AN ONTOLOGY-BASED APPROACH FOR DELAY ANALYSIS

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I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

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ABSTRACT

AN ONTOLOGY-BASED APPROACH FOR DELAY ANALYSIS

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Delay is a common problem of construction sector. Recent improvements in the sector increased the competition and this led the construction projects to be more complex than before and difficult to be completed in time. This situation not only increased the delay problems, but also made the analysis of delays difficult and that caused further problems as disputes between parties to the contract. Sound knowledge in delay analysis subject is needed to enhance the solution of the delay problem in construction projects. So, this study aims to share knowledge in delay analysis issue by construction of a delay analysis ontology that provides direct and comprehensive knowledge. The constructed ontology may ease the information sharing process and provide a base for the usage of information in computers for different purposes especially in risk and claim management processes. It may enable companies to create their own knowledge bases and decision support systems that may achieve improvement in the knowledge and its usability. To meet this objective, detailed literature review on delay subject is carried out and an ontology on delay analysis issue is created. The created ontology is validated through its comparison with three different case studies.

Keywords: Construction sector, Delay, Delay Analysis, Ontology

ÖZ

GECİKME ANALİZİ İÇİN ONTOLOJİ-TABANLI BİR YAKLAŞIM

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Gecikme inşaat sektöründe sıklıkla karşılaşılan sorunlardan biridir. Sektördeki son gelişmeler rekabeti artırmış, bu da projelerin eskiye göre daha karmaşık olmasına ve zamanında tamamlanamamasına neden olmuştur. Bu durum, yalnızca gecikme problemlerinin artmasıyla sınırlı kalmamış, problemlerin analizini zorlaştırmış ve sözleşme tarafları arasında hukuksal anlaşmazlıklar gibi sorunların da yaşanmasına neden olmuştur. İnşaat projelerindeki gecikmelerin çözümlenmesini geliştirmek için gecikme analizi konusunda sağlıklı bir bilgi birikimine ihtiyaç vardır. Bu nedenle bu çalışmada; doğrudan ve kapsamlı bilgi sağlayan bir gecikme analizi ontolojisinin kurulmasıyla, gecikme analizi konusunda bilgi paylaşımı amaçlanmıştır. Kurulan ontoloji sayesinde; bilgi paylaşım yöntemi kolaylaştırılabilecek, ayrıca bilginin çeşitli amaçlarla, özellikle risk ve hak talep yönetimi süreçlerinde, bilgisayar ortamında kullanımını sağlayabilecek bir baz oluşturulabilecektir. Ontoloji; şirketlerin kendi bilgi tabanlarını ve karar destek sistemlerini kurmalarını sağlayabilecek, böylelikle bilginin ve bilgi kullanımının gelişmesine yardımcı olabilecektir. Bu amaçla, detaylı bir literatür araştırması yapılmış ve gecikme analizi konusunda bir ontoloji oluşturulmuştur. Geliştirilen ontolojinin üç ayrı örnek olay ile kıyaslanmasıyla geçerliliği doğrulanmıştır.

Anahtar Kelimeler: İnşaat sektörü, Gecikme, Gecikme Analizi, Ontoloji

To my beloved family...

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ABS	As-Built Schedule
ADR	Alternative Dispute Resolution
AI	Artificial Intelligence
API	Application Programming Interface
CCD	Contractor Caused Disruption
CDC	Contract Document Clarification
CM	Construction Management
CPAT	Contemporaneous Period Analysis Technique
CPM	Critical Path Method
DAML	DARPA Agent Markup Language
DARPA	Defense Advanced Research Projects Agency
DIR	Daily Inspection Reports
DSS	Decision Support System
e-COGNOS	COnsistent knowledGe management across prOjects and between enterpriSes in the construction domain
EOT	Extension of Time
FIPA	Foundation for Intelligent Physical Agents

FLogic	Frame Logic
HTML	HyperText Markup Language
IR	Intermediate Representation
IS	Information Systems
KE	Knowledge Engineering
KIF	Knowledge Interchange Format
KM	Knowledge Management
LD	Liquidated Damages
LOOM	Lexical OWL Ontology Matcher
MRR	Material Receiving Reports
OCML	Operational Conceptual Modeling Language
OIL	Ontology Inference Layer
OKBC	Open Knowledge Base Connectivity
OOP	Object-Oriented Programming
OWL	Web Ontology Language
PCI	Potential Cost Incidents
RDF	Resource Description Framework
RDF(S)	RDF Schema
RFI	Request for Information
SCL	Society for Computers and Law

SHOE	Simple HTML Ontology Extensions
TOVE	Toronto Virtual Enterprise
UML	Unified Modeling Language
WBS	Work Breakdown Structure
XML	Extensible Markup Language
XOL	Ontology Exchange Language

CHAPTER 1

INTRODUCTION

This chapter starts with a brief *introduction to construction delays* and following that introduces the *problem statement*, *aim and objective* and *scope of the study* together with information of *research methodology* and *thesis organization*.

1.1 Introduction to Construction Delays

"Time is of the essence in the completion of this contract" is the decisively used main clause of construction contracts. It certainly implies that every obligation in the contract would be completed in its time, otherwise leads to breach of the contract (Davenport, 1995; Wild, 2006). Thus, contractor is contractually obliged to achieve the goal in this limited time. However, generally the case is not that simple and the causes for delay lie in the risky nature of construction sector. Despite the fact that today's construction projects are much more strengthened against delay issue than the projects in the past, risk of delay still stands with the projects that bid under stiff competition. Also need of coordination of many trades rushes the challenge up and once the time limit is exceeded delay becomes the subject of debate (Shi et al., 2001; Trauner et al., 2009). Besides the time obligations, time is money in construction industry and contractual parties also have to meet their own financial obligations. Therefore in case of a delay, this touchy situation should be analyzed in great detail and liabilities and entitlements of each party should be determined properly (Faridi and El-Sayegh, 2006). Proper analysis of delays and preservation of good relationships with good faith help to minimize the delay problem, otherwise they rush up the problem. So this shows the importance of delay and delay analysis in construction sector.

1.2 Problem Statement

Construction delay is the common and serious problem of the construction sector. Despite the generality of the delay problem, challenging nature of the construction industry still makes the delay analysis issue to be on the front burner. Since analysis of delay is difficult, in case of the misuse of the processes of delay analysis, potential of conflict between parties to the construction contract emerges. Once the stable relationship between parties destroyed, further problems easily find their way out. Thus, comprehensive knowledge in delay analysis issue is needed to compete with problems caused by delay. Moreover, this direct and sound knowledge of delay analysis may also provide a guidance and enable its users to do the things right from the beginning and prevent the delay problem. In addition to these; in practical terms, creation of a database on delay analysis for the use of companies may ease the understanding and execution of delay analysis process and serve as a reference for the future projects. Such database may improve the learning from projects and also from mistakes and improve the knowledge in issue. Also creation of a decision support system may help the participants to decide at crucial points and so enhance prevention, assessment and analysis of delays (Sun and Meng, 2009). At this point, ontologies that provide the heart of the knowledge sharing come to the help of the delay analysis issue. An ontology may act as a vocabulary of the delay analysis domain and provide the easy understanding of the debate. With its ability of easy adaptation to the machines world, ontology facilitates its usage in different software programs with different purposes. So; an ontology provides the easy sharing of knowledge, and can form the basis of a such database for companies and provide the help in delay analysis process. Since there is no ontology created on delay analysis issue before, development of the delay analysis ontology on this purpose is aimed for this research study.

1.3 Aim and Objective of the Study

Aim and objective of the study is to develop a delay analysis ontology:

(1) to integrate the information on delay analysis available in literature
(2) to provide easy sharing of the knowledge
(3) to help risk management process by serving as a checklist that may increase the possibility of prevention of delays
(4) to help the delay analysis process that forms the basis of claim management and
(5) to form a basis for delay analysis databases or decision support systems for companies

1.4 Scope of the Study

The study is totally focused on literature review for the data acquisition step of ontology. First, literature review is done to understand the basics of ontology. Then, literature review on delay analysis is carried out for the formation of basics of the delay analysis ontology. Extensive internet search (namely papers) and books on delay analysis, claim management, ontologies and semantic web form the boundaries of this research.

1.5 Research Methodology

As the fundamental requirement of ontologies, the common and most frequently occurring terms and important concepts of delay analysis are defined through the literature review on delay analysis. Nouns in the sentences that are used to express the delay analysis domain constitute the concepts of the ontology, whereas verbs constitute the relations of the ontology (Noy and McGuinness, 2001). So the delay analysis ontology is defined in few sentences that are able to be read through ways formed by passages from the surrounding classes to the core class “delay”. The details of the ontology are formed according to the well-known methodology that is named as METHONTOLOGY (Gómez-Pérez et al., 1996). First concepts of the ontology are defined and the concept taxonomy is presented. Accordingly, rest of the details of the ontology is presented through tabular and graphical notations. Finally the concept model of delay analysis ontology is obtained.

For the demonstration and validation of the ontology, three case studies of claim analysis are used. Most occurring terms of the each study is defined as in the step of formation of the ontology. Then terms of the cases are compared with the ontology created. So, it is seen that ontology has enough concepts to represent the real world knowledge of delay analysis for these case studies and has the ability to ease the claim management processes like ones in the case studies.

Finally, ontology is loaded into a mostly used ontology construction program which is named as Protégé.

1.6 Thesis Organization

Chapter 2, presents the literature review on construction delay, Chapter 3 continues on with the literature review on ontology, Chapter 4 handles the details of ontology development, Chapter 5 presents the validation of the ontology and finally Chapter 6 concludes the study.

CHAPTER 2

LITERATURE REVIEW ON CONSTRUCTION DELAY

This chapter focuses on the presentation of what is taken from the literature review on construction delay. It starts with *brief summary* and *definitions*; and the rest is structured on the main topics of delay as *types*, *causes*, *responsibility*, *impact*, *mitigation*, *analysis*, *claim*, *notice* and finally *prevention* of delay. The data are generally indicated in forms of taxonomies through tables after presentation of brief information to provide easiness in the formation of ontology in further chapters.

2.1 Brief Summary

Projects are deemed to be successful in case of they are finished on time, within budget and meeting quality standards as stated in contract (Chan and Kumaraswamy, 1997; Frimpong et al., 2003). However, construction projects involve many trades and are exposed to many variables and unpredictable factors. Also, parties in a contract have a potential for changing their mind or making mistakes during planning and execution of project. So, "projects change" and are rarely completed within schedule (Assaf and Al-Hejji, 2006). In other words change is inevitable in construction projects, so this means delay is inevitable (Peters, 2003). As a natural result of delays, delay claims occur. Fair negotiation and timely settlement of claims are beneficial for the sake of all parties (Bubshait and Cunningham, 1998; Lee et al., 2005b). Unless amicable solutions to claims are found, disputes arise and battle of time and money starts unfortunately with consumption of time and money (Doyle, 2005).

Toor and Ogunlana (2008) summarize the importance of delay problem with the various studies (Arditi et al., 1985; Long et al., 2004; Sambasivan and Soon, 2007) indicating that construction delays are common. Additionally, construction delay is known as one of the most recurring problems of the construction sector (Faridi and El-Sayegh, 2006). It adversely affects project success in terms of time, cost, quality and also safety. On the other hand, delays may lead disputes that result in protracted solution periods and even total abandonments (Aibinu and Jagboro, 2002; Al-Khalil and Al-Ghafly, 1999; Toor and Ogunlana, 2008). Furthermore, in countries that construction greatly contributes to the development of the country; effects of delay do not remain limited to the construction projects and sector only, unfortunately, also spread to the overall economy of the country (Abdul-Rahman et al., 2006; Faridi and El-Sayegh, 2006). Besides its importance in the economy, construction sector has its complex, dynamic and risky structure as its characteristic feature that provides fertile ground for delays (Odeh and Battaineh, 2002).

Construction sector is one of the most risky industrial environments with its complex and dynamic structure. Basically, construction is creation of an end product through ideas, more precisely through plans and specifications. It also requires coordination of multiple parties working under pressure with the potentiality of dealing with problems many of which are beyond control. (Abdul-Rahman et al., 2006; Peurifoy and Ledbetter, 1985). Additionally, use of advanced technology with new standards and the flexibility of owners in making additions and changes, made construction projects rather complex. This situation triggers the problems and conflicts among parties when they need the cooperation above all (Abdul-Malak et al., 2002). Besides all of these complicating factors, more emphasis is given on the management of construction projects to mitigate the risky nature. When delays are taken into consideration, processing with a mismanaged project likes deliberately walking through a minefield. On the other hand, a perfectly managed project does not assure a delay-free environment, however it grants a widely cleaned field. At this point, project management tools and techniques play a remarkable role in the effective management of projects (Frimpong et al., 2003).

As it is stated earlier, construction projects are often faced with delays and projects finish later than the dates fixed in construction contracts. Naturally delays bring damages for parties and claims often arise. This leads the parties to search for the causes and responsibilities of the delays. Various methods for the analysis of delays have been used for the determination of causes and apportionment of responsibility of delays (Farrow, 2007). Especially the use of methods based on critical path method (CPM) scheduling provides an exhaustive and reliable analysis of delays. With these methods; judgments of where the delay occurred, how it affected the single activities in the plan, or how it affected the project as a whole, and who is responsible for the delay are much more easily made. Despite these improved methods; since projects are now more complex than they were before, analysis of delays still needs considerable effort (Abdul-Malak et al., 2002).

Delay analysis is fundamentally based on three elements of delay which are; causation, liability and damages (Arditi and Patel, 1989). Causation provides the identification and quantification of delays also searches for the effect of delay to the program. Liability is directly linked to the causation and refers to the responsible party for the delay. Finally through damages, loss of delay is shared between the responsible parties and entitlements are given to aggrieved parties if they are applicable (Beşoğul, 2006).

A medium-sized construction project may consist of hundreds of activities that planned to be constructed at its scheduled time. Despite that, series of delays may occur during the life of the project and actual construction time of many of these activities may be put forward. Project delay, which is total delay at the end of the project, needless to say consists of delays of these individual activities. However, a delay of an activity may partially or totally take part in the project delay, or it may not turn into a project delay. Therefore, investigation of which activities contribute to project delay and what their parts are in the whole form the basis of analysis of delays and help to indicate the causes and responsibilities (Shi et al., 2001). In light of this investigation, damages are shared between responsible parties.

With the development of the construction sector, time became the crucial element of construction projects and always had the potential of affecting obligations of all parties in a contract. The time set in the construction contract is vital for both the owner and the contractor (Faridi and El-Sayegh, 2006). Because delays bring the cost overruns for both owners and contractors. Owners may suffer from lost profits, additional rentals and interests, whereas contractors may suffer from additional field costs, lost productivity costs and overhead costs (Assaf and Al-Hejji, 2006; Householder and Rutland, 1990; Toor and Ogunlana, 2008). Delay analysis provides the determination of this wide variety of damages. After the determination process, damages are compensated by the responsible parties through claims.

Completing the project on time levelly shows the success of all project participants in the construction contract. Even so, contractor has a big role in the success with the ability of proper organization and control of the project and establishment of coordination between the parties that are directly linked with construction. However, usually especially the construction phase of the project has its surprises like unforeseen events (Chan and Kumaraswamy, 1997). Regardless of how much the project is perfectly managed, as Trauner et al. (2009) stated, everything may not go according to the plan and parties of the contract may find themselves at odds. So analysis of delays; to say in detail identification of causes, responsibilities and damages of delays provides basis for the claims and their negotiations. Any claim should be settled through fair and successful negotiations to prevent it returning a dispute. Otherwise, the troublesome phases of dispute resolution like litigation may increase the cost and time loss spent (Abdul-Malak et al., 2002; Kartam, 1999).

Since delay and delay analysis have become crucial elements of project performance, prevention of delays may be enhanced through increase in the awareness of their importance and comprehensive knowledge. Delays may be caused due to some managerial issues at company level such as inexperience of the contributors and their poor decisions at critical points, repeated mistakes – not learning from mistakes, inability to access the required information or lack of knowledge in project execution. Knowledge acquired through each unique project may help to enhance management of the project in hand or future projects. So, knowledge management in delay and delay analysis issue should be improved through learning from projects with providing the possibility of collecting feedback from the contributors and supervisory control of participants that would sustain the communion and development (Abdul-Rahman et al., 2008). Establishment of such database, memory or decision support system provides documentation, retrieval and utilization of the past project data and enhances the knowledge and management of problems. So ontologies easily base these attempts and provide efficient use of knowledge (El-Diraby and Zhang, 2006). Therefore, possible use of the ontology in such company specific attempts on delay analysis motivates this study and constitutes one of the main objects of the study.

2.2 Definitions

Basic questions of “what is delay?” and “what is delay analysis?” are replied in this section to start with the meaning of these concepts and to lay the foundations.

2.2.1 What is Delay?

Delay is any occurrence; generally slowing down of the construction process, namely less efficient work output that causes prolongation of time and the project not to finish on time (Ibbs and Nguyen, 2007; Ndekugri et al., 2008; Stumpf, 2000). It is simply the time overrun since it causes something to be performed later than planned by not acting timely. Essentially delay means cost to the parties of contract. Schedules would be the identifiers of delays with their milestones or completion dates that are set before (Assaf and Al-Hejji, 2006; El-Razek et al., 2008; Hoshino et al., 2007; Trauner et al., 2009).

2.2.2 What is Delay Analysis?

Delay analysis is the process of investigation of the delay events for the purpose of sharing the financial responsibilities between the parties to the delay with justification and quantification of impacts of delay as time and cost. Detailed data provided through the construction of project are analyzed and delay analysis techniques are used to reach solution with follow-up of a delay analysis methodology (Braimah and Ndekugri, 2009; Farrow, 2007; Ndekugri et al., 2008).

2.3 Types of Delay

Classification of delays is made through different angles such as their *origin*, *timing*, *compensability*, *content* and *criticality*. Presentation of delay through different categories provides a clear understanding of the delay and facilitates the delay analysis process.

2.3.1 Delays Classified by Their Origin

Classification of delays according to their origin simply implies the cause and the responsibility of the delay. A delay may be generated by various causes of delays that gather under responsibilities of owner, contractor or neither of them. Thus, delays can be in owner's responsibility as (1) *owner caused delays*, in contractor's responsibility as (2) *contractor caused delays*, or in neither party's responsibility as (3) *third party caused delays* (Kartam, 1999).

2.3.2 Delays Classified by Their Timing

Timing of delay is crucial element of delay analysis. Delays can occur alone or together during a construction process. The isolated ones, namely delays occurring alone are *independent delays (classic delays)*. Generally, things are more complicated and several delays come into action together and form *concurrent delays*

(Alaghbari et al., 2007; Kartam, 1999). Also a delay can trigger another delay and series of delays can be formed in this way, so these delays are called *serial delays* where initial delay is responsible from the rest (Battikha, 1994; Beşoğul, 2006; O'Brien, 1976; Stumpf, 2000). Finally, a newly defined delay type is available as *pacing delay* that represents the deliberate delay or the choice of slowing down the work of one party because of an already existing delay of the other party (Zack, 2000).

2.3.3 Delays Classified by Their Compensability

With the help of the cause and responsibility of delays, delays are also classified by their compensability. Accordingly delays are either *excusable* or *non-excusable*. Basically, excusable delays bring compensation or time extension to contractor and non-excusable delays bring compensation to owner (liquidated damages) if the completion date is postponed. Non-excusable delays refer to the contractor's (or his subcontractor's) own fault and responsibility, so they are not compensable to contractor (neither cost compensation nor extension of time) whereas; excusable delays are beyond the control and so responsibility of contractor. Since excusable delays are not attributable to contractor's actions or inactions, contractor should be entitled to time extension. According to the causes of delays, excusable delays are further categorized as *excusable compensable* and *excusable non-compensable* delays by distinguishing the delays caused by owner (or his agents) and third parties respectively. So in case of an owner delay, contractor is entitled to both time extension and cost compensation to overcome the damages caused by owner's inability to meet the obligations. However when an external delay occurs like unforeseen events; since neither contractor nor owner has a part in it, none of the parties burden the cost damages for other party. Namely; as it is stated by Williams (2003), "*when each party has contributed to a delay, each party then bears its own costs of the delay*". Only time extension is given in third party caused delays if otherwise is not stated in the contract. Generally, excusable compensable delays are handled in no damage clauses under exculpatory clauses; similarly excusable non-compensable delays under force majeure clauses and non-excusable delays under liquidated damages clauses (Alaghbari et al., 2007; Alkass et al., 1996; Bordoli and Baldwin, 1998; Finke, 1999; Kartam, 1999; Kraiem and Diekmann, 1987; Lee et al., 2005b; Ndekugri et al., 2008; Yates and Epstein, 2006).

2.3.4 Delays Classified by Their Content

Delays are also classified according to their content as; date, total, extended, additional, sequence and progress delays to provide more denotation on type of delay for the sake of analysis. Bordoli and Baldwin (1998) present that the delays on activities that start or finish later than the planned start or finish dates irrespective of the preceding activities are called *date delays*. Delays that are caused by complete stoppage of work form the *total delays*. Following these, an increase in the duration of an activity and the related delay is named as *extended delay*, whereas an addition of an activity to the planned works results in *additional delay*. Finally, *sequence delays* refer to the activities that could not be completed in their original sequence and *progress delays* form the delays that are caused due to lack of progress in the construction of work.

2.3.5 Delays Classified by Their Criticality

Some delays occur but do not affect the completion date of the project, so these delays are considered as delays to progress or non-critical delays. However, critical delays are the main concern that occur on the critical activities of the construction process and affect contract completion date. So delays are classified according to critical path as *critical delays* or *non-critical delays* (Ndekugri et al., 2008).

In light of this information, types of delay can be summarized as in the following table (Table 2.1).

Table 2.1: Types of delay

TYPES		
1st level	**2nd level**	**Source**
Delays Classified By Their Origin	*Owner caused delays*	[117]
	Contractor caused delays	[117]
	Third party caused delays	[117]
Delays Classified By Their Timing	*Independent/Classic delays*	[28], [33], [156], [187]
	Concurrent delays	[13], [14], [28], [33], [82], [117], [122], [156], [187]
	Serial delays	[28], [33], [156], [187]
	Pacing delays	[8], [102], [226], [227]
Delays Classified By Their Compensability	*Excusable compensable delays*	[13], [14], [35], [82], [117], [122], [129], [149], [215], [222]
	Excusable non-compensable delays	[13], [14], [35], [82], [117], [122], [129], [149], [215], [222]
	Non-excusable delays	[13], [14], [35], [82], [117], [122], [129], [149], [215], [222]
Delays Classified By Their Content	*Date delays*	[35]
	Total delays	[35]
	Extended delays	[35]
	Additional delays	[35]
	Sequence delays	[35]
	Progress delays	[35]
Delays Classified By Their Criticality	*Critical delays: Delay to completion*	[107], [149]
	Non-critical delays: Delay to progress	[107], [149]

2.4 Causes of Delay

Causes base the main elements of the delay analysis with the direct implication of the related responsibilities of delays. Analysis of delay is broadly based on identification of causes since it is quantification of delay, determination of causation and assessment of responsibility in its simplest form (Hoshino et al., 2007; Kartam, 1999; Williams et al., 2003). With the complex and multi-party nature of today's construction sector, it became much more difficult to examine the causes of delays. There are lots of studies available for the causes of delays in construction projects in different countries. For the easiness of delay analysis, grouping the factors basically according to their responsibility is preferable. Delays can be either in control of owner or contractor, or they can be beyond control and caused because of external factors. On this purpose, extensive search for the causes of construction delays is made through literature review and all the available factors are grouped in three groups as *owner causes*, *contractor causes* and *external causes*. This section provides the integration of various causes of delay that are available in the literature. This part has a great role in the analysis of delays, also it can take initial attention to the possible causes and provide a basic step in the consideration of prevention of delays. The studies on causes of delays that are taken into consideration can be summarized as the follows:

Arditi et al. (1985) identify and rank reasons for delays in public projects in Turkey through surveys with owners as public agency and contractors of works for public agency.

Assaf et al. (1995) carry out a study on large building construction projects in Saudi Arabia and rank 56 factors of delay in order of importance under groups of materials, manpower, equipment, financing, changes, government relations, scheduling and controlling, environment and contractual relationships.

Chan and Kumaraswamy (1997) study causes of time overrun in Hong Kong construction projects. They identify 83 causes in groups of project-related factors, client-related factors, design team-related factors, contractor-related factors, materials factors, labor factors, plant/equipment factors and external factors. Also ranking of the factors according to their importance is available in the study.

Odeh and Battaineh (2002) determine the most important 28 causes of delay in traditional construction contracts and categorize them under groups of client, contractor, consultant, material, labor and equipment, contract, contractual relationships and external factors.

Alwi and Hampson (2003) determine the most important causes of delays within multi-storey building projects in Indonesia. Factors are presented in groups of people, professional management, design and documentation, material, execution and external. Accordingly, ranking of the factors is made through large and small contractors.

Frimpong et al. (2003) study causes of delay and cost overruns in construction of groundwater projects in a developing countries; Ghana as a case study; and investigate and rank 26 factors of delay that are extracted from previous investigations in groundwater drilling projects in Ghana.

Similarly Assaf and Al-Hejji (2006) investigate causes of delay and their importance in large construction projects in Saudi Arabia. Through their study, 73 causes of delay are identified and grouped as project, owner, contractor, consultant, design, materials, equipment, labors and external.

Through a study on a basis of like the ones previously presented, Faridi and El-Sayegh (2006) identify significant factors causing delay in the United Arab Emirates construction industry. They handle 44 factors that are categorized in groups of contractor, consultant/designer, owner, financial, planning and scheduling, contractual relationship, government regulations and unforeseen conditions.

Aibinu and Odeyinka (2006) identify 44 causative factors for construction delays in Nigeria. The factors are ranked and grouped as client-related, quantity surveyor-related, architect-related, structural engineer-related, services engineer-related, contractor-related, subcontractor-related, suppliers-related and external factor.

Beşoğul (2006) studies reasons of delays in steel construction projects and presents potential sources of change in three groups as; contractor-related, owner-related and external factors.

Sambasivan and Soon (2007) investigate causes and effects of delays in Malaysian construction industry. The causes are taken from study of Odeh and Battaineh (2002) and ranked through surveys conducted with clients, consultants and contractors. Effects and causes of delays are matched between and ranked according to their importance.

El-Razek et al. (2008) gather 87 causes of delay through literature review in groups of financing, manpower, changes, contractual relationships, environment, equipment, rules and regulations, materials and scheduling and control. In addition to that, factors that are suitable for projects in Egypt are identified through surveys and most important factors are ranked. Both the factors of literature review and the survey results of the presented study are taken into consideration in this research study.

Toor and Ogunlana (2008) identify and rank problems causing delays in major construction projects in Thailand. Problems are grouped as problems of client, problems of designers, problems of project manager, problems of contractor, problems of labor, problems of finance, problems of contract, problems of communication, problems of site and environment, and finally problems due to other factors.

Al-Kharashi and Skitmore (2009) make literature review and obtain 112 factors and group these under categorization of Odeh and Battaineh's (2002) study. Accordingly they further investigate the effects of each factor with the likely effect in future through surveys between clients, contractors and consultants working in the Saudi Arabian construction industry.

Sun and Meng (2009) present a taxonomy for change causes and effects in construction projects. Taxonomy of change causes opens to three main branches as external causes, organizational causes and project internal causes. Further external causes divide into environmental factors, political factors, social factors, economical factors and technological factors. Similarly organizational factors consist of process related, people related and technology related causes. Finally; client generated, design consultant generated, contractor/subcontractor generated causes and others constitute the project internal factors.

Sarıkaya (2010) studies causes of delay and their effects on construction projects in Turkey and groups the factors as factors of finance related delays, labor related delays, changes/revision related delays, contractual related delays, environmental related delays, equipment related delays, rules and regulations related delays, material related delays and project management and control related delays.

In addition to the presented studies; many other studies directly on identification of causes of delays, and studies that include investigations on already presented causes of delays are available in literature. All of the used ones are not mentioned in text but will be presented through the sources of factors in the following table (Table 2.2).

In light of the literature review on causes of delays, the taxonomy of causes is formed. As it is previously stated, main concepts of the taxonomy are structured as; *owner causes*, *contractor causes* and *external causes* with the idea of responsibilities of delays. This grouping does not provide the final word on responsibilities, because responsibilities are handled in contracts and may be assigned to different parties of the contract and accordingly awarding strategy may change (Ibbs and Nguyen, 2007; Turner and Turner, 1999). What presented here is the general opinion that is got through the literature review. Some of the causes are taken as direct wording of the sources presented whereas, some of them are either merged, divided or ascribed to previously presented factors. The final unified form of the taxonomy of factors is presented in Table 2.2. The stars at the beginning of the factor groups (*group name) indicate the levels of subcategories of the taxonomy. Updated version of the table through the further chapter named validation (Chapter 5) is presented.

