16	-46	-35	-32	-35	-39	-44	-70	-60	-41	-45	-70	-88	-114	-											
66	1CU-L0-TRRM-HVC-100	1st Fix HVAC	12	-4	-3	-17	-11	-16	-46	-35	-32	-35	-39	-44	-70	-63	-41	-26	-45	-68	-94	-117	-										
67	1CU-L0-TRRM-HVC-110	2nd Fix HVAC	12	-4	-3	-17	-11	-16	-46	-35	-32	-35	-39	-44	-70	-63	-41	-26	-45	-68	-94	-117	-101	-									
68	1CU-L0-TRRM-FFE-100	Door Shuttering & Ironmongery	0	-16	-14	-28	-23	-27	-58	-47	-44	-25	-51	-55	-82	-75	-66	-38	-56	-80	-105	-117	-101	-84	-								
69	1CU-L0-TRRM-ELC-120	Installation of Step down Transformer	0	-16	-14	-28	-23	-27	-58	-47	-44	-25	-51	-55	-82	-75	-66	-38	-56	-80	-105	-117	-101	-84	-								
70	1CU-BL-GNRL-DSG-100	Submit Draft Close out Documents	0	-17	-16	-32	-26	-31	-61	-51	-47	-45	-54	-59	-87	-84	-53	-76	-74	-81	-83	-86	-85	-98	-87	-95	-74	-72	-97	-91	-		
71	1CU-EV-GNRL-ELC-110	Statutory Body approvals	0	-17	-16	-32	-26	-31	-61	-51	-47	-45	-54	-59	-87	-75	-69	-58	-74	-93	-114	-117	-101	-93	-84	-46	-51	-37	-75	-102	-		
72	1CU-EV-GNRL-TNC-100	Testing, Energization and Power on	0	-17	-16	-32	-26	-31	-61	-51	-47	-45	-54	-59	-87	-75	-69	-58	-74	-93	-114	-117	-101	-93	-84	-46	-51	-37	-75	-102	-		
	FINAL TESTING AND SNAGGING																																
73	1CU-BL-GNRL-TNC-120	Final Testing,Snagging and Desnagging works Irrigation system	0	-17	-16	-32	-26	-31	-61	-51	-47	-45	-54	-59	-87	-75	-69	-58	-74	-93	-114	-117	-101	-93	-90	-84	-70	-66	-75	-102	-91	-	
74	1CU-BL-GNRL-TNC-130	Final Testing,Snagging and Desnagging works Electronic Safety and Security system	0	-17	-16	-32	-26	-31	-61	-51	-47	-45	-54	-59	-87	-75	-69	-58	-74	-93	-114	-117	-101	-93	-90	-84	-70	-66	-75	-102	-91	-94	-72
75	1CU-BL-GNRL-TNC-140	Final Testing,Snagging and Desnagging works Electrical system	0	-17	-16	-32	-26	-31	-61	-51	-47	-45	-54	-59	-87	-75	-69	-58	-74	-93	-114	-117	-101	-93	-90	-84	-70	-66	-75	-102	-91	-94	-84
76	1CU-BL-GNRL-TNC-150	Final Testing,Snagging and Desnagging works SCADA and BMS systems	0	-17	-16	-32	-26	-31	-61	-51	-47	-45	-54	-59	-87	-75	-69	-58	-74	-93	-114	-117	-101	-93	-90	-84	-77	-66	-75	-102	-91	-94	-92

Figure D.1. Contemporaneous Critical Path - TSWA (cont.).

APPENDIX E: INCIDENCE OF RISK EVENTS

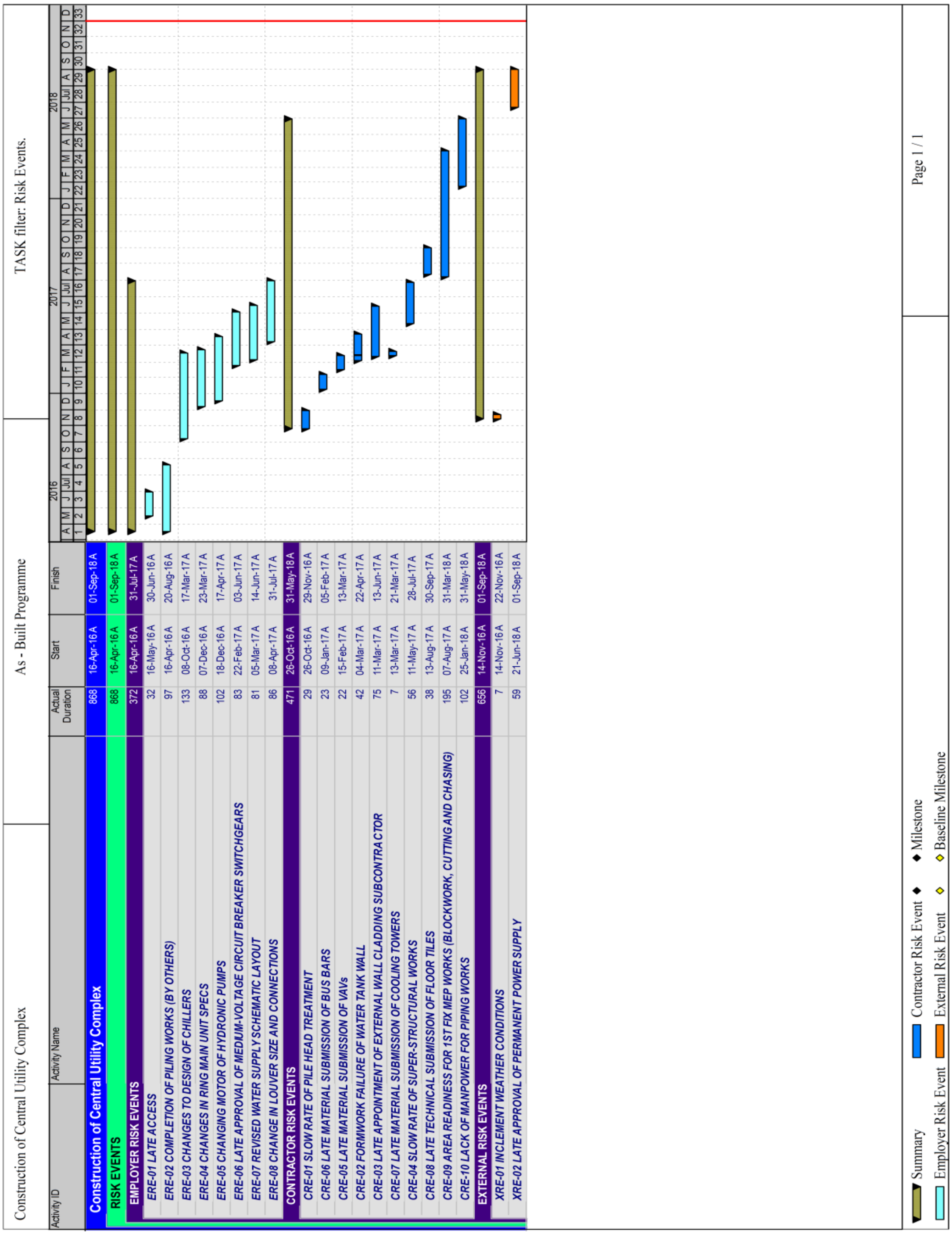


Figure E.1. Incidence of Risk Events.