Table 2.2: Taxonomy of causes of delay

CAUSES OF DELAY	Source
OWNER CAUSES	
Design Related Causes	[18], [24], [48], [77], [199]
Insufficient data collection, survey and site investigation prior to design	[24], [111], [161], [189], [212]
Unclear and inadequate details in drawings	[24], [161], [184], [212]
Incomplete/Defective/Poor design drawings, specifications or documents	[7], [18], [28], [33], [77], [111], [159], [184], [189], [191], [220], [222]
Inaccurate estimates - errors or omissions in quantity estimating/inaccurate bills of quantities	[134], [189], [221]

Table 2.2: Taxonomy of causes of delay (continued)

CAUSES OF DELAY	Source
OWNER CAUSES	
Design Related Causes (continued)	[18], [24], [48], [77], [199]
Errors and omissions in design documents and defective specifications	[11], [138], [184], [199]
Inaccurate design information	[138], [159]
Inaccurate design documentation	[138]
Disagreements on design specifications	[20], [220]
Lack of standardization in design	[199]
Citation of inadequate specification	[18], [189]
Design errors made by designers	[74], [77], [144], [161], [177]
Mistakes and discrepancies in design documents	[24], [48], [123], [161], [189], [212], [221]
Inconsistency between drawings and site conditions	[189]
Complexity of project design	[24], [48], [161], [220]
Inadequate design-team experience	[24], [48], [123], [161], [189], [220]
Insufficient training of designers	[220]
Non-use of advanced engineering design software	[24], [161], [212]
Delays in design information	[20], [24], [123], [144], [161], [189], [212], [221]
Change orders by owner during construction/Owner initiated variations	[7], [24], [28], [48], [77], [107], [123], [134], [144], [152], [159], [161], [189], [191], [212], [220], [221], [222]
Necessary changes/variations of works	[123], [115], [134], [137], [138], [144], [189]
Design changes/modifications by owner or his agent during construction	[11], [18], [20], [77], [74], [152], [158], [159], [161], [177], [189], [221]
Design changes in respond to site conditions	[152], [189]
Design changes due to poor brief, errors and omissions	[152], [189]
Changes in material types and specifications during construction	[24], [25], [48], [74], [77], [161], [177], [212]
Change orders by deficiency design	[152], [220]
Excessive scope changes and constructive changed orders	[111], [114], [152], [184], [191], [199]
Delay in issuance of change orders by the owner	[10]
Improper or delayed change orders	[28]
Changes in owner's requirements	[220]
Long waiting time for approval of drawings	[24], [107], [123], [137], [138], [189], [222]
Long waiting time for approval of test samples and materials	[24], [123], [138], [177], [189]
Late in revising and approving design documents by owner	[10], [24], [161], [212]
Slow drawing revision and distribution	[18]
Poor quality of design - wrong/improper/impractical design	[18], [138], [144], [199], [220]
Low constructability of design	[199]
Over-design increasing the overall cost	[199]
Poor communication and coordination between designers	[138], [159], [199], [220]

Table 2.2: Taxonomy of causes of delay (continued)

CAUSES OF DELAY	Source
OWNER CAUSES	
Design Related Causes (continued)	[18], [24], [48], [77], [199]
Insufficient communication between the owner and designer in design phase	[144], [177]
Misunderstanding of owner's requirements by design engineer	[24], [161]
Slow decision making by designers	[144], [220]
Slow information delivery between designers	[220]
Slow correction of design errors	[159]
Lack of involvement of design team during construction stage	[199]
Consultant Causes	[24], [77], [157], [189]
Delay in performing inspection and testing by consultant	[10], [24], [85], [161], [184]
Delay in approving major changes in the scope of work by consultant	[10], [24], [157], [161], [212]
Late in reviewing and approving design documents by consultant	[10], [24], [74], [77], [134], [157], [161]
Waiting time for sample materials approval	[10], [25], [74], [77], [138]
Waiting time for site inspection and approval of quality control tests or results by consultant	[77], [134], [159], [184],
Slow preparation and approval of shop drawings by consultant	[11], [25], [28], [137], [144], [177]
Slow preparation of scheduling networks and revisions by consultant while construction is in progress	[25], [74]
Poor inspection and testing procedure used in project by consultant	[25], [74], [177]
Poor contract management by consultant	[85], [157], [199]
Poor quality assurance and quality control by consultant	[157]
Inflexibility (rigidity) of consultant	[10], [24]
Lack of experience on the part of the consultant	[10], [13], [18], [24], [161], [212]
Lack of experience on the part of the consultant's site staff (managerial and supervisory personnel)	[13], [191]
Absence of consultant's site staff	[13]
Conflicts between consultant and design engineer	[10], [24], [123], [161]
Poor communication and coordination by consultant with other parties	[10], [18], [24], [123], [134], [138], [161], [177], [191], [199], [212]
Poor information dissemination/provision by consultant	[7], [18]
Late preparation of interim valuation by consultant	[7]
Late valuation of variation works by consultant	[7]
Delayed and slow supervision in making decisions	[13], [18], [85]
Delay in the approval of contractor submissions by the consultant engineer	[7], [85], [138], [191]
Late issuance of instruction by the consultant engineer	[7], [13], [137], [184]
Slow response by the consultant engineer regarding testing and inspection	[191]
Slow response by the consultant engineer to contractor inquiries	[191]
Inaccurate site investigation by consultant	[161]
Poor site management and supervision by consultant	[7], [134]

Table 2.2: Taxonomy of causes of delay (continued)

CAUSES OF DELAY	Source
OWNER CAUSES	
Consultant Causes (continued)	[24], [77], [157], [189]
Inadequate project management assistance by consultant	[161]
Replacement of key personnel by consultant	[10]
Improper selection of subsequent consultants	[220]
Problems due to company organization of consultant	[10], [144]
Fraud by consultant	[10], [199]
Owner's Financial Causes	[25], [74], [77], [177], [199]
Delays in contractor's progress payments (of completed work) by owner	[10], [20], [24], [25], [28], [33], [48], [74], [77], [85], [138], [144], [158], [159], [161], [177], [184], [191], [212]
Problems with partial payments during construction	[74], [177]
Owner's cash flow problem	[7], [85], [144]
Payment delays by owner	[11], [138], [189], [199]
Poor project financing by owner	[25], [48], [157], [158]
Failure to fund the project on time	[28]
Funding changes, i.e., shortage of funding	[189]
Financial problems (delayed payments, financial difficulties, and economic problems)	[13], [138], [220]
Lack of finance to complete the work by the owner	[10]
Non-payment of contractor claim	[10]
Financial constraints faced by the owner	[191]
Changes in material prices in unit-priced contracts	[10], [85], [191]
Owner Generated Causes	[7], [24], [48], [77], [157], [199]
Selecting the type of project bidding and award (negotiation, lowest bidder, etc.)	[10], [24], [85], [144]
Lack of clear bidding process/Exceptionally low bids	[111], [134], [144], [199]
Insufficient time for bid preparation	[111]
Selecting the type of construction contract/project delivery system (Turnkey, design-build, general contracting, construction only,.)	[10], [24], [177]
Selection of inappropriate contract type	[138]
Selection of inappropriate type of main construction	[123]
Imbalance in the risk allocation by owner	[134], [138]
Inappropriate contractor or consultant selection	[138], [199]
Improper project feasibility study	[161], [199]
Delay in site preparation and delivery	[10], [24], [107], [144], [159], [161], [184], [191], [212], [222]
Difficulty in site acquisition/Failure to provide property	[28], [138], [189], [203]
Restricted access to the site/Poor site access and availability	[28], [33], [134], [138], [144], [184], [199]
Failure of the employer over ingress and egress	[138], [189], [203]
Failure of the employer to provide right of way	[28]
Problems/Delays in materials, labor or goods that are in responsibility of the owner	[28], [33], [111], [134], [184], [203], [222]
Lack of working knowledge of owner	[13]

Table 2.2: Taxonomy of causes of delay (continued)

CAUSES OF DELAY	Source
OWNER CAUSES	
Owner Generated Causes (continued)	[7], [24], [48], [77], [157], [199]
Lack of experience of owner in construction projects	[161]
Lack of capable owner's representative	[161], [199]
Failure on the part of the owner to review and approve design documents, schedules, and material on time	[10], [28], [33], [159], [212]
Failure on the part of the owner to properly coordinate multiple contractors	[28], [33], [159], [184], [222]
Unrealistic time/cost/quality targets/expectations and requirements by owner	[48], [138], [184]
Unrealistic information expectations by owner	[138]
Confusing and ambiguous requirements by owner	[199]
Slow responses from the owner's organization	[199]
Change in scope of work or in construction detail	[33]
Introduction of major changes in requirements	[28]
Failure to give timely orders/instructions for work by owner	[28], [33], [137], [184], [222]
Inadequate information and supervision by the owner	[28], [33], [222]
Interference by other prime contractors working for the owner	[28]
Nonadherence to contract conditions by owner	[74], [177]
Suspension of work or wrongful termination by owner	[10], [24], [28], [33], [161], [177], [184], [191], [212], [220]
Insufficient or ill-integrated basic project data that is needed to be provided by owner	[220]
Contract Related Causes	[157], [199]
Mistakes and discrepancies in contract documents due to owner	[134], [157], [158], [177], [199]
Inadequate contract administration	[138], [159]
Incomplete/erroneous contract documentation	[138]
Inadequate definitions/contract clauses in contract	[24], [161]
Disagreements on contract clauses	[20]
Poor interpretation of contract clauses	[138]
Inappropriate contract form	[138]
Poor knowledge of local statues	[138]
Poor scope definition	[159], [220]
Poor contract familiarity/Owner's contracting procedures	[138]
Contract and specification interpretation disagreement	[158]
Poor contract interpretation	[138]
Ineffective delay penalties in contract	[10], [24], [161], [177]
Unavailability of financial incentives for contractor for finishing ahead of schedule in contract	[10], [24], [25], [74], [161], [177]
Unrealistic contract duration imposed by owner	[20], [48], [77], [123], [134], [144], [157], [177], [189], [220]
Work imposed that is not part of the contract by owner	[203]
Owner's late contract award	[7], [159]
Contract modifications (replacement and addition of new work to the project and change in specifications)	[13], [74], [77], [144], [177]

Table 2.2: Taxonomy of causes of delay (continued)

CAUSES OF DELAY	Source
OWNER CAUSES	
Contractual Relationship Related Causes	[74], [77], [157], [177]
Owner's personality and characteristics	[48], [77]
Owner's interference/Unnecessary interference by the owner	[10], [33], [157], [159], [191], [216], [221], [222]
Uncooperative owner	[10], [25], [74], [77], [177]
Excessive bureaucracy by owner's administration	[10], [74], [77], [177], [220]
Slowness in decision making process by owner	[7], [10], [13], [18], [20], [24], [25], [74], [77], [85], [138], [144], [157], [159], [161], [177], [191], [212]
Conflicts between joint-ownership of the project	[10], [24], [25], [74], [123], [161], [177], [212]
Conflicts between owner and other parties (contractor)	[24], [25], [74], [123], [158]
Faulty negotiations and obtaining of contracts	[25], [74], [138], [177]
Poor communication and coordination by owner with other parties (construction parties and government authorities)	[10], [18], [24], [25], [74], [134], [138], [144], [161], [177], [191], [199], [212]
Inappropriate overall structure linking all parties in project	[10], [123], [189]
Lack of communication and coordination between the parties involved in construction	[13], [18], [77], [111], [134], [138], [157], [177], [199]
Low speed of decision making involving all project teams	[85], [123]
Low speed of decision making within each project team	[85], [123]
Slow information flow between project team members	[85], [123], [138]
Replacement of key personnel by owner	[10]
High turnover in owner's technical personnel	[20]
Negotiation by knowledgeable people	[10]
Delay in the settlement of contractor claims by the owner	[10], [191]
CONTRACTOR CAUSES	
Material Related Causes	[18], [24], [25], [48], [74], [157], [177]
Delay in delivery of materials	[7], [10], [13], [18], [20], [24], [25], [28], [74], [85], [144], [159], [161], [177], [191], [212], [221]
Poorly scheduled delivery of material to site	[18], [85]
Delay in manufacturing special building materials	[10], [24], [25], [77], [161], [212]
Problems due to imported materials and plant items	[20], [74], [85], [158]
Problems due to proportion of off-site prefabrication	[48]
Late procurement of materials	[10], [20], [24], [85], [212]
Poor/Inappropriate procurement method/programming of construction materials	[48], [85], [138], [161]
Unavailability of materials on site on time	[10], [13], [77], [85], [107], [111], [191]
Inappropriate/Inadequate use (misuse) of material	[18], [134], [144], [159]
Poor material handling on site	[18], [159]
Improper tools for materials	[221]
Poor quality of materials	[18], [20], [157], [159], [161], [221]

Table 2.2: Taxonomy of causes of delay (continued)

CAUSES OF DELAY	Source
CONTRACTOR CAUSES	
Material Related Causes (continued)	[18], [24], [25], [48], [74], [157], [177]
Poor storage of material	[18]
Damage of sorted materials while they are needed urgently	[10], [24], [25], [74], [161], [177], [212], [221]
Unforeseen material damages	[7]
Noncompliance of material to specifications	[7]
Rework due to defective material	[159]
Rejected material	[28]
Unreliable material suppliers	[161]
Changes in materials prices in fixed-priced contracts	[10], [85], [191]
Changes in materials specifications	[10], [191]
Shortage of construction materials in market	[7], [10], [13], [20], [24], [48], [74], [77], [85], [115], [123], [138], [157], [161], [177], [191], [212]
Equipment Related Causes	[24], [25], [48], [74], [157], [177]
Equipment breakdown/failure and maintenance problem	[7], [10], [24], [25], [48], [74], [77], [85], [157], [159], [161], [177], [191], [212], [221]
Unavailability of equipment and tool on site	[7], [10], [13], [18], [24], [25], [74], [77], [85], [111], [115], [123], [138], [144], [157], [159], [161], [177], [191], [212], [221]
Shortage of construction equipment and tools in market	[7], [13], [24], [25], [48], [74], [77], [85], [115], [138], [157], [159], [161], [177], [191], [212]
Inadequate skill of equipment-operator	[7], [10], [24], [25], [74], [177], [212]
Low productivity and efficiency of equipment	[10], [24], [25], [48], [74], [161], [177], [212]
Failure to provide sufficient equipment	[28]
Lack of high-technology mechanical equipment/Outdated equipment	[10], [18], [24], [74], [177], [212]
Poor/Wrong selection of equipment/Improper equipment	[18], [48], [161], [221]
Inadequate/Insufficient/Ineffective equipment used for the works	[10], [18], [28], [134], [144], [191], [222]
Equipment delivery problem	[7], [25], [28], [74], [85], [144], [159], [177], [221]
Deficiencies in equipment allocation	[20], [161], [222]
Slow mobilization of equipment	[161]
Rejected equipment	[28]
Labor Related Causes	[24], [25], [48], [74], [157], [177], [199]
Unavailability of site labors	[7], [10], [13], [24], [25], [48], [74], [77], [85], [115], [144], [157], [177], [212], [221]
Unqualified/Inadequate experienced labor	[13], [24], [25], [48], [74], [77], [134], [144], [161]

Table 2.2: Taxonomy of causes of delay (continued)

CAUSES OF DELAY	Source
CONTRACTOR CAUSES	
Labor Related Causes (continued)	[24], [25], [48], [74], [157], [177], [199]
Low skilled manpower/Unskilled labor	[10], [13], [18], [158], [159], [177], [199]
Low productivity/efficiency level of labors	[10], [13], [24], [48], [74], [77], [144], [157], [159], [161], [177], [199], [212], [221]
Weak motivation and morale of labors	[48], [159], [161]
Poor workmanship	[28], [107], [134], [138], [144], [159], [189], [222]
Unavailability of technical professionals in the contractor's organization	[10], [20], [33], [85], [115], [191]
Poor distribution of labor	[18], [222]
Slow mobilization of labor	[161]
Too much overtime for labor	[18], [159]
Severe overtime and shifts	[159], [199]
Absenteeism problems of labor	[161], [199]
Labor and management relations	[74], [177]
Problems due to nationality of labors	[10], [24], [25], [74], [177]
Personal conflicts among labors	[10], [24], [123], [161], [212]
Labor injuries	[74], [177]
Unavailability of skilled/qualified labor/craft	[20], [33], [85], [115], [123], [134], [159], [191]
Unavailability of local labor	[199]
Non-cooperation from labor unions	[199]
Contractor's Financial Causes	[25], [74], [77], [177], [199]
Difficulties in financing project by contractor	[7], [10], [20], [24], [25], [48], [74], [77], [85], [138], [144], [159], [177], [191], [199], [212]
Late payment to subcontractor by the main contractor	[77], [85], [191]
Contractor's financial problems	[13], [107]
Problems in cash flow management	[10], [28], [85], [144]
Contractor's financial obligations	[159]
Subcontractor Causes	[7], [189]
Poor subcontracting (system)	[48], [144]
Delays in subcontractor's work/Delay caused by subcontractor	[10], [24], [33], [48], [77], [107], [123], [134], [157], [159], [189], [212], [221]
Lack of subcontractor's skills	[13], [18]
Lack of subcontractor's experience	[13], [18]
Unreliable subcontractors	[161]
Poor performance of subcontractors and nominated suppliers	[28], [138], [158], [177], [199]
Bankruptcy by subcontractor or supplier	[28], [159], [221]
Subcontractor's financial difficulties	[7]
Poor communication and coordination by subcontractor with contractor/other parties	[144], [177]

Table 2.2: Taxonomy of causes of delay (continued)

CAUSES OF DELAY	Source
CONTRACTOR CAUSES	
Subcontractor Causes (continued)	[7], [189]
Frequent change of subcontractors (because of their inefficient work)	[10], [24], [161], [177], [212]
Time spent to find appropriate subcontractors for each task	[74]
Conflicts between different subcontractors' schedules in execution of project	[24], [25], [74], [123], [177], [212]
Subcontractor interference	[221]
Interference with other trades (trade stacking)	[7], [159]
Slow mobilization by subcontractor	[7], [28], [33]
Rework due to subcontractor	[159]
Health and Safety Related Causes	
Accident during construction	[24], [28], [33], [107], [134], [159], [161], [212]
Unsafe practices during construction	[159]
Damage to structure	[74], [177]
Problems due to site safety considerations/Poor safety conditions	[138], [189], [199]
Problems due to site security considerations	[189]
Problems due to site restrictions	[189]
Lateness in safety facilities reinforcement	[189]
Loose safety rules and regulations within the contractor's organization	[10]
Safety rules and regulations are not followed within the contractor's organization	[191]
Problems due to site pollution and noise	[199]
Environmental protection and mitigation costs	[114]
Theft/Vandalism inside the site	[33], [159]
Scheduling and Controlling Related Causes	[74], [77], [177]
Creation of the schedule too optimistic	[159], [221]
Overestimation of the labor productivity	[77]
More work exists than planned	[221]
Lack of database in estimating activity duration and resources	[25], [74], [77], [177], [220]
Inaccurate estimate of materials, labor output, equipment production rates	[115], [144], [159]
Inaccurate evaluation of projects time/duration	[158], [220]
Improper or wrong cost estimation	[85], [220]
Nonuse of appropriate software for scheduling and controlling	[158]
Contractors' planning and scheduling problems	[7]
Unrealistic project schedule	[199]
Poor judgment and experience of involved people in estimating time and resources	[25], [74], [177]
Lack of experiences in project management & scheduling process	[177]
Lack of experiences and information preparing in price quotation	[177]

Table 2.2: Taxonomy of causes of delay (continued)

CAUSES OF DELAY	Source
CONTRACTOR CAUSES	
Scheduling and Controlling Related Causes (continued)	[74], [77], [177]
Lack of training personnel and management support to model the construction operation	[25], [74], [177]
Unavailability of the construction/project management group for the project	[77]
Unavailability of managerial and supervisory personnel	[123]
Improper technical study by the contractor during the bidding stage	[10], [191]
Inadequate early planning of the project	[25], [74], [144], [177]
Unreasonable or unpractical initial plan	[220]
Insufficient or ill-integrated basic project data that is needed to be provided by contractor	[220]
Poor project planning and scheduling by contractor	[10], [18], [20], [28], [85], [115], [138], [144], [159], [161], [191], [199], [212], [220]
Ineffective control of the project progress by the contractor/Inadequate progress review	[10], [74], [77], [85], [177], [191]
Poor quality of site documentation	[18], [138]
Inefficient work breakdown structure	[10]
Problems with timelines of project information	[74], [177]
Staffing problems (overstaffing/understaffing)	[28], [74], [159], [177]
Transportation problems	[20], [74]
Overcrowded work area/Congestion	[111], [159]
Complexity of works	[158], [220]
Using obsolete technology	[161], [199]
Large number of participants of project	[199]
Involvement of several foreign designers and contractors	[199]
Contractor Generated Causes	[7], [24], [48], [77], [157], [189]
Conflicts between contractor and other parties (consultant and owner)	[10], [24], [25], [74], [123], [158], [177], [212]
Poor communication and coordination by contractor with other parties	[10], [13], [18], [24], [28], [134], [138], [144], [161], [177], [191], [199], [212]
Lack of consultation of contractor/project manager with owner	[199]
Lack of proper training and experience of contractor/project manager	[158]
Poor/Inadequate contractor experience/Inexperienced contractor	[10], [48], [77], [115], [123], [134], [144], [157], [161], [189], [199]
Contractor's lack of geographical experience	[115]
Contractor's lack of project type experience	[115]
Unsuitable leadership style of construction/project manager	[77], [123], [189], [199]
Unsuitable management structure and style of contractor	[123], [189]
Nonutilization of professional construction/contractual management	[177]
Inadequate managerial skills/Inadequate site/project management skills	[123], [189]

Table 2.2: Taxonomy of causes of delay (continued)

CAUSES OF DELAY	Source
CONTRACTOR CAUSES	
Contractor Generated Causes (continued)	[7], [24], [48], [77], [157], [189]
Lack of responsibility of contractor/project manager	[199]
Lack of authority of contractor/project/site manager	[20]
Unreasonable risk allocation by contractor	[199]
Poor contract management by contractor	[74], [85], [107], [144], [177], [199]
Poor subcontract management	[159]
Poor site management/inspection and supervision by contractor	[7], [10], [13], [18], [20], [24], [28], [48], [77], [107], [123], [134], [144], [157], [159], [161], [189], [199]
Poor site management and slow site clearance	[159], [161], [199]
Poor labor supervision	[159]
Poor control of site resource allocation/Lack of available resources	[28], [77], [123], [138], [189], [199], [222]
Poor resource allocation by contractor	[Case Project A]
Delay of field survey by contractor	[10]
Inefficient quality assurance and quality control	[10], [191], [199], [221]
Poor site layout	[18], [159], [199]
Poor site storage capacity	[159], [199]
Poor logistic control by contractor	[189]
Poor trade coordination	[159], [222]
Contractor's deficiencies in planning and scheduling at preconstruction stage	[24], [115], [123], [157], [189]
Improper construction methods/techniques implemented by contractor	[10], [18], [24], [74], [77], [157], [159], [161], [177], [191], [199], [212], [221]
Inadequate contractor's work	[10], [20], [24], [212], [222]
Mistakes in soil investigation	[25], [74], [177]
Poor qualification of the contractor's technical staff/Incompetent technical staff assigned to the project	[10], [24], [33], [191], [199], [212]
Incompetent project team	[161]
Excessive turnover in contractor's staff	[159]
Replacement of key personnel by contractor	[10]
Lack of site contractor's staff	[13]
Contractor's failure to coordinate the work, i.e., deficient planning, scheduling, and supervision	[33]
Failure to utilize tools to manage the project symmetrically by contractor/project manager	[199]
Inadequate instructions by contractor	[159]
Lack of timely decisions and corrective actions by contractor/project manager	[199]
Slow response by contractor/project manager	[199]
Low contractor productivity	[28], [33]
Construction mistakes and defective work	[13], [33], [77], [85], [138], [157]
Errors committed during field construction on site	[25], [74], [177]
Rework due to errors during construction	[10], [24], [107], [111], [159], [161], [212]

Table 2.2: Taxonomy of causes of delay (continued)

CAUSES OF DELAY	Source
CONTRACTOR CAUSES	
Contractor Generated Causes (continued)	[7], [24], [48], [77], [157], [189]
Delay in site mobilization	[10], [24], [28], [33], [107], [191], [212], [222]
Delay in preparation of contractor submissions	[10]
Mistakes and discrepancies in contract documents due to contractor	[134], [157], [158], [177], [199]
Nonadherence to contract conditions by contractor	[74], [177]
Risk and uncertainty associated with projects	[158]
Non-familiarity of contractor with local regulations	[115]
Ineffective contractor head office involvement in the project	[10]
Problems due to company organization of contractor	[10], [144]
Internal company problems of contractor	[10]
Ill defined duties and responsibilities by contractor's company organization	[20], [199]
Inadequate decision making mechanism of contractor's company organization	[20]
Lack of contractor's administrative personnel	[10], [191]
Problems due to other work on hold	[10]
Project fraud and corruption	[158]
Fraud by contractor	[10], [199]
Opportunistic behavior of contractor	[138]
EXTERNAL CAUSES	
Inclement Weather Causes	[7], [13], [18], [20], [33], [85], [114], [115], [134], [137], [138], [144], [158], [161], [177], [184], [191], [199], [203], [220]
Hot weather effect on construction activities	[24], [25], [74], [159], [177], [212]
Humidity effect on construction activities	[221]
Inclement weather effect on construction activities	[48]
Wind effect on construction activities	[74], [159], [177]
Rain effect on construction activities	[24], [25], [74], [159], [177], [221]
Snow effect on construction activities	[221]
Freezing effect on construction activities	[159], [221]
Environmental Causes	[74], [177], [189], [199]
Unexpected foundation conditions encountered in the field	[25], [74], [177]
Unexpected subsurface conditions (geological problems/water table problems, etc.)	[24], [25], [48], [74], [77], [85], [161], [177], [212]
Unforeseen site conditions	[13], [18], [24], [74], [138], [157], [159], [177], [189], [199], [222]
Unforeseen ground conditions (rock, acid, sediment basin)	[13], [85], [123], [134], [138], [144], [189], [199]
Delay in providing services from utilities (such as water, electricity)	[24], [161], [212]
Unavailability of utilities on site (such as, water, electricity, telephone, etc.)	[24], [25], [74], [177]

Table 2.2: Taxonomy of causes of delay (continued)

CAUSES OF DELAY	Source
EXTERNAL CAUSES	
Environmental Causes (continued)	[74], [177], [189], [199]
Lack of temporary facilities on site (buildings, phones, electricity, etc.)	[177], [199]
External work due to public agencies (roads, utilities and public services)	[13]
Difficulties in obtaining energy (electricity, fuel)	[20]
Transportation delays beyond control	[13], [20], [107], [177]
Locational project restrictions	[115]
Interferences of existing utilities	[134], [159]
Unanticipated utilities	[159]
Work damaged by others	[159]
Noise level too high	[159]
Environmental issues	[159]
Force Majeure Causes	[83], [107], [137], [203]
***Acts of God**	[20], [28], [74], [156], [159], [161], [184], [199]
****Geological Disasters**	[20], [62], [74], [159], [161], [184], [199]
Avalanches	[148]
Earthquakes	[156], [161], [189]
Landslides	[148]
Volcanic eruptions	[148]
****Hydrological Disasters**	[148]
Floods	[28], [33], [74], [156], [161], [177], [189]
Limnic eruptions	[148]
Tsunamis	[148]
****Meteorological Disasters**	[148]
Blizzards	[148]
Cyclones	[148]
Droughts	[148]
Hurricanes	[74], [161], [177]
Tornadoes	[148], [156]
Storms	[148]
****Health Disasters**	[148]
Epidemics	[28], [33], [220]
Famines	[28], [33], [177]
****Wildfires and Bushfires**	[148], [156]
***Unexpected Situations**	
Nationalization	[83]
Government sanction	[83]
Blockage	[83]
Embargo	[83]
Labor dispute	[7], [74], [83], [107], [159], [161], [177], [184], [221]

Table 2.2: Taxonomy of causes of delay (continued)

CAUSES OF DELAY	Source
EXTERNAL CAUSES	
***Unexpected Situations (continued)**	
Strike	[7], [28], [33], [74], [83], [114], [137], [156], [159], [161], [177], [184], [221]
Lockout or interruption or failure of electricity or telephone service	[33], [83], [137]
War	[33], [83], [161]
Invasion	[83]
Act of foreign/public enemies	[28], [83]
Hostilities	[83]
Civil war	[83]
Rebellion	[83]
Revolution	[83]
Insurrection	[83]
Military or usurped power or confiscation	[83]
Terrorism or threat of terrorism	[83]
Theft/Vandalism outside of the site	[33], [159]
Rules and Regulations Related Causes	[25], [74], [77], [177]
Obtaining permits/approvals from the municipality/different government authorities	[7], [24], [25], [74], [77], [138], [144], [159], [161], [177], [184], [212], [221]
Obtaining (working) permits for laborers	[25], [74], [191], [212]
Obtaining transportation permit	[77]
Building permits approval process	[74], [138], [159], [177]
Problems related to using of building codes in design of projects	[25], [74], [177]
Delay in performing final inspection and certification by a third party	[24], [159], [161], [212]
Environmental concerns and restrictions	[48], [134], [221]
Traffic control regulation and restriction at job site	[24], [161], [177], [212]
Conservation restrictions	[189]
Restricted use of labor	[203]
Limitation of working hours	[203]
Prevention of contractor's resource	[203]
Inability to obtain labor, goods or materials (shortage through statutory action)	[203]
Work in pursuance of a body's statutory obligations	[203]
Legal issues arising due to local government rules and regulations	[199]
Lack of cooperation from local authorities	[199]
Difficulties in obtaining construction licenses	[20]
Government actions and inactions regarding ordinances, construction law, and etc.	[33]
Changes in government regulations and laws	[159], [161], [177], [191], [212]
Worker's compensation board shutdown	[159]
Acts of government (sovereign or contractual)	[28]

Table 2.2: Taxonomy of causes of delay (continued)

CAUSES OF DELAY	Source
EXTERNAL CAUSES	
Rules and Regulations Related Causes (continued)	[25], [74], [77], [177]
Acts of another contractor in performance of a government contract	[28]
Quarantine restrictions	[28]
Freight embargoes	[28]
Local government pressures	[114]
Economical Causes	[189]
Economic development cycle and its impact on demand	[189]
Inflation impact on material, equipment and labor price fluctuation	[85], [144], [189]
Market competition	[189]
Inflation/Escalation of prices	[7], [85], [138], [158], [161], [199]
Price/Financial fluctuations	[114], [161], [177]
Fluctuation of currency/exchange rate	[158]
Unstable interest rate	[158], [199]
Poor economic conditions (currency, inflation rate, etc.)	[13], [85]
Unforeseeable financial and economic crises	[161], [199]
Prices of some materials shooting up or the constructed project being devalued	[33]
Political Causes	[189]
Changes in government policies (environmental protection, sustainability, waste recycle, brown field use, etc.)	[13], [24], [157], [158], [189], [221]
Changes in legislations on employment, and working conditions	[13], [24], [157], [189], [221]
Political pressure	[189]
Weak regulation and control	[158]
Government regulations	[7]
Social Causes	[189]
Demography change and its impact on labor demand and supply	[189]
Skill shortage on certain trades	[189]
Problems with neighboring community	[157], [161]
Problems with local residents	[189]
Effect of cultural factors	[24], [25], [74]
Civil commotion/disturbances	[7], [137], [203]
Effects of other organizations	[189]
Social and cultural factors	[177]
Technological Causes	[189]
Problems with new materials	[189]
Problems with new construction methods	[189]
Technological complexity	[189]
Technical challenges	[114]

2.5 Responsibility of Delay

As it is stated earlier, generally non-excusable delays are in responsibility of contractor and no compensation is given to contractor. Excusable compensable delays mean owner's causes are in action, so the responsibility totally falls on owner. Sometimes neither party can be responsible because of the delay, as in the case of external delays like force majeure situations. However, sometimes concurrent delays can occur and make the parties share the responsibility. If delays are concurrent then accordingly responsibilities of the delay may come as combinations of responsibilities. If delays of one party are concurrent, then simply the responsibility is of that party; whereas when more than one party are in action then responsibilities are shared. So, responsibility of delays can be named in total as; in case of a delay, either *owner (or his agents)* is *responsible* or *contractor (or his subcontractors)* is *responsible*, or *neither contractual party* is *responsible* or *both contractual parties* are *responsible* (Alaghbari et al., 2007). Since subcontractor is not directly linked to owner (through a contract), his contract with contractor provides the relation through contractor. Contractor-subcontractor relation provides the same positions with an owner-contractor relation. This is why subcontractor's responsibility is actually owner's responsibility on paper. The case is same with the owner and his agents; consultant, design team, engineer, etc. (Carnell, 2000; O'Brien, 1976).

2.6 Impact of Delay

When a delay occurs, generally it brings its damages with itself. Delay is already spent additional time on work with the corresponding additional cost. At the macro level it may affect national economic growth and development of industry and cause monetary loss. At the micro level, in other words at project level, it affects owner and contractor in terms of money (Abdul-Rahman et al., 2008; Arditi et al., 1985; Lo et al., 2006; Mezher and Tawil, 1998; Odeh and Battaineh, 2002). Owner or contractor or they may together bear the brunt and have to afford the losses. The change caused by delay may bring additional costs in forms of late completion, lost productivity, increased costs, etc. Acceleration and other mitigation measures taken can also be thought as an impact or loss of a delay. Moreover, delays lead reduction in quality, damage of reputation and decrease in developers' financial and sales commitments (Benson, 2006; Xiao and Proverbs, 2003). Besides, delays may lead to disputes with their difficult resolution periods, total abandonment and finally also contract termination (Abdul-Rahman et al., 2006; Arditi and Pattanakitchamroon, 2006; Sambasivan and Soon, 2007). So change, namely losses should be recovered by responsible parties for the continuity of the contract and prevention of further losses. Determination of the losses is made through delay analysis; first with the help of identification of delays, secondly with the corresponding responsibility for the delays. Calculation of the loss is fundamentally based on and formed with the contract provisions and the various documents of project that assist the structuring of the claim (Trauner et al., 2009). Some impacts of delay are also considered under the cost overrun heading of the impacts with their corresponding costs such as acceleration costs, lost productivity costs, disruption costs and legal costs. In light of all this information impacts of delay that are presented in this research are *time overrun*, *cost overrun*, *disruption*, *lost productivity*, *acceleration*, *dispute*, *total abandonment* and *contract termination*.

2.6.1 Time Overrun

Delay is increase in completion time of an activity in itself, so time overrun is natural impact of it. However sometimes delays occur on non-critical activities and consume available float of the activity and do not create any time overrun when the contract completion date is considered. On the contrary, there is also another idea that consumption of float is already a loss since usage of float is a separate issue in delay analysis. Delays on non-critical activities may not be attributed as delays in some contracts so distinction should be made at the beginning of contract. Although these; regardless of delay is defined with respect to contract completion date or only in activity base, delay equals to time overrun.

2.6.2 Cost Overrun

Any delay in the completion of project may consume the budgeted costs for risks and also may cause further unanticipated costs to parties to the contract (Ndekugri et al., 2008). Owner may encounter losses due to not having the facility, namely loss of use; whereas contractor and his subcontractors may face with losses due to prolonged presence on construction site (Scott et al., 2004). As it is the case in time overrun, delay equals to money; since more time is required to conclude the project, more resources are also required (as time equals to money). So, cost damages of delay are attributed to the main parties to the contract as *owner's costs* and *contractor's costs*. Further owner's costs and contractor's costs are divided into *direct (primary) costs* and *indirect (secondary) costs* as meeting the exact cost increase that is directly linked to the time increase, and costs due to consequential (or ripple) effects that are indirectly caused by delay respectively (Kartam, 1999; Nguyen, 2007; Turner and Turner, 1999).

2.6.2.1 Owner's Costs

Owner's direct costs may be attributed as direct increase in the costs due to increased project completion; like cost of alternate facilities, increased financing costs and extended overhead costs. Besides these; *owner's indirect costs* may be deemed as costs because of not having the facility in time, the loss of income and lost profits. When the owner is a government department, effects increase as confusion in public development plans, disturbance in budget execution plan for government authority and public inconvenience. All of these effects could be associated with costs of not having the facility (Al-Kharashi and Skitmore, 2009). If contractor is in culpable delay, owner's damages are compensated through contractually stated liquidated damages as contractor becomes liable to pay to the owner a fixed amount of money for each day that the project is behind the contract completion date. Since costs of owner are difficult to measure, reimbursement of damages is preferred through the liquidated damages clause. Generally liquidated damages clause is specified, however if it is not applicable (if it does not take part in contract or legally unenforceable), owner requests his damages based on actual (or general) damages suffered (Coertse, 2011; Lee et al., 2005b; Longley and De Witt, 2006; Trauner et al., 2009; Williams, 2003).

2.6.2.2 Contractor's Costs

Contractor's costs are simply additional costs due to prolonged construction duration, increased overhead costs and expenses accordingly as *contractor's direct costs* and loss of profit as *contractor's indirect costs* since contractor is prevented from possibility of working with other projects (Al-Kharashi and Skitmore, 2009; Ndekugri et al., 2008). Increased field costs and overhead costs are main costs of the contractor in case of a delay. Some of the contractor's direct costs are as follows:

- ✓ **Home office overhead costs:** are general and administrative costs that the contractor spends for operation of his home office, but that cannot be directly allocated to a particular project or contract like; home office rent, office equipment, salaries of office personnel, etc. Normally, the accounting stream of the contractor meets the home office overhead costs and the contractor may include home office overhead costs in some part of the bid price for each project; but in case of an owner caused delay, they should be measured and compensated. Since the cost is not project specific and difficult to determine, well known formulae are created for the calculation of home office overhead costs (Hudson formula, Emden formula, Eichleay formula, Canadian Method, Calculation Using Actual Records, and Net Present Value Analysis). Home office overhead costs of formally suspended projects are called *extended home office overheads*, whereas partially or informally suspended projects experience *unabsorbed home office overhead costs* (Niesse, 2004; Sgarlata and Brasco, 2004; Trauner et al., 2009; Turner and Turner, 1999).
- ✓ **Extended and increased field costs:** are direct site costs of contractor that are calculated through increased units of work. In case of a delay;

contractor's field staff and field equipment would stay on site more than planned, and consume resources to continue on work, and may also encounter escalation in prices. So; additional labor, material (with storage), equipment (with idle time) costs and site overheads constitute the extended and increased field costs of contractor (Trauner et al., 2009).

- ✓ **Lost productivity costs:** are costs encountered due to factors that generate loss of productivity like site congestion, shifts in construction season, erratic staffing, etc. (Trauner et al., 2009). Lost productivity is taken as a separate impact of delay besides its costs presented (here) under contractor's direct costs, since costs (cost overrun) and lost productivity are handled as different categories of impact of delay.
- ✓ **Acceleration costs:** are costs that are simply the difference between what the accelerated activities cost and what would the activities cost if they were not accelerated - namely planned costs of activities. The costs may be previously agreed in contract or set just before the action for mitigation taken (Trauner et al., 2009; Winter et al., 2002). Acceleration is separately taken as an impact of delay and also presented in mitigation of delays in the further sections of this study.
- ✓ **Costs of noncritical delays:** constitute the issue related with the debate on usage of the float of the project. If they are accountable by contract, contractor's costs due to noncritical delays that are attributed to owner may be compensated by owner and vice versa (Trauner et al., 2009).
- ✓ **Consulting and legal costs:** are the costs of claiming and dispute resolution procedure. Generally, these costs are not compensated from the other party. Each party should bear their own costs from the beginning, but these costs may be attributed to the other party through a changes clause in contract, or may compensated through settlement of claims, or may be taken into consideration in calculation of contingency in tender (Trauner et al., 2009).

The full list of the costs of owner and contractor is available in the following table (Table 2.3) in the form of taxonomy prepared for the impact of delay.

2.6.3 Disruption

Winter et al. (2002) state disruption as "*disruption (as distinct from delay) is disturbance, hindrance or interruption to a contractor's normal working methods, resulting in lower efficiency*", whereas they define delay in its simplest form as "*lateness*". Carnell (2000) explains delay as works that take longer than planned and disruption as works that are performed more difficult. It is uneconomical or abortive work regardless of its effect on project completion (Turner and Turner, 1999). Since delay is a change in itself, it may cause further changes as disruption and continue to affect the performance of contractor. Actually, disruption itself is not a problem however it may have adverse effects on the project. It may lead further late completion to the project or may not (Thomas, 1993; Trauner et al., 2009; Winter et al., 2002). So, sometimes delays occur in form of disruptions or disruptions cause delays but not necessarily (Williams et al., 2003).

2.6.4 Lost Productivity

Trauner et al. (2009) state that "*the delay may either directly cause the inefficiency or be caused by the inefficiency*". Simply, efficiency is the work performed per units of resources consumed to perform that work. When works consume more resources than planned, they are deemed as inefficient. So inefficiency, which is also called as lost productivity, is one of the major impacts of delay since delay breaks the continuous rhythm of the performance and causes further damages in forms of productivity loss. It is difficult to quantify costs due to lost productivity. So different methods are available for calculation of lost productivity costs as measured mile method, total cost method and modified total cost method. These methods are also questionable by some bodies, so calculation of lost productivity costs is needed to be agreed in contract to prevent disagreements (Aibinu, 2009).

2.6.5 Acceleration

Acceleration is the action taken to complete the works in less time than planned. It is the major mitigating action in case of a delay and so it is also an impact of delay. Generally works are accelerated to save money by avoiding delay damages or reducing overhead costs, allowing an earlier income from the facility, freeing the contractor to begin other work, providing early use of facility or a commitment to a user. So, contractor may try to recover damages due to his culpable delay by acceleration which is called "*constructive acceleration*". In addition to this; owner may insist on acceleration in cases of contractor is irresponsible for the delay where this type of acceleration is named "*directive acceleration*". Costs of acceleration should either be stated in contract or be evaluated in detail before embarking it, because sometimes simply delays with their damages may be innocent when they are compared with costs of acceleration (Carnell, 2000; Hegazy et al., 2005; Hoshino et al., 2007; Thomas, 1993; Trauner et al., 2009; Winter et al., 2002). Details of costs are available in the acceleration costs under contractor's direct costs in the following table (Table 2.3) and the measures of acceleration will be handled in the mitigation section later in this chapter.

2.6.6 Dispute

Since delay causes time overrun and cost overrun in projects and further impacts, it leaves both contractor and owner in a lurch and this triggers the battle between contractors and owners. Sometimes parties stay clear and preserve the relations and provide amicable settlement in case of a claim. However, sometimes parties cannot succeed to provide required information and be unable to communicate their positions. In such cases it is difficult to settle and when settlement is not provided, delay may cause further claims (counter-claims) and disputes that harden the situation. So dispute is an important and hurtful impact of delay (Alaghbari et al., 2007; Palles-Clark, 2006). Some studies (Abdul-Rahman et al., 2006; Aibinu and Jagboro, 2002) indicate that third party claims, litigation and arbitration are impacts of delay separately. These are thought to be handled under "dispute impact" in this study since disputes are unsettled forms of claims and generally result with these and other dispute resolution techniques.

2.6.7 Total Abandonment

Condition of the project may come to any degree that causes the contractor to do nothing other than stopping the work. Excessive changes, inadequate designs, frequent owner interference and other factors that are beyond the control of contractor may cause this situation. In case of an abandonment, contractor should be reasonable in his decision and prove his case accordingly. Otherwise, he would be responsible for the damages due to wrongly abandonment of project (Poulin, 2008).

2.6.8 Contract Termination

When contract becomes no more profitable then it may be get terminated (Davenport, 1995). Generally owners may terminate the contract and assign contractor to stop the work and leave the construction site. Accordingly, owner takes the control of material and equipment on site and continues the construction with assignment of a new contractor if possible. However, owner (or may be other party to contract) should be reasonable and have sound factors behind to carry out this decision, otherwise he would be responsible from his acts (Patrick et al., 2010). So contract termination is a possible impact of serious delays and unsettled disputes.

After presentation of elements of impact of delay in text, the following table presents further detail especially on cost overrun impact with the indication of other impacts in the taxonomy. The factors in bold depict the main factors and the basic levels of the taxonomy.

Table 2.3: Taxonomy of impact of delay

IMPACT	
FACTORS	**Source**
TIME OVERRUN	[2], [6], [16], [22], [176], [200], [212]
COST OVERRUN	[2], [6], [16], [22], [176], [200], [212]
Owner's Costs	
Liquidated Damages	[151], [200]
Owner's Direct Costs	[151]
Loss of key resources (staffing and equipment)	[171]
Reduction of shareholder equity	[171]
Costs for the owner's staff	[151], [200]
Costs for additional design services	[200]
Cost for project inspection	[151], [200]
Costs for maintaining current facilities	[200]
Costs for additional rentals	[171], [200]
Costs for additional storage	[200]
Governmental fines and penalties	[171]
Temporary lodging costs	[200]
Additional moving expense	[200]
Increased financing costs	[151], [200]
Extra inflation or fluctuation costs	[203]
Extended overhead costs	[200]
Escalation costs	[200]
Missed market penetration	[171]
Interest charges	[171]
Claims by follow-on contractors	[200]
Claims by third parties	[171]
Extended warranties	[200]
Owner's Indirect Costs	[117], [151]
Loss of income/revenue/profit	[200]
Lost rents	[151]
Costs to the public for not having the facility	[10], [200]
Contractor's Costs	
Contractor's Direct Costs	[1], [151]
Extended and Increased Field Costs	[200], [217]
Additional Labor Costs	[1], [200]
Escalation of labor cost	[151], [200]
Additional direct labor cost	[200]
Additional idle labor cost	[200]
Additional union supervisory personnel cost	[200]
Additional Material Costs	[1], [200]
Escalation of material cost	[151], [181], [200]
Deterioration in conditions of material	[203]
Additional material storage costs	[200]

Table 2.3: Taxonomy of impact of delay (continued)

IMPACT	
FACTORS	**Source**
Additional Equipment Costs	[1], [200]
Escalation of equipment cost	[151], [200]
Additional working/productive time	[203]
Additional standing/idle time	[151], [203]
Extra cost for replacement of unavailable equipment	[200]
Costs of bringing to site and commissioning	[200], [203]
Costs of dismantling and removing from site	[203]
Extended Site Overhead Costs	[1], [149], [151], [181], [203], [217]
Site preliminaries	[1]
Site infrastructure	[1], [149]
Connecting and mobilizing utilities	[151]
General site equipment	[1]
Cranes	[1]
Providing a jobsite office	[151]
Supervising the project	[149], [151]
Mobilization/Demobilization costs	[151]
Home Office Overhead Costs	[1], [149], [181], [200]
Extended Home Office Overhead Costs	[151], [200], [217]
Rent	[200]
Utilities	[181], [200]
Furnishings	[200]
Office equipment	[181], [200]
Executive staff	[181], [200]
Support and clerical staff not assigned to the field	[181], [200]
Estimators and schedulers not assigned to the field	[200]
Mortgage costs	[200]
Real estate taxes	[181], [200]
Non-project-related bond or insurance expenses	[181], [200]
Depreciation of equipment and other assets	[181], [200]
Office supplies (paper, staples, etc.)	[181], [200]
Advertising	[200]
Marketing	[200]
Interest	[200]
Accounting and data processing	[181], [200]
Professional fees and registrations	[200]
Unabsorbed Home Office Overhead Costs	[1], [151], [217], [200]
Lost Productivity Costs	[151], [200]
Loss of rhythm	[189], [217]
Lower morale	[189]
Schedule compression	[189]
Resequencing of work	[189], [200]
Trade stacking	[189], [217]
Staff turnover	[189]

Table 2.3: Taxonomy of impact of delay (continued)

IMPACT	
FACTORS	**Source**
Lost Productivity Costs (continued)	[151], [200]
Team changes	[189]
Less qualified labor	[189]
Loss of learning curve	[189]
Site congestion	[189], [217]
Poor safety conditions	[189]
Poor coordination	[189]
Shifts in the construction season	[200]
Unavailability of resources	[200]
Changes in manpower levels and distribution	[200]
Additional manpower	[200]
Erratic staffing	[200]
Variations in preferred/optimum crew size	[200]
Multiple-shift work	[189], [217]
Unbalanced gangs	[189], [217]
Acceleration Costs	[200]
Additional material costs due to acceleration	[200]
Additional equipment costs due to acceleration	[200]
Labor premiums for acceleration	[200]
Inefficiency due to acceleration	[200]
Miscellaneous expenses due to acceleration	[200]
Costs of Noncritical Delays	[200]
Escalation of labor costs due to noncritical delay	[200]
Additional material costs due to noncritical delay	[200]
Additional equipment costs due to noncritical delay	[200]
Additional supervision for noncritical delay	[200]
Inefficiency due to noncritical delay	[200]
Disruption Costs	[200]
Consulting and Legal Costs	[200]
Extended Temporary Utility and Facility Costs	[200]
Extended Maintenance and Protection Costs	[200]
Extended Warranty Costs	[200]
Increased Bond Costs	[200]
Increased Financing Costs	[1]
Demolition Costs	[189]
Waste Costs on Abandoned Work	[189]
Contractor's Indirect Costs	[151], [1]
Loss of profits, bonuses or opportunity costs (on the delayed project / on other projects)	[149], [151], [200]
Destruction of business	[151]
Increased risk (Loss of float and Increased sensitivity to further delays)	[189]
Quality damages	[189]
Quality degradation	[189]

Table 2.3: Taxonomy of impact of delay (continued)

IMPACT	
FACTORS	**Source**
Contractor's Indirect Costs (continued)	[151], [1]
Damage to reputation	[189]
DISRUPTION	[2], [16], [22], [46], [200], [216], [217]
LOST PRODUCTIVITY	[2], [22], [200]
ACCELERATION	[22], [200]
Constructive acceleration	[46], [97], [102], [200], [222]
Directive acceleration	[97], [102], [200], [222]
DISPUTE	[6], [16], [176], [212]
TOTAL ABANDONMENT	[2], [6], [176], [212]
CONTRACT TERMINATION	[2], [22]

2.7 Mitigation of Delay

When a delay is encountered, parties may analyze the situation and determine the possible effects of it to make the decision of whether the situation could be enhanced or not. Generally, contractor is obliged by the contract to take mitigating actions in case of any delay if it is applicable. If it is an excusable delay, contractor should do his best to mitigate the delay after notification of extension of time claim. Also contractor is contractually obliged to take mitigating actions in case of a non-excusable delay (Palles-Clark, 2006; Yogeswaran et al., 1998). Small changes made at this step whenever the flexibility of the construction program allows, prevent the bigger problems as much as possible and as long as the cost of mitigation is reasonable (Bordoli and Baldwin, 1998). The situation is stated by Winter et al. (2002) as "*The contractor's duty to mitigate its loss has two aspects - first, the contractor must take reasonable steps to minimize its loss; and secondly, the contractor must not take unreasonable steps that increase its loss*." A reasonable mitigation may be determined by the factors of costs of the delay, costs of the mitigation and what the contractor knew at the time of delay (Finke, 1999). If it is not a directive by owner, since contractor bears the risk of the new construction method, the savings that come from mitigation are attributed to the contractor (Trauner et al., 2009). Possible mitigation matters can be named as; *changing the work sequence*, *accelerating the work*, *changing the contract*, *making improvements* and could be followed with their details through the following table (Table 2.4).

Table 2.4: Taxonomy of mitigation matters

MITIGATION	Source
Changing the Work Sequence	[35], [200], [224]
Deleting some work items	[200]
Allowing more of the critical work to occur at the same time	[200]
Accelerating the Work	[6]
Increasing manpower	[35], [200]
Adding equipment	[200], [217]
Expediting the delivery of materials	[35], [221]
Working outside planned working hours	[2], [200], [217]
Extra shifting	[2]
Improving conditions e.g. providing temporary heat	[221]
Changing the Contract	[200]
Changing the materials used	[200]
Changing the method of construction	[2], [200]
Relaxing the contract restrictions	[200]
Asking for a change in design	[2]
Making Improvements	
Improvement of productivity	[2], [200]
Improvement of communications between parties	[221]
Conducting work methods improvement studies	[221]
Asking for more site meetings with all functional groups	[2]
Asking top management for more executive authorities to project manager	[2]
Protection of uncompleted work	[2]
Timely and reasonable reprocurement	[2]
Timely changing or cancellation of purchase orders	[2]

2.8 Analysis of Delay

Analysis of delay is made through some *techniques*, which have their own *advantages* and *disadvantages*, with the help of *selection criteria* for the determination of suitable technique. Also, there are some *methodology steps* available to guide the analysis when using the technique and *data* required for an objective analysis. Finally, there are *issues* relating to analysis of delay that needed to be taken into consideration during analysis and also in planning. All these topics will be held in the following sections.

2.8.1 Delay Analysis in General

Delay analysis is the core subject of construction debates since delays naturally occur in construction projects. As it is stated earlier; delays are common for construction projects and with the development in the sector, projects became more complex than before. Accordingly parties to a contract are much more informed about the delay issue and generally take delay into consideration from the planning of the project with the enhanced planning tools available (Sakka and El-Sayegh, 2007). Trauner et al. (2009) state that all project professionals should know the basic types of delays; understand the situations that lead to compensation; know to use the project data in determination, quantification and assessment of the cause of delay; and determine the effects on project and quantify costs damages. So in its simplest form, delay analysis is determination of causation, liability and damages of delay (Arditi and Patel, 1989). Although today planning and tracking processes are much more powerful than before, the tools used and detailed techniques provided to analyze delays do not prevent occurrence of delays or directly ease the analysis of delays. It is still a challenge to isolate, identify and quantify effects of delays since the delays occur in a complex form with respect to the complex projects. Today’s projects are designed to meet many variables including various project needs, motivation of participants, building risk with some unpredictable circumstances, etc. So delays may come into action in a combined effect of the forms of actions/inactions of parties, changes and unforeseen events. When delays occur in that complicated form, generally parties become unable to settle the situation and see the solution in assignment of the total responsibility to the other party. Generally parties have difficulty in analyzing delays and get help from experts for settlement of their claim and also for resolution of the dispute (Braimah and Ndekugri, 2009; Ibbs and Nguyen, 2007; Trauner et al., 2009).

2.8.2 Importance of Delay Analysis

Since delay is one of the most common problems of construction projects and causes further disputes and even compelling litigation processes, proper analysis of delays constitutes the heart of delay debate. Creation of claims on a sound basis with adequate use of delay analysis; and accordingly analysis of the claims or disputes with convenient use of delay analysis help the prevention of knotty problems due to delay. So in case of a delay; equitable allocation of responsibility and clear determination of timing, cause, and effect of the delay through delay analysis are needed. The analysis figures out what actually happened in the project, when and how the delay impacted the project and who caused it. With respect to this analysis, remedy of the delay is claimed to cure the situation and continue on with least damages as possible. Analysis of delays provides the determination of extension of time due and compensation attributed. So analysis of delays is also used in analysis of claims, if claims are not settled, it is also used in resolution of disputes. However; as long as comprehensive analysis of delays is provided with reliable records, claims may not turn into disputes that bring litigation and further problems (Adhikari et al., 2006; Kartam, 1999; Shi et al., 2001).

2.8.3 Delay Analysis Techniques

There are lots of analysis techniques available in the literature for delay analysis with their own drawbacks that limit their capabilities. As long as the techniques are used with the information of their capabilities, a properly carried out analysis would provide reliable results regardless of the limitations of the techniques. So, proper methodology steps should be followed during analysis of delays (Trauner et al., 2009). In addition to that, as the available techniques vary in capabilities, the delay cases that are in debate and needed to be analyzed also varies. Thus selection of the most suitable technique is the crucial step in analysis of delays. According to the study of Ndekugri et al. (2008), simplistic methods (namely global impact technique, net impact technique and as-planned vs. as-built technique) are much more known and used in practice by parties to the contract whereas sophisticated methods (dynamic techniques rather than as-planned vs. as-built technique) are not much known and used less due to the effort needed to perform.

2.8.3.1 Types of Techniques

Techniques are considered as *static techniques* or *dynamic techniques* according to their basis as CPM schedules or not. There are also many modified techniques presented to overcome the existing drawbacks of the well-known techniques (Ibbs and Nguyen, 2007). However every attempt is not presented here, only the most cited techniques are taken into consideration. Because success of each technique is hidden in its usage process and every analyst may improve the methodology as a response to the need of the specific case that should be analyzed. So, techniques that will be introduced in this study can be seen through the following table (Table 2.5).

Table 2.5: Delay analysis techniques

DELAY ANALYSIS TECHNIQUES	Source
Static Techniques	[35], [149]
i.Entropy technique	[35], [219]
ii.Scatter diagram technique	[35], [219]
iii.S-curve technique/Dollar to time relationship/Technique based on dollars	[40], [96], [149], [117], [200], [219]
iv.Global impact technique (Bar chart analysis)	[5], [22], [78], [116], [226] ([4], [14], [15], [35], [40], [69], [78], [149], [174], [200], [215], [219])
v.Net impact technique (Bar chart analysis)	[5], [14], [15], [35], [40], [78], [116], [149], [174], [215], [219] ([4], [14], [15], [35], [40], [69], [78], [149], [174],[200], [215], [219])
Dynamic Techniques	[35], [96], [149]
i.As-planned vs as-built technique	[4], [5], [14], [15], [39], [40], [57], [78], [104], [116], [149], [174], [198], [215], [219], [226]
ii.Impacted as-planned technique	[4], [5], [14], [35], [39], [40], [57], [78], [104], [116], [117], [119], [135], [149], [174], [198], [200], [215], [219], [226]
iii.Collapsed as-built technique (/But for) (Unit subtractive/Gross subtractive)	[4], [5], [15], [22], [35], [39], [40], [57], [69], [78], [104], [117], [119], [129], [135], [141], [149], [174], [181], [198], [200], [219], [226] ([200])

Table 2.5: Delay analysis techniques (continued)

DELAY ANALYSIS TECHNIQUES	Source
Dynamic Techniques (continued)	[35], [96], [149]
iv.Window analysis technique (/Snapshot/Current period analysis (CPA))	[4], [5], [14], [15], [22], [35], [39], [40], [57], [69], [78], [82], [98], [104], [116], [117], [119], [149], [181], [198], [200], [215], [219], [226]
v.Time impact analysis technique (/Fragnet)	[4], [5], [14], [15], [22], [39], [40], [57], [69], [78], [96], [104], [116], [149], [174], [181], [198], [200], [215], [222]

2.8.3.1.1 Static Techniques

Static techniques are the basic techniques that are based on simply bar charts rather than CPM schedules. *Entropy technique*, *scatter diagram technique* and *s-curve technique (with the idea of cost value of the work is directly related with the progress of the work performed)* are the primitive methods of this kind (Trauner et al., 2009). However analysis based on bar chart schedules as *global impact technique* and *net impact technique* are worth to mention at this point.

Analysis Using Bar Chart Schedules: Today most of the projects are scheduled with CPM schedules. However bar chart schedules are still used in planning due to their easiness in representation and usage. Bar chart schedules have less detail when they are compared with CPM schedules. Additionally, bar charts do not provide relations between activities and also the critical path. These limitations damage the effectiveness of their usage in both planning and analysis of delays. As the level of information decreases, subjectivity increases accordingly in analysis of delays. Still bar charts can be used as a base in delay analysis since they depict the planned programme of the activities. Analysis using bar chart schedules may give reliable results as long as the analyst knows the limitations and usage of the bar chart schedules in delay analysis in addition to the sound knowledge of the case in hand. Even it is not depicted in bar chart schedules; every project has its own critical path. So analyst must first identify the critical path of the bar chart schedule with the extra available information of the project. Then creation of the as-built bar chart schedule with the updates including the changes occurred should be provided. Accordingly, the comparison between as-planned and as-built schedules may depict the facts behind the delay. The method and the accuracy of the analysis change according to the detail of the as-planned schedule and the factual material available to build the as-built schedule (Trauner et al., 2009). This type of scheduling and analysis technique may be suitable for projects with few activities related on a linear basis. It is not suitable for complex projects with complex logic design behind with loads of activities (Doyle, 2005). Well-known techniques based on bar chart schedules may be named as *global impact technique* and *net impact technique*.

- ✓ **Global Impact Technique:** simply plots the delays on a bar chart schedule and identifies global impact of the delays by summing up each delay duration. Global impact technique is preferable when detailed calculations are not possible but it is not recommended since it assumes that every delay in the project has an equal impact, does not provide a cause and effect and ignores concurrent delays (Arditi and Pattanakitchamroon, 2006; Farrow, 2007).
- ✓ **Net Impact Technique:** is basically the same technique with the global impact technique with the only difference of the partial refinement in concurrent delays issue. The concurrent delays are reduced to one delay and taken into consideration together to prevent extra counting in the total delay (Farrow, 2007).

2.8.3.1.2 Dynamic Techniques

Dynamic techniques are the preferable delay analysis techniques that are based on CPM schedules. Since dynamic models consider the change in original logic, they may be much more accurate than a static model that only considers the baseline logic (Tieder, 2008). The most interpreted dynamic techniques in the literature are *as-planned vs. as-built technique, impacted as-planned technique, collapsed as-built* *technique, windows analysis technique* and *time impact analysis technique* (Ndekugri et al., 2008).

- ✓ **As-planned vs. As-built Technique:** (also named as Impacted As-Built Technique / Adjusted As-Built Technique / Total Time Technique) It is the most well-known and commonly used technique between parties to a construction contract. It is based on comparison of as-planned CPM schedule and the as-built CPM schedule and accordingly observation of the difference. The as-built critical path is determined and the activities are compared with their planned versions on the as-planned schedule and variances from the plan are observed through actual and planned start and finish dates and durations. The impact of the delays with their causes and responsibilities are determined (Arditi and Pattanakitchamroon, 2006; Braimah and Ndekugri, 2009; Farrow, 2007; Ndekugri et al., 2008). This technique may be used in its simplest form as only the observational comparison of the activities on graphical basis without the details provided by CPM schedule. Besides, the technique has the potential to be used as sophisticated version on a daily basis for the delay periods of the project (Tieder, 2008).
- ✓ **Impacted As-planned Technique:** (also named as What If Technique / Baseline Adding Impacts Technique) In this technique, the delay (or the impact) is added to the as-planned CPM schedule, which is taken as baseline during the analysis, and new completion date of the project is determined. The difference between the planned completion date and the current completion date indicates the effect due to the inserted delay. It is possible to load both party delays together, however generally parties prefer to insert only the delays attributable to the other party and calculate the total delay caused by the other party. This is why the technique is also called "what if technique". It basically concentrates on 'what' the schedule would be 'if' the particular delays did not happen. When it is used in this way, it ignores the concurrent delays and would give unreliable results in complex situations (Arditi and Pattanakitchamroon, 2006; Farrow, 2007; Kim et al., 2005; Ndekugri et al., 2008; Tieder, 2008; Trauner et al., 2009). It is subject to the

analyst to load the delays in total or one by one according to the complexity of the situation and detail of the analysis. It is also possible to contemporaneously track the progress with regular updates using this technique (Braimah and Ndekugri, 2009; Kartam, 1999).

- ✓ **Collapsed As-built Technique:** (also named as But For Technique / Subtractive As-Built Technique) Trauner et al. (2009) define collapsed as-built technique as "*the logical opposite of an impacted as-planned analysis*". For this technique, first an accurate as-built CPM schedule is procured or constructed and used as a baseline. Then delays are subtracted from the schedule and the schedule is re-analyzed. The obtained difference between the contract completion dates constitutes the impact of the subtracted delay (Doyle, 2005; Trauner et al., 2009). The technique is also called as "but for technique" since it indicates how the project would have progressed 'but for' the delays (Ndekugri et al., 2008). It is also used against other parties by removing only the other party caused delays and depicting when the project would have been completed but for the other party's delays (Arditi and Pattanakitchamroon, 2006; Farrow, 2007; Lee et al., 2005b; Mbabazi et al., 2005; Tieder, 2008; Zack, 2000). As it is the case with impacted as-planned technique; when collapsed as-built technique focuses on only one party delays, it fails to recognize concurrent delays of complex projects (if exist) (Kim et al., 2005). Analyst is free to pull out all the delays in a single shot which is named by Trauner et al. (2009) as "gross subtractive as-built technique" or delays may be pulled out one by one as named again "unit subtractive as-built technique" according to the characteristics of the delay case (Braimah and Ndekugri, 2009).
- ✓ **Windows Analysis Technique:** (also named as Contemporaneous Period Analysis Technique (CPAT) / Snapshot Technique) This technique basically divides the construction period into time slices (windows - called "digestible" time periods by Hegazy and Zhang (2005)) and determines the effects of the delays of each party in the selected time frame (period) to the contract completion date. The CPM schedule is analyzed through periodic updates in

forms of windows. The analyst selects the most suitable window for the analysis according to the delay period, the changes in critical path of the schedule, dates of schedule revisions/updates and contractually mandated dates/milestones (if applicable). Generally, the period prior to delay is taken as the first window and analyzed (updated) as the portion before delay. For this first step of the analysis, as-planned CPM schedule is taken as baseline and updated. Then the time period including the whole delay (window is generally bordered with the end of the delay) is taken as another window with the as-built information up to the end of window and as-planned information for the rest of the schedule and analyzed (updated again). For this and next steps of the analysis, the updated schedule in the previous step of each one is taken as baseline and updated. The difference between project completion dates between two steps indicates the impact caused by the delay or delays included in the last window. The technique is continued on with all the other remaining windows updated in this way (Arditi and Pattanakitchamroon, 2006; Braimah and Ndekugri, 2009; Farrow, 2007; Kao and Yang, 2009; Kim et al., 2005; Ndekugri et al., 2008; Trauner et al., 2009; Williams, 2003). Thus concurrency issue is tried to be enhanced since delays are handled together in the selected time frame. In addition to this, dynamic nature of the critical path is preserved during analysis since the critical path is considered during selection of the window and the schedule is continuously updated with intervals during the analysis (Doyle, 2005). The more the number of window intervals with shorter durations is applied, the more accuracy in the analysis is provided. For complicated projects the periods could be arranged on a daily basis for the delay periods to increase accuracy. So updates provide contractor’s as-built schedule to be up-to-date and current as-planned schedule be ready for the remaining of the work. Since this technique overcomes the many drawbacks of the previous ones, it is highly recommended by experts, courts, boards, practitioners and researchers. However due to its effort and expensiveness it is not much known and generally not used by parties to the construction contract (Finke, 1999;

Hegazy and Zhang, 2005; Ibbs and Nguyen, 2007; Kartam, 1999; Ndekugri et al., 2008; Tieder, 2008).

- ✓ **Time Impact Analysis Technique:** (also named as Fragnets Technique / Subnetworks Technique) This technique is basically a variation of the windows analysis technique, so the idea behind the technique is the same with windows analysis technique. The only difference in this method is; rather than a time period with possible delays in it, a specific delay is used directly to update the process. Updates are generally done immediately before and immediately after the delay. This technique is also called fragnets technique which implies “fragmentary networks”. Delays or changes are depicted sometimes with these fragnets and inserted to the schedule. As it is the case in windows analysis technique, baseline is as-planned CPM schedule for the first step and the latest updated schedules for the rest; and also again the difference between completion dates of before and after the delay inserted indicates the impact of the delay. Time impact technique is able to be used on a day-by-day basis to increase the accuracy of the technique. It is a widely accepted method and has a significant merit as it is recommended by Society for Computers and Law (SCL) (Arditi and Pattanakitchamroon, 2006; Braimah and Ndekugri, 2009; Doyle, 2005; Farrow, 2007; Ndekugri et al., 2008; Tieder, 2008; Trauner et al., 2009; Williams, 2003; Winter et al., 2002).

2.8.3.2 Advantages and Disadvantages of Delay Analysis Techniques

As it is stated in the previous section, there are various techniques available for analysis of delays. However none of the techniques presented is perfect, each of them has its own advantages and disadvantages (or limitations) (Kao and Yang, 2009; Sgarlata and Brasco, 2004). They either include an assumption or have subjective assessment or theoretical projection and so forth. However success of the techniques is hidden in their usage. First the user of the techniques should have the knowledge, understanding and skill for both construction related issues as scheduling, construction methods, estimating, costing, construction law, scheduling tool; and capabilities of techniques (Ndekugri et al., 2008). As long as the user selects the technique according to the specific case of delay and performs the analysis with the idea of capabilities of techniques, reliable results would be obtained whatever the technique is selected (Farrow, 2007; Trauner et al., 2009). The techniques do not have stringent rules and are open to flexible use according to the need. For example one may use a technique, which proposes loading of delays in total, by adding delays one by one according to the delay case to overcome some disadvantages of the technique. Additionally, some techniques may be analyzed by dividing delays in sections and also on a daily basis to overcome the issues of inability to analyze concurrent delays and ignorance of dynamic nature of critical path (Hegazy and Zhang, 2005; Kim et al., 2005). There are also many modified techniques available each of which are created with the purpose to overcome a different disadvantage of a technique (Tieder, 2008). Popescu-Kohler (1998) studies various improvements to overcome the drawbacks of the techniques. There are also many other studies that aim to enhance a single method within the issue. Braimah and Ndekugri (2009) present a study that mentions most of the modified methods available in literature. However since the basic techniques are handled in this study, the advantages and disadvantages of their pure form are presented in Table 2.6 as follows. The wording "depends" in parenthesis implies the different opinions of writers with the related sources next to it. Since techniques are open to enhancement in drawbacks, sometimes split in opinions occurs in that area.