APPENDIX F: BASELINE CRITICAL PATH

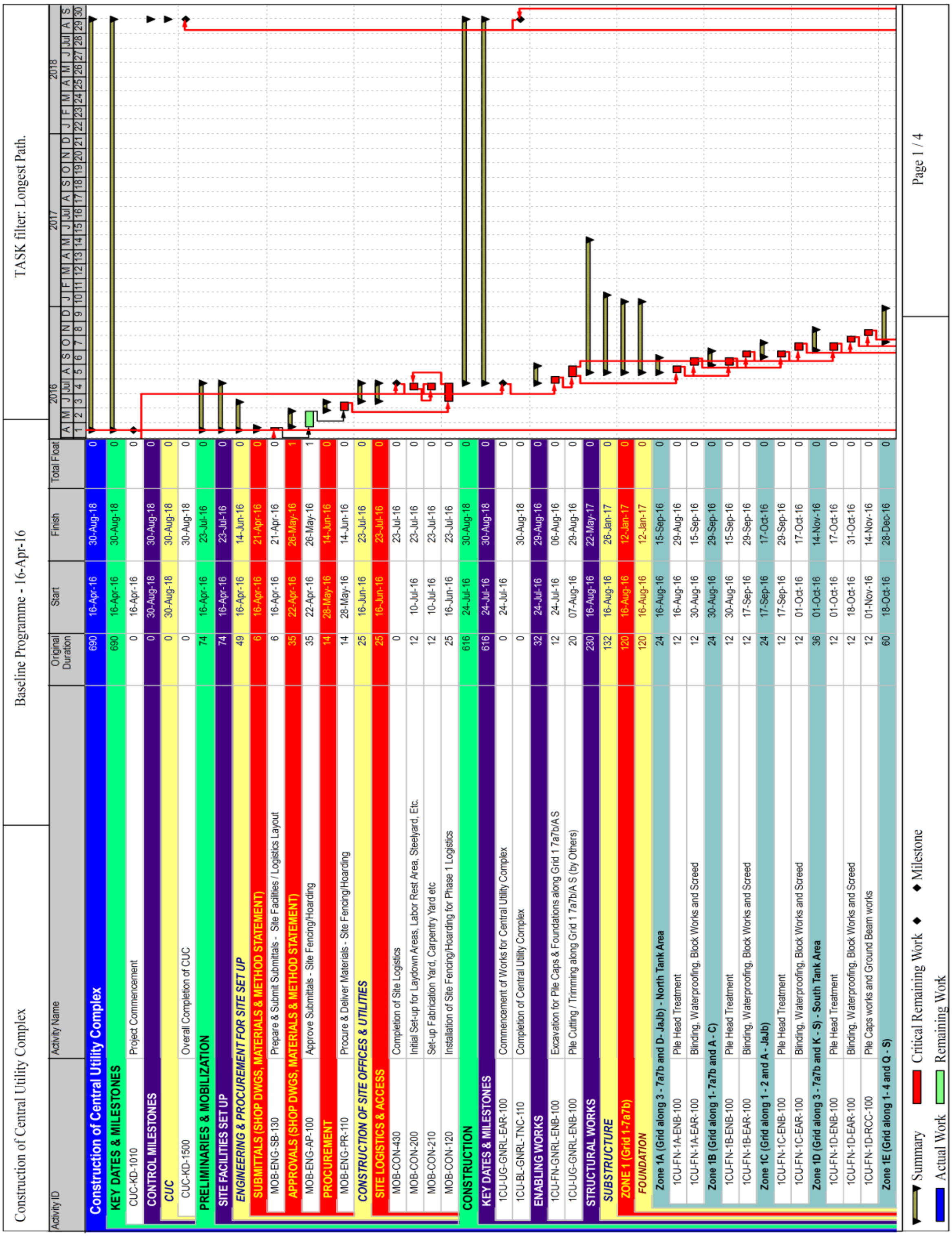
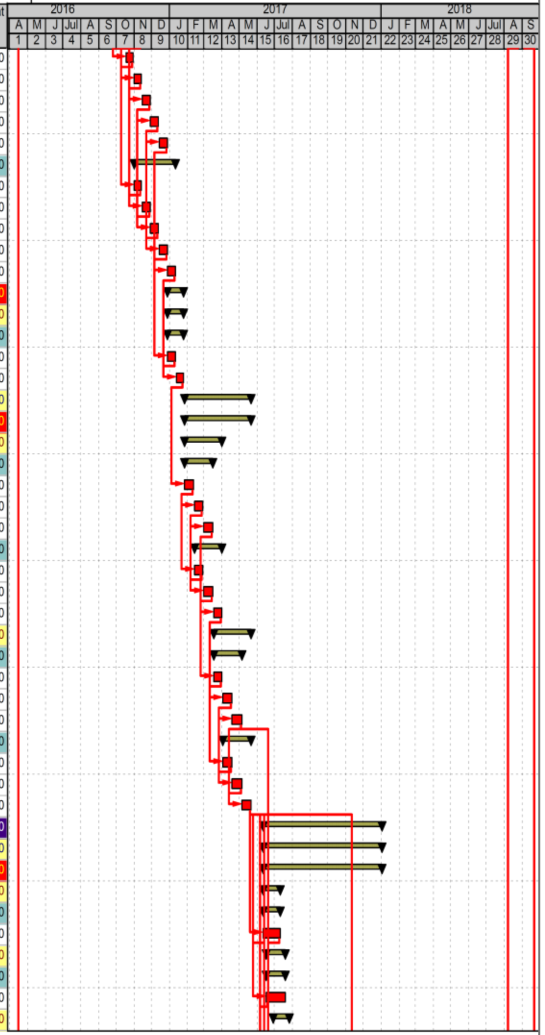


Figure F.1. Baseline Critical Path.

Construction of Central Utility Complex | Baseline Programme - 16-Apr-16 | TASK filter: Longest Path.