Table 2.6: Advantages and disadvantages of delay analysis techniques

ADVANTAGES & DISADVANTAGES			
Advantages	**Source**	**Disadvantages**	**Source**
Global Impact Technique			
Advantages of Global Impact Technique		**Disadvantages Of Global Impact Technique**	
Simple	[78], [174]	*Concurrent delays not recognized*	[14], [78], [174]
Inexpensive	[174]	*Not scrutinize delay types*	[14], [22], [69], [78], [174]

Table 2.6: Advantages and disadvantages of delay analysis techniques (continued)

ADVANTAGES & DISADVANTAGES			
Advantages	**Source**	**Disadvantages**	**Source**
Global Impact Technique (continued)			
Advantages of Global Impact Technique		**Disadvantages Of Global Impact Technique**	
Easy to understand and use	[78], [174]	*Not demonstrate cause and effect*	[78]
No need to detailed as-built information	[174]	*Failure to consider the dynamic nature of critical path*	[78]
Easy when detailed calculations not possible	[22]	*Ignores reality*	[78]
		Overestimates total delay	[215]
Net Impact Technique			
Advantages of Net Impact Technique		**Disadvantages of Net Impact Technique**	
Simple	[78], [174]	*Concurrent delays not recognized*	[174]
Inexpensive	[174]	*Not scrutinize delay types*	[14], [69], [174], [215]
Easy to understand and use	[78], [174]	*Not demonstrate cause and effect*	[78]
No need to detailed as-built information	[174]	*Failure to consider the dynamic nature of critical path*	[78]
Partial refinement in concurrent issue	[14], [78], [215]	*No network so no true effect on completion*	[14], [174]
		Acceleration not recognized	[174]
		Disruption not recognized	[174]
As-planned vs As-built Technique			
Advantages of AsPlanned vs AsBuilt Technique		**Disadvantages of AsPlanned vs AsBuilt Technique**	
Simple	[17], [22], [40], [78], [149]	*Not much reliable*	[22]
Inexpensive	[17], [40], [78], [149]	*Not dealing events separately*	[22]
Easy to understand and use	[40], [149], [174]	*Lacks systematic procedure*	[22]
No need for networked schedule	[174]	*Failure to consider the dynamic nature of critical path*	[22], [39], [40], [122]
Not much requirement to adjusted schedule	[22], [174]	*Not scrutinize delay types (depends)*	[126], [215] ([22])
As-planned and as-built schedules are both taken into consideration	[22], [174]	*Not demonstrate cause and effect*	[126], [185]
		Concurrent delays not recognized (depends)	[17], [39], [185], [217] ([22], [174])
		Redistribution of resources not recognized	[39], [217]
		Resequencing of work not recognized	[17], [39], [217]
		Mitigation not recognized	[17], [217]

Table 2.6: Advantages and disadvantages of delay analysis techniques (continued)

ADVANTAGES & DISADVANTAGES			
Advantages	**Source**	**Disadvantages**	**Source**
As-planned vs As-built Technique (continued)			
Advantages of AsPlanned vs AsBuilt Technique		**Disadvantages of AsPlanned vs AsBuilt Technique**	
		Acceleration not recognized (depends)	[17], [39], [217] ([22])
		Need for as-planned and as-built schedules	[174]
		Inability to deal with complex delay situations	[17], [40], [78], [122]
		Used only retrospectively	[126]
Impacted As-planned Technique			
Advantages of Impacted AsPlanned Technique		**Disadvantages of Impacted AsPlanned Technique**	
Simple	[119], [126], [200]	*Very theoretical method*	[17]
Easy to understand and use	[126], [174]	*Relies heavily on the planned schedule not the actual work performed*	[17], [22], [44], [78], [174], [200]
No need an as-built schedule	[17], [126], [149], [174]	*Assumption of that the planned construction sequence remains valid*	[40], [149], [200]
Not much requirement to adjusted schedule	[174]	*Ignores actual as-built schedule*	[119], [185], [200]
		Ignores the changes to programme logic	[22], [119], [126], [174], [185], [200], [215]
		Concurrent delays not recognized	[22], [119], [174], [185]
		Acceleration not recognized	[22], [200]
		Resequencing not recognized	[22], [126], [200]
		Failure to consider the dynamic nature of critical path	[22], [40], [149], [200]
		Inability to deal with complex delay situations	[126]
Collapsed As-built Technique			
Advantages of Collapsed AsBuilt Technique		**Disadvantages of Collapsed AsBuilt Technique**	
Simple	[22], [119], [174], [217]	*Highly subjective*	[17], [22], [185], [200], [217]
Inexpensive	[22]	*Failure to consider the dynamic nature of critical path*	[17], [22], [39], [40], [149], [200]
Easy to understand and use	[17], [126], [174]	*Concurrent delays not recognized*	[17], [22], [39], [119], [126], [174], [217]
Incurs less time and effort	[22]	*Resequencing not recognized*	[17], [39], [126], [185], [217]
Factual information based less theoretical	[17], [22], [40], [126], [174], [200]	*Redistribution of resources not recognized*	[126], [217]

Table 2.6: Advantages and disadvantages of delay analysis techniques (continued)

ADVANTAGES & DISADVANTAGES			
Advantages	**Source**	**Disadvantages**	**Source**
Collapsed As-built Technique (continued)			
Advantages of Collapsed AsBuilt Technique		**Disadvantages of Collapsed AsBuilt Technique**	
Uses only one schedule	[174]	*Acceleration not recognized*	[17], [22], [39], [126], [185], [217]
No requirement to as-planned schedule	[22], [174]	*Mitigation not recognized*	[17]
Results with good accuracy	[149], [174]	*Changes not recognized*	[174]
		Great deal effort in identifying the as-built critical path	[40], [149], [174], [200]
		Accuracy depend on the quality of the information based	[78], [174]
		Depends on as-built schedule only	[174], [185]
		Ignores the as-planned schedule	[119], [174]
Window Analysis Technique			
Advantages of Windows Analysis Technique		**Disadvantages of Windows Analysis Technique**	
Concurrent delays recognized	[14], [78]	*Expensive*	[40], [149]
Ability to scrutinize delay types	[14], [117], [119]	*Considerable time and effort is required*	[40], [98], [149]
Effect of each delay in CPM is recognized	[14]	*Ambiguity in concurrent delays due to selection of period*	[119]
Ability to take care of the dynamic nature of critical path	[40], [78], [117], [149]	*No mechanism for time shortened activities*	[119]
Assess mitigation	[78]	*Detailed project records are needed*	[40]
Consider actual progress and revised programs	[78]		
Time Impact Analysis Technique			
Advantages of Time Impact Analysis Technique		**Disadvantages of Time Impact Analysis Technique**	
Most credible and reliable results	[22], [149], [174]	*Expensive*	[22], [40], [78], [149]
Dynamic nature of CPM is recognized	[22], [40]	*Difficult to understand*	[174]
Ability to scrutinize delay types	[22]	*Takes time and effort*	[22], [40], [149], [200]
Ability to assess consumption of float	[22]	*Requires large amount of information*	[22]
Concurrent delays recognized	[4], [22], [78], [126], [174], [217]	*Need to have good accurate documentation on site*	[17], [78], [185]
Acceleration recognized	[22], [126], [174], [217]		
Resequencing recognized	[22], [126]		
Disruption recognized	[174], [217]		

Table 2.6: Advantages and disadvantages of delay analysis techniques (continued)

ADVANTAGES & DISADVANTAGES			
Advantages	**Source**	**Disadvantages**	**Source**
Time Impact Analysis Technique (continued)			
Advantages of Time Impact Analysis Technique		**Disadvantages of Time Impact Analysis Technique**	
Effect of particular delay in CPM is taken into consideration	[14]		
Recommended by Society for Computers and Law (SCL)	[17], [40], [126]		
Consider actual progress and revised programs	[78]		
Planned schedule is taken into consideration	[174]		
Contemporaneous analysis of delays is possible	[174]		

2.8.3.3 Selection Criteria for Delay Analysis Techniques

Since several techniques are available for delay analysis, selection of the technique is another matter. As it is stated earlier, the success of a technique depends on its user's knowledge in the capabilities of techniques and the selection of the most appropriate technique for the delay case encountered. The user must make a clear distinction between why a particular method may or may not be suitable for the specific case in hand (Sgarlata and Brasco, 2004). Arditi and Pattanakitchamroon (2006) present a table for comparison of delay analysis techniques according to various factors and mention the possible factors for selection of a technique as:

> *The selection of the proper analysis method depends upon a variety of factors including information available, time of analysis, capabilities of the methodology, and time, funds and effort allocated to the analysis. ... The selection of a suitable analysis method depends heavily on the availability of scheduling data, the familiarity of the analyst with the capabilities of the software used in the project, clear specifications in the contract concerning the treatment of concurrent delays and the ownership of float.*

In light of this information and the available data on selection criteria in literature, criteria are defined as follows (Adhikari et al., 2006; Arditi and Pattanakitchamroon, 2006, 2008; Farrow, 2007; Hoshino et al., 2007; Sağlam, 2009; Winter et al., 2002):

- ✓ **Time of analysis:** (terms of contract) is a criterion that focuses on how the type of analysis is determined in contract. Some contracts award delays at the end of the project that actually cause delay to completion (retrospective analysis), whereas the others award the likely effect of a delay to project completion when the project is in progress (prospective analysis) (Winter et al., 2002). It is the selection of analysis type according to when the analysis is made in the life time of the project. It is selection of whether it is hindsight which allows retrospective analysis of actual delays with actual dates, or real time analysis with contemporaneous project information, or foresight that prospectively analyzes the schedule and obtains potential delays with the plan for remaining of the project (Palles-Clark, 2006; Tieder, 2008; Yates and Epstein, 2006).
- ✓ **Capabilities of techniques:** (nature of proof) is the criterion that seeks the drawbacks of the techniques and matches the related technique according to the nature of proof needed.
- ✓ **Schedule type/quality:** this criterion asks either it is possibly a small project with a bar chart scheduling or a large project with detailed CPM scheduling. Simply it is matching of methods suitable with either bar chart scheduling or CPM scheduling.
- ✓ **Schedule used:** is the criterion that searches for the types of schedules used or created during construction of the project. Namely it is the matching of which type of the schedule can be used for which technique.
- ✓ **Availability of data:** (information/factual material/records available) seeks the available data in hand and matches the possible analysis techniques.
- ✓ **Type of analysis:** is the criterion that seeks either the analysis will be observative or additive or subtractive.
- ✓ **Nature of claim:** (reason for delay analysis/nature of causative events) this criterion simply focuses on what is claimed. If only justification of time

namely extension of time is claimed then entitlement-based (theoretical) analysis that investigates the possible consequences of events are able to be used. Whereas if also time compensation is claimed, then actual-based analysis is preferred to be used (Farrow, 2007).

- ✓ **Amount in claim:** indicates the amount stated in the claim. If it is big then sophisticated methods may be used however if not, there is no need to take that effort.
- ✓ **Time/Cost/Effort allocated for analysis:** seeks the techniques that will respond to the high, moderate or low effort (also time and cost) that would be spent.
- ✓ **Project duration/scale/complexity:** is the criterion that implies the short scale projects with short durations may be able to be resolved by simple techniques, whereas complex projects with long durations may need sophisticated techniques.
- ✓ **Availability of expertise/software:** (skill) criterion implies that sophisticated techniques require high expertise and skill with the usage of enhanced software. However simple techniques may not require high levels of expertise and software.

The details of the selection criteria and the related selectable techniques are presented in the following table (Table 2.7). Since time impact analysis technique is a version of windows analysis technique; wherever time impact analysis is advised, windows analysis is also advised in this study (and vice versa).

Table 2.7: Selection criteria for delay analysis techniques

SELECTION CRITERIA		
Selection Criterion	**Selectable Technique**	**Source**
Time of Analysis: (Terms of contract)		[17], [22], [39], [58], [102], [126], [217], [222]
Hindsight: retrospective analysis/actual delays		[4], [22], [162], [222]
	As-planned vs as-built technique	[22], [39], [174], [217]
	Impacted as-planned technique	[22], [174], [198]

Table 2.7: Selection criteria for delay analysis techniques (continued)

SELECTION CRITERIA		
Selection Criterion	**Selectable Technique**	**Source**
Time of Analysis: (Terms of contract) (continued)		[17], [22], [39], [58], [102], [126], [217], [222]
Hindsight: retrospective analysis/actual delays		[4], [22], [162], [222]
	Collapsed as-built technique	[22], [39], [69], [174], [217]
	Window analysis technique	
	Time impact analysis technique	[22], [174], [217]
Real time: contemporaneous analysis/potential delays		[22], [222]
	Impacted as-planned technique	[22], [198]
	Window analysis technique	[117]
	Time impact analysis technique	[22]
Foresight: prospective analysis/potential delays		[4], [22], [162], [222]
	Impacted as-planned technique	[22], [40], [117], [174], [198], [217]
	Window analysis technique	[117]
	Time impact analysis technique	[39], [174], [217]
Capabilities of Techniques: (Nature of proof)		[22], [217]
Float consumption/Critical path		[22]
	As-planned vs as-built technique (depends)	[22], [174]
	Impacted as-planned technique	[22], [174]
	Collapsed as-built technique	[22], [174]
	Window analysis technique	
	Time impact analysis technique	[22], [174]
Concurrent delay		[22]
	As-planned vs as-built technique	[22], [174]
	Window analysis technique	
	Time impact analysis technique	[4], [22], [78], [126], [174], [217]
Resequencing/Changes		[22]
	As-planned vs as-built technique (depends)	[22]
	Collapsed as-built technique	[22]
	Window analysis technique	
	Time impact analysis technique	[22], [126]
Dynamic nature of CPM		[22]
	Window analysis technique	[40], [78], [149]
	Time impact analysis technique	[22], [40]
Acceleration		[22]
	As-planned vs as-built technique	[22], [174]
	Window analysis technique	
	Time impact analysis technique	[22], [126], [174], [217]

Table 2.7: Selection criteria for delay analysis techniques (continued)

SELECTION CRITERIA		
Selection Criterion	**Selectable Technique**	**Source**
Schedule Type/Quality		[4], [17], [22], [23], [39], [102], [126]
Bar chart schedules/Small project		[4], [22], [23], [174]
	As-planned vs as-built technique	[4], [22], [23], [174]
CPM network schedules/Large project		[4], [22], [23]
	Impacted as-planned technique	[4], [22], [23]
	Collapsed as-built technique	[4], [22], [23]
	Window analysis technique	
	Time impact analysis technique	[4], [22], [23]
Schedule Used		
As-planned schedule		[22], [174]
	As-planned vs as-built technique	[22], [174]
	Impacted as-planned technique	[22], [174]
	Window analysis technique	
	Time impact analysis technique	[22], [174]
As-built schedule		[22], [174]
	As-planned vs as-built technique	[22], [174]
	Collapsed as-built technique	[22], [174]
	Window analysis technique	
	Time impact analysis technique	[22], [174]
Contemporaneous schedules		[22], [23], [39], [102], [174]
	Window analysis technique	
	Time impact analysis technique	[22], [23], [39], [102], [174]
Adjusted schedules		[22]
	Impacted as-planned technique	[22], [174]
	Collapsed as-built technique	[22], [174]
	Window analysis technique	
	Time impact analysis technique	[22], [174]
Fragnets		[22]
	Impacted as-planned technique (depends)	[22]
	Collapsed as-built technique (depends)	[22]
	Window analysis technique	
	Time impact analysis technique	[22]
Availability of Data: (information/factual material/records available)		[17], [22], [39], [58], [126], [217]
Only as-built records	Collapsed as-built technique	[22], [174], [217]
Only networked as-planned programme	Impacted as-planned technique	[217]
Only bar chart and no CPM	As-planned vs as-built technique	[22], [174]
No planned network programme and no as-built records	Impacted as-planned technique	[217]

Table 2.7: Selection criteria for delay analysis techniques (continued)

SELECTION CRITERIA		
Selection Criterion	**Selectable Technique**	**Source**
Availability of Data: (information/factual material/records available) (continued)		[17], [22], [39], [58], [126], [217]
Good as-planned network programme and no update/no as-built records	Impacted as-planned technique	[4], [22], [217]
No/poor as-planned programme - Little scheduling information and good as-built records	Collapsed as-built technique	[4], [22], [174], [217]
Networked/Unnetworked as-planned programme and networked/unnetworked as-built programme	As-planned vs as-built technique	[217]
Updated as-planned programme and little/no information on network logic	As-planned vs as-built technique	[217]
Unnetworked as-planned programme and as-built records	As-planned vs as-built technique	[217]
Networked as-planned and not updated	As-planned vs as-built technique	[22], [174]
	Impacted as-planned technique	[22], [174]
Networked as-planned programme and as-built records	As-planned vs as-built technique	[217]
	Window analysis technique	
	Time impact analysis technique	[217]
Networked as-planned and updated networked as-planned	As-planned vs as-built technique	[22], [174], [217]
	Window analysis technique	
	Time impact analysis technique	[22], [174]
Type of Analysis		[22]
Observative		[22], [174]
	As-planned vs as-built technique	[22]
Additive		[22], [174]
	Impacted as-planned technique	[22], [174]
	Window analysis technique	
	Time impact analysis technique	[22], [174]
Subtractive		[22], [174]
	Collapsed as-built technique	[22], [174]
Nature of Claim: (Reason for delay analysis/Nature of causative events)		[17], [39], [58], [78], [126]
Only justification of time: Extension of time/Entitlement-based (theoretical) techniques		[22], [78]
	Global impact technique	[78]
	Net impact technique	[78]
	Impacted as-planned technique	[22], [39], [78], [174]
	Collapsed as-built technique	[22], [39], [78], [174]
Also for recovery of money/reimbursement of loss and expense: Compensation/Actual-based techniques		[22], [78]
	As-planned vs as-built technique	[78]
	Window analysis technique	[78]
	Time impact analysis technique	[22], [78], [174]

Table 2.7: Selection criteria for delay analysis techniques (continued)

SELECTION CRITERIA		
Selection Criterion	**Selectable Technique**	**Source**
Amount in Claim		[17], [22], [23], [39], [102], [126], [217]
Moderate		[217]
	As-planned vs as-built technique	[217]
	Impacted as-planned technique	[217]
	Collapsed as-built technique	[217]
High		[217]
	Window analysis technique	[217]
	Time impact analysis technique	[22], [217]
Time/Cost/Effort Allocated for Analysis		[4], [17], [22], [23], [102], [126], [217]
Low		[22]
	As-planned vs as-built technique	[22]
	Impacted as-planned technique	[22], [217]
Moderate		
	Collapsed as-built technique	[22], [217]
High		
	Window analysis technique	
	Time impact analysis technique	[22], [217]
Project Duration/Scale/Complexity		[23], [39], [78], [102], [126]
Short duration project/Small contract values: Simple techniques		[23], [78], [102]
	As-planned vs as-built technique	[22], [102]
	Impacted as-planned technique	[217]
	Collapsed as-built technique	[217]
Long duration project/High contract values: Sophisticated techniques		[23], [78], [102]
	Window analysis technique	
	Time impact analysis technique	[22], [217]
Availability of Expertise/Software: (skill)		[17], [22], [39], [78], [102]
Inexperienced staff: Simple techniques		[23]
	As-planned vs as-built technique	[22]
	Impacted as-planned technique	[217]
	Collapsed as-built technique	[217]
Experienced staff/Specialized approach: Sophisticated techniques		[23]
	Window analysis technique	
	Time impact analysis technique	[22], [217]

2.8.4 Methodology Steps for Delay Analysis

Since project participants are much more informed about delays and their huge impacts today, measures for avoiding delays gained importance and methodologies for proper analysis of delays is needed (Kartam, 1999). Ibbs and Nguyen (2007) present previous study of Al-Saggaf (1998) as "*a formal schedule analysis procedure with the following five steps: (1) data gathering; (2) data analysis; (3) identification of the root cause; (4) classification of the type of delay; and (5) assigning responsibility*". Besides this methodology that presents main parts of the analysis, Bordoli and Baldwin (1998) present step-by-step methodology for assessment of construction delays. Following on that, similarly, Kartam (1999) presents a methodology on a step-by-step basis that also implies the usage of contemporaneous period analysis technique (windows analysis technique). There are also studies that present methodology for each technique separately besides general guidelines as the study of Doyle (2005) and Trauner et al. (2009). In addition to these, the study of Carnell (2000) groups the analysis process under three steps as tender analysis, programme analysis and event analysis. These three basic steps form the main groups of the methodology presented in this study. *Tender and programme analysis* constitute the steps for investigation of integrity of tender, reliability and constructability of the plan and programme with the information of actual intentions of contractor. Namely it is the objective part of the analysis by indication of whether the works were able to be constructed in the intended manner or not. Whereas, *event analysis* forms the subjective part and includes the steps of identification and analysis of the delay event and its impact on project. Accordingly, all of the presented methodologies are merged and presented in one unit in this study. As it is the case in study of Kartam (1999) contemporaneous period analysis technique (as well as time impact analysis technique) is taken as base for the steps of the methodology (Ibbs and Nguyen, 2007). It is assumed that a methodology for a sophisticated method would be suitable for a simple method by eliminating the details not existing in the simple method. Namely the idea behind the methodology of complicated technique may easily guide the simpler one. So, separate methodology steps are not presented for each technique in this study. Finally the combined methodology is available in the Table 2.8.

Table 2.8: Methodology steps for delay analysis

METHODOLOGY STEPS	Source
Tender and Programme Analysis	[46]
i. Gather Data Available	[12], [104], [117]
Get acquainted with all project documents.	[117]
Understand contractor submitted claim (if exists).	[117]
ii. Analyze Original Schedule	[117], [200]
Analyze contractor's original CPM schedule (determine appropriateness: is it realistic and reasonable?).	[46], [117], [200]
Examine the level of detail in work breakdown structure (WBS).	[46], [117]
Examine the logic utilized to interrelate various activities (examine logical relationships and lead-lag factors between activities).	[14], [46], [117]
Examine the durations imposed to activities.	[14], [46]
Examine the planned production rate of activities through parameters of duration and amount of work accomplished in that duration.	[117]
Examine the project resources' utilization.	[14], [46], [117]
iii. Develop As-Built Schedule	[117]
Develop project's as-built schedule (ABS) (if not provided).	[117]
Summarize daily inspection reports to serve as foundation.	[117]
Plot daily inspection reports (DIR) summary sheets.	[117]
Develop various levels of detail for ABS.	[117]
iv. Analyze As-Built Schedule	[117], [200]
Compare actual dates, duration, and logic with original ones by superimposing the schedules in CPM.	[117], [200]
Calculate actual production rates and compare with original ones.	[117]
Compare actual resources utilized with planned ones.	[117]
Event Analysis	[46], [117]
i. Identify Delay Period	[117]
Identify and analyze delay disruption periods.	[117]
Identify when the delay occurred.	[69]
Identify how long the delay lasted.	[69]
Identify what notice was given formal or informal.	[69]
ii. Analyze Cause and Effect	[12], [46], [104], [117]
Analyze cause and effect of specific issues.	[12], [104], [117]
Identify which activity the delay affected.	[69]
Identify what caused the delay.	[12], [69], [104]
Identify who was responsible for the act or omission that caused the delay.	[69]
Identify which particular day or days the delay affected and to what extent.	[69]

Table 2.8: Methodology steps for delay analysis (continued)

METHODOLOGY STEPS	Source
Event Analysis	[46], [117]
iii. Identify Concurrent Delays	[117]
Identify and analyze concurrent delays.	[117]
iv. Apply Analysis Technique	
Apply adequate technique for analyzing delay claims: contemporaneous period analysis technique (CPAT).	[117]
Identify and classify the first relevant event.	[35]
Identify progress at that delay date.	[35]
Update and reanalyze the network: specify the project is ahead or behind the schedule at delay date.	[35]
Simulate the first relevant event and reanalyze the network: specify the potential delay.	[35]
Consider mitigating action.	[35]
Consider the effect of omissions.	[35]
Apply the same procedure for subsequent relevant events.	[35]
v. Analyze Claim	[117]
Analyze and evaluate the contractor submitted claim (if applicable).	[117]
vi. Calculate Compensations	[117]
Summarize various analyses to calculate compensations of time or cost.	[117]
vii. Present Results	[35]
Present the results with a tally of category of delays and corresponding completion dates.	[35]
viii. Negotiate Claim	[117]
Conduct effective meetings to discuss, negotiate, and settle claims.	[117]

2.8.5 Data Used for Delay Analysis

Data constitute the power of delay analysis and the accuracy of the analysis depends on the quality of information available. Proper documentation at pre-construction phase prevents many probable delays that may occur during construction phase and also forms a base for the further data recording and delay analysis. More data available means more detailed analysis can be done and more credible results are got (Farrow, 2007). So ensuring contemporaneous project data, namely providing a continuous and sound record keeping during life time of the project leads the success of project tracking and delay analysis (Carmichael and Murray, 2006; Jergeas and Hartman, 1994; Trauner et al., 2009; Yates and Epstein, 2006). As it is stated in the previous section ("methodology steps for delay analysis"), delay analysis starts with gathering all data available for analysis. Accordingly, first the reliability of the contract documents as tender, planned schedules and programmes and also subcontract documents and so on should be investigated. Care should be given on what contract clauses state about the delay related issues. After that, analysis of what had occurred; namely the delay, its causes, impact, responsibility and claim are investigated through data which constitute the post-contract documents. So taxonomy of data is categorized as *contract documents* and *post-contract documents*. Contract documents are presented with subcategories *main contract documents* (with subcategories of its parts) and *subcontract documents* and post-contract documents are further divided into groups of *major schedules*, *particular schedules*, *updated plans and programmes* and *records* (with its subcategories). Details of the taxonomy are available in the following table. Before that the important elements of data as schedules and contract clauses are explained more as in the following sections.

2.8.5.1 Schedules

Schedule indicates the estimate of time required to construct a project through details of activities, time of activities and sequence of activities. Contractor depicts his plan through schedules and submits to owner's review and approval. Both owner and contractor track the progress of works through schedule updates and deal with changes and delays. Contractor may use the schedule for contemporaneous analysis whereas owner's consultant may use it on a retrospective basis. A perfectly created and updated schedule serves as periodic snapshots of the project during construction process and underlies the creation of contemporaneous project information. Schedule needs to be regularly updated to continue depicting the actual process of work and the remaining of the work if works are not completed. Since critical path evolves during construction process, the same evolving critical path should be caught through updates (Finke, 1999; Kartam, 1999; Trauner et al., 2009). So schedules not only depict the plan to the participants of the project but also base the tracking process and so management of the project. Besides their vital role in planning, monitoring and controlling; schedules also form the basis of delay analysis. So, properly maintained and updated schedules help to prevent possible delays due to poor planning and control; and in case of a delay, ease the analysis of delays and settlement of claims and so prevent further disputes and delays. The basic types of schedules are *narrative schedules* (narrative description of schedule), *Gantt charts* (or *bar chart schedules* that depicts the plan through a chart of activities vs. time sequence), *linear scheduling* (or *lobscheduling* used in projects with repetitive and linear nature) and with its most enhanced form as *CPM scheduling*. Selection of the type of scheduling depends on the nature, size, complexity of the project and its needs according to the preferences of the scheduling entity and requirements of contract. Bar chart scheduling and CPM scheduling are the most used types of scheduling. Bar chart schedules are much more suitable for and capable of small projects with limited activities; however they are easy to set, present and communicate so these make bar charts still valuable in use. CPM scheduling is the one that properly handles complex projects with its enhanced capabilities. It is a dynamic tool that stays alive through updates during construction process and always provides the true match between what is constructed on site and what is constructed by tool. Accordingly, CPM scheduling is the only scheduling type that is capable of analysis of complex delay situations (Conlin and Retik, 1997; Householder and Rutland, 1990; Ibbs and Nguyen, 2007; Jaafari, 1984; Kartam, 1999; Tieder, 2008; Trauner et al., 2009). So, Carnell (2000) mentions the collocation of both methods as bar charts for the ones who performs the work and CPM schedules for the ones planning and controlling the works. During construction process and delay analysis process, schedules are used according to the need in the forms of (Alkass et al., 1996; Arditi and Patel, 1989; Finke, 1999; Kraiem and Diekmann, 1987; Williams, 2003):

- ✓ **As-planned schedule:** is the original schedule for completing the work. It does not include the information of progress of works. Only depicts the planned activities with critical paths and project start and finish dates.
- ✓ **Adjusted schedule/Updated schedule:** is the schedule depicting impacts by schedule variances on as-planned schedule. So it is the updated version of the as-planned schedule with the delays and changes encountered. It depicts how the as-planned schedule is turned into as-built schedule.

- ✓ **As-built schedule:** is the actual or final adjusted schedule that represents the actual sequence of works through entire project.
- ✓ **Entitlement schedule:** is the impacted as-planned schedule or collapsed as-built schedule to depict the entitlement of owner or contractor. Simply it depicts the how the progress would be without certain class of delays.
- ✓ **As-projected schedule:** is the schedule created for the remainder of the project with the as-built information that is loaded up to date and as-planned for the rest.

These schedules are grouped as *major schedules* in this study. There are also other versions of schedules that are constructed in detail to serve for a particular need which are grouped as *particular schedules*.

2.8.5.2 Contract Clauses

Any contract clause plays a vital role in delay analysis. Every contract has its own tailor-made style, however there are some standard clauses that need to be clearly set for the sake of delay analysis. Particularly delay analysis is based on contract clauses such as clauses that pinpoint extension of time allowable and assist in apportionment of responsibility (Shi et al., 2001). Contracts should be strengthened and made certain through amendments to standard forms, because when contract is thought, as Carnell (2000) states "*certainty is much more important than fairness*". Accordingly, further obligations should be handled as implied terms and ambiguous terms should be redefined. Wording of a contract plays a crucial role since what is not said in contract is as important as what is said (Davenport, 1995). In this study only the clauses that are mentioned through literature review on delay analysis are taken into consideration. Some of the important clauses are explained as follows:

- ✓ **Extension of time clause:** focuses on keeping the construction time definite. Extension of time provides contractor extra time to complete his works, whereas enables owner to preserve his rights against further liquidated damages by stating new contract completion date and preventing it to become "time at large" (Carnell, 2000; Palles-Clark, 2006; Thomas, 1993; Yogeswaran et al., 1998). Time at large principle gets in action if the affected contract completion date is not set through an award of extension of time, where contractor would be obliged to complete the works in a "reasonable time" (Davenport, 1995; Turner and Turner, 1999). Accordingly; since there is not a completion date set contractually, liquidated damages would not apply for owner (Longley and De Witt, 2006). Differently from these, extension of time does not automatically imply compensation of costs to contractor, where compensation should be claimed based on a separate clause from extension of time clause (namely "delay damages clauses") (Winter et al., 2002; Yogeswaran et al., 1998). Extension of time situations can simply be the owner-caused delays and third party caused delays like; force majeure situations, inclement weather, civil commotion, strikes and lockouts, etc. (Longley and De Witt, 2006). Extension of time and liquidated damages are generally taken into action through the practical completion date if else is not stated in contract (Carnell, 2000).

- ✓ **Liquidated damages clause:** is simply the owner's entitlement in case of a delay in completion. Parties in a contract previously get agreement on the damages that can be compensated in case of a delay. Liquidated damages are generally used to meet owner's damages in case of a contractor delay (Davenport, 1995; Turner and Turner, 1999). Since it is difficult to accurately measure owner's costs, liquidated damages are preferred rather than actual (or general) damages. Reasonable estimation of the amount and the period for assessment of liquidated damages should be clearly set. Liquidated damages may also be defined gradually or on a hourly basis (Longley and De Witt, 2006; Thomas, 1993; Trauner et al., 2009). In case of an owner caused delay, liquidated damages that owner is rightful for other delays would only apply if the contract date is extended and set again (Farrow, 2007). It seems to be a clause that protects owner, however since it is contractually set from the beginning, it enables contractor to know the amount that would be risked and to make his plans accordingly (Crowley et al., 2008).