Activity ID	Activity Name	Original Duration	Start	Finish	Total Float
1CU-FN-1E-ENB-100	Pile Head Treatment	12	18-Oct-16	31-Oct-16	0
1CU-FN-1E-EAR-100	Blinding, Waterproofing, Block Works and Screed	12	01-Nov-16	14-Nov-16	0
1CU-FN-1E-RCC-100	Pile Caps works	12	15-Nov-16	28-Nov-16	0
1CU-FN-1E-EAR-110	Backfilling works	12	29-Nov-16	13-Dec-16	0
1CU-FN-1E-RCC-110	Slab on Grade	12	14-Dec-16	28-Dec-16	0
Zone 1F (Grid along 1- 2 and K - S)		60	01-Nov-16	12-Jan-17	0
1CU-FN-1F-ENB-100	Pile Head Treatment	12	01-Nov-16	14-Nov-16	0
1CU-FN-1F-EAR-100	Blinding, Waterproofing, Block Works and Screed	12	15-Nov-16	28-Nov-16	0
1CU-FN-1F-RCC-100	Pile Caps works	12	29-Nov-16	13-Dec-16	0
1CU-FN-1F-EAR-110	Backfilling works	12	14-Dec-16	28-Dec-16	0
1CU-FN-1F-RCC-110	Slab on Grade	12	29-Dec-16	12-Jan-17	0
ZONE 2 (Grid 8 -2')		24	29-Dec-16	26-Jan-17	0
FOUNDATION		24	29-Dec-16	26-Jan-17	0
Zone 2D (Grid along 8 - 12 and K - N)		24	29-Dec-16	26-Jan-17	0
1CU-FN-2D-EAR-110	Backfilling works	12	29-Dec-16	12-Jan-17	0
1CU-FN-2D-RCC-110	Slab on Grade	12	14-Jan-17	26-Jan-17	0
SUPERSTRUCTURE		98	28-Jan-17	22-May-17	0
ZONE 2 (Grid 8 -2')		98	28-Jan-17	22-May-17	0
LEVEL 00		56	28-Jan-17	02-Apr-17	0
Zone 2D (Grid along 8 - 12 and K - N)		42	28-Jan-17	16-Mar-17	0
1CU-L0-2D-RCC-100	Construction of Verticals	14	28-Jan-17	12-Feb-17	0
1CU-L0-2D-RCC-110	Construction of Beams	14	13-Feb-17	28-Feb-17	0
1CU-L0-2D-RCC-120	Construction of Slab @ Level 01	14	01-Mar-17	16-Mar-17	0
Zone 2E (Grid along 8 - 12 and O - S)		42	13-Feb-17	02-Apr-17	0
1CU-L0-2E-RCC-100	Construction of Verticals	14	13-Feb-17	28-Feb-17	0
1CU-L0-2E-RCC-110	Construction of Beams	14	01-Mar-17	16-Mar-17	0
1CU-L0-2E-RCC-120	Construction of Slab @ Level 01	14	18-Mar-17	02-Apr-17	0
LEVEL 01		56	18-Mar-17	22-May-17	0
Zone 2D (Grid along 8 - 12 and K - N)		42	18-Mar-17	06-May-17	0
1CU-L1-2D-RCC-100	Construction of Verticals	14	18-Mar-17	02-Apr-17	0
1CU-L1-2D-RCC-110	Construction of Beams	14	03-Apr-17	18-Apr-17	0
1CU-L1-2D-RCC-120	Construction of Roof RCC slab and Hollow Core Slab	14	19-Apr-17	06-May-17	0
Zone 2E (Grid along 8 - 12 and O - S)		42	03-Apr-17	22-May-17	0
1CU-L1-2E-RCC-100	Construction of Verticals	14	03-Apr-17	18-Apr-17	0
1CU-L1-2E-RCC-110	Construction of Beams	14	19-Apr-17	06-May-17	0
1CU-L1-2E-RCC-120	Construction of Roof RCC slab and Hollow Core Slab	14	07-May-17	22-May-17	0
INTERNAL FINISHES & MEP		164	11-Jun-17	03-Jan-18	0
Level 00		164	11-Jun-17	03-Jan-18	0
MEP/UTILITIES/SERVICE AREA		164	11-Jun-17	03-Jan-18	0
CHEMICAL DOSING ROOM (GF-21')		20	11-Jun-17	11-Jul-17	0
FINISHES		20	11-Jun-17	11-Jul-17	0
1CU-L0-TCRM-BLK-140	Block Work	20	11-Jun-17	11-Jul-17	0
TECHNICAL GALLERY FOR OUTGOING LOOP (GF-14 & GF-15)		24	17-Jun-17	19-Jul-17	0
FINISHES		24	17-Jun-17	19-Jul-17	0
1CU-L0-TCGL-BLK-100	Block Work	24	17-Jun-17	19-Jul-17	0
MV ROOM 1 & 2 (GF-09 & GF-10)		24	29-Jun-17	26-Jul-17	0

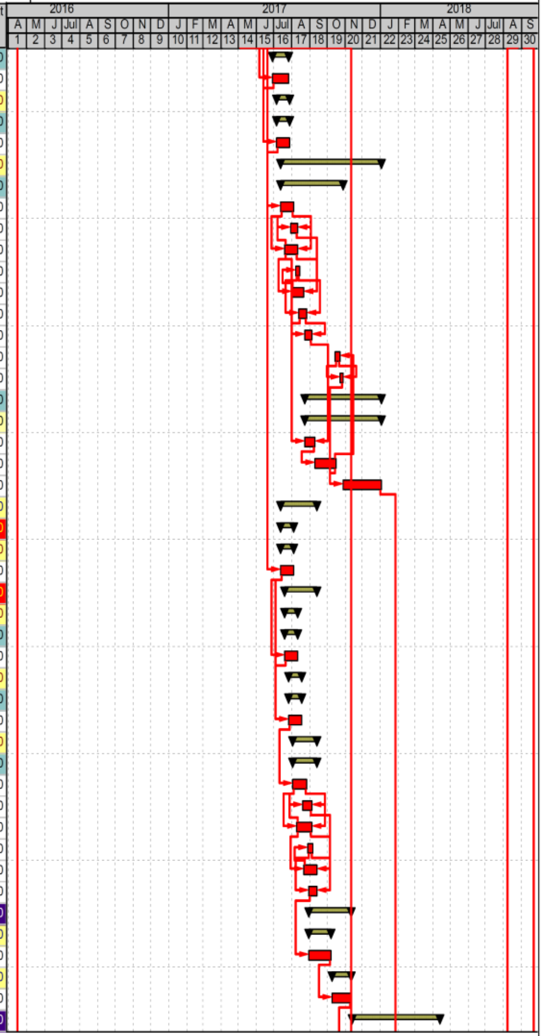


Summary | Critical Remaining Work | ◆ Milestone | Actual Work | Remaining Work | Page 2 / 4

Figure F.1. Baseline Critical Path (cont.).

Construction of Central Utility Complex	Baseline Programme - 16-Apr-16	TASK filter: Longest Path.