- ✓ **Exculpatory clauses: (**No damages for delay clause) are used to excuse a party from some responsibilities. The general form of exculpatory clauses for delay is “no damages for delay clause”. By this clause compensable delays are restricted, namely for certain causes of delay contractor is entitled to extension of time but not compensation (Trauner et al., 2009). These clauses may be used to pass the entire risk of delay damages to contractor by freeing owner from compensation of contractor (Kraiem and Diekmann, 1987; Leishman, 1991). The level of the risk that is passed to the contractor is set through the extent of the causes included in the clause (Thomas and Messner, 2003).
- ✓ **Force majeure clauses:** are the clauses that handle the causes of delay mainly as Acts of God. These causes generally provide a relief from the cost damages for the two parties and make contractor entitled to a reasonable time extension (O'Brien, 1976).
- ✓ **Bonus or incentive clauses:** are the clauses that operate as an inverse of the liquidated damages clauses. The aim is to motivate contractor for an early completion by assignment of a bonus for the each day before the contract completion date. Its amount is totally up to the owner and if a change occurs in completion date, the newly stated (current) contract completion date through extension of time is valid for computation of bonuses (Trauner et al., 2009).
- ✓ **Records clause:** is the clause that indicates the agreement on the frequency, issue and type of the records to be kept by the responsible parties (Winter et al., 2002).

Full list of the possible required data (documents) can be seen in the following table (Table 2.9). Updated version of the table through the further chapter named validation (Chapter 5) is presented.

Table 2.9: Taxonomy of data used in analysis of delay

DATA				Source
Contract Documents				[203]
	Main Contract Documents			
		Tender		[1], [46]
			Site report	[Case Project B]
			Geological report	[Case Project B]
		Contract Clauses		[200]
			Time is of the essence clause	[41], [222]
			Contract performance period: Commencement of contract time (Contract award and Notice to proceed) and Contract completion	[41], [46], [222]
			Interim milestones clause	[41]
			Practical completion/Substantial completion and initial certificate	[41], [46], [63]
			Defects liability period clause	[46]
			Final completion and certificate	[46]
			Early occupancy clause	[41]
			Exclusion clauses	[46]
			Notice provisions: Time of notice, Notice procedures, Actual notice, Oral notice, Prejudice and Waiver	[41], [46], [196], [222]
			Scheduling provisions	[41], [200]
			Ownership of float clauses	[65], [181], [225]
			Records clause/Clauses for documentation	[217], [222]
			Coordination clauses	[41]
			Changes clause/Variation clause	[41], [63], [67], [68], [181], [196], [200], [217]
			Differing site conditions clause: Type1/Type2 conditions, Site inspection, Schedule extensions, Recovery of costs and Disclaimers	[41], [200]
			Force majeure clauses	[222]
			Exculpatory clauses: No damages for delay clause	[41], [46], [131], [156], [181], [197], [200], [222]
			Suspension of work clause	[41], [200]
			Termination clauses: Termination for default and Termination for convenience	[41]
			Extension of time clause	[41], [68], [196], [200], [203], [222]
			Delay damages clauses/Loss and expense clause	[61], [200], [203]
			Liquidated damages clause	[41], [61], [137], [196], [200], [203], [222]
			Valuation clause	[203]
			Bonus or incentive clauses/Early completion clause	[200], [222]
			Clauses related to claims	[200], [222]
			Disputes clause	[50], [106], [109], [156], [200], [203], [222]
		Conditions of Contract		[200]
		Specifications and Drawings		[46], [111], [203]
		Bills of Quantities		[200], [203]

Table 2.9: Taxonomy of data used in analysis of delay (continued)

DATA	Source
Design Drawings	[200]
Method of Statements	[27], [200]
Plans and Programmes	[27], [200], [217]
Schedules	
Narrative schedules	[200]
Gantt charts/Bar chart schedules	[58], [200]
Linear scheduling/Lobscheduling	[58], [200]
CPM scheduling	[58], [200]
Subcontract Documents	[200], [203]
Post-contract Documents	[203]
Major Schedules	
As-planned schedule: the original schedule	[8], [14], [21], [22], [28], [82], [122], [200], [215], [219]
Adjusted/Updated schedule: schedule depicting impacts by changes on as-planned schedule	[8], [14], [21], [22], [28], [111], [122], [200], [215], [219]
As-built schedule: actual/final adjusted schedule	[8], [14], [21], [22], [28], [82], [111], [122], [200], [215], [219]
Entitlement schedule: impacted as-planned schedules/collapsed as-built schedules	[8], [14], [21], [28], [82], [215], [219]
As-projected schedule: schedule created for the remainder of the project	[21], [28], [215]
Particular Schedules	[196]
Schedule of resources to comply with the original and each revision	[196]
Schedule of anticipated plant output	[196]
Schedule of anticipated productivity for various activities	[196]
Schedule of anticipated overtime (and the costs thereof) in order to comply with the original and each revision	[196]
Schedule showing required access dates	[46]
Schedule of design freeze dates	[46]
Schedule of information release	[46]
Further descriptive schedules necessary for use	[203]
Updated Plans and Programmes	[27], [200], [217]
Records	
Registers	
Drawing register: details of amendments and revisions made to plans	[1]
Risk register	[158]
Diaries	
Project records/reports diary	[15], [200], [228]
Site/Field reports diary	[46], [156], [196], [217]
Construction progress reports diary	[1], [27], [111], [219]
Weather reports diary	[1], [111], [217]
Temperature reports diary	[1], [111]
Resource assignments and allocation reports diary	[1]

Table 2.9: Taxonomy of data used in analysis of delay (continued)

DATA	Source
Diaries (continued)	
Labor records diary	[1], [217], [228]
Foremen reports diary	[171]
Equipment records diary	[1]
Material records diary	[1]
Personal diaries	[156]
Diaries of key staff	[196]
Simple appointment diaries kept by those involved in the project	[46]
Logs	[117]
Daily logs	[200]
Submittal logs	[1], [117], [171], [200]
Request for information (RFI) log	[117], [200]
Contract document clarification (CDC) log	[117]
Potential cost/schedule (PCI) incidents log	[117]
Change order log	[219]
Claims' log	[117]
Site Records	
Time sheets for field labor	[171], [200], [228]
Transmission sheets	[46]
Punch lists	[156]
Purchase orders with suppliers	[200]
Materials invoices/receipts	[15], [203], [217]
Delivery records of equipment and materials	[1], [111]
Wage sheets/Payroll records	[156], [200], [203]
Records of resource data and costs	[15]
Pay requests	[200]
Plant records	[196], [203]
Records of supervision and inspection	[1], [15], [111]
Records of weather conditions and its effect on progress	[196], [228]
Area release forms	[171]
System turnover packages	[171]
Reports	[156], [200], [228]
Labor productivity reports	[1], [111], [171], [219]
Material receiving reports (MRRs)	[1], [171], [217]
Equipment utilization reports	[171]
Daily inspection reports (DIR)	[117], [171], [200]
Contractor caused disruption (CCD) report	[117]
Cost reporting data	[1], [15], [111], [171], [200]
Weekly and monthly reports	[156]
CPM reports with narrative with each updating	[156]
Quality control reports	[219]
Accident and site safety report	[1], [111]
Occurrence reports	[15]
Reports on special aspects which have arisen	[203]

Table 2.9: Taxonomy of data used in analysis of delay (continued)

DATA	Source
Formal Submittals	
Instructions issued by architect	[27], [111], [217]
Directions issued by the contractor	[203]
Confirmations of oral instructions or directions	[111], [203]
Notices and other formal documents	[156], [203]
Change order forms	[15], [111], [117], [156], [200]
Files on delays and disturbance	[1], [156]
Files on time extensions	[156]
Architect's certificates for payment	[203]
Architect's certificates especially on matters other than payment	[46], [203]
Interim valuations in support of architect's certificates for payment	[203]
Records of Actual Data	
Records of actual resources	[196]
Records of actual plant output on key activities	[196]
Records of actual productivity on key activities	[196]
Records of actual cash flow	[196]
Records of actual overtime worked and the costs thereof	[196]
Records of Accounting Data	
Cost and value of work executed each month (for the project)	[196]
Cost and value of work executed each month for all projects (company turnover)	[196]
Allowance for overheads and profit in the tender sum	[196]
Cost of head office overheads each month (quarterly or yearly if not monthly basis)	[196]
Profit (or loss) made by the company for each accounting period	[196]
Cash flow forecast based on the original and each revision	[196]
Statements prepared for the calculation of fluctuations on the traditional basis	[203]
Progress payment applications and certificates	[1]
Media Records	
Dated photographs of the site at large or of special pieces of work	[1], [27], [46], [111], [196], [200], [203], [228]
Video records showing sequence and method of working	[1], [46], [111], [196], [200]
Tape recordings	[46]
Computer records	[46]
Minutes of Meetings	[27], [111]
Notes	[15]
Memos to the file	[156], [171], [200]
Individual and private compositions	[203]
Correspondence Data	[1], [200], [219]
General correspondence	[200]
Project correspondence	[200]
Job site correspondence	[111], [171]

Table 2.9: Taxonomy of data used in analysis of delay (continued)

DATA	Source
Correspondence Data (continued)	[1], [200], [219]
Correspondence between parties to the contract	[111]
Correspondence between members of the professional team	[46]
Correspondence with subcontractors and consultants	[46]
Correspondence with statutory undertakers	[46]
Correspondence with third parties	[46]
Correspondence by e-mails	[171], [200]
Correspondence by letters	[27]
Correspondence by fax messages	[Case Project A]
Notes of telephone calls	[46], [111]
Notes of conversations	[46], [111]
Witness Data	
Personal observation by the owner's field team and CPM consultant	[156]
The statements of the personnel involved in the project	[46]
Expert witness statements	[27], [46]
Site investigation	[203]
Interviews	[203]

2.8.6 Issues in Delay Analysis

There are still some areas exist in delay analysis that have the potential to stir the trouble up unless they are clearly set from the beginning. These factors are generally explained in contracts (and should be) to prevent conflicts that may be caused by these issues. Because these factors have the potential to affect the analysis regardless of the technique selected. The heading issues that affect the analysis are concurrent delays, float ownership, theories of critical path and scheduling software options and drawbacks of analysis techniques (Arditi and Pattanakitchamroon, 2006; Bordoli and Baldwin, 1998). Thus, list of the issues in delay analysis are available in Table 2.10. Updated version of the table through the further chapter named validation (Chapter 5) is presented.

Table 2.10: Issues in delay analysis

ISSUES		Source
Float Ownership Issue		[22], [96], [103], [122], [179], [200], [224]
The float belongs to the project: whoever "gets to it first"		[4], [22], [38], [179], [217], [224]
The float belongs to the contractor		[38], [224]
The float belongs to either party so long as it is reasonably utilized		[38], [122], [200], [224]
Scheduling Options Issue		[22]
Retained logic vs Progress override		[22]
Theories of critical path (Longest path theory/Float theory)		[22]
Use of multiple calendars		[22]
Use of constraint/mandatory functions		[22]
Use of unconventional logic - start to finish		[22]
Use of long or negative lag times		[22]
Concurrent Delays Issue		[22]
	Definition of Concurrent Delays Issue	[22]
	That occur at the same time: Concurrent delay	[22]
	That occur sequentially but effects felt at the same time: Sequential Delays with Concurrency effect	[22]
	Analysis of Concurrent Delays Issue	[Case Project A], [38], [179]
	Easy rule	[Case Project A], [105], [122]
	Fair rule	[Case Project A], [105], [122]
Interrelated Delays Issue		[179]
Early Completion Issue		[38], [179], [222]
Delay after Completion Issue		[38], [179], [217]
Prolongation Costs Issue		[179]
Pacing Delay Issue		[8], [102], [226], [227]
Drawbacks of Analysis Techniques Issue		
Inability to identify the progress of the project at the time the delay occurred		[35]
Inability to identify the changing/dynamic nature of the critical path		[35]
Inability to identify mitigation/acceleration/the effects of action taken to minimize potential delays		[22], [35], [144], [217]
Inability to identify the effects of time shortened activities		[22], [35], [144], [217]
Inability to identify the effect of early completion		[22], [35], [144], [217]
Inability to identify the effects of inter-dependence of delays		[46]
Inability to identify concurrency		[217]
Inability to identify resequencing of programme		[217]
Inability to identify redistribution of resources		[217]

Table 2.10: Issues in delay analysis (continued)

ISSUES	Source
Usage of Analysis Technique Issue	[117]
Adequate update to preserve dynamic nature of the schedules	[104], [144], [200]
Adequate selection of the window size/the fragnet itself	[104], [144], [200]
Inadequate consideration of baseline changes along the project	[144]
No consideration of resource (over-)allocation in delay analysis	[104], [144]

2.8.6.1 Float Ownership Issue

Float is the valuable commodity of the project that provides flexibility. It implies the amount of time that an activity can be delayed without affecting the project completion date. However, when delays consume the available float of an activity, the activity may turn into a critical activity and start to delay the project. So usage of float is a considerable debate issue in analysis of delays (Kraiem and Diekmann, 1987; Trauner et al., 2009). Contractor may use float to provide flexibility in time and budget, whereas owner may use to accommodate the change orders in project and also the budget in cost-plus contracts (Adhikari et al., 2006; Arditi and Pattanakitchamroon, 2006; Householder and Rutland, 1990). Yogeswaran et al. (1998) mention three different possible usage of float in a project which is previously presented by McDonald and Baldwin (1989) as:

- ✓ ***The float belongs to the project:*** stands on the idea of "whoever gets to it first". Namely, when one party causes a delay and uses the float first; the other party gets responsible because of the delay by their fault which would not affect the project completion date if the first party did not use the available float (Adhikari et al., 2006; Arditi and Pattanakitchamroon, 2006; Braimah, 2008; Carnell, 2000; Winter et al., 2002).
- ✓ ***The float belongs to the contractor:*** asserts that the float is the time resource of the contractor and he should use it through his management operations. However contractor has the potential to use it maliciously (Braimah, 2008; Carnell, 2000).

- ✓ ***The float belongs to either party so long as it is reasonably utilized:*** this idea is as a compromise of the first two options. The float is viewed as a shared commodity of the project and can be used by either party when it is needed as long as it does not affect the other party. Neither party is assigned to total usage of it and also neither party is able to use it without a reasonable need. This obligation can be contractually established and the party that would be affected has the right to notify the other party that is using the float (Braimah, 2008; Kraiem and Diekmann, 1987; Trauner et al., 2009).

Since parties to the contract are free to specify the clauses according to their needs, some of the owners may contractually take over the total usage of float for themselves. This may guarantee the owner in a cost-plus contract. However, since floats are the guarantees of the contractor during lifetime of a project, in case of a fixed-price contract, this may cause contractors to add more contingency to the bid price to guarantee themselves. So, one sided usage of the floats by owner may cause higher bid prices than expected. In addition to that; contractor uses float for establishing the resource leveling in his plans, thus limiting his flexibility may cause extra costs to the contractor due to erratic resourcing of the project and such. Accordingly, contractor may seek solutions by deceit in the plans to create his own floats in the planning which would make him deviate from his main purpose (Householder and Rutland, 1990; Sgarlata and Brasco, 2004). Thus, usage of the float according to the needs by both parties of the contract is preferable for the creation of convenient working environment for all parties in the project. However, whatever the option is selected it should be strongly stated in the contract to prevent ambiguities (Zack, 1993). Winter et al. (2002) state that if it is not handled in contract “whoever gets it first” rule applies for the solution of cases (Arditi and Pattanakitchamroon, 2006; Scott et al., 2004).

2.8.6.2 Scheduling Options Issue

Scheduling issues affect the analysis results since they are founded on the CPM principles lying in the CPM schedules. Scheduling programs provide some flexibility to ease the planning of projects however these options may cause problems when they are reached in delay analysis process. Some of the issues that are due to the scheduling options are presented by Arditi and Pattanakitchamroon (2006) as follows:

- ✓ ***Retained logic vs. Progress override:*** Some project planning tools include options about details of the scheduling like retained logic or progress override. During updating process; retained logic option preserves the relationships between activities and does not schedule the remaining duration of the progressed activity until its all predecessors are completed, whereas progress override option ignores the relationships between activities and allows the activity to progress without delay (Trauner et al., 2009). So in analysis, these two options cause different results according to the logic adapted. The option that will be used should be stated in contract to prevent disputes due to the ambiguity in that area.
- ✓ ***Theories of critical path (Longest path theory/Float theory):*** It is possible to define a critical path in terms of longest path of the schedule or according to the total float of activities. However these two options provide inconsistent results when delay analysis is applied. Traditionally, the path with the lowest float was always indicating the critical path. The new scheduling tools provide different options as use of multiple calendars that cause different levels of float in one path and destroy the definition of float. This made the longest path theory more powerful than the float theory (Trauner et al., 2009). Since there are options of the critical path that give different results, it should be agreed in the contract.
- ✓ ***Use of multiple calendars:*** Different calendars can be defined to the activities that use different resources with different working times. This option causes differences in float times on the same path so this leads critical and non-

critical activities on a path and makes the critical path less definable. Thus this option is another source of problem during analysis of delays.

In addition to these, there are also other acts in a scheduling software that causes inconsistent results. The most stated ones are; *use of constraint/mandatory functions, use of unconventional logic - start to finish* and *use of long or negative lag times*. To prevent the conflicts that may be caused because of these ambiguities in analysis, each option should be agreed contractually (Adhikari et al., 2006; Arditi and Pattanakitchamroon, 2006).

2.8.6.3 Concurrent Delays Issue

Concurrent delays issue is one of the liveliest debates of the issues in analysis of delays. The *definition of concurrent delays issue* and the *analysis of concurrent delays issue* are the main topics that are concentrated on in concurrent delays issue.

2.8.6.3.1 Definition of Concurrent Delays Issue

Concurrent delays are basically the delays that occur at the same time, namely various causes contribute to the same result. However, there is no universally accepted definition of concurrent delay (Scott et al., 2004; Turner and Turner, 1999). Some authors name only the simultaneous delays that are caused by different parties as concurrent delays (Kartam, 1999; O'Brien, 1976; Winter et al., 2002), whereas the others name any delays (even if caused by the same party) concurrent as long as they act simultaneously (Hoshino et al., 2007). So, any more than one delay occurring in the same time is named as concurrent delay in this study. There is widely quoted definition of Rubin et al. (1983) of concurrent delays as, "*the term concurrent delays is used to describe two or more delays that occur at the same time, either of which had it occurred alone, would have affected the ultimate completion date*". Winter et al. (2002) also mention the sequential delays that would not occur at the same time but which their effects are felt at the same time. So to distinguish these type of delays from concurrent delays, they propose the term "*concurrency effect*" for those sequential delays (Adhikari et al., 2006; Alkass et al., 1996; Arditi and Pattanakitchamroon, 2006; Ibbs et al., 2011; Kraiem and Diekmann, 1987; Trauner et al., 2009). So, definition of "*concurrent delay*" should be made in detail from the beginning of a contractual agreement.

2.8.6.3.2 Analysis of Concurrent Delays Issue

As definition of the concurrent delays is still a debate, analysis of concurrent delays is a much more heated debate. In the previous section it is stated that any delay could be concurrent with each other. So; two contractor delays, or two owner delays, etc. may occur together and form a concurrent delay with responsibility to a single party. However the case is not that simple always, and delays of different parties occur at the same time and obstruct the analysis of responsibilities and awards (Rubin et al., 1983). Generally parties try to get rid of their responsibilities by hiding behind the excuses of concurrent delays and accusing the other parties (Ibbs et al., 2011). Carnell (2000) summarizes the situation as "*events are common to each party and the reasons are the mirror image of each other and that the objectives are mutually exclusive*". Accordingly; if an extension of time is granted to contractor, employer's liquidated damages fail. This makes the parties to go into the battle. There are solution offers available for the analysis of concurrent delays issue in literature (Rubin et al., 1983). Most of them simply advise that when a contractor and an owner delay occur concurrently, contractor's extension of time due to owner delay should not be affected or reduced (Scott et al., 2004; Winter et al., 2002). Generally, when a contractor and an owner delay is concurrent, the situation simply turns into an excusable delay and extension of time is granted and no compensation is due to either party (also it is the case when an excusable and non-excusable delay is concurrent). Namely, the idea behind is that is the well-known "*where both parties contribute to the delay neither can recover damages, unless there is clear evidence by which we can apportion the delay and the expense attributable to each party*". Simply both parties are penalized by contributing to the delay. So contractor is not compensated and owner is not awarded to liquidated damages. It is also based on the prevention principle where "*a man should not be allowed to recover damages for what he himself caused*" (Davenport, 1995). This states the basics of the "*easy rule*" which is generally referred in the literature (first by Kraiem and Diekmann, 1987) when apportionment of delays is not possible (Finke, 1999; Ibbs et al., 2011; Rider and Long, 2009). Hoshino et al. (2007) present a table for concurrent delays and their net effects. This table also summarizes the solution offers available in literature that are generally based on easy rule (Alkass et al., 1996; Bubshait and Cunningham, 1998; Kraiem and Diekmann, 1987; Rubin et al., 1983; Yogeswaran et al., 1998). The adapted version of the table is available as Table 2.11 including the possible versions of concurrent delays with the corresponding effects and the awards due. "EOT" refers to extension of time, whereas "LD" refers to liquidated damages. Pacing delay issue will be held in the following section (as "Pacing Delay Issue").

Table 2.11: Concurrent delays analysis based on "easy rule" (adapted from Hoshino et al., 2007)

CONCURRENT DELAYS ANALYSIS BASED ON "EASY RULE"			
Delay Event	**Concurrent with**	**Net Effect and Award**	**Source**
Owner Delay	Another Owner Delay or Nothing	Compensable to Contractor, Non-Excusable to Owner	[14], [28], [102], [172], [215]
		EOT + Compensation	[14], [28], [102], [172], [215]
Contractor Delay	Another Contractor Delay or Nothing	Non-Excusable to Contractor, Compensable to Owner	[102]
		LD	[102]
Force Majeure Delay	Another Force Majeure Delay or Nothing	Excusable but Not Compensable to Either Party	[14], [102]
		EOT	[14], [102]
Owner Delay	Contractor Delay	Excusable but Not Compensable to Either Party	[4], [14], [44], [102], [122]
		EOT	[4], [14], [44], [102], [122]
Owner Delay	Force Majeure Delay	Excusable but Not Compensable to Either Party	[14], [28], [102], [122], [172], [215]
		EOT	[14], [28], [102], [122], [172], [215]

Table 2.11: Concurrent delays analysis based on "easy rule" (adapted from Hoshino et al., 2007) (continued)

CONCURRENT DELAYS ANALYSIS BASED ON "EASY RULE"			
Delay Event	**Concurrent with**	**Net Effect and Award**	**Source**
Contractor Delay	Force Majeure Delay	Excusable but Not Compensable to Either Party	[14], [22], [28], [102], [122], [172], [215]
		EOT	[14], [22], [28], [102], [122], [172], [215]
Owner Delay	Contractor Pacing	Compensable to Contractor, Non-Excusable to Owner	[102]
		EOT + Compensation	[102]
Owner Pacing	Contractor Delay	Non-Excusable to Contractor, Compensable to Owner	[102]
		LD	[102]

Besides easy rule, Kraiem and Diekmann (1987) also mention "*fair rule*" for analysis of concurrent delays. As previously stated, easy rule was not allowing apportionment of cost damages. So, fair rule focuses on investigation of dominant and root causes of the concurrent delays and advices accordingly apportionment of the days and damages between contributors of the delay (Braimah, 2008). There is no universally agreed approach for the apportionment of damages (Doyle, 2005; Ibbs et al., 2011). In case of combined causes, a root cause may be defined as the most basic (main) reason for the undesirable condition (Josephson and Hammarlund, 1999). Some concurrent delays may occur with same duration and time period, and so they ease the analysis. However; most of the concurrent delays are partially concurrent and start and finish with different dates, and accordingly they harden the situation. So, the analyst should consider many factors to determine the contribution of each delay which are stated by Kim et al. (2005) as "*the relation of the specific delay to the project critical path, total float times of succeeding activities affected by the delay, the overlapping of delays, and the selection of delay analysis increments*".

As a result, analysis of the concurrent delays issue is a big deal and parties to the contract should contractually agree on the analysis and apportionment method that would be held in case of a concurrent delay (Ibbs et al., 2011). Above all of these, Thomas (1993) also presents analysis of concurrent delays which are on critical and non-critical paths respectively. This may be another issue in the issue of concurrent delays and needed to be stated and analyzed with great care.

2.8.6.4 Interrelated Delays Issue

Scott et al. (2004) state with the referencing of Majid and McCaffer (1998) as some of the delays can be interrelated even if they are not concurrent. So this provides another issue that may cause conflict due to the ambiguity presented.

2.8.6.5 Early Completion Issue

Scott et al. (2004) mention the issue as an ambiguity in what happens when a contractor is expecting an early completion, encounters an owner delay and cannot finish in time. So, the questions heat the debate as whether the contractor should be entitled to time extension/compensation or not. Also, it is not definite that the owner should facilitate an early completion or not. These possibilities should also be included in contract to prevent conflicts and make gray areas black or white (Braimah, 2008; Yates and Epstein, 2006).

2.8.6.6 Delays after Completion Issue

This issue ensues in cases of an owner delay when contract completion date is behind and contractor is in culpable delay. Question of whether extension of time to the contractor for recovery of owner delay is due or not. Also amount of the extension is a further debate of the issue (Braimah, 2008). So these ambiguities should be stated in contract to set solutions from the beginning.

2.8.6.7 Prolongation Costs Issue

In some cases, contractor encounters an owner delay in some period during construction and generally gets compensation after contract completion date. However, prolongation costs namely the site overheads of the contractor during the delayed period are not stable during the project life. So the debate here is that which prolongation costs should be taken as base for the calculation of compensation. This issue should also be explained in contract to clear the ambiguities (Scott et al., 2004; Trauner et al., 2009).

2.8.6.8 Pacing Delay Issue

Pacing delay is a type of delay that indicates the intentional slowing down of the works by a party due to an already existing delay of the other party. In other words, a delay caused by one party, creates a float in the activity that is in the responsibility of the other party. So rather than completing the activity in time and waiting for the end of the other party's delay, works may be slowed down for efficient usage of resources available. However, this becomes an issue at the point of the proof of the things that had actually happened like that. Parties may accuse that it is culpable delay rather than a pacing delay. So, the pacing delay issue should be contractually supported and parties should be notified before the action is taken (Al-Gahtani, 2006; Zack, 2000).

2.8.6.9 Drawbacks of Analysis Techniques Issue

As it is stated earlier, every delay analysis technique has its own advantages and disadvantages. The success of the techniques are achievable as long as they are selected according to the cases of delays and the analyst is informed about the capabilities of the technique that will be used (Trauner et al., 2009). So the analyst has the potential to clarify the issues related to the drawbacks of the analysis technique that would be used. Also the issue on analysis techniques can be strengthened through related contract provisions.

2.8.6.10 Usage of Analysis Techniques Issue

There are also issues that may lead inconsistent results in techniques used due to the choices of analyst using it. For example, choices of the window periods in the window analysis and decision of the fragnets to be inserted play a vital role in the accuracy of analysis technique. Also, frequency of updates identifies the convenience of the critical path obtained in analysis with the actual critical path (Trauner et al., 2009). Inadequate consideration of baseline and no consideration of over-allocation of resources during analysis may be named as other issues during the usage of analysis (Ibbs and Nguyen, 2007; Menesi, 2007). The issues can be summarized as:

- ✓ *Adequate update to preserve dynamic nature of the schedules*
- ✓ *Adequate selection of the window size/the fragnet itself*
- ✓ *Inadequate consideration of baseline changes along the project*
- ✓ *No consideration of resource (over-)allocation in delay analysis*

2.9 Claim for Delay

Diekmann and Nelson (1985) define claim in their study as "*the seeking of consideration or change, or both, by one of the parties to a contract based on an implied or express contract provision*". Previously it is stated that delays are inevitable, so are claims (Cheung et al., 2002; Chong and Rosli, 2009). Claim is the natural consequence of changes and delays; since something happens, it is needed to be cured according to the rights of the parties. Carnell (2000) indicates the situation as "*delays and claims result from matters which mean that the works are not carried out precisely as envisaged in that contract".* So, parties claim the *remedy* (*time compensation* or *cost compensation*) through their contractual rights and try to settle. In a sort of way; claim is the redistribution of responsibility, power and interest, risks between the parties to the contract to reach the agreement again (Cui et al., 2010). Claims are needed to be effectively settled among the parties in the claim (*claimant* and *responsible*) in an amicable environment to prevent further disputes and losses accordingly (Abdul-Malak et al., 2002; Sgarlata and Brasco, 2004). There are different *kinds of claims* that are needed to be presented through a guideline (*parts of claim*) to meet an expository skeleton. In *result*, claims reach either an amicable *settlement* or the way to settlement is extended and obstructed through challenging processes of *dispute* and *dispute resolution*. Finally claims are *awarded* following either settlement of claims or disputes.

2.9.1 Kinds of Claims

One can claim everything as long as it is legally recognized, so there are various claims available. Between all, *time related claims* are notable ones with *counter-claims* when delay analysis is thought. Since delay is a contentious issue, generally parties cannot compromise on the analysis and most of the claims exist with their counter-claims (Thomas, 1993). Generally claims are supported through contract and claimed as claim under contract or claim for breach of contract. However, when contract prevents someone from claiming, then it is possible to claim for restitution based on unjust enrichment (*restitutionary quantum meurit*) (Davenport, 1995). The other kinds of claims that are extracted from literature review on delay analysis could be followed through Table 2.12.

Table 2.12: Kinds of delay claims

KINDS OF CLAIMS		Source
Variation Claims		[63], [67], [228]
	Extra work claims	[228]
	Different site conditions claims/Latent condition claims	[63], [228]
	Acceleration claims	[196], [228]
	Interest claim	[217]

Table 2.12: Kinds of delay claims (continued)

KINDS OF CLAIMS		Source
Time Related Claims		
	Extension of time claim	[46], [63], [137], [196]
	Liquidated damages claim	[46], [63], [137]
	Prolongation claim	[63], [196]
	Global/Composite/Rolled-up/Ambit claim	[56], [63], [196], [203], [217]
	Disruption/Loss of productivity claim	[46], [196], [215]
Quantum Meurit Claims		
	Total cost claim	[63]
	Contractual quantum meurit (Quantum meurit under contract)	[63]
	Restitutionary quantum meurit (Quantum meurit on unjust enrichment)	[63]
Claims after Termination by Frustration		[63]
Defective Work Claims		[63]
Licensing and Building Claims		[63]
Counter-claims		[196]

2.9.2 Parts of Claims

Claim should be issued in a specified time and in definite form of a written document. Because generally contracts specify time limits and procedures for claiming and any inaction of a party in that area may cause them to lose their rights for the claim (Trauner et al., 2009). It is simply the indication of why some particular things prolonged and deviated from the original plan, namely indication of activities delayed by a period of time which caused (or likely to cause) a delay to the project in a simple and fact based manner (Carnell, 2000). In representation of claim, parties at least must prove the liability of the party against whom they are making the claim, causation and damage (Tieder, 2008). Similarly it is also possible to think the main components of claims as damages, entitlement and relief (Chuen). So, a claim should include the following parts to clearly depict the situation and need. A guideline for presentation of claim is indicated in Table 2.13.

Table 2.13: Parts of claims

PARTS OF CLAIMS	Source
Introduction	
Date of the claim	[56]
Names of the parties	[196]
Addresses of the parties	[56]
Contract name	[56]
Contract number	[56]
Contract sum	[196]
The form of contract and any amendments thereto	[196]
Details of tender and acceptance	[196]
Dates for commencement and completion	[196]
Phased completion (if applicable)	[196]
Description of the works	[196]
The programme	[196]
Liquidated damages for delay	[196]
Summary of Facts	
Actual date of commencement and practical completion	[196]
Actual dates of sectional or partial completion (if applicable)	[196]
Summary of applications for extensions of time	[196]
Extensions of time awarded	[196]
Summary of claims submitted	[196]
Final account and claims assessed (if any)	[196]
Amount of latest certificate and retention	[196]
Payments received	[196]
Liquidated damages deducted (if applicable)	[196]
Basis of Claim	
Contract provisions relied upon	[27], [46], [196]
Common law provisions	[196]
Contractual analysis	[196]
Contractual entitlement	[27]
Contractual compliance	[27]
Explanation of the basis of the claim	[196]
Details of Claim	
Key dates	[196]
The date of delay commenced	[56]
The date of notice of delay	[56]
Identification of the notices served and relied upon	[46]
Description of events	[27], [46], [196]
Description of causes and effects	[27], [46], [196]
Explanation of the differing item already required by contract	[200]
References to relevant documents and specific contract clauses that apply	[196], [200]
Narrative of history of effects	[196], [203]
Distinguish causes and effects as EOT and financial effect	[196]
A detailed breakdown of damages with supporting information	[200]
Analysis of the schedule showing the effect on schedule	[27], [200]

Table 2.13: Parts of claims (continued)

PARTS OF CLAIMS	Source
Details of Claim (continued)	
Applicable details - public holidays etc.	[56]
Current completion date	[56]
An explanation of liability of the claim	[27], [200]
Summary of records and particulars	[27], [56]
Extensive use of schedules	[196]
Programmes	[196]
Diagrammatic illustration	[196]
Tables	[196]
Evaluation of Claim	
Details of calculation of additional costs ascertained	[196], [203]
Statement of Claim	
Statement setting out the claimant's alleged entitlements and relief	[27], [46], [196], [203]
Appendices	[196], [203]
Copies of all documents	[196]

2.9.3 Result of Claims

Claims are either settled in an amicable environment or dismissed (or rejected) because of the conflicting parties about validity of the claim, or amount of money or time claimed; and caused re-claims and further problems like dispute to the parties of claim. So, efficient and effective resolution of delay claims depend on the clear analysis of causation and effect that leads strong determination of the amount (Diekmann and Nelson, 1985; Scott et al., 2004).