Activity ID	Activity Name	Original Duration	Start	Finish	Total Float
FINISHES		24	29-Jun-17	26-Jul-17	0
1CU-L0-MVRM-BLK-100	Block Work	24	29-Jun-17	26-Jul-17	0
ATS ROOM 1 & 2 (GF-11 & GF-12)		20	06-Jul-17	29-Jul-17	0
FINISHES		20	06-Jul-17	29-Jul-17	0
1CU-L0-ELRM-BLK-100	Block Work	20	06-Jul-17	29-Jul-17	0
STEP DOWN TRANSFORMER ROOM (GF-05,GF-06 & GF-35)		143	13-Jul-17	03-Jan-18	0
FINISHES		88	13-Jul-17	28-Oct-17	0
1CU-L0-TRRM-BLK-100	Block Work	20	13-Jul-17	05-Aug-17	0
1CU-L0-TRRM-BLK-110	Sub Frames Fixing	12	30-Jul-17	12-Aug-17	0
1CU-L0-TRRM-BLK-120	Marking, Cutting & Chasing Walls for MEP Services	20	20-Jul-17	12-Aug-17	0
1CU-L0-TRRM-FLR-100	Floor Screed	6	08-Aug-17	14-Aug-17	0
1CU-L0-TRRM-BLK-130	Plastering Works	18	01-Aug-17	21-Aug-17	0
1CU-L0-TRRM-WLL-100	Wall Finishes	12	13-Aug-17	26-Aug-17	0
1CU-L0-TRRM-CEL-100	Ceiling Finishes	8	24-Aug-17	04-Sep-17	0
1CU-L0-TRRM-FLR-110	Floor Finishes	8	15-Oct-17	23-Oct-17	0
1CU-L0-TRRM-FFE-100	Door Shuttering & Ironmongery	4	24-Oct-17	28-Oct-17	0
MEP WORKS		107	24-Aug-17	03-Jan-18	0
ELECTRICAL		107	24-Aug-17	03-Jan-18	0
1CU-L0-TRRM-ELC-100	1st Fix Electrical / ELV	12	24-Aug-17	09-Sep-17	0
1CU-L0-TRRM-ELC-110	2nd Fix Electrical / ELV	30	10-Sep-17	16-Oct-17	0
1CU-L0-TRRM-ELC-120	Installation of Step down Transformer	55	29-Oct-17	03-Jan-18	0
Level 01		53	13-Jul-17	14-Sep-17	0
PUBLIC/COMMON AREAS		20	13-Jul-17	05-Aug-17	0
GENERAL WORKS		20	13-Jul-17	05-Aug-17	0
1CU-L1-PUBL-BLK-100	Block Work	20	13-Jul-17	05-Aug-17	0
MEP/UTILITIES/SERVICE AREA		47	20-Jul-17	14-Sep-17	0
SPARE PARTS AND REFRIGERANT STORAGE (1F-02)		20	20-Jul-17	12-Aug-17	0
FINISHES		20	20-Jul-17	12-Aug-17	0
1CU-L1-STRM-BLK-100	Block Work	20	20-Jul-17	12-Aug-17	0
PUMP ROOM (1F-12)		20	27-Jul-17	19-Aug-17	0
FINISHES		20	27-Jul-17	19-Aug-17	0
1CU-L1-PMRM-BLK-100	Block Work	20	27-Jul-17	19-Aug-17	0
COOLING CHILLER ROOM WITH MOBILE CRANE (1F-05 & 1F-17)		35	03-Aug-17	14-Sep-17	0
FINISHES		35	03-Aug-17	14-Sep-17	0
1CU-L1-CHRM-BLK-100	Block Work	20	03-Aug-17	26-Aug-17	0
1CU-L1-CHRM-BLK-110	Sub Frames Fixing	12	20-Aug-17	04-Sep-17	0
1CU-L1-CHRM-BLK-120	Marking, Cutting & Chasing Walls for MEP Services	20	10-Aug-17	04-Sep-17	0
1CU-L1-CHRM-FLR-100	Floor Screed	6	29-Aug-17	06-Sep-17	0
1CU-L1-CHRM-BLK-130	Plastering Works	18	22-Aug-17	13-Sep-17	0
1CU-L1-CHRM-WLL-100	Wall Finishes	12	30-Aug-17	14-Sep-17	0
ENVELOPE FINISHES		60	30-Aug-17	12-Nov-17	0
NORTH ELEVATION		30	30-Aug-17	08-Oct-17	0
1CU-EV-NORT-WLL-100	External Plaster and Painting Works	30	30-Aug-17	08-Oct-17	0
EAST ELEVATION		30	09-Oct-17	12-Nov-17	0
1CU-EV-EAST-WLL-100	External Plaster and Painting Works	30	09-Oct-17	12-Nov-17	0
EXTERNAL WORKS		128	13-Nov-17	14-Apr-18	0



Summary · Critical Remaining Work ◆ · ◆ Milestone · Actual Work · Remaining Work

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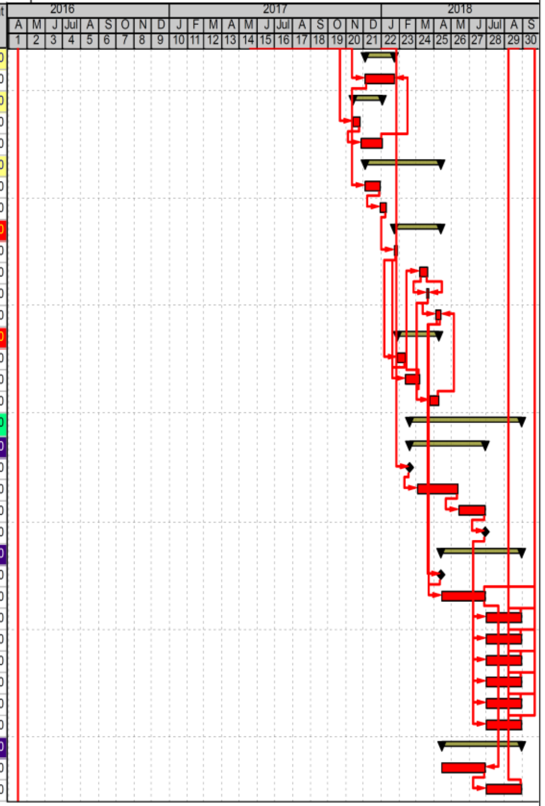
Figure F.1. Baseline Critical Path (cont.).

Construction of Central Utility Complex | Baseline Programme - 16-Apr-16 | TASK filter: Longest Path.

Activity ID	Activity Name	Original Duration	Start	Finish	Total Float
EXTERNAL WORKS & HARD LANDSCAPING		42	04-Dec-17	24-Jan-18	0
1CU-UG-EXTR-EXT-100	Grading and Sub Base works	42	04-Dec-17	24-Jan-18	0
UNDERGROUND FUEL TANK		42	13-Nov-17	03-Jan-18	0
1CU-UG-EXTR-EAR-100	Excavation for Underground Fuel Tank	12	13-Nov-17	26-Nov-17	0
1CU-UG-EXTR-ELC-110	Installation of Underground Fuel Tank and MEP Works	30	27-Nov-17	03-Jan-18	0
GUARD ROOM		110	04-Dec-17	14-Apr-18	0
1CU-FN-EXTR-RCC-110	Foundation works and SOG	21	04-Dec-17	30-Dec-17	0
1CU-BL-EXTR-RCC-100	Verticals and Slab	8	31-Dec-17	09-Jan-18	0
FINISHES		69	24-Jan-18	14-Apr-18	0
1CU-EV-EXTR-BLK-100	Block Work	4	24-Jan-18	28-Jan-18	0
1CU-EV-EXTR-FLR-110	Floor Finishes	12	08-Mar-18	21-Mar-18	0
1CU-EV-EXTR-FFE-100	Door Shuttering & Ironmongery	4	20-Mar-18	24-Mar-18	0
1CU-EV-EXTR-FFE-110	Final Finishes & Cleaning	8	05-Apr-18	14-Apr-18	0
MEP WORKS		61	29-Jan-18	09-Apr-18	0
1CU-EV-EXTR-ELC-100	MEP First Fix	12	29-Jan-18	11-Feb-18	0
1CU-EV-EXTR-ELC-110	MEP Second Fix	21	12-Feb-18	07-Mar-18	0
1CU-EV-EXTR-ELC-120	MEP Final Fix	14	25-Mar-18	09-Apr-18	0
TESTING & COMMISSIONING WORKS		151	18-Feb-18	30-Aug-18	0
READINESS FOR POWER ON AND WILD AIR		99	18-Feb-18	28-Jun-18	0
1CU-EV-GNRL-ELC-100	Readiness of Transformer, MV Rooms and ATS Rooms for Power on requirement	0		18-Feb-18	0
1CU-EV-GNRL-ELC-110	Statutory Body approvals	60	04-Mar-18	13-May-18	0
1CU-EV-GNRL-TNC-100	Testing, Energization and Power on	28	14-May-18	28-Jun-18	0
1CU-EV-GNRL-ELC-130	Availability of Power on	0		28-Jun-18	0
FINAL TESTING, SNAGGING & DESNAGGING WORKS		104	14-Apr-18	30-Aug-18	0
1CU-RF-GNRL-FLR-100	Completion of Finishes at Roof	0		14-Apr-18	0
1CU-BL-GNRL-TNC-190	Final Testing ,Snagging and Desnagging Works Finishes	52	15-Apr-18	28-Jun-18	0
1CU-BL-GNRL-TNC-160	Final Testing,Snagging and Desnagging works HVAC & Ventilation system	52	30-Jun-18	30-Aug-18	0
1CU-BL-GNRL-TNC-120	Final Testing,Snagging and Desnagging works Irrigation system	52	30-Jun-18	30-Aug-18	0
1CU-BL-GNRL-TNC-130	Final Testing,Snagging and Desnagging works Electronic Safety and Security system (Fire A	52	30-Jun-18	30-Aug-18	0
1CU-BL-GNRL-TNC-140	Final Testing,Snagging and Desnagging works Electrical system	52	30-Jun-18	30-Aug-18	0
1CU-BL-GNRL-TNC-150	Final Testing,Snagging and Desnagging works SCADA and BMS systems	52	30-Jun-18	30-Aug-18	0
1CU-BL-GNRL-TNC-170	Final Testing,Snagging and Desnagging works Plumbing system	52	30-Jun-18	30-Aug-18	0
PROJECT CLOSEOUT DOCUMENTS		104	15-Apr-18	30-Aug-18	0
1CU-BL-GNRL-DSG-100	Submit Draft Close out Documents	52	15-Apr-18	28-Jun-18	0
1CU-BL-GNRL-DSG-110	Submit Project Close out Documents	52	30-Jun-18	30-Aug-18	0



Summary | Critical Remaining Work | ◆ Milestone | Actual Work | Remaining Work

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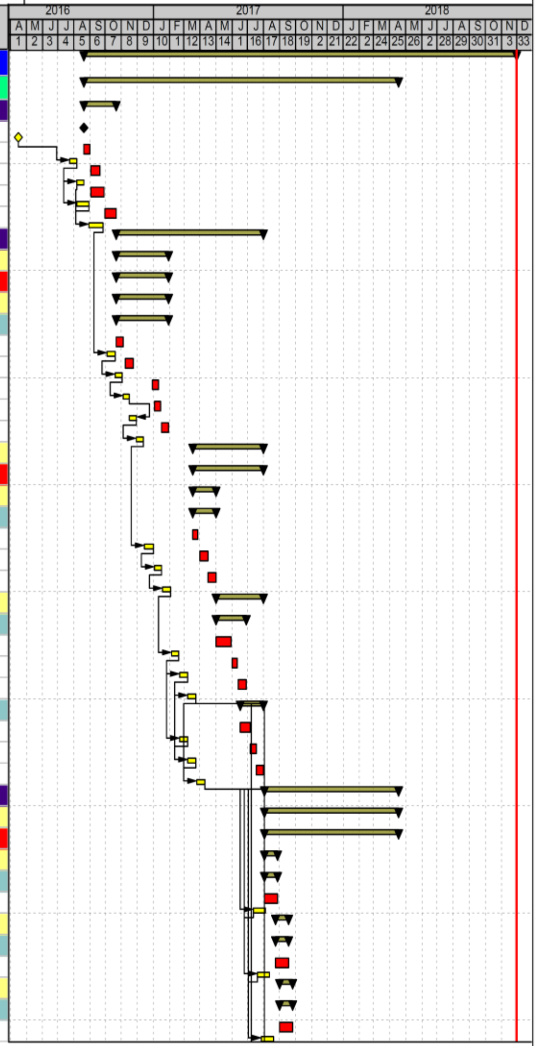
Figure F.1. Baseline Critical Path (cont.).

APPENDIX G: AS-BUILT CRITICAL PATH

Construction of Central Utility Complex		Retrospective Longest Path As of - 30-Nov-18					TASK filter: As-Built Critical Path.
Activity ID	Activity Name	Baseline Duration	Baseline Late Start	Baseline Late Finish	Actual Start	Actual Finish	Actual Duration
Construction of Central Utility Complex		690	24-Jul-16	30-Aug-18	20-Aug-16 A	30-Nov-18 A	667
CONSTRUCTION		472	24-Jul-16	05-Feb-18	20-Aug-16 A	18-Apr-18 A	492
ENABLING WORKS		126	24-Jul-16	28-Sep-16	20-Aug-16 A	22-Oct-16 A	48
1CU-BL-GNRL-ENB-100	Completion of Piling works (by Others) and Access to Site	0	24-Jul-16		20-Aug-16 A		0
1CU-FN-GNRL-ENB-100	Excavation for Pile Caps & Foundations along Grid 1 7a7b/A S	12	24-Jul-16	06-Aug-16	20-Aug-16 A	01-Sep-16 A	12
1CU-FN-GNRL-ENB-110	Excavation for Pile Caps & Foundations along Grid 8 2'/A S	12	03-Sep-16	19-Sep-16	03-Sep-16 A	19-Sep-16 A	12
1CU-UG-GNRL-ENB-100	Pile Cutting / Trimming along Grid 1 7a7b/A S (by Others)	20	07-Aug-16	29-Aug-16	03-Sep-16 A	28-Sep-16 A	20
1CU-UG-GNRL-ENB-110	Pile Cutting / Trimming along Grid 8 2'/A S (by Others)	20	03-Sep-16	28-Sep-16	29-Sep-16 A	22-Oct-16 A	16
STRUCTURAL WORKS		156	08-Oct-16	18-May-17	22-Oct-16 A	31-Jul-17 A	227
SUBSTRUCTURE		58	08-Oct-16	23-Jan-17	22-Oct-16 A	29-Jan-17 A	83
ZONE 2 (Grid 8 -2')		58	08-Oct-16	23-Jan-17	22-Oct-16 A	29-Jan-17 A	83
FOUNDATION		58	08-Oct-16	23-Jan-17	22-Oct-16 A	29-Jan-17 A	83
Zone 2A (Grid along 8 - 12 and F - JaJb)		58	08-Oct-16	23-Jan-17	22-Oct-16 A	29-Jan-17 A	83
1CU-FN-2A-ENB-100	Pile Head Treatment	12	08-Oct-16	23-Oct-16	22-Oct-16 A	05-Nov-16 A	12
1CU-FN-2A-EAR-100	Blinding, Waterproofing, Block Works and Screed	12	24-Oct-16	06-Nov-16	08-Nov-16 A	23-Nov-16 A	13
1CU-FN-2A-RCC-100	Pile Caps works and Tunnel works	12	22-Dec-16	05-Jan-17	31-Dec-16 A	11-Jan-17 A	10
1CU-FN-2A-EAR-110	Backfilling works	12	26-Dec-16	09-Jan-17	02-Jan-17 A	15-Jan-17 A	12
1CU-FN-2A-RCC-110	Slab on Grade	12	10-Jan-17	23-Jan-17	16-Jan-17 A	29-Jan-17 A	12
SUPERSTRUCTURE		98	24-Jan-17	18-May-17	18-Mar-17 A	31-Jul-17 A	104
ZONE 2 (Grid 8 -2')		98	24-Jan-17	18-May-17	18-Mar-17 A	31-Jul-17 A	104
LEVEL 00		42	24-Jan-17	13-Mar-17	18-Mar-17 A	01-May-17 A	38
Zone 2A (Grid along 8 - 12 and F - JaJb)		42	24-Jan-17	13-Mar-17	18-Mar-17 A	01-May-17 A	38
1CU-L0-2A-RCC-100	Construction of Verticals	14	24-Jan-17	08-Feb-17	18-Mar-17 A	28-Mar-17 A	9
1CU-L0-2A-RCC-110	Construction of Beams	14	09-Feb-17	25-Feb-17	01-Apr-17 A	16-Apr-17 A	13
1CU-L0-2A-RCC-120	Construction of Slab @ Level 01	14	26-Feb-17	13-Mar-17	17-Apr-17 A	01-May-17 A	12
LEVEL 01		56	14-Mar-17	18-May-17	02-May-17 A	31-Jul-17 A	66
Zone 2A (Grid along 8 - 12 and F - JaJb)		42	14-Mar-17	02-May-17	02-May-17 A	29-Jun-17 A	39
1CU-L1-2A-RCC-100	Construction of Verticals	14	14-Mar-17	29-Mar-17	02-May-17 A	30-May-17 A	23
1CU-L1-2A-RCC-110	Construction of Beams	14	30-Mar-17	15-Apr-17	01-Jun-17 A	12-Jun-17 A	7
1CU-L1-2A-RCC-120	Construction of Roof RCC slab and Hollow Core Slab	14	16-Apr-17	02-May-17	13-Jun-17 A	29-Jun-17 A	8
Zone 2B (Grid along 8 - 12 and A - E)		42	30-Mar-17	18-May-17	18-Jun-17 A	31-Jul-17 A	32
1CU-L1-2B-RCC-100	Construction of Verticals	14	30-Mar-17	15-Apr-17	18-Jun-17 A	06-Jul-17 A	11
1CU-L1-2B-RCC-110	Construction of Beams	14	16-Apr-17	02-May-17	06-Jul-17 A	18-Jul-17 A	10
1CU-L1-2B-RCC-120	Construction of Roof RCC slab and Hollow Core Slab	14	03-May-17	18-May-17	19-Jul-17 A	31-Jul-17 A	10
INTERNAL FINISHES & MEP		115	13-Jul-17	05-Feb-18	02-Aug-17 A	18-Apr-18 A	215
Level 00		115	13-Jul-17	05-Feb-18	02-Aug-17 A	18-Apr-18 A	215
MEP/UTILITIES/SERVICE AREA		115	13-Jul-17	05-Feb-18	02-Aug-17 A	18-Apr-18 A	215
STEP DOWN TRANSFORMER ROOM (GF-05,GF-06 & GF-35)		20	13-Jul-17	05-Aug-17	02-Aug-17 A	28-Aug-17 A	22
FINISHES		20	13-Jul-17	05-Aug-17	02-Aug-17 A	28-Aug-17 A	22
1CU-L0-TRRM-BLK-100	Block Work	20	13-Jul-17	05-Aug-17	02-Aug-17 A	28-Aug-17 A	22
STORAGE ROOM (GF-33 & GF-33)		20	27-Sep-17	21-Oct-17	24-Aug-17 A	18-Sep-17 A	20
FINISHES		20	27-Sep-17	21-Oct-17	24-Aug-17 A	18-Sep-17 A	20
1CU-L0-STRM-BLK-100	Block Work	20	27-Sep-17	21-Oct-17	24-Aug-17 A	18-Sep-17 A	20
BATTERY ROOM (GF-07 & GF-08)		20	05-Oct-17	28-Oct-17	31-Aug-17 A	26-Sep-17 A	20
FINISHES		20	05-Oct-17	28-Oct-17	31-Aug-17 A	26-Sep-17 A	20
1CU-L0-ELRM-BLK-140	Block Work	20	05-Oct-17	28-Oct-17	31-Aug-17 A	26-Sep-17 A	20