2.9.3.1 Dispute and Dispute Resolution

The increased complexity of projects, compelling circumstances, increase in number of participants, more business interactions and arguments, and challenging competition between parties make the things more difficult in construction industry (Kumaraswamy and Yogeswaran, 1998). Also, poorly prepared contracts and lack of proper records kept during construction make the analysis process more difficult. So;

the parties to the contract generally analyze the cases hardly, accordingly become not able to adequately demonstrate the case and come into a conflict that further squeezes the situation and leads challenging litigation processes for settlement of disputes (Aibinu, 2009; Badman, 2007; Carnell, 2000; Tazelaar and Snijders, 2010). Longley and De Witt (2006) state the importance of the demonstration of the factual evidence as "*Your claim is only as good as the evidence that you have got to support. You could have the best contractual argument in the world, but without evidence, it is not worth anything.*" So as well as keeping proper records during construction, being able to use them properly in claiming process is also important (Carnell, 2000). Davenport (1995) states that "*it is not an army of lawyers and a mountain of paper that wins claims.*" Effective use of the records plays a crucial role in depicting the case and rights clearly. Unfortunately, the cases that are dispersed to litigation are not easily settled because litigation generally does not provide a solution without spending of further money and time through its exhaustive, time-consuming and expensive processes (Abdul-Malak et al., 2002). Even the party that wins the litigation may lose a considerable amount of money. Accordingly, as long as disputes are not settled; they may cause further delays, undermine the team spirit or damage the reputation and business relationships (Chan and Suen, 2005a, 2005b; Cheung and Suen, 2002; Iyer et al., 2008). The parties to a dispute may not be able to concentrate on and achieve success with other projects during these long periods (Yates and Epstein, 2006). Because of that, it is highly advisable to settle claims as they occur through amicable negotiations. O'Brien (1976) underlines the significance of settlement in a claim (or dispute) issue with his phrase as "*When in doubt – Settle. When uncertain – Settle. When in the right – Settle.*" If the success in settlement of claims is not achieved, resolution of disputes may be sought in Alternative Dispute Resolution (ADR) methods which are the solutions that are in the mid between amicable settlement and litigation processes. ADR methods are aimed at to allow the parties to resolve their disputes themselves or by assistance of a third party; through providing their own agreeable and workable solutions. When further amicable negotiations do not respond to the disputes, resolution by a third party like dispute review boards, arbitrators or judges is needed (Carnell, 2000; Chong and Rosli, 2009; Jones, 2006; Turner and Turner, 1999; Winter et al., 2002).

Negotiation is generally not accepted as a formal dispute resolution method, however since it can be used in different forms and times during processes of claim, conflict or dispute; it is taken as a dispute resolution method in this study. The well known methods of dispute resolution can be ordered as negotiation, arbitration, mediation, litigation and expert determination (Chan and Suen, 2005a). There are many other methods available most of which are explained in study of Tait (2008) and accordingly presented in the table below. As it is previously stated, legal process may harm the spirit of the working environment and collaboration between parties of the project which may affect the outcomes and profits of parties. So, alternative dispute resolution methods have emerged and provide resolution of disputes while parties protect their relationships. Also, generally alternative dispute resolution methods bear less cost and are settled in shorter durations than litigation since they are custom crafted to suit a particular case (Fenn et al., 1997; Koolwijk, 2006; Latham, 1994; Marcus, 1988; Rubin and Quintas, 2003). Advantages of alternative dispute resolution are presented by Treacy (2005) as:

- ✓ *reduced time to disposition*
- ✓ *less costly discovery*
- ✓ *more effective case management*
- ✓ *increased confidentiality*
- ✓ *facilitation of early, direct communication and understanding among the parties of the essential issues on each side of the dispute*
- ✓ *preservation of ongoing party relations*
- ✓ *savings in trial expenses*
- ✓ *providing qualified, neutral experts to hear complex matters*

In light of these, dispute resolution methods are grouped as *resolution by negotiation* (amicable/direct negotiation) and *resolution by third party* which is further divided into subcategories of *alternative dispute resolution* and *litigation*. Additionally, alternative dispute resolution is presented with its subcategories of available methods. Parties in a claim or dispute should select the most suitable method for their case by ensuring with sound knowledge not only in their case but also the available methods. So, various methods of dispute resolution are available in the following table (Table 2.14).

Table 2.14: Dispute resolution methods

DISPUTE RESOLUTION METHODS	Source
Resolution By Negotiation	[1], [33], [49], [50], [55], [79], [112], [120], [138], [184], [196], [203], [223], [227]
(Negotiated settlement/Amicable negotiation/Direct negotiation)	[1], [33], [49], [50], [55], [79], [112], [120], [138], [184], [196], [203], [223], [227]
Resolution By Third Party	[196]
Alternative Dispute Resolution	[140], [196]
Expert determination/Neutral evaluation	[49], [50], [79], [112], [120], [173], [193], [196], [201], [203]
Private judging/Rent a judge	[1], [50], [173], [193]
Executive tribunal	[79], [193]
Adjudication	[49], [50], [54], [55], [79], [112], [120], [127], [138], [193], [203]
Conciliation	[54], [79], [106], [112], [127], [193], [196], [203], [223]
Mediation	[1], [33], [49], [50], [54], [55], [79], [106], [112], [120], [127], [138], [173], [184], [193], [196], [201], [203], [223], [227]
Facilitation	[112]
Minitrial	[1], [49], [50], [112], [120], [173], [193], [203]
Arbitration	[1], [33], [49], [50], [55], [79], [106], [109], [112], [120], [127], [138], [173], [184], [196], [201], [203], [223], [227]
Dispute review boards	[1], [49], [50], [112], [173], [193], [201], [223]
Dispute resolution adviser	[49], [50]
Med-arb	[49], [50], [112], [193]
Litigation	[33], [49], [50], [55], [79], [112], [120], [184], [196], [203], [223], [227]

2.9.3.2 Settlement and Award

Claims are either settled by direct negotiations through an amicable environment or turned into disputes and got settled by various ways of dispute resolution methods. If the claims are relied on proper quantification of delay with evaluation of causation and effect, and presented through accepted guidelines by contracts; they may be efficiently and effectively settled through direct negotiations. Because guidelines provide presentation of facts in a scientific, systematic, clear and unbiased form; rather than presentation of judgments. This provides parties to get a deal in situation and to negotiate actually what should be negotiated (Kartam, 1999; Scott et al., 2004; Trauner et al., 2009). Otherwise, already complex situation turns into a more complex form and gets stuck in the ways of dispute resolution processes. In both ways, claims are settled and awarded to cure the problems. Possible awards of a claim can be *extension of time* to contractor, *liquidated damages* compensation to owner, *cost compensation* to contractor or *extension of time together with cost compensation* to contractor.

2.10 Notice for Delay/Mitigation/Claim

Parties should give a written notice for situations stated in contract not to lose their legal rights. In case of a delay, both parties to the contract are obliged to notify the other party when they meet a sign of any delay situation (Winter et al., 2002; Yogeswaran et al., 1998). This notification makes the parties to think on the situation together and to decide if any mitigation action could be taken or not. Accordingly each mitigation action should be notified; because since it is a change to the contract, it should be the common decision of parties. Otherwise, contractor ends up with his actions that are not recognized or compensated by owner (Palles-Clark, 2006; Scott and Harris, 2004). For the claiming procedure, each party should give a notice of claim through the way that is defined by contract. Unless claims are notified, they may not be awarded since the parties lose their rights due to the breach of contract (Davenport, 1995; Longley and De Witt, 2006; Sgarlata and Brasco, 2004; Thomas, 1993; Turner and Turner, 1999). Notice procedures should be clearly set in contracts with the information of maximum time allowed for the last notification date (Abdul-Malak et al., 2002).

2.11 Prevention of Delay

Effort should be given from the beginning of a project to establish harmonious relations between parties and to provide a strong document base to prevent problems related with delays. Factual, precise, complete and accurate documents help in tracking process of the project and also provide the proper analysis of delays (O'Brien, 1976). Focus should be first prevention of delays, however when delay occurs, mitigation and proper analysis of it are needed. So, steps of prevention should be kept in mind during every phase of a construction project, namely from conception to completion phase. All parties to the contract should understand in detail the possible causes of delays and the prevention measures that would help to avoid from delays (Abdul-Rahman et al., 2006; Toor and Ogunlana, 2008). Aibinu (2009) states that to establish everything on a sound basis, what is needed first is conducting a detailed pre-contract negotiation to make a deal in every contentious issue that may be met during life of the project and adds: "*higher levels of pre-contract negotiation were also associated with a higher quality of decision making, while higher levels of the quality of the decision-making process were associated with a lower intensity of conflict.*" Accordingly, properly established contracts base the power of the projects and success of the parties to the contract. Contracts should be clearly written and parties should have full knowledge of the contract before signing it and during construction (Jergeas and Hartman, 1994; Zaneldin, 2006). Besides its general provisions, project specific provisions may help to form the contract that responds to the every need in the life time of the project and handles the risks. Risks are the combination of factors that impact the main goals of the project as time, cost and quality. So the risks may either be easily identified and their impacts can be predicted (foreseeable risks), or not be known until their occurrences (unforeseeable risks) (Ehsan et al., 2010). Adequate allocation of foreseeable risks between the parties that would control them best with the minimum cost is required. A risk that could not be allocated to anyone can be assigned to owner if it is mutually agreeable. Otherwise, contractor can add this risk in his contingency amount in the bid with inclusion of other unforeseeable risks in the project (Aibinu and Jagboro, 2002; Kim et al., 2005; Sgarlata and Brasco, 2004). Adding the percentage of the cost of the project as a contingency in bid amount is a traditional approach to meet the risks and possible delays in construction of project (Al-Kharashi and Skitmore, 2009). So, sometimes it is preferable to leave something just as a risk and to take it into consideration in bidding price or to bear the costs when it occurs (Jannadia et al., 2000). In its basic form as it is stated by Latham (1994); measures should be avoiding problems, sharing the problems when they are inevitable and resolving disputes and other problems as soon as possible (Turner and Turner, 1999). In addition to these, during the construction process, the essential measure that should be taken is to provide proper updates that help the project to be adequately tracked. This contemporaneous analysis of project during construction also constitutes the main part of the sound data that ease the analysis process and provide objectivity in analysis in case of a delay. In addition to this, previously agreed record keeping processes deployed during construction phase constitute the main elements of the analysis process. Accordingly; one who would use the scheduling tool in planning, updating and analysis processes, must be familiar with the capabilities of tools and techniques that would be used because the tools are effective as long as its users have the grasp of their usage (Aibinu, 2009; Trauner et al., 2009; Winter et al., 2002). Also new ways of bidding process rather than lowest price like partnering, provide more satisfying roles to the participants of the project and enhance the working environment and communication and coordination between parties (Carnell, 2000; Rubin and Quintas, 2003; Scott and Harris, 2004; Zack, 1993). Moreover investment in human relations and caring in training of the personnel help to improve the productivity and good relations that provide contribution of whole project participants in working harmony (Egan, 1998; Faridi and El-Sayegh, 2006). Diekmann and Girard (1995) present the principles set out by Vorster (1993) as “start right” and “stay right” which imply establishment of the contract properly at the beginning and timely resolution of disputes before causing further legal problems respectively. So, every situation should be communicated and resolved immediately to provide the continuation of good relations and the working environment. Finally; parties should do their best to avoid claims, and behave in a proactive manner rather than a reactive manner through redundant claims (Love et al., 2010; Williams, 2003;

Zaneldin, 2006). So, focusing on prevention matters during all phases of a construction project plays a vital role in prevention, mitigation and analysis of delays.

2.11.1 Prevention Matters

There are variable prevention measures available in the literature. Thus prevention matters are presented in form of taxonomy as in Table 2.15. All of the matters are grouped under *prevention during planning*, *prevention during construction* and *prevention during analysis*. Matters are later grouped under subcategories according to their area of interest. These measures either directly help to prevent problems, or support analysis or mitigation of problems to block further problems or disputes. The full list of the prevention matters is available in the following table (Table 2.15).

Table 2.15: Taxonomy of prevention matters

PREVENTION	Source
Prevention During Planning	
Contract Related Prevention Matters	
Standard forms of contract should be used, as both parties are generally familiar with the obligations assumed by each party.	[138], [146]
Special contracting provisions and practices that have been used successfully on past projects should be used.	[228]
Proper production of contract documentation and reasonable interpretation of the contract should be achieved.	[26], [66], [138]
Proper, complete and consistent contract documents, work details, drawings and specifications have to be ready and provided before commencement of work.	[184], [200], [203]
Clarity, common sense, and precision in the drafting of contract language with no ambiguity should be provided.	[26], [228]
Adequate time should be provided to plan and develop the contract documentation.	[138]
Accurate initial cost estimates should be provided in the contract documentation.	[212]
Detailed examination and acceptance of tender focused on pricing and programme is needed.	[203]
Owner should make sure that adequate provision has been allowed in tender prices for the fulfillment of statutory and contractual responsibilities.	[134]
The contract should be read several times before signing it to understand any unclear clauses.	[50], [56], [111], [228]
The quality of documentation that is produced should be improved, initially by adhering to policies and procedures, especially those embedded within quality assurance.	[138]

Table 2.15: Taxonomy of prevention matters (continued)

PREVENTION	Source
Prevention During Planning	
Contract Related Prevention Matters (continued)	
Attention should be paid to contract details, such as making sure the language versions of the contract are consistent with each other.	[50]
There should be single point responsibility for managing and coordinating the documentation process.	[138]
Before signing of contract clear analysis of needings should be determined by both parties.	[203]
Providing a third party to read contract documents before the bidding stage is needed.	[228]
The contract details should be studied by a lawyer before signing or entering into an agreement.	[50]
Adopting a new approach to contract award procedure by giving less weight to prices and more weight to the capabilities and past performance of contractors is needed.	[26], [134], [157], [212]
Owner should reject exceptionally low bids which have not taken proper account of the risks involved.	[134]
Instead of competitive tendering use of negotiated or selective tendering with a policy whereby contractors openly present their margins and how they priced the project relies trust and cooperation between parties.	[70], [138]
Reliable contractor's tender policy should be provided.	[203]
Adopting new approaches to contracting such as design-build and construction management (CM) types of contracts is needed.	[134], [157]
Greater consideration should be given to procurement method selection/contracting.	[138], [203]
Partnering should be introduced as a new form of contract to develop cooperative and problem solving attitudes on projects through a risk-sharing philosophy and by establishing trust among partners.	[70], [109], [134], [138], [146], [173], [178], [228]
Clear agreement on the period of notice to commence for mobilization is needed.	[196]
Clear agreement on the timetables of information and other requirements is needed.	[50]
Proper site handing over and possession provided by proper recording especially for the dates and chorology of events of the site handing over is needed.	[184]
Complete definition of scope from inception to completion and mutually understanding is needed.	[26], [56], [114], [138]
Insuring the sufficiency of drawings and specifications by strengthening the language and content of clauses by including comprehensive scheduling provisions and voiding unrealistic performances is needed.	[19]
Owners should incorporate requirements for scheduling and schedule control in the contract documents.	[77]
Clear agreement on drawing and delivery process with schedule (between contractors and consultants) for preparation, submittal and approval of drawings is needed.	[5], [26], [77]
Realistic and agreed-upon time schedules by all parties should be established.	[199]
Clear agreement on software for preparation of program is needed.	[5]
Clear agreement on options of scheduling tool like decision of scheduling logic mode to be used as retained logic or progress override is needed.	[22]
Clear agreement on the factors of various issues of delay analysis is needed.	[22]
Clear agreement on the procedure for maintaining and updating the program is needed.	[5]
Clear agreement on ownership of float is needed.	[5], [22]

Table 2.15: Taxonomy of prevention matters (continued)

PREVENTION	Source
Prevention During Planning	
Contract Related Prevention Matters (continued)	
Clear agreement on treatment of concurrent delays is needed.	[22]
Clear agreement on procedure for gathering and keeping records and rules of evidence for claims is needed.	[5], [184], [196], [200], [217]
Clear provisions on approval of the works should be provided.	[203]
Clear provisions on variations and provisional sums should be provided.	[203]
Clear provisions on problems with site possession, access, ground and other conditions is needed.	[203]
Clear provisions on certificates and payment are needed: agreements on how payments are paid, when they are paid, and in which currency, etc.	[50]
Exact terms of performance standards should be specified.	[50]
The contract should include a change order provision and provide a proper mechanism for processing and evaluating change orders.	[26], [180]
Care should be taken by the owner on the scheduling clauses, change orders, and delay damages clauses.	[200]
If the contract is rampant with exculpatory language, especially in the area of no-damages-for-delay, the contractor should carefully consider accepting the risks involved because some projects are not worth the risk of bidding.	[200]
Reasonable time frame for notice should be considered in contract, given the opportunity for parties to ensure that work can be altered or accomplish as required by notice given.	[184]
Clear agreement on notice provisions in contract documents, including how, when, and to whom notice of problems must be given.	[5]
Clear agreement on method of dispute resolution that has the confidence of all parties with the dispute resolution clause is needed.	[46], [50], [109], [146], [200]
Parties might negotiate and agree on methodologies, techniques, and procedure for assessing and resolving different aspects of delay and disruption claims.	[5]
Establishment of proactive claims management in contract is needed.	[138]
Establishing time limits for the filing of claims by the contractor should be considered.	[200]
Clear agreement on acceleration procedure and its compensation is needed.	[5], [111]
Clear agreement on claim for payment of interest on compensation is needed - the rate of interest and the circumstances in which it will be paid.	[5]
Clear agreement on cost of preparing claims is needed - whether claimable or not.	[5]
Enforcing liquidated damage clauses and offering incentives for early completion is needed.	[157], [200]
Including provision of adequate compensation to contractors and consultants is needed.	[199]
Contractor should properly inspect and examine the site and its surroundings in detail and to satisfy himself before submitting his tender and signing the contract.	[67], [138], [205]
Contractor shall be fully responsible for the review of the engineering design and details of the works and shall inform the employer of any mistakes or incorrectness in such design and details which would affect the works.	[205]
Once the time for the completion was made to be essence and fixed in the contract, parties should make sure that they were actually bonded to the contract to provide timely delivery of project.	[184]

Table 2.15: Taxonomy of prevention matters (continued)

PREVENTION	Source
Prevention During Planning	
Contract Related Prevention Matters (continued)	
Clear description of assessment on final certificate and claim for work done is needed.	[184]
Control of subcontracting on quality, programme, design and price should be established.	[203]
Risk Related Prevention Matters	
Risk assessment should be conducted to identify areas of potential problems and to establish proactive management of risk.	[26], [56], [138], [146]
A realistic risk assessment should be devised by consulting experts for reliable sources.	[50]
More than media sources or immediate partners should be used to evaluate the risks, and always there should be a contingency plan for an emergency.	[50]
Adequate contingency allowance should be used for potential additional costs in areas of uncertainty.	[16], [85], [109], [146]
Owners should exercise robust change control/risk mitigation plan, with particular emphasis on comprehensive project planning and risk assessment at the projects from their outset.	[26], [134], [199]
Achieving a more equitable/fair allocation of risks between contracting parties should be provided.	[26], [134]
Allocation of risks to the parties that can best control it is needed to increase the integrity and acceptance of the contract and to have positive impact on parties' relationships.	[26], [146], [181], [203]
A risk register is needed in place for the project as early as possible (e.g. from tender stage).	[158]
Proper identification, allocation and management of risks should be provided.	[56], [158]
Cost and/or time implication should be assigned to all identified risks on the risk register whenever possible.	[158]
The risk register should be ensured to be open to all relevant members of the project team.	[158]
A strategy already developed is needed to solve each of the identified risks in case they come to fruition.	[158]
A risk workshop should be conducted involving all relevant project parties at the outset of the project in order to identify potential risks.	[158]
Encouraging, emphasizing and striving for a risk sharing regime should be provided when possible (it may aid in buttressing partnership and openness among the project parties).	[158]
Risks should not be used to mask project problems or deficiencies in planning.	[158]
Looking out for opportunities is needed to improve cost and time performance during risk analysis.	[158]
Project participants should be familiar with significant causes of delays and plan to avoid or at least mitigate their impact on project success.	[77]
Relations Related Prevention Matters	
Developing human resource management is needed to help improve labor skills and productivity.	[77], [157]
Behavioral assessment of project team members should be made.	[138]
Having a sound understanding of the staff's personality type is needed - their emotional intelligence and how they are able to cope with the pressures associated with their role in the specific project.	[138]

Table 2.15: Taxonomy of prevention matters (continued)

PREVENTION	Source
Prevention During Planning	
Relations Related Prevention Matters (continued)	
Development of an emotionally intelligent team that is able to stimulate creativity and solve problems that arise during design and construction to manage conflict more effectively and resolve issues through negotiation should be provided.	[138]
Relations at multiple levels - senior management and project level - should be promoted.	[146]
Teambuilding should be conducted to develop common project goals and processes, and discuss interests and expectations.	[109], [114], [146]
Joint training in negotiations and problem-solving should be set up.	[146]
The sharing of knowledge through the establishment of inter-organizational communities of practice would encourage joint problem solving and possibly reduce the incidence of conflict between parties.	[138]
Owners should ensure appropriate allocation of responsibilities among project participants and enforce a clear accountability structure within their own organization.	[134]
The role and responsibility of respective parties should be understood clearly before the commencement of project whether is in the main contract or subcontract work.	[26], [184]
The roles of superintendent officer, either the architect or engineer, should be given full control authorization for his execution of work; immediate instruction can be obtained in fast way to expedite of work progress.	[184]
Problem solving ability should be increased with processes and policies that promote fast decision making at the project level.	[2], [146]
Owner should devise ways to improve the authority structure and decision-making mechanism in their organizations.	[2], [20]
Everyone in the project should be kept informed about actions of each other during the project.	[146]
Establishment of good faith cooperation between the parties is needed.	[26], [212]
Project participants should establish and maintain open lines of communication.	[26], [212]
The communication of plans should be improved from planners to users (e.g., have meetings to discuss work scope in detail with contractors).	[146]
More frequent site meetings should be held between the parties, in order to verify that the works are progressing normally and are executed in accordance with the contract.	[199], [205], [212]
Continuous involvement of stakeholders in constructive dialogue should be provided.	[199]
Constructability reviews should be conducted to reduce the interaction between operations during the different stages of the project.	[146], [228]
Owners should develop a better understanding of the different facets of the construction delivery process, set clear project requirements and maintain close involvement in project implementation.	[134]
Value engineering should be used and constructability should be implemented during the different stages of the project.	[114], [134], [180]
Continuous work-training programs should be established for personnel to update their knowledge and be familiar with project management techniques and processes and have effective and efficient performances.	[85], [212]
Employers, consultants and contractors should adopt a proactive approach in resolving claims and disputes by providing proper training and relevant resources to ensure effective implementation.	[134]
Developing a crack skill qualification framework is needed in order to provide career paths for tradesmen.	[134]

Table 2.15: Taxonomy of prevention matters (continued)

PREVENTION	Source
Prevention During Planning	
Relations Related Prevention Matters (continued)	
Top management of owners should drive improvements in safety performance through proper procurement and contractual arrangements.	[134]
Owners and project teams should secure teamwork, good practice and commitment from all parties at a project level through a jointly developed project pact.	[134]
Owners should prohibit total subletting and exercise tighter control over the performance and management of subcontractors.	[134]
Reliable production management process should be established to improve the reliability of workflow.	[146]
Management Related Prevention Matters	
Application of various project management techniques have to be made from the conception to the completion stage, which include managing various risks associated with the project in its every stage.	[71]
Skillful and determined management are required both before and during construction to handle the threats and challenges that lead to claims.	[26]
An effective disciplinary mechanism should be developed to tackle non-performers by sharing information among owners on the performance of their consultants and contractors.	[134]
All team members should be paid realistic level of fees for the work they undertake.	[138]
Selection of contractors and consultants should be done with great attention.	[138]
The selected contractor must have sufficient experience, technical capability, financial capability, and sufficient manpower to execute the project.	[121], [176]
Contractors should make sure that their company organization is compatible with the size and type of the job they undertake.	[20], [176]
Owners should agree with subcontractors in light of contractors.	[203]
Assignment of experienced managers and superintendents/site supervisors with strong cooperative skills and attitudes is needed.	[121], [146], [199]
Hiring of an independent supervising engineer is needed to monitor the progress of the work and ensure timely delivery of materials.	[121]
Owners, consultants and contractors should ensure that they have the right personnel with the right qualifications to manage their projects.	[114], [176]
All construction stakeholders (owner, consultants, designers and contractors) should form an independent commission for performance evaluation.	[199]
Proper site management and (monitoring) supervision should be established.	[2], [212]
All project participants should recognize that conflicts are inevitable and the conflict management is a needed to produce a good working environment.	[212]
Improved intelligence on market conditions should be provided.	[138]
Up-to-date technology utilization should be established.	[212]
Using of proper and modern construction equipment is required.	[212]
Appropriate funding levels should always be determined at the planning stage of the project so that regular payment should be paid to all parties.	[85], [138]
Adequate and available source of finance should be ensured.	[121]
Attention should be paid not to deal with insolvent partners.	[50]
Owners must insure the works and people.	[203]

Table 2.15: Taxonomy of prevention matters (continued)

PREVENTION	Source
Prevention During Planning	
Scheduling Related Prevention Matters	
Proper planning, scheduling, documenting and coordination of works by contractor during planning are needed.	[114], [138], [184], [200], [212], [217]
A realistic project schedule should be established that secures the involvement and agreement of all project participants should be prepared and routinely updated and maintained.	[26]
A preconstruction planning of project tasks and resource needs should be performed.	[121]
Contractor should provide a properly organized labor and material histograms with a resource schedule.	[46]
Contractor should properly identify the dates that he is likely to require certain information from owner/architect.	[46]
A strategy on how to deal with tighter scheduling requirements should be established.	[228]
Being capable of appropriate use of the methodologies is needed with multidisciplinary knowledge, understanding, and skills, particularly in the areas of scheduling, construction methods, estimating, costing, construction law, and information technology tools.	[149]
A well-trained construction manager must not only understand the benefits and shortcomings of each approach, but also why a particular approach may or may not be well suited for analyzing the delay encountered.	[181]
Proper understanding of the problems and adequate use of management tools is needed.	[199]
The project manager must be aware of the different scheduling capabilities and options for each software tool.	[200]
Proper training in the use of any software is essential.	[200]
Critical-path-method scheduling, cost control and productivity analysis should be used to monitor progress and detect any change in productivity and/or cost.	[180]
Prevention Matters for Complexity of Works	
Breaking the project down into manageable chunks is needed.	[158]
Making sure the project is properly understood before embarking on it is needed.	[158]
Detailed review of the information relating to the work before embarking on it is needed.	[158]
A project execution plan should be developed for the work before starting on it.	[158]
Having enough resources to deal with the complexity is needed.	[158]
Allocating to the project experienced personnel that have handled similar type of complexity in the past is needed.	[158]
Incorporating longer lead-in time/sufficient time for complex works or phases of the project is required.	[158]
Ensuring as much design as possible is done for the complex work or project before commencing is needed.	[158]
Ensuring adequate coordination of design and activities preceding and following the complex work is required.	[158]
Calling in specialists to advise and contribute to the planning and management of complex works/projects should be provided.	[158]
Utilizing in-house expertise for the management of complex projects is needed.	[158]
Conducting workshops and brainstorming session to generate ideas and for problem-solving before and during the complex work/project is needed.	[158]

Table 2.15: Taxonomy of prevention matters (continued)

PREVENTION	Source
Prevention During Planning	
Prevention Matters for Complexity of Works (continued)	
Overlaying a risk analysis process specifically for a complex phase or activity in a project is required.	[158]
One team should run with the complex work/project from beginning to the end where possible and practical.	[158]
One should think holistically when planning a complex project by considering logistics, interfaces, etc. e.g. having a preconstruction services department that will not only plan the project but take a holistic look at the project rather than just having planning department as customary.	[158]
Subcontractors should be ensured with the capability to deal with the complexity is procured for the project when needed.	[158]
Getting as much information on the complex part of the project and sequence all activities is required.	[158]
Ensuring every element of the design has an aspect on the programme and using 4D modeling to show how the work will be built (i.e. have a plan and test it to see how it works) is advised.	[158]
When a complex project is broken down into manageable chunks, one should clearly understand how the complexities interact with each other.	[158]
Building in the risk of delay and higher cost allowances for complex projects is needed.	[158]
Project Duration Related Prevention Matters	
Ensuring the project planner is well trained in the construction process is required.	[158]
Preparation of the project programme with input from the construction site management/ production team is required.	[158]
The programme should be developed using science based methods augmented by experience and not relying on gut feeling alone.	[158]
Owner should be educated and advised on alternative if an unachievable/unrealistic project timescale is stipulated.	[158]
Owners who are unwilling to yield to professional advice must have the courage to refuse unrealistic project timescale.	[158]
Developing the project programme of works using experienced planners that have appreciation of the various construction disciplines is needed.	[158]
A process mapping exercise should be conducted to validate the time allocated to a project.	[158]
Enough time should be allocated during tender planning for the proper development of the project programme.	[158]
One should make sure when possible that the programme is developed by or in conjunction with someone that is experienced in the relevant type of project.	[158]
One should make sure the programme is built up from the first principle using metrics of how long typical activities take rather than using assessment only (ensuring that the time allocated to activities is quantifiable).	[158]
Design Related Prevention Matters	
Proper design reviews and audits should be established.	[138]
The overall project schedule should be ensured that it includes adequate time for all parties to perform their work, including design phase, bid phase and contract duration.	[200]
Comprehensive and complete design preparation at the right time should be provided.	[199]
Reasonable time for the design team should be allowed to produce clear and complete design and documentation.	[138], [180], [228]

Table 2.15: Taxonomy of prevention matters (continued)

PREVENTION	Source
Prevention During Planning	
Design Related Prevention Matters (continued)	
Owners should allow sufficient time for proper consideration of all relevant factors of a project and to mobilize the necessary resources to deliver projects.	[134]
Owners must make sure that sufficient time, money and effort are allocated to the feasibility study and design process.	[20], [121]
Owners should consult with knowledgeable advisors to determine a reasonable duration to specify in the contract documents.	[200]
Designers should analyze in a careful, detailed manner to determine the time required to perform the work considering the project, the site, the weather, and so forth.	[200]
Involvement of contractor earlier in the design process is needed to resolve planning issues that occur on-site.	[138], [199]
Owners and stakeholders (e.g. end-users) need to be kept constantly informed and integrated within the design process.	[138]
Efficient quality control techniques and mechanisms that can be used during the design process to minimize errors, mismatches, and discrepancies in contact documents must be established.	[228]
Clear distinction between a design change and a design development should be made at the outset of a project.	[158]
The cause of a design change should be always determined.	[158]
Determination of the provision of the design change within the building contract is required.	[158]
Identification of potential design changes as a risk and devising a strategy for managing the risk is needed especially in design and build projects.	[158]
The project should be designed in great detail at the outset whenever possible.	[158]
Change management procedure should be agreed and put in place before the commencement of projects (incorporating this into the contract if possible).	[158]
Open discussion by the relevant project party should be provided before the project start about how design changes will be managed and incorporating this into the contract if possible.	[158]
Contractor Related Prevention Matters	
Contractors need to act early to obtain permits and approvals from the different government agencies.	[77]
Contractors must plan their work properly and provide the entire schedule to the owners.	[176]
Contractor should assess the time allowed by the contract to determine if enough time is provided to perform the work without the use of extraordinary resources.	[200]
Contractors must include in its bid the cost for additional effort (such as overtime) required to meet the contract completion date.	[200]
Contractors should approach every contract with the intent of early completion.	[200]
Contractors must make sure they have a sound financial backing.	[176]
Appropriate construction methods should be selected by contractor.	[156], [212]
Contractor should provide a proper method statement showing the construction technique.	[46]
Effective and efficient material procurement systems should be established within projects by contractors.	[85], [212]
Thorough resource planning and development of the project concept is needed by contractors.	[199]

Table 2.15: Taxonomy of prevention matters (continued)

PREVENTION	Source
Prevention During Planning	
Contractor Related Prevention Matters (continued)	
Contractors need to give awareness on level of labor's skill, supervisor's ability to coordinate the project, quality of equipment and material used in order to minimize the problems.	[212]
Contractors should be aware of stock control problems with materials and should consider using more effective material scheduling techniques.	[20]
Subcontractor Related Prevention Matters	
Subcontractors should clearly communicate to the general contractor the time and schedule to which the bid applies.	[200]
Subcontractors should seriously consider whether to bid on contracts with extensive exculpatory (general contractor protective) language or not.	[200]
Properly directing the subcontractor is needed to ensure that they know what is expected of them in relation to the project.	[158]
Developing a good working relationship with subcontractors is essential.	[158]
A system for early identification of non-performance in subcontract works/packages should be put in place in order to nip it in the bud as soon as possible.	[158]
Performance measurements should be utilized to monitor the output/performance of subcontractors on their work package.	[158]
A committed supply chain that can be used should be ensured.	[158]
A process in place is needed that mutually allows non-performing subcontractors to be removed from the supply chain.	[158]
A partnering/collaborative relationship with the subcontractor should be ensured (this may ensure the subcontractor gives a better than normal service).	[158]
A progress-performance-payment rule in the subcontract should be incorporated where possible, e.g. that stipulates a certain amount can only be earned/paid when certain requirements have been met/a stage has been achieved in the project.	[158]
A stringent process is needed in place for selecting subcontractors into the supply chain.	[158]
Subcontractors doing major/critical part of the project should be involved with the internal planning process, i.e. early involvement of relevant subcontractors, e.g. at pre-tender stage in order to advise on design before having cost and time implications (early engagement).	[158]
A prompt system of payment to subcontractors for jobs that have been done should be ensured (this boosts morale and may prevent financial difficulty by subcontractor).	[158]
Relationship and communicating at management/board level of the subcontractors' companies should be built.	[158]
Holding significant retention on serial non-performing subcontractors is needed as it may serve as a deterrent/be used to remedy any non-performance issue that may occur.	[158]
Reduction of the retention is advisable for trusted and the best performing subcontractors.	[158]
Finding and understanding the root cause of any non-performance and working with the subcontractor is needed to see how to be of help.	[158]
Going through the different layers of the subcontractor's management is needed to ensure that a nonperformance situation is improved.	[158]
The selection of the cheapest subcontractor should be avoided if there is doubt on performance track record.	[158]
Taking time to understand the implementation strategy a subcontractor intends to adopt for a subcontract package and ensuring it fits well with the cost and time performance requirements of the project is needed.	[158]

Table 2.15: Taxonomy of prevention matters (continued)

PREVENTION	Source
Prevention During Planning	
Subcontractor Related Prevention Matters (continued)	
One should make sure subcontractors are allocated adequate time to complete subcontract work packages.	[158]
Seeing the benefits in having a small but quality closely knit supply chain that is well known rather than having a large supply chain where subcontractors are hardly known is required.	[158]
Sharing with individual subcontractors their evaluations and reviewing their weaknesses with them so that they can improve on it going forward is advisable.	[158]
One should have knowledge of the best projects the company's subcontractors are best able to undertake and allocate these to them and avoid giving subcontractors projects they are not good at.	[158]
Having a training system/regime in place for subcontractors is needed in order to indoctrinate them in the ways of the company, e.g. control processes, tools and techniques, etc. (and they will have no excuses to say they don't know what you want).	[158]
Having more than one subcontractor for a particular trade/package to encourage healthy competition is needed.	[158]
Prevention During Construction	
Contract Implementation Related Prevention Matters	
Proper knowledge of contract during construction and referring the contract all the time is needed.	[215]
Proper operation of contract machinery is needed.	[46]
A consistent and complete project documentation should be maintained from start to finish.	[26], [228]
Good practice and coordination should be established during execution of works.	[46]
Effective scheduling and rescheduling during execution of works is needed.	[215]
Tracking Related Prevention Matters	
Contractor should properly track progress of project via updated plan.	[200]
Contractor should collate and maintain adequate, relevant and contemporaneous information of the project.	[69]
Contemporaneous project schedules and updating should be used to keep the analysis objective and reliable.	[200]
As with creating and updating schedule, one must have a familiarity with scheduling terminology and be able to accurately interpret the data and results displayed by the schedule.	[200]
Updating the schedule periodically is needed to make it continue to reflect the contractor's as-built progress to-date and current as-planned schedule for performing the remaining work.	[82]
Maintaining proper job records on a timely manner is needed.	[111], [215], [228]
Programs should be get accepted and updated in time.	[176], [179]
The work should be monitored closely by making inspections at appropriate times.	[176]
Owner's representative should ensure quality project work, project safety, and/or compliance with environmental regulations.	[200]

Table 2.15: Taxonomy of prevention matters (continued)

PREVENTION	Source
Prevention During Construction	
Tracking Related Prevention Matters (continued)	
All lights, guards, fencing and watching for the protection of the works should be provided and maintained and the materials and equipment should be utilized therefore for the safety and convenience of the public or others.	[205]
Consultants should produce documentation properly undertaking design verifications, reviews and audits.	[138]
Consultants should improve their internal management practices by involving and providing a sense of ownership of the process.	[138]
Required information should be delivered to correct person in the right manner to avoid any late transmission of information.	[184]
The relationship between parties has to be preserved no matter since how long the relationship had established.	[184]
Owner Related Prevention Matters	
Owner should make site available at the right time.	[203]
Owner should provide continuous access to the site.	[196]
Owner should provide sufficient info in sufficient time to enable the contractor to carry out the works by the due completion date.	[196]
Owner should not interfere frequently during the execution and keep making major changes to the requirements.	[176]
Owner should work closely with the financing bodies and institutions to release the payment on schedule during construction.	[176]
Owner must make quick decisions to solve any problem that arise during the execution of work.	[176]
Owner should ensure that negotiation in relation to payment issue is carried out in proper manner during construction.	[184]
Owner should take certain action in emergency.	[203]
Change Related Prevention Matters	
Contractor should timely carry out the directions of architect through change orders.	[156]
Focus is needed on minimization of change orders.	[199]
Timely responses to needs should be provided.	[19], [111]
Changes should be dealt with when they occur involving all main participants.	[26]
All the relevant project parties should be notified of how they will be impacted and the schedule and cost implication of a change before going ahead with the change.	[158]
Owner's representative must manage changes and change order process.	[200]
Qualification of change orders is needed before signing-off to preserve the rights when risk of extra damages exists.	[215]
Ensuring the time and cost implication of a change is always determined and agreed before going ahead with the change whenever possible.	[158], [179]
If a contractor submits a change request because of a design problem, the designer must take all necessary measures to ensure that its decisions are fair and impartial.	[200]
The basis for payment in advance should be agreed on before the accelerative measures are taken.	[111], [179], [217]
Change orders must be signed before starting doing these changes on site.	[228]
Provision/allocation of enough resources (labor, equipment, etc.) is needed to cope with a design change.	[158]
Design changes should be adequately highlighted and updated on all relevant project documentations (e.g. drawings, specifications, reports, etc.).	[158]

Table 2.15: Taxonomy of prevention matters (continued)

PREVENTION	Source
Prevention During Construction	
Change Related Prevention Matters (continued)	
Ensuring prompt resolution to design change queries, issues and authorization requests is needed.	[158]
All design changes should be captured on a register with corresponding cost and schedule implications for discussion during project team meetings.	[158]
A design manager is needed where possible with responsibility for the management of the design change process and reviewing related information as it comes in.	[158]
No one should make a design change without the knowledge or authorization of the relevant project party, e.g. project manager.	[158]
Efficient analysis of the direct and indirect consequence (domino effect) of a design change on other activities or areas of the project is needed as one change can precipitate other changes.	[158]
Design changes should be reasonably timed when possible, e.g. late design changes may greatly impact the ability to control the project cost and schedule.	[158]
Freezing design at the appropriate stage of a project or implementing intermediate design freezes at various project stages depending on the type of contract is needed.	[158]
The risk register should not be solely kept in the corporate office but communicated to the construction management and site team as well.	[158]
The risk register should be reviewed at all relevant progress meetings including meetings with the site based team.	[158]
The risk register should be a live document that is updated regularly.	[158]
The relevant project parties should be swiftly informed if unforeseen circumstances affect the programme/lead-in times.	[158]
Constantly monitoring the progress and being open minded to improving the programme and cost plan is required as things become clearer and to other options available.	[2], [158]
Integration of subcontractors into the site management team (where possible, practicable and feasible) is needed all through the course of the work.	[158]
Delay Response Related Prevention Matters	
The contractor should be notified as early as possible of any employer delays of which architect is aware.	[217]
Contractor should give reasonable notice of delay or any of claim in time to architect, contract administrator, engineer or project manager.	[156], [162], [196], [217]
Contractor should immediately take reasonable steps to mitigate the effect in case of a delay as it is stated in contract.	[217]
Contractor should identify the causes of delay and relevant event, give particulars of the expected effects, estimate the extent and tell the story.	[46], [162]
Contractor should establish the documentation of all delays and changes in writing in a timely manner.	[156], [200]
Claiming Related Prevention Matters	
Filing notice of potential claims is needed for preservation of rights.	[215]
Proper devising of the documentation system for claims is needed.	[19]
An overall comprehensive step-by-step procedure should be followed for tracking and managing the claims submitted by contractors.	[228]
Claims should be submitted by closely following the steps stipulated in the contract conditions.	[228]
All applicable notice requirements under the contract must be fulfilled before a contractor is entitled to compensation for a delay claim.	[181]

Table 2.15: Taxonomy of prevention matters (continued)

PREVENTION	Source
Prevention During Construction	
Claiming Related Prevention Matters (continued)	
Contractors should know their rights with the suspension of work and claiming for damages exactly and timely use them if needed.	[156], [203]
Once a claim has been presented, the owner and contractor should come to an agreement concerning the claim.	[228]
Claim Response Related Prevention Matters	
Timely dispute resolution processes should be provided.	[19], [66]
Responding in time to contractor's claims and awarding for excusable delays is needed.	[19]
Owner's representative should be able to evaluate time extensions and additional costs by properly maintaining a current CPM schedule and detailed performance records, and by seeking adequate information from the contractor	[200]
Extensions of time should be dealt with as soon as possible after the delaying event is recognized leading to the requirement for interim assessments.	[111], [179], [217]
Prevention During Analysis	
Prevention Matters During Analysis	
If the analyst notes serious errors in the logic of the schedule, he or she should consider not accepting the contractor's schedule as a valid tool to measure the delays.	[200]
The analyst must not change the logic or durations to produce a schedule that seems more representative.	[200]
If the as-built schedule is complex, reconstruction of as-built schedule with the available information is required.	[217]
The validity of the schedule is subjective; therefore, the analyst should always seek help from a qualified scheduling consultant before making this determination.	[200]
If the schedule does not reflect the reality of the job progress, then it may be wiser to abandon the schedule and perform a delay analysis using the as-built approach.	[200]
Upon reviewing the CPM schedule, the analyst may question the validity of the durations assigned to specific activities based on his or her own knowledge of the project, estimating skills, and experience.	[200]
The delay analysis should rely on the contemporaneous project schedules as the basis of analysis to create objectivity as much as possible.	[200]
The analysis must accurately consider the contemporaneous information when the delays were occurring.	[200]
When a contemporaneous schedule is not available to measure critical project delays, the analyst should use an as-built analysis to identify the critical delay, which is based on an as-built diagram.	[200]
Schedules should not be created after the fact that: Creating schedules after the fact that for measuring delays should be prevented.	[200]
The analyst should be familiar with the specific software used to create and update the schedules, given the different scheduling options available in each software package.	[200]
The analyst should gather all of the contractor's schedules throughout the duration of the project - the as-planned schedule and all subsequent schedule updates.	[200]
The analyst should get "electronic copies" - a copy of the computer file - for each of the schedules.	[200]
A review of project correspondence or as-built information near the time of the schedule revisions should assist the analyst in determining the causes.	[200]
The analyst should focus on determining the source and magnitude of all critical project delays without regard to the party responsible to achieve an objective analysis.	[200]

Table 2.15: Taxonomy of prevention matters (continued)

PREVENTION	Source
Prevention During Analysis	
Prevention Matters During Analysis (continued)	
First the analyst should find what is the delay irrespective of the reliable party, determining the party responsible for this delay should be a separate task.	[200]
The analysis should account and identify for all project delays and savings throughout the duration of the project.	[200]
When assessing the contractor's entitlement to compensation for prolongation, the site overheads included in the tender should not be used.	[179]
For disruption ''the measured mile'' approach (i.e., comparing the same work in disrupted and undisrupted conditions) is suggested as the best way to handle it.	[179]

2.11.2 Matching between Causes of Delay and Related Prevention Matters

As it is stated previously, main concern of parties to a contract should be prevention of delays first. So, knowledge in delay and delay analysis issues not only helps restraining delays, but also eases analysis process and prevents further problems in case of a delay. Especially causes of delay and corresponding prevention matters may help most to take this action in the first stage. In light of these, detailed investigation of causes of delay and prevention matters are presented in previous sections of this chapter. Accordingly, this section focuses on matching of some causes of delay with their related prevention matters that may help to prevent their occurrences. Some of the factors are matched with more than one prevention matters and vice versa. Details are available in the following table (Table 2.16).

Table 2.16: Table of causes matched with corresponding prevention matters

Cause Factor	Prevention Matter
Incomplete/Defective/Poor design drawings, specifications or documents	Proper, complete and consistent contract documents, work details, drawings and specifications have to be ready and provided before commencement of work.
	Efficient quality control techniques and mechanisms that can be used during the design process to minimize errors, mismatches, and discrepancies in contact documents must be established.

Table 2.16: Table of causes matched with corresponding prevention matters (continued)

Cause Factor	Prevention Matter
Unclear and inadequate details in drawings	Efficient quality control techniques and mechanisms that can be used during the design process to minimize errors, mismatches, and discrepancies in contact documents must be established.
Inaccurate estimates - errors or omissions in quantity estimating/inaccurate bills of quantities	Accurate initial cost estimates should be provided in the contract documentation.
	Designers should analyze in a careful, detailed manner to determine the time required to perform the work considering the project, the site, the weather, and so forth.
Errors and omissions in design documents and defective specifications	Efficient quality control techniques and mechanisms that can be used during the design process to minimize errors, mismatches, and discrepancies in contact documents must be established.
Inaccurate design information	Efficient quality control techniques and mechanisms that can be used during the design process to minimize errors, mismatches, and discrepancies in contact documents must be established.
Disagreements on design specifications	Owners and stakeholders (e.g. end-users) need to be kept constantly informed and integrated within the design process.
Inconsistency between drawings and site conditions	Designers should analyze in a careful, detailed manner to determine the time required to perform the work considering the project, the site, the weather, and so forth.
Complexity of project design	Ensuring adequate coordination of design and activities preceding and following the complex work is required.
	Ensuring as much design as possible is done for the complex work or project before commencing is needed.
	The project should be designed in great detail at the outset whenever possible.
Inadequate design-team experience	Development of an emotionally intelligent team that is able to stimulate creativity and solve problems that arise during design and construction to manage conflict more effectively and resolve issues through negotiation should be provided.
Delays in design information	Comprehensive and complete design preparation at the right time should be provided.
	Clear agreement on drawing and delivery process with schedule (between contractors and consultants) for preparation, submittal and approval of drawings is needed.
Change orders by owner during construction/Owner initiated variations	Owner should not interfere frequently during the execution and keep making major changes to the requirements.
Necessary changes/variations of works	The contract should include a change order provision and provide a proper mechanism for processing and evaluating change orders.
Design changes/modifications by owner or his agent during construction	Determination of the provision of the design change within the building contract is required.
Design changes in respond to site conditions	Designers should analyze in a careful, detailed manner to determine the time required to perform the work considering the project, the site, the weather, and so forth.
Design changes due to poor brief, errors and omissions	Efficient quality control techniques and mechanisms that can be used during the design process to minimize errors, mismatches, and discrepancies in contact documents must be established.

Table 2.16: Table of causes matched with corresponding prevention matters (continued)

Cause Factor	Prevention Matter
Change orders by deficiency design	Efficient quality control techniques and mechanisms that can be used during the design process to minimize errors, mismatches, and discrepancies in contact documents must be established.
Excessive scope changes and constructive changed orders	Complete definition of scope from inception to completion and mutually understanding is needed.
Delay in issuance of change orders by the owner	The contract should include a change order provision and provide a proper mechanism for processing and evaluating change orders.
Improper or delayed change orders	The contract should include a change order provision and provide a proper mechanism for processing and evaluating change orders.
Changes in owner's requirements	Owner should not interfere frequently during the execution and keep making major changes to the requirements.
Long waiting time for approval of drawings	Clear agreement on drawing and delivery process with schedule (between contractors and consultants) for preparation, submittal and approval of drawings is needed.
Slow drawing revision and distribution	Proper design reviews and audits should be established.
Poor quality of design - wrong/improper/impractical design	Efficient quality control techniques and mechanisms that can be used during the design process to minimize errors, mismatches, and discrepancies in contact documents must be established.
Low constructability of design	Constructability reviews should be conducted to reduce the interaction between operations during the different stages of the project.
	Value engineering should be used and constructability should be implemented during the different stages of the project.
Poor communication and coordination between designers	Project participants should establish and maintain open lines of communication.
Insufficient communication between the owner and designer in design phase	Project participants should establish and maintain open lines of communication.
Misunderstanding of owner's requirements by design engineer	Project participants should establish and maintain open lines of communication.
	Owners and stakeholders (e.g. end-users) need to be kept constantly informed and integrated within the design process.
Slow decision making by designers	Owner should devise ways to improve the authority structure and decision-making mechanism in their organizations.
Slow correction of design errors	Problem solving ability should be increased with processes and policies that promote fast decision making at the project level.
Poor contract management by consultant	Consultants should improve their internal management practices by involving and providing a sense of ownership of the process.
Poor communication and coordination by consultant with other parties	Project participants should establish and maintain open lines of communication.
Delays in contractor's progress payments (of completed work) by owner	Owner should work closely with the financing bodies and institutions to release the payment on schedule during construction.
Failure to fund the project on time	
Payment delays by owner	

Table 2.16: Table of causes matched with corresponding prevention matters (continued)

Cause Factor	**Prevention Matter**
Poor project financing by owner	Adequate and available source of finance should be ensured.
Lack of finance to complete the work by the owner	
Selecting the type of project bidding and award (negotiation, lowest bidder, etc.)	Adopting a new approach to contract award procedure by giving less weight to prices and more weight to the capabilities and past performance of contractors is needed.
	Adopting new approaches to contracting such as design-build and construction management (CM) types of contracts is needed.
	Partnering should be introduced as a new form of contract to develop cooperative and problem solving attitudes on projects through a risk-sharing philosophy and by establishing trust among partners.
Lack of clear bidding process/Exceptionally low bids	Adopting a new approach to contract award procedure by giving less weight to prices and more weight to the capabilities and past performance of contractors is needed.
	Instead of competitive tendering use of negotiated or selective tendering with a policy whereby contractors openly present their margins and how they priced the project relies trust and cooperation between parties.
Selection of inappropriate type of main construction	Owners should develop a better understanding of the different facets of the construction delivery process, set clear project requirements and maintain close involvement in project implementation.
Imbalance in the risk allocation by owner	Owners should ensure appropriate allocation of responsibilities among project participants and enforce a clear accountability structure within their own organization.
Inappropriate contractor or consultant selection	Selection of contractors and consultants should be done with great attention.
Improper project feasibility study	Owners must make sure that sufficient time, money and effort are allocated to the feasibility study and design process.
Delay in site preparation and delivery	Proper site handing over and possession provided by proper recording especially for the dates and chorology of events of the site handing over is needed.
	Owner should make site available at the right time.
Restricted access to the site/Poor site access and availability	Owner should provide continuous access to the site.
Failure of the employer over ingress and egress	
Lack of capable owner's representative	Owner's representative should be able to evaluate time extensions and additional costs by properly maintaining a current CPM schedule and detailed performance records, and by seeking adequate information from the contractor
Failure on the part of the owner to review and approve design documents, schedules, and material on time	Proper design reviews and audits should be established.

Table 2.16: Table of causes matched with corresponding prevention matters (continued)

Cause Factor	Prevention Matter
Failure on the part of the owner to properly coordinate multiple contractors	Relations at multiple levels - senior management and project level - should be promoted.
Unrealistic time/cost/quality targets/expectations and requirements by owner	Realistic and agreed-upon time schedules by all parties should be established.
	Owner should be educated and advised on alternative if an unachievable/unrealistic project timescale is stipulated.
	Owners who are unwilling to yield to professional advice must have the courage to refuse unrealistic project timescale.
Slow responses from the owner's organization	Timely responses to needs should be provided.
	Owner must make quick decisions to solve any problem that arise during the execution of work.
	Responding in time to contractor's claims and awarding for excusable delays is needed.
Inadequate information and supervision by the owner	Assignment of experienced managers and superintendents/site supervisors with strong cooperative skills and attitudes is needed.
	Hiring of an independent supervising engineer is needed to monitor the progress of the work and ensure timely delivery of materials.
Mistakes and discrepancies in contract documents due to owner	Proper production of contract documentation and reasonable interpretation of the contract should be achieved.
	Proper, complete and consistent contract documents, work details, drawings and specifications have to be ready and provided before commencement of work.
Incomplete/erroneous contract documentation	Proper production of contract documentation and reasonable interpretation of the contract should be achieved.
	Proper, complete and consistent contract documents, work details, drawings and specifications have to be ready and provided before commencement of work.
Inadequate definitions/contract clauses in contract	The contract should be read several times before signing it to understand any unclear clauses.
Disagreements on contract clauses	
Poor interpretation of contract clauses	
Poor knowledge of local statues	Owner should make sure that adequate provision has been allowed in tender prices for the fulfillment of statutory and contractual responsibilities.
Poor scope definition	Complete definition of scope from inception to completion and mutually understanding is needed.
Poor contract familiarity/Owner's contracting procedures	Standard forms of contract should be used, as both parties are generally familiar with the obligations assumed by each party.
Contract and specification interpretation disagreement	Proper production of contract documentation and reasonable interpretation of the contract should be achieved.
Poor contract interpretation	

Table 2.16: Table of causes matched with corresponding prevention matters (continued)

Cause Factor	Prevention Matter
Unavailability of financial incentives for contractor for finishing ahead of schedule in contract	Enforcing liquidated damage clauses and offering incentives for early completion is needed.
Unrealistic contract duration imposed by owner	The overall project schedule should be ensured that it includes adequate time for all parties to perform their work, including design phase, bid phase and contract duration.
	Owners should consult with knowledgeable advisors to determine a reasonable duration to specify in the contract documents.
Owner's interference/Unnecessary interference by the owner	Owner should not interfere frequently during the execution and keep making major changes to the requirements.
Uncooperative owner	Establishment of good faith cooperation between the parties is needed.
Excessive bureaucracy by owner's administration	Project participants should establish and maintain open lines of communication.
Slowness in decision making process by owner	Owner must make quick decisions to solve any problem that arise during the execution of work.
Faulty negotiations and obtaining of contracts	Instead of competitive tendering use of negotiated or selective tendering with a policy whereby contractors openly present their margins and how they priced the project relies trust and cooperation between parties.
Poor communication and coordination by owner with other parties (construction parties and government authorities)	Project participants should establish and maintain open lines of communication.
Inappropriate overall structure linking all parties in project	
Lack of communication and coordination between the parties involved in construction	
Low speed of decision making involving all project teams	Problem solving ability should be increased with processes and policies that promote fast decision making at the project level.
Low speed of decision making within each project team	
Slow information flow between project team members	Required information should be delivered to correct person in the right manner to avoid any late transmission of information.
Replacement of key personnel by owner	Owners, consultants and contractors should ensure that they have the right personnel with the right qualifications to manage their projects.
High turnover in owner's technical personnel	
Delay in the settlement of contractor claims by the owner	Responding in time to contractor's claims and awarding for excusable delays is needed.

Table 2.16: Table of causes matched with corresponding prevention matters (continued)

Cause Factor	Prevention Matter
Delay in delivery of materials	Hiring of an independent supervising engineer is needed to monitor the progress of the work and ensure timely delivery of materials. Effective and efficient material procurement systems should be established within projects by contractors.
Poorly scheduled delivery of material to site	
Late procurement of materials	Effective and efficient material procurement systems should be established within projects by contractors.
Poor/Inappropriate procurement method/programming of construction materials	
Inappropriate/Inadequate/misuse of material	Contractors need to give awareness on level of labor's skill, supervisor's ability to coordinate the project, quality of equipment and material used in order to minimize the problems.
Poor quality of materials	
Unforeseen material damages	
Poor material handling on site	Contractors should be aware of stock control problems with materials and should consider using more effective material scheduling techniques.
Poor storage of material	
Damage of sorted materials while they are needed urgently	
Improper tools for materials	Using of proper and modern construction equipment is required.
Equipment breakdown/failure and maintenance problem	Using of proper and modern construction equipment is required.
Low productivity and efficiency of equipment	
Failure to provide sufficient equipment	
Lack of high-technology mechanical equipment/Outdated equipment	
Poor/Wrong selection of equipment/Improper equipment	
Inadequate/Insufficient/Ineffective equipment used for the works	
Poor distribution of labor	Thorough resource planning and development of the project concept is needed by contractors.
Poor workmanship	
Unqualified/Inadequate experienced labor	Developing human resource management is needed to help improve labor skills and productivity.
Low skilled manpower/Unskilled labor	
Low productivity/efficiency level of labors	
Weak motivation and morale of labors	

Table 2.16: Table of causes matched with corresponding prevention matters (continued)

Cause Factor	Prevention Matter
Difficulties in financing project by contractor	Contractors must make sure they have a sound financial backing.
Contractor's financial problems	
Problems in cash flow management	
Late payment to subcontractor by the main contractor	A prompt system of payment to subcontractors for jobs that have been done should be ensured (this boosts morale and may prevent financial difficulty by subcontractor).
Poor subcontracting (system)	Taking time to understand the implementation strategy a subcontractor intends to adopt for a subcontract package and ensuring it fits well with the cost and time performance requirements of the project is needed.
Lack of subcontractor's skills	Subcontractors should be ensured with the capability to deal with the complexity is procured for the project when needed.
Lack of subcontractor's experience	
Poor performance of subcontractors and nominated suppliers	A system for early identification of non-performance in subcontract works/packages should be put in place in order to nip it in the bud as soon as possible.
	Performance measurements should be utilized to monitor the output/performance of subcontractors on their work package.
	A process in place is needed that mutually allows non-performing subcontractors to be removed from the supply chain.
	A progress-performance-payment rule in the subcontract should be incorporated where possible, e.g. that stipulates a certain amount can only be earned/paid when certain requirements have been met/a stage has been achieved in the project.
	Holding significant retention on serial non-performing subcontractors is needed as it may serve as a deterrent/be used to remedy any non-performance issue that may occur.
	Finding and understanding the root cause of any non-performance and working with the subcontractor is needed to see how to be of help.
	Going through the different layers of the subcontractor's management is needed to ensure that a nonperformance situation is improved.
	Having a training system/regime in place for subcontractors is needed in order to indoctrinate them in the ways of the company, e.g. control processes, tools and techniques, etc. (and they will have no excuses to say they don't know what you want).
Poor communication and coordination by subcontractor with contractor/other parties	Subcontractors should clearly communicate to the general contractor the time and schedule to which the bid applies.
	Developing a good working relationship with subcontractors is essential.
	A partnering/collaborative relationship with the subcontractor should be ensured (this may ensure the subcontractor gives a better than normal service).
	Relationship and communicating at management/board level of the subcontractors' companies should be built.

Table 2.16: Table of causes matched with corresponding prevention matters (continued)

Cause Factor	Prevention Matter
Conflicts between different subcontractors' schedules in execution of project	Integration of subcontractors into the site management team (where possible, practicable and feasible) is needed all through the course of the work.
Subcontractor interference	
Interference with other trades (trade stacking)	
Accident during construction	Top management of owners should drive improvements in safety performance through proper procurement and contractual arrangements.
Unsafe practices during construction	
Problems due to site safety considerations/Poor safety conditions	
Lateness in safety facilities reinforcement	
Loose safety rules and regulations within the contractor's organization	
Problems due to site pollution and noise	Owner's representative should ensure quality project work, project safety, and/or compliance with environmental regulations.
Environmental protection and mitigation costs	
Damage to structure	All lights, guards, fencing and watching for the protection of the works should be provided and maintained and the materials and equipment should be utilized therefore for the safety and convenience of the public or others.
Theft/Vandalism inside the site	
Creation of the schedule too optimistic	A realistic project schedule should be established that secures the involvement and agreement of all project participants should be prepared and routinely updated and maintained.
Overestimation of the labor productivity	
Inaccurate estimate of materials, labor output, equipment production rates	
Inaccurate evaluation of projects time/duration	
Unrealistic project schedule	
Nonuse of appropriate software for scheduling and controlling	Clear agreement on software for preparation of program is needed.
	Proper training in the use of any software is essential.
	Proper understanding of the problems and adequate use of management tools is needed.
	The project manager must be aware of the different scheduling capabilities and options for each software tool.
Contractors' planning and scheduling problems	Proper planning, scheduling, documenting and coordination of works by contractor during planning are needed.
Poor project planning and scheduling by contractor	

Table 2.16: Table of causes matched with corresponding prevention matters (continued)

<table>
<tr><th>Cause Factor</th><th>Prevention Matter</th></tr>
<tr><td>Poor judgment and experience of involved people in estimating time and resources</td><td rowspan="2">Developing the project programme of works using experienced planners that have appreciation of the various construction disciplines is needed.</td></tr>
<tr><td>Lack of experiences and information preparing in price quotation</td></tr>
<tr><td>Lack of training personnel and management support to model the construction operation</td><td>Calling in specialists to advise and contribute to the planning and management of complex works/projects should be provided.</td></tr>
<tr><td>Unavailability of the construction/project management group for the project</td><td></td></tr>
<tr><td>Unavailability of managerial and supervisory personnel</td><td>Assignment of experienced managers and superintendents/site supervisors with strong cooperative skills and attitudes is needed.</td></tr>
<tr><td>Improper technical study by the contractor during the bidding stage</td><td rowspan="4">Enough time should be allocated during tender planning for the proper development of the project programme.</td></tr>
<tr><td>Inadequate early planning of the project</td></tr>
<tr><td>Unreasonable or unpractical initial plan</td></tr>
<tr><td>Insufficient or ill-integrated basic project data that is needed to be provided by contractor</td></tr>
<tr><td rowspan="8">Ineffective control of the project progress by the contractor/Inadequate progress review</td><td>Hiring of an independent supervising engineer is needed to monitor the progress of the work and ensure timely delivery of materials.</td></tr>
<tr><td>Proper site management and (monitoring) supervision should be established.</td></tr>
<tr><td>Contractor should properly track progress of project via updated plan.</td></tr>
<tr><td>Updating the schedule periodically is needed to make it continue to reflect the contractor’s as-built progress to-date and current as-planned schedule for performing the remaining work.</td></tr>
<tr><td>Constantly monitoring the progress and being open minded to improving the programme and cost plan is required as things become clearer and to other options available.</td></tr>
<tr><td>Critical-path-method scheduling, cost control and productivity analysis should be used to monitor progress and detect any change in productivity and/or cost.</td></tr>
<tr><td>The work should be monitored closely by making inspections at appropriate times.</td></tr>
<tr><td>More frequent site meetings should be held between the parties, in order to verify that the works are progressing normally and are executed in accordance with the contract.</td></tr>
</table>

Table 2.16: Table of causes matched with corresponding prevention matters (continued)

Cause Factor	Prevention Matter
Poor quality of site documentation	The quality of documentation that is produced should be improved, initially by adhering to policies and procedures, especially those embedded within quality assurance.
	There should be single point responsibility for managing and coordinating the documentation process.
	A consistent and complete project documentation should be maintained from start to finish.
Inefficient work breakdown structure	Thorough resource planning and development of the project concept is needed by contractors.
Staffing problems (overstaffing/understaffing)	
Overcrowded work area/Congestion	
Problems with timelines of project information	Clear agreement on the timetables of information and other requirements is needed.
Complexity of works	Breaking the project down into manageable chunks is needed.
	Making sure the project is properly understood before embarking on it is needed.
	Detailed review of the information relating to the work before embarking on it is needed.
	A project execution plan should be developed for the work before starting on it.
	Having enough resources to deal with the complexity is needed.
	Allocating to the project experienced personnel that have handled similar type of complexity in the past is needed.
	Incorporating longer lead-in time/sufficient time for complex works or phases of the project is required.
	Ensuring as much design as possible is done for the complex work or project before commencing is needed.
	Ensuring adequate coordination of design and activities preceding and following the complex work is required.
	Calling in specialists to advise and contribute to the planning and management of complex works/projects should be provided.
	Utilizing in-house expertise for the management of complex projects is needed.
	Conducting workshops and brainstorming session to generate ideas and for problem-solving before and during the complex work/project is needed.
	Overlaying a risk analysis process specifically for a complex phase or activity in a project is required.
	One team should run with the complex work/project from beginning to the end where possible and practical.
	One should think holistically when planning a complex project by considering logistics, interfaces, etc. e.g. having a preconstruction services department that will not only plan the project but take a holistic look at the project rather than just having planning department as customary.
	Subcontractors should be ensured with the capability to deal with the complexity is procured for the project when needed.