As-Planned Activities ◇ As-Planned Milestone As-Built Summary
As-Built Longest Path Activities ◆ As-Built Milestone

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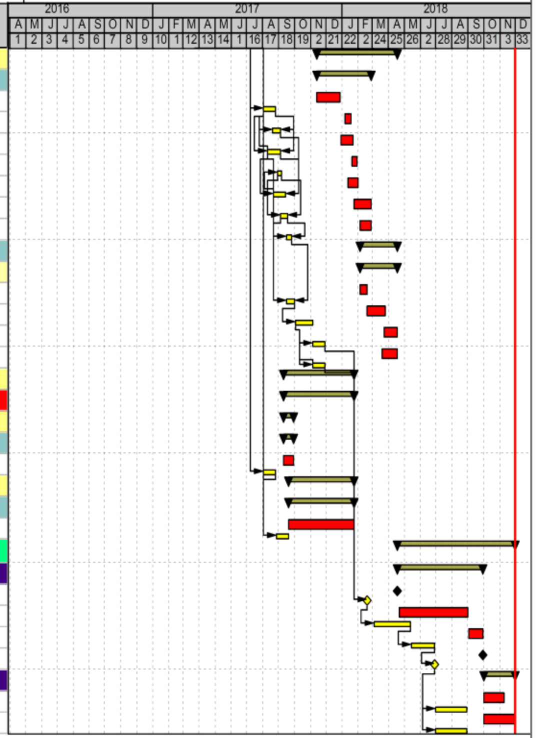
Figure G.1. As-Built Critical Path.

Construction of Central Utility Complex		Retrospective Longest Path As of - 30-Nov-18					TASK filter: As-Built Critical Path.
Activity ID	**Activity Name**	**Baseline Duration**	**Baseline Late Start**	**Baseline Late Finish**	**Actual Start**	**Actual Finish**	**Actual Duration**
GENERATOR ROOMS (GF-01 & GF-02) and Totalizing Room (GF-03)		97	12-Oct-17	05-Feb-18	13-Nov-17 A	18-Apr-18 A	131
FINISHES		44	12-Oct-17	02-Dec-17	13-Nov-17 A	27-Feb-18 A	88
1CU-L0-GERM-BLK-100	Block Work	20	12-Oct-17	04-Nov-17	13-Nov-17 A	28-Dec-17 A	37
1CU-L0-GERM-BLK-110	Sub Frames Fixing	12	29-Oct-17	11-Nov-17	06-Jan-18 A	18-Jan-18 A	11
1CU-L0-GERM-BLK-120	Marking, Cutting & Chasing Walls for MEP Services	20	19-Oct-17	11-Nov-17	31-Dec-17 A	23-Jan-18 A	19
1CU-L0-GERM-FLR-100	Floor Screed	6	07-Nov-17	13-Nov-17	20-Jan-18 A	30-Jan-18 A	9
1CU-L0-GERM-BLK-130	Plastering Works	18	31-Oct-17	20-Nov-17	13-Jan-18 A	01-Feb-18 A	17
1CU-L0-GERM-WLL-100	Wall Finishes	12	12-Nov-17	25-Nov-17	24-Jan-18 A	26-Feb-18 A	28
1CU-L0-GERM-CEL-100	Ceiling Finishes	8	23-Nov-17	02-Dec-17	05-Feb-18 A	27-Feb-18 A	19
MEP WORKS		61	23-Nov-17	05-Feb-18	05-Feb-18 A	18-Apr-18 A	62
ELECTRICAL		61	23-Nov-17	05-Feb-18	05-Feb-18 A	18-Apr-18 A	62
1CU-L0-GERM-ELC-100	1st Fix Electrical / ELV	12	23-Nov-17	06-Dec-17	05-Feb-18 A	18-Feb-18 A	11
1CU-L0-GERM-ELC-110	2nd Fix Electrical / ELV	30	07-Dec-17	14-Jan-18	19-Feb-18 A	25-Mar-18 A	29
1CU-L0-GERM-ELC-130	Installation of Totalizing Panel A & B	21	13-Jan-18	05-Feb-18	24-Mar-18 A	17-Apr-18 A	21
1CU-L0-GERM-ELC-120	Installation of Engine Generators and Daily Fuel Tank	21	13-Jan-18	05-Feb-18	20-Mar-18 A	18-Apr-18 A	25
Level 01		40	03-Aug-17	23-Nov-17	10-Sep-17 A	24-Jan-18 A	112
MEP/UTILITIES/SERVICE AREA		40	03-Aug-17	23-Nov-17	10-Sep-17 A	24-Jan-18 A	112
COOLING CHILLER ROOM WITH MOBILE CRANE (1F-05 & 1F-17)		20	03-Aug-17	26-Aug-17	10-Sep-17 A	30-Sep-17 A	16
FINISHES		20	03-Aug-17	26-Aug-17	10-Sep-17 A	30-Sep-17 A	16
1CU-L1-CHRM-BLK-100	Block Work	20	03-Aug-17	26-Aug-17	10-Sep-17 A	30-Sep-17 A	16
AHU ROOM (1F03, 1F-04,1F-07 & 1F-09)		20	01-Nov-17	23-Nov-17	21-Sep-17 A	24-Jan-18 A	102
FINISHES		20	01-Nov-17	23-Nov-17	21-Sep-17 A	24-Jan-18 A	102
1CU-L1-AHRM-BLK-100	Block Work	20	01-Nov-17	23-Nov-17	21-Sep-17 A	24-Jan-18 A	102
TESTING & COMMISSIONING WORKS		151	18-Feb-18	30-Aug-18	18-Apr-18 A	30-Nov-18 A	175
READINESS FOR POWER ON AND WILD AIR		99	18-Feb-18	28-Jun-18	18-Apr-18 A	29-Sep-18 A	122
1CU-EV-GNRL-ELC-100	Readiness of Transformer, MV Rooms and ATS Rooms for Power (	0		18-Feb-18		18-Apr-18 A	0
1CU-EV-GNRL-ELC-110	Statutory Body approvals	60	04-Mar-18	13-May-18	21-Apr-18 A	01-Sep-18 A	99
1CU-EV-GNRL-TNC-100	Testing, Energization and Power on	28	14-May-18	28-Jun-18	02-Sep-18 A	29-Sep-18 A	20
1CU-EV-GNRL-ELC-130	Availability of Power on	0		28-Jun-18		29-Sep-18 A	0
FINAL TESTING, SNAGGING & DESNAGGING WORKS		52	30-Jun-18	30-Aug-18	02-Oct-18 A	30-Nov-18 A	50
1CU-BL-GNRL-TNC-130	Final Testing,Snagging and Desnagging works Electronic Safety an	52	30-Jun-18	30-Aug-18	02-Oct-18 A	10-Nov-18 A	33
1CU-BL-GNRL-TNC-150	Final Testing,Snagging and Desnagging works SCADA and BMS s	52	30-Jun-18	30-Aug-18	02-Oct-18 A	30-Nov-18 A	50



As-Planned Activities ◇ As-Planned Milestone — As-Built Summary
As-Built Longest Path Activities ◆ As-Built Milestone

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Figure G.1. As-Built Critical Path (cont.).

APPENDIX H: CONTEMPORANEOUS CRITICAL PATH – APABW

			0	-31	-26	-52	-84	-69	-87	-90	-102	-92
SN	ID	Risk Event Name	AP DD: 16-Apr-16	W1 DD: 20-Aug-16	W2 DD: 7-Oct-16	W3 DD: 17-Mar-17	W4 DD: 14-Jun-17	W5 DD: 31-Jul-17	W6 DD: 21-Apr-18	W7 DD: 21-Jun-18	W8 DD: 1-Sep-18	W9 DD: 30-Nov-18
1	1CU-FN-GNRL-ENB-100	Excavation for Pile Caps & Foundations along Grid 1 7a7b/A S	0	-31	-							
2	1CU-UG-GNRL-ENB-100	Pile Cutting / Trimming along Grid 1 7a7b/A S (by Others)	0	-31	-							
3	1CU-FN-1A-ENB-100	Pile Head Treatment	0	-31	-							
4	1CU-FN-1A-EAR-100	Blinding, Waterproofing, Block Works and Screed	0	-31	-							
5	1CU-FN-1B-ENB-100	Pile Head Treatment	0	-31	-							
6	1CU-UG-GNRL-ENB-110	Pile Cutting / Trimming along Grid 8 2'/A S (by Others)	3	-25	-26	-						
7	1CU-FN-2A-ENB-100	Pile Head Treatment	3	-28	-26	-						
8	1CU-FN-2A-EAR-100	Blinding, Waterproofing, Block Works and Screed	3	-28	-26	-						
9	1CU-FN-2B-ENB-100	Pile Head Treatment	3	-28	-26	-						
10	1CU-FN-2B-EAR-100	Blinding, Waterproofing, Block Works and Screed	3	-28	-26	-						
11	1CU-FN-2C-ENB-100	Pile Head Treatment	3	-28	-26	-						
12	1CU-FN-2C-EAR-100	Blinding, Waterproofing, Block Works and Screed	3	-28	-26	-						
13	1CU-FN-2D-EAR-100	Blinding, Waterproofing, Block Works and Screed	3	-28	-26	-						
14	1CU-FN-2D-RCC-100	Pile Caps works and Tunnel works	3	-28	-26	-						
15	1CU-FN-2D-EAR-110	Backfilling works	0	-28	-26	-						
16	1CU-FN-2D-RCC-110	Slab on Grade	0	-28	-26	-						
17	1CU-L0-2D-RCC-100	Construction of Verticals	0	-28	-26	-						
18	1CU-L0-2E-RCC-100	Construction of Verticals	0	-28	-26	-17						
19	1CU-L0-2D-RCC-110	Construction of Beams	0	-28	-26	-20						
20	1CU-L0-2A-RCC-100	Construction of Verticals	33	-2	19	-52	-					
21	1CU-L0-2B-RCC-100	Construction of Verticals	33	-2	19	-52	-					
22	1CU-L0-2A-RCC-110	Construction of Beams	33	-2	19	-52	-					
23	1CU-L0-2B-RCC-110	Construction of Beams	33	-2	19	-52	-					
24	1CU-L0-2A-RCC-120	Construction of Slab @ Level 01	33	-2	19	-52	-					
25	1CU-L1-2A-RCC-110	Construction of Beams	33	-2	19	-52						
26	1CU-L1-2A-RCC-100	Construction of Verticals	33	-2	19	-52	-					
27	1CU-L0-2B-RCC-120	Construction of Slab @ Level 01	33	-2	19	-52	-84	-				
28	1CU-L1-2B-RCC-100	Construction of Verticals	33	-2	19	-52	-84	-				
29	SRS44433070	DRW-CUC-FNS-L0-Prepare & Submit Design or Shop Dwgs to Client / Consultant	26	9	9	10	-84	-				
30	1CU-L1-2D-RCC-100	Construction of Verticals	0	-27	-23	-20	-84	-				
31	1CU-L1-2D-RCC-110	Construction of Beams	0	-27	-23	-20	-84	-				
32	SRA44433070	DRW-CUC-FNS-L0-Review / Approval of Design or Shop Dwgs by Client / Consultant	31	18	18	18	-84	-				
33	1CU-L1-2E-RCC-110	Construction of Beams	0	-27	-23	-20	-84	-				
34	1CU-L1-2D-RCC-120	Construction of Roof RCC slab and Hollow Core Slab	0	-27	-23	-20	-84	-				
35	1CU-L0-PUBL-BLK-100	Block Work	18	-6	-2	-28	-84	-53				
36	FAB26250000	Manufacturing / Fabrication of Materials	42	49	49	-17	-80	-69				
37	SHP26250000	Shipment / Transportation of Materials	42	49	49	-17	-80	-69				
38	DEL26250000	Delivery of Materials at Site	36	42	42	-12	-64	-69				
39	STR26250000	Material Required Date on Site	36	42	42	-12	-64	-69				
40	1CU-L0-TRRM-ELC-110	2nd Fix Electrical / ELV	0	-27	-23	-52	-77	-69				
41	1CU-L0-TRRM-FLR-110	Floor Finishes	0	-27	-23	-52	-77	-69				
42	1CU-L0-TRRM-FFE-100	Door Shuttering & Ironmongery	0	-27	-23	-52	-77	-69				
43	1CU-L0-TRRM-ELC-120	Installation of Step down Transformer	0	-27	-23	-52	-77	-69				
44	1CU-EV-GNRL-ELC-100	Readiness of Transformer, MV Rooms and ATS Rooms for Power on requirement	0	-27	-23	-52	-77	-69				
45	1CU-EV-GNRL-ELC-110	Statutory Body approvals	0	-27	-26	-52	-75	-69	-46	-37	-102	
46	1CU-L0-PUBL-BLK-110	Marking, Cutting & Chasing Walls for MEP Services	18	-6	-2	-28	-77	-53	-			
47	1CU-L0-PUBL-BLK-120	Sub Frames Fixing	18	-6	-2	-28	-77	-53	-			
48	1CU-L0-MSRM-FLR-100	Floor Screed	18	-6	-2	-31	-77	-53	-			
49	1CU-L0-WETT-FLR-100	Floor Waterproofing	18	-6	-2	-31	-77	-53	-			
50	1CU-L0-WETT-FLR-110	Floor Screed	18	-6	-2	-31	-77	-53	-			
51	1CU-L0-PUBL-BLK-130	Plastering Works	18	-6	-2	-31	-77	-53	-			
52	1CU-L0-OFFC-FLR-100	Floor Screed	18	-6	-2	-31	-77	-53	-			
53	1CU-L0-MSRM-FLR-120	Floor Screed	18	-6	-2	-31	-77	-53	-			
54	1CU-L0-CORR-FLR-100	Floor Screed	18	-6	-2	-31	-77	-53	-			
55	1CU-L0-PUBL-PLM-140	1st Fix Water Supply Ceilings (Piping Supports)	18	-6	-2	-31	-77	-53	-			

Figure H.1. Contemporaneous Critical Path – APABW.

			0	-31	-26	-52	-84	-69	-87	-90	-102	-92
SN	ID	Risk Event Name	AP DD: 16-Apr-16	W1 DD: 20-Aug-16	W2 DD: 7-Oct-16	W3 DD: 17-Mar-17	W4 DD: 14-Jun-17	W5 DD: 31-Jul-17	W6 DD: 21-Apr-18	W7 DD: 21-Jun-18	W8 DD: 1-Sep-18	W9 DD: 30-Nov-18
56	1CU-L0-PUBL-PLM-160	2nd Fix Water Supply Ceilings (Piping, Fittings, Insulation & Connections)	13	-6	-2	-31	-77	-53	-			
57	1CU-L0-PUBL-TNC-110	2nd HVAC Fix Chilled Water (Piping, Insulation, Valves & Testing)	12	-6	-2	-31	-77	-53	-			
58	1CU-L0-PUBL-HVC-120	2nd Fix HVAC (Ducts, Insulation, Dampers & Accessories)	12	-6	-2	-31	-77	-53	-			
59	1CU-L0-PUBL-HVC-130	2nd Fix HVAC (Installation of FCU's & Connections)	12	-6	-2	-31	-77	-53	-			
60	1CU-L0-WETT-CEL-110	Ceiling Closure	12	-6	-2	-31	-77	-53	-			
61	1CU-L0-WETT-WLL-110	Paint 1st Coat (Primer, Putty & Basecoat)	12	-6	-2	-31	-77	-53	-			
62	1CU-L0-WETT-FLR-120	Floor Tiles	12	-6	-2	-31	-77	-53	-			
63	1CU-L0-WETT-FFE-110	Door Frames Fixing	12	-6	-2	-31	-77	-53	-			
64	1CU-L0-WETT-WLL-120	Paint 2nd Coat	12	-6	-2	-31	-77	-53	-			
65	1CU-L0-WETT-FFE-120	Kitchen Cabinet Carcass	12	-6	-2	-31	-77	-53	-			
66	1CU-L0-WETT-FFE-130	Door Shuttering & Ironmongery	12	-6	-2	-31	-77	-53	-			
67	1CU-L0-PUBL-FFS-120	Final Fix Fire Fighting (Sprinkler Heads, Fixtures, FHRC, Etc.)	12	-6	-2	-31	-77	-53	-61	-		
68	1CU-L0-CORR-WLL-120	Final Coat Paint	12	-6	-2	-31	-77	-53	-61	-		
69	1CU-L0-CORR-WLL-130	Final Wall Finishes	12	-6	-2	-31	-77	-53	-61	-		
70	1CU-L0-CORR-FFE-120	Fittings & Furniture	12	-6	-2	-31	-77	-53	-61	-		
71	1CU-L1-CHRM-HVC-140	Installation of Chiller Control Panels 8 Nos	67	51	52	-49	-30	-30	-87	-		
72	1CU-EVN-NORT-FCD-110	Installation of Terracotta Cladding	35	41	41	-16	-47	-47	-33,8	-90	-	
73	1CU-EVE-EAST-FCD-110	Installation of Terracotta Cladding	35	41	41	-16	-47	-47	-33,8	-90	-	
74	1CU-EVS-SOUT-FCD-110	Installation of Terracotta Cladding	35	41	41	-16	-47	-47	-34	-90	-	
75	1CU-EVW-WEST-FCD-110	Installation of Terracotta Cladding	31	20	20	-20	-52	-52	-40	-90	-	
76	1CU-EV-GNRL-TNC-100	Testing, Energization and Power on	0	-27	-26	-52	-75	-69	-46	-37	-102	-
77	1CU-BL-GNRL-TNC-120	Final Testing,Snagging and Desnagging works Irrigation system	0	-27	-26	-52	-75	-69	-84	-66	-102	-
78	1CU-BL-GNRL-TNC-130	Final Testing,Snagging and Desnagging works Electronic Safety and Security system (Fire Alarm)	0	-27	-26	-52	-75	-69	-84	-66	-102	-72
79	1CU-BL-GNRL-TNC-140	Final Testing,Snagging and Desnagging works Electrical system	0	-27	-26	-52	-75	-69	-84	-66	-102	-84
80	1CU-BL-GNRL-TNC-150	Final Testing,Snagging and Desnagging works SCADA and BMS systems	0	-27	-26	-52	-75	-69	-84	-66	-102	-92

Figure H.1. Contemporaneous Critical Path – APABW (cont.).