Table 2.16: Table of causes matched with corresponding prevention matters (continued)

Cause Factor	Prevention Matter
Complexity of works	Getting as much information on the complex part of the project and sequence all activities is required.
	Ensuring every element of the design has an aspect on the programme and using 4D modeling to show how the work will be built (i.e. have a plan and test it to see how it works) is advised.
	When a complex project is broken down into manageable chunks, one should clearly understand how the complexities interact with each other.
	Building in the risk of delay and higher cost allowances for complex projects is needed.
Using obsolete technology	Up-to-date technology utilization should be established.
Large number of participants of project	The sharing of knowledge through the establishment of inter-organizational communities of practice would encourage joint problem solving and possibly reduce the incidence of conflict between parties.
	Establishment of good faith cooperation between the parties is needed.
	More frequent site meetings should be held between the parties, in order to verify that the works are progressing normally and are executed in accordance with the contract.
	Owners and project teams should secure teamwork, good practice and commitment from all parties at a project level through a jointly developed project pact.
Involvement of several foreign designers and contractors	The role and responsibility of respective parties should be understood clearly before the commencement of project whether is in the main contract or subcontract work.
Conflicts between contractor and other parties (consultant and owner)	All project participants should recognize that conflicts are inevitable and the conflict management is a needed to produce a good working environment.
	Project participants should establish and maintain open lines of communication.
Poor communication and coordination by contractor with other parties	Project participants should establish and maintain open lines of communication.
	Teambuilding should be conducted to develop common project goals and processes, and discuss interests and expectations.
	The sharing of knowledge through the establishment of inter-organizational communities of practice would encourage joint problem solving and possibly reduce the incidence of conflict between parties.
	Relationship and communicating at management/board level of the subcontractors' companies should be built.
Lack of consultation of contractor/project manager with owner	Teambuilding should be conducted to develop common project goals and processes, and discuss interests and expectations.
	The sharing of knowledge through the establishment of inter-organizational communities of practice would encourage joint problem solving and possibly reduce the incidence of conflict between parties.
Lack of proper training and experience of contractor/project manager	The selected contractor must have sufficient experience, technical capability, financial capability, and sufficient manpower to execute the project.
Poor/Inadequate contractor experience/Inexperienced contractor	

Table 2.16: Table of causes matched with corresponding prevention matters (continued)

Cause Factor	Prevention Matter
Contractor's lack of geographical experience	The selected contractor must have sufficient experience, technical capability, financial capability, and sufficient manpower to execute the project.
Contractor's lack of project type experience	
Unsuitable leadership style of construction/project manager	Assignment of experienced managers and superintendents/site supervisors with strong cooperative skills and attitudes is needed.
Unsuitable management structure and style of contractor	
Inadequate managerial skills/Inadequate site/project management skills	
Lack of responsibility of contractor/project manager	
Lack of authority of contractor/project/site manager	
Nonutilization of professional construction/contractual management	Skillful and determined management are required both before and during construction to handle the threats and challenges that lead to claims.
Poor contract management by contractor	
Unreasonable risk allocation by contractor	Achieving a more equitable/fair allocation of risks between contracting parties should be provided.
	Allocation of risks to the parties that can best control it is needed to increase the integrity and acceptance of the contract and to have positive impact on parties' relationships.
	Proper identification, allocation and management of risks should be provided.
Poor subcontract management	Control of subcontracting on quality, programme, design and price should be established.
	Properly directing the subcontractor is needed to ensure that they know what is expected of them in relation to the project.
Poor site management/inspection and supervision by contractor	Proper site management and (monitoring) supervision should be established.
Poor site management and slow site clearance	
Poor labor supervision	
Poor control of site resource allocation/Lack of available resources	
Delay of field survey by contractor	

Table 2.16: Table of causes matched with corresponding prevention matters (continued)

Cause Factor	Prevention Matter
Poor resource allocation by contractor	Thorough resource planning and development of the project concept is needed by contractors.
Poor site storage capacity	Contractors should be aware of stock control problems with materials and should consider using more effective material scheduling techniques.
Poor logistic control by contractor	One should think holistically when planning a complex project by considering logistics, interfaces, etc. e.g. having a preconstruction services department that will not only plan the project but take a holistic look at the project rather than just having planning department as customary.
Contractor's deficiencies in planning and scheduling at preconstruction stage	Calling in specialists to advise and contribute to the planning and management of complex works/projects should be provided.
Improper construction methods/techniques implemented by contractor	Appropriate construction methods should be selected by contractor.
Inadequate contractor's work	Contractor should provide a proper method statement showing the construction technique.
Mistakes in soil investigation	Contractor should properly inspect and examine the site and its surroundings in detail and to satisfy himself before submitting his tender and signing the contract.
Poor qualification of the contractor's technical staff/Incompetent technical staff assigned to the project	Owners, consultants and contractors should ensure that they have the right personnel with the right qualifications to manage their projects.
Incompetent project team	
Excessive turnover in contractor's staff	
Replacement of key personnel by contractor	
Lack of site contractor's staff	
Contractor's failure to coordinate the work, i.e., deficient planning, scheduling, and supervision	Proper planning, scheduling, documenting and coordination of works by contractor during planning are needed.
	Good practice and coordination should be established during execution of works.
Failure to utilize tools to manage the project symmetrically by contractor/project manager	Proper understanding of the problems and adequate use of management tools is needed.
Lack of timely decisions and corrective actions by contractor/project manager	Problem solving ability should be increased with processes and policies that promote fast decision making at the project level.
	Development of an emotionally intelligent team that is able to stimulate creativity and solve problems that arise during design and construction to manage conflict more effectively and resolve issues through negotiation should be provided.
Slow response by contractor/project manager	Problem solving ability should be increased with processes and policies that promote fast decision making at the project level.

Table 2.16: Table of causes matched with corresponding prevention matters (continued)

Cause Factor	Prevention Matter
Delay in site mobilization	Proper site management and (monitoring) supervision should be established.
Mistakes and discrepancies in contract documents due to contractor	Proper, complete and consistent contract documents, work details, drawings and specifications have to be ready and provided before commencement of work.
Risk and uncertainty associated with projects	If the contract is rampant with exculpatory language, especially in the area of no-damages-for-delay, the contractor should carefully consider accepting the risks involved because some projects are not worth the risk of bidding.
	Risk assessment should be conducted to identify areas of potential problems and to establish proactive management of risk.
	Allocation of risks to the parties that can best control it is needed to increase the integrity and acceptance of the contract and to have positive impact on parties' relationships.
	Proper identification, allocation and management of risks should be provided.
	Encouraging, emphasizing and striving for a risk sharing regime should be provided when possible (it may aid in buttressing partnership and openness among the project parties).
	Adequate contingency allowance should be used for potential additional costs in areas of uncertainty.
Problems due to company organization of contractor	Contractors should make sure that their company organization is compatible with the size and type of the job they undertake.
Internal company problems of contractor	
Ill defined duties and responsibilities by contractor's company organization	
Inadequate decision making mechanism of contractor's company organization	
Lack of contractor's administrative personnel	Owners, consultants and contractors should ensure that they have the right personnel with the right qualifications to manage their projects.
Fraud by contractor	Selection of contractors and consultants should be done with great attention.
Opportunistic behavior of contractor	

CHAPTER 3

LITERATURE REVIEW ON ONTOLOGY

This chapter first sets the *definition of ontology* and gives *brief information about ontologies* and continues on with the *importance* and *usage* of ontologies. *Methods and methodologies* used with *tools and languages* used to build ontologies are mentioned. Finally chapter is concluded with *examples of ontologies*.

3.1 What is Ontology?

Ontology is principally a philosophical term that represents the study of nature of being, existence or reality as such through the categorization of information with the indication of relations. It forms a part of metaphysics, which is the branch of philosophy, and specifically searches for the being of such, first causes of things, or things do not change (Ontology; Van Inwagen, 2010). In short, it is the study of kinds of things that exist with the systematic explanation, namely "carving the world at its joints" (Chandrasekaran et al., 1999; Gómez-Pérez et al., 2004). Even the word of ontology implies the purpose and lexical nature of ontologies with the combination of Greek "ontos" and "logos" with the meanings of being and word respectively (Breitman et al., 2007). Potential words for describing knowledge about the domain are provided through the sorts of objects, properties of objects and relations between objects. An ontology is a collection of facts about a domain (Chandrasekaran et al., 1999).

The term of ontology is first used in philosophy in the nineteenth century by a German philosopher (Rudolf Gockel) on the purpose of study of "being" (Breitman et al., 2007). Today, there are many definitions of ontology available depending on the fields they are used. Apart from the philosophical origin of the word ontology, the word ontology is started to be increasingly used in Knowledge Engineering (KE) in 1990s with the need of unified forms of information in engineering field (Corcho et al., 2003; Shangguan, 2009). One of the most widely used definitions especially in the field of Information Systems (IS) is: "an ontology is a formal conceptualization of a real world, sharing a common understanding of this real world" (Lammari and Métais, 2004). Corcho et al. (2003) investigate wide range of the definitions of ontology in literature and also include the information of evolution of these definitions. They state the Gruber's definition (1993a, 1993b) "an explicit specification of a conceptualization" as the most quoted one in the literature and by the ontology community. Gruber (1993a) summarizes the definition of ontology as:

> *An ontology is an explicit specification of a conceptualization. The term is borrowed from philosophy, where an ontology is a systematic account of Existence. For knowledge-based systems, what "exists" is exactly that which can be represented. When the knowledge of a domain is represented in a declarative formalism, the set of objects that can be represented is called the universe of discourse. This set of objects, and the describable relationships among them, are reflected in the representational vocabulary with which a knowledge-based program represents knowledge. Thus, we can describe the ontology of a program by defining a set of representational terms. In such an ontology, definitions associate the names of entities in the universe of discourse (e.g., classes, relations, functions, or other objects) with human-readable text describing what the names are meant to denote, and formal axioms that constrain the interpretation and well-formed use of these terms.*

Following inclusion of a series of ontology definitions, Corcho et al. (2003) conclude the definition subject as "*ontologies aim to capture consensual knowledge in a generic and formal way, and that they may be reused and shared across applications (software) and by groups of people*".

From the Artificial Intelligence (AI) view, ontology is either (1) a representation vocabulary that is specialized for a domain or subject matter or (2) a body of knowledge that describes a domain in concern (Chandrasekaran and Josephson, 1997).

The following table (Table 3.1) presents the various definitions of ontology in literature.

Table 3.1: Various definitions of ontology in literature

Definition	**Source**
"An ontology defines the basic terms and relations comprising the vocabulary of a topic area as well as the rules for combining terms and relations to define extensions to the vocabulary."	(Neches et al., 1991)
"A specification of a representational vocabulary for a shared domain of discourse - definitions of classes, relations, functions, and other objects - is called an ontology."	(Gruber, 1993a)
"An ontology is an explicit specification of a conceptualization."	(Gruber, 1993a) (Gruber, 1993b)
"An ontology is the statement of a logical theory."	(Gruber, 1993b)
"An ontology is the set of objects that exist in a domain."	(Bouaud et al., 1995)
"A logical theory which gives an explicit, partial account of a conceptualization."	(Guarino et al., 1995)
"It [an ontology] provides the means for describing explicitly the conceptualization behind the knowledge represented in a knowledge base."	(Bernaras et al., 1996)
"Ontologies are defined as a formal specification of a shared conceptualization."	(Borst, 1997)
"An ontology is a formal description of entities and their properties; it forms a shared terminology for the objects of interest in the domain, along with definitions for the meaning of each of the terms."	(Fox and Grüninger, 1997)
"An ontology is a hierarchically structured set of terms for describing a domain that can be used as a skeletal foundation for a knowledge base."	(Swartout et al., 1997)
"Ontologies are content theories about the sorts of objects, properties of objects, and relations between objects that are possible in a specified domain of knowledge."	(Chandrasekaran et al., 1999)
"An ontology may take a variety of forms, but it will necessarily include a vocabulary of terms and some specification of their meaning. This includes definitions and an indication of how concepts are inter-related which collectively impose a structure on the domain and constrain the possible interpretations of terms."	(Uschold and Jasper, 1999)
"An ontology defines a common vocabulary for researchers who need to share information in a domain. It includes machine-interpretable definitions of basic concepts in the domain and relations among them."	(Noy and McGuinness, 2001)
"Ontologies aim to capture consensual knowledge in a generic and formal way, and that they may be reused and shared across applications (software) and by groups of people."	(Corcho et al., 2003)

Table 3.1 Various definitions of ontology in literature (continued)

Definition	**Source**
"An ontology is some formal description of a domain of discourse, intended for sharing among different applications, and expressed in a language that can be used for reasoning."	(Noy, 2004)
"An ontology is a formal conceptualization of a real world, sharing a common understanding of this real world."	(Lammari and Métais, 2004)
"Ontologies provide a framework for representing, sharing, and managing domain knowledge through a system of concept hierarchies (taxonomies), associative relations (to link concepts across hierarchies), and axioms that allows reasoning in a semantic way."	(El-Diraby et al., 2005)

3.2 Introduction to Ontologies

Ontologies are content theories that search for identification of specific classes of objects and relations of a domain (Chandrasekaran et al., 1999). They define the basic terms as concepts, which are description of "knowledge items" in form of "knowledge representations", and constitute the vocabulary of the subject matter with the help of relations and rules between the terms (Neches et al., 1991; Rezgui, 2006; Sugumaran and Storey, 2002). Thus, Jenz (2003) states what an ontology includes as:

- ✓ *Concepts (things) in the domains of interest*
- ✓ *Relationships between those things*
- ✓ *Properties (and property values) of those things*
- ✓ *The functions and processes involving those things*
- ✓ *Constraints on and rules about those things*

Concepts can be anything, any notion or idea in the domain of interest and relations provide the representation of any interaction between the concepts (Uschold and King, 1995). Functions enable the definition of special case of relations. Constraints and rules provide declaration of deeper meaning in the ontology like axioms that represent sentences that are always true. It is not mentioned in Jenz's study (2003) separately but smallest pieces of concepts, namely elements of the domain are represented by instances (Gómez-Pérez and Benjamins, 1999).

Ontologies are basically taxonomic tree of conceptualizations from general objects at the top level to the specific ones at the bottom level (Chandrasekaran et al., 1999). When taxonomies are improved with the enough information through relations and rules for modeling a domain, they become ontology (Neches et al., 1991).

A taxonomy represents the information based on a father-son relationship style with limited relationships such as; generalization, is-a or type-of. Definitions of attributes for the terms are also not allowed by taxonomies. So the higher capacity of the ontology for representation of information distinguishes it from the taxonomies (Breitman et al., 2007).

However, sometimes taxonomies are considered as ontologies since they provide a conceptualization of a domain. So the ontology community distinguishes these ontologies from the other ontologies as lightweight and heavyweight ontologies respectively. Lightweight ontologies are generally including concepts, concept taxonomies, relationships between concepts and properties of concepts; whereas, heavyweight ontologies add axioms and constraints to lightweight ontologies for modeling the domain in detail (Corcho et al., 2003).

Apart from the classification as lightweight and heavyweight ontologies, Bodenreider et al. (2003) classify ontologies according to their extent as domain ontologies and upper-level ontologies. Whilst domain ontologies are representation of specialized vocabularies of some domain or subject matter, upper-level ontologies describe generic knowledge that consists of many fields (El-Diraby et al., 2005).

Another classification of ontologies is provided by Gruber (1993a) as: representation ontologies and content ontologies. Representation ontologies are the ones that are designed on a framework but do not offer any guidance about modeling process. Content ontologies are ontologies that provide some guidance on the modeling and conceptualization of the ontology.

Gómez-Pérez and Benjamins (1999) mention the types of ontologies according to the usage of ontologies as; knowledge representation ontologies, general/common ontologies, top-level ontologies, meta-ontologies, domain ontologies, linguistic ontologies, task ontologies, domain-task ontologies, method ontologies and application ontologies. Details with these ontologies and related examples are also available in their study.

According to these classification details, the delay analysis ontology that will be created in this study may be deemed to be a lightweight (since it will not include axioms and constraints), domain (since it is not upper ontology - only specialized vocabulary) and representation (since it does not provide any guidance) ontology respectively.

When it comes to why ontologies are needed to be developed, Noy and McGuinness (2001) explain the reasons as:

- ✓ *To share common understanding of the structure of information among people or software agents*
- ✓ *To enable reuse of domain knowledge*
- ✓ *To make domain assumptions explicit*
- ✓ *To separate domain knowledge from the operational knowledge*
- ✓ *To analyze domain knowledge*

Construction of an ontology may be thought as a set of data and establishment of their structure for other programs to use (Noy and McGuinness, 2001). Modeling the domain, namely the design issue of the ontology is mentioned by Gruber (1993b) as:

> *Formal ontologies are designed. When we choose how to represent something in an ontology, we are making design decisions. To guide and evaluate our designs, we need objective criteria that are founded on the purpose of the resulting artifact, rather than based on a priori notions of naturalness or truth.*

In light of this explanation, Gruber (1993b) proposes design criteria for creation and evaluation of an ontology developed with the purpose of shared conceptualization. The five design criteria are as follows:

1. **Clarity:** An ontology should provide objective, formal and complete definitions of terms to effectually communicate the meanings of defined terms.
2. **Coherence:** An ontology should be coherent, namely inferences made through ontology should be consistent with the definitions in ontology (Gómez-Pérez, 2001).
3. **Extendibility:** An ontology should provide a monotonic extendibility, in other words addition of new terms to the ontology should be done without the necessity of changing the existing terms. So ontology should be receptive for the new words to serve for the purpose on use of shared vocabulary.
4. **Minimal encoding bias:** An ontology should be conceptualized at the knowledge level without depending on a particular symbol-level encoding.
5. **Minimal ontological commitment:** An ontology should make as few claims as possible about the world being modeled to set free developers of the ontology for specialization of the ontology as required and intended (Fidan, 2008; Gómez-Pérez, 2001; Gruber, 1993b).

There are also some fundamental rules for ontology design and development that illuminate the subject of ontology. Noy and McGuinness (2001) mention the basic rules as:

> 1. *There is no one correct way to model a domain— there are always viable alternatives. The best solution almost always depends on the application that you have in mind and the extensions that you anticipate.*
> 2. *Ontology development is necessarily an iterative process.*
> 3. *Concepts in the ontology should be close to objects (physical or logical) and relationships in your domain of interest. These are most likely to be nouns (objects) or verbs (relationships) in sentences that describe your domain.*

So, as it can be seen through the fundamental steps, primarily scope and design of ontologies are in concern. Since ontologies are created on a purpose, the purpose of the ontology guides its developers on design of the ontology. So, ontology design is a creative process and carries the traces of its developers. Ability of the creator of the ontology constitutes the quality of the ontology (Breitman et al., 2007). Embodiment of the ontology is not much cared as well as its quality is assessed by its usage. Accordingly, an ontology should not cover all the information about a domain. The scope should be kept limited according to the use of the ontology to provide the serviceability of the ontology. Secondly, iterative process is needed for the presentation of the real world knowledge ideally. Construction of an ontology is totally a gradual and evolving process (Lima et al., 2005). Each update made through construction of the ontology, helps to improve the ontology and makes it one step closer to the real world knowledge that intended to be presented. Finally, in the last fundamental rule, Noy and McGuinness (2001) state heart of the ontology design as, nouns in sentences that describe domain constitute objects, namely concepts in an ontology whereas; verbs in sentences correspond to relations of the concepts in the ontology. In light of this, concepts are defined in the form of *classes* (and *subclasses*) that constitute the taxonomy and properties (or roles) of the concepts are defined as *slots* in an ontology. Further information can be given through the restrictions on slots with the *facets* defined. After structuring the skeleton of the ontology, finally main data are loaded as *instances* of classes, namely members of classes, to complete the ontology. So development of an ontology can be defined respectively in its simplest form as:

1. definition of classes,
2. formation of the taxonomic class-subclass hierarchy,
3. definition of slots and facets with the allowed values,
4. creation of individual instances (Noy and McGuinness, 2001).

Development methodologies and tools and languages will be handled in detail in following sections of this chapter.

Besides studies on development of ontologies, Gómez-Pérez (2001) presents an ontology evaluation criterion for their content and development process for the created ontologies that would be published or used. So, evaluation and assessment of ontologies became also important as development of ontologies with the increase in creation and usage of ontologies. Details on the evaluation process of ontologies could be seen in the study of Gómez-Pérez (2001). Differently from study of Gómez-Pérez (2001), Fox and Grüninger (1997) also present evaluation criteria based on investigation of ontology characteristics such as; functional completeness, generality, efficiency, perspicuity, precision/granularity and minimality. Operationalization process of the criteria could be found in the study in detail. In addition to evaluation processes, there are also ontology analysis tools available like Chimera (McGuinness et al., 2000) to ease the assessment of ontologies (Noy and McGuinness, 2001). Ontology evaluation is a needed and important step for the reliability of ontologies (Mladenić et al., 2009).

For the evaluation of ontologies, expert interviews, case studies, comparative analysis of industry documents and competency questions are possible methods (El-Diraby and Zhang, 2006; Gruninger and Fox, 1995; Tserng et al., 2009).

3.3 Importance of Ontologies

Ontological analysis of a domain clarifies the structure of knowledge and provides the heart of knowledge representation with the vocabulary for that domain (Bouaud et al., 1995; Chandrasekaran et al., 1999; Gruber, 1993a). Ontologies capture the real world knowledge and encode with the facts and relationships (Sugumaran and Storey, 2002). Also ontologies, enable knowledge sharing and reuse, and prevent others to create everything from the beginning for a different purpose in the same domain (Chandrasekaran et al., 1999; Ugwu et al., 2005). Possibility of reuse and integration of different ontologies provide an important functionality in knowledge sharing (Lammari and Métais, 2004). On the subject of importance of ontologies, Bouaud et al. (1995) include Guarino's (1994) direct words in their study as *"... a rigorous ontological foundation for knowledge representation can improve the quality of the knowledge engineering process, making it easier to build at least understandable (if not reusable) knowledge base*". As it is stated earlier; creation of ontology for a domain, besides its providing a common understanding of the information structure and opportunity to analyze the domain knowledge, provides separation of domain knowledge from operational knowledge, makes domain assumptions explicit and enables reuse of domain knowledge. The ontology becomes a reference model for usage by both human and software on many purposes of work (Lee et al., 2006; McGuinness, 2002; Noy and McGuinness, 2001). Thus an ontology provides a common understanding of concepts, and so brings flexibility and agility with its representation style (Jenz, 2003).

Lima et al. (2005) mention the importance of ontologies subject with presenting three main advantages of ontologies as follows:

1. **Interoperability:** ontologies provide a means of interoperability for effective sharing and communication of knowledge.
2. **Object-orientation:** concepts in an ontology are represented in an object-oriented form, like Unified Modeling Language (UML). This facilitates the probable design of a software system that would use the ontology, and also eases the update process of the ontology.
3. **Knowledge representation:** Unlike data exchange standards and UML, ontologies represent the knowledge through taxonomies (that provide consistent vocabularies with classification of concepts), relationships (that enable the indication of detailed information through ability of linking concepts between different levels), and axioms (that provide involvement of information at human wisdom level to define the boundaries of concepts).

At this point, it is worth to mention that the main difference between ontology and object-oriented programming (OOP) is that OOP only uses taxonomic relations of “is-a” and “kind-of”. However; it cannot be said that it is a simplified version of ontology, since they both have their own merit in engineering field (Shangguan et al., 2009).

3.4 Usage of Ontologies

Ontologies are widely used in artificial intelligence (AI) to specify consensus on a specific content for sharing and reuse of knowledge (Gruber, 1993b). Information retrieval systems, digital libraries, integration of heterogeneous information sources and internet search engines have the potential to use ontologies for the categories and subcategories of information that are needed to ease the process. Similarly, object-oriented design of software systems depends on creation and reuse of ontologies with the objects, their attributes and their procedures of the subject domain (Chandrasekaran et al., 1999). Besides object-oriented community; Knowledge Engineering (KE), software engineering and database communities widely use ontologies for different purposes such as; natural language processing, Knowledge Management (KM), representation of knowledge, problem solving techniques, electronic commerce (e-commerce), intelligent information integration, cooperative information systems, agent-based software engineering and the semantic web, etc. (Breitman et al., 2007; Corcho et al., 2003; Pandit and Zhu, 2007; Tserng et al., 2009).

In the process of time, construction of ontologies has started to move from the AI laboratories to the desktops of domain experts. Ontologies took their place on the World-Wide Web especially as large taxonomies for categorizing Web sites (such as on Yahoo!) and categorizing products for sale and their futures (such as on Amazon.com). So, ontologies provide an enhancement in the ability of the web engines that are strained to the limit (Hendler, 2001).

In respect of the web issue, ontologies take web one step further and provide the generation of semantic web. Semantic web is basically offering the conversion of data on web into a form that makes the machines understand the meaning. So, this ensures machines to exchange the knowledge not the data through set of ontologies (El-Diraby et al., 2005). By favor of semantic web, “web of the future” is aimed to be created with the usage of machine-readable networks for the data. In this way categorization of the information in a standard way to facilitate its access (search, retrieval, representation, extraction, interpretation, and maintenance) would be provided and better co-operation of people and computers would be enabled (Berners-Lee et al., 2001; Breitman et al., 2007; Wang and Xue, 2008).

Wherever the data are coded; with the help of the semantic layer, it would be able to be interacted and exchanged in a meaningful way (Breitman et al., 2007). Semantic annotations with relations loaded, help the machines to recognize the facts rather than unstructured text (Horrocks, 2008). The created semantic networks provide the storage of information like the way of human brain for storing long term knowledge, and act as an extension of human memory that keeps the information effectively available (Katifori et al., 2008). The semantic enrichment in the traditional database is needed for the operability of the excessive information to provide the easiness in extraction of the useful and intended information (Mladenić et al., 2009; Shangguan et al., 2009). The success of the semantic web would be based upon the proper usage of ontologies that underpins the semantic interoperability (Ugwu et al., 2005).

The improvement of semantic web provides enhancement in e-business supply chains (El-Diraby et al., 2005). As a part of e-business, with the increase in the importance of e-commerce applications, product information management became essential. Ontologies not only provide precise definition of product and services, but also make them readily available in a shareable, manageable, flexible and scalable form. So, the quality of e-commerce system can be enhanced with the use of semantically enriched product information that is open to improvement. This also provides the interoperability between other systems, and gives hope to creation of an upper e-commerce ontology with wide range of diverse business processes and product standards. So, ontologies can be used as data, and knowledge bases can also be established from ontologies (Lee et al., 2006; Noy and McGuinness, 2001).

Specifically; usage of ontologies for establishment of corporate memories is worth to mention at this point, since possible users of the ontology of this study would be companies as it mentioned earlier in the introduction section. Corporate memories are used to share and store the information in a company and ontologies are one of the possible and suitable techniques for that purpose. So, delay analysis ontology of this study also serves for the same purpose for companies and may be used as part of a corporate memory (or database) (Gómez-Pérez et al., 2004).

3.5 Methods and Methodologies for Ontology Development

Methods and methodologies for ontology development basically refer to what to do when building ontologies. With the rise in the usage of ontologies, need for reusing the available ontologies and need for common and practical methods have increased. The absence of such guidelines slowed down the development process of the ontologies and with the prevention of reuse of ontologies; instead of improving the already created ones, developers had to create their ontologies from scratch. The situation is mentioned by Gómez-Pérez and Benjamins (1999) as:

> *The ontology building process is a craft rather than an engineering activity. Each development team usually follows its own set of principles, design criteria and phases in the ontology development process. The absence of commonly agreed on guidelines and methods hinders the development of shared and consensual ontologies within and between teams, the extension of a given ontology by others and its reuse in other ontologies and final applications. If ontologies are built on a small scale, some activities can be skipped. But, if you intend to build large-scale ontologies with some guarantees of correctness and completeness, it is advisable to steer clear of anarchic constructions and to follow a methodological approach.*

So, as it is stated by Gómez-Pérez and Benjamins (1999); during the 1990s and first years of 2000s, each team for ontology development had their own principles and design for building the ontology. In light of this, some of these efforts were: Cyc method by Lenat and Guha with the Cyc Project (1990), Uschold and King's method with the Enterprise Project (1995), Gruninger and Fox's methodology with the Toronto Virtual Enterprise (TOVE) project (1995), KACTUS approach by Bernaras et al. with the Esprit KACTUS project (1996), METHONTOLOGY (Gómez-Pérez et al., 1996), SENSUS-based method (Swartout et al., 1997), On-To-Knowledge methodology (Staab et al., 2001) and CO4 protocol (Euzenat, 1996) (Corcho et al., 2003; Gómez-Pérez et al., 2004; Breitman et al., 2007). Breitman et al. (2007) also add the Lexicon-based ontology development method (Breitman and do Prado Leite, 2003) and simplified methods as Ontology development 101 (Noy and McGuinness, 2001) and Horrocks ontology development method (Horrocks, 2003).

The common properties of most of these methodologies are: first step is identification of the purpose of the ontology, secondly need for domain knowledge acquisition comes out and finally need for ontology evaluation is required (Gómez-Pérez, 2001). In their study, Corcho et al. (2003) make a detailed comparison between these domain-independent methods of Cyc, Uschold and King, Gruninger and Fox, KACTUS, METHONTOLOGY, SENSUS and On-To-Knowledge. They conclude that METHONTOLOGY is the most mature approach between all and the one that is recommended by the Foundation for Intelligent Physical Agents (FIPA) for ontology development. The following table (Table 3.2) indicates the considered features in this study.

In addition, Gómez-Pérez et al. (2004) enhance the aforementioned study (Corcho et al., 2003) and present a comparison between the methods of the same group. They name METHONTOLOGY as the approach that has the most accurate descriptions of activities. Also in this study, METHONTOLOGY could be seen as the most favorable methodology from the point of technological support. It is suitable for the use of tools, which are provided to ease development of ontology, such as ODE, WebODE, OntoEdit and Protégé. Finally, study indicates the wide usage and acceptance of the method (Gómez-Pérez et al., 2004). So, METHONTOLOGY is selected for the guidance of this study.

Table 3.2: Comparison of methodologies for building ontologies (Corcho et al., 2003)

Feature			Cyc	Usdhold and King	Grüninger and Fox	KACTUS	METHONTOLOGY	SENSUS	On-To-Knowledge
Project management processes	Project initiation		Not proposed	Not proposed	Not proposed	Not proposed	Not proposed	Not proposed	Proposed
	Project monitoring and control		Not proposed	Not proposed	Not proposed	Not proposed	Proposed	Not proposed	Proposed
	Ontology quality management		Not proposed	Not proposed	Not proposed	Not proposed	Not proposed	Not proposed	Proposed
Ontology development-oriented processes	Pre-development processes	Concept exploration	Not proposed	Not proposed	Not proposed	Not proposed	Not proposed	Not proposed	Proposed
		System allocation	Not proposed	Not proposed	Not proposed	Not proposed	Not proposed	Not proposed	Not proposed
	Development processes	Requirements	Not proposed	Proposed	Proposed	Proposed	Described in detail	Proposed	Proposed
		Design	Not proposed	Not proposed	Described	Described	Described in detail	Not proposed	Proposed
		Implementation	Proposed	Proposed	Described	Proposed	Described in detail	Described	Proposed
	Post-development processes	Installation	Not proposed	Not proposed	Not proposed	Not proposed	Not proposed	Not proposed	Not proposed
		Operation	Not proposed	Not proposed	Not proposed	Not proposed	Not proposed	Not proposed	Not proposed
		Support	Not proposed	Not proposed	Not proposed	Not proposed	Not proposed	Not proposed	Not proposed
		Maintenance	Not proposed	Not proposed	Not proposed	Not proposed	Proposed	Not proposed	Proposed
		Retirement	Not proposed	Not proposed	Not proposed	Not proposed	Not proposed	Not proposed	Not proposed
Integral processes	Knowledge acquisition		Proposed	Proposed	Proposed	Not proposed	Described in detail	Not proposed	Proposed
	Verification and validation		Not proposed	Proposed	Proposed	Not proposed	Described in detail	Not proposed	Proposed
	Ontology configuration management		Not proposed	Not proposed	Not proposed	Not proposed	Described in detail	Not proposed	Proposed
	Documentation		Proposed	Proposed	Proposed	Not proposed	Described in detail	Not proposed	Proposed
	Training		Not proposed	Not proposed	Not proposed	Not proposed	Not proposed	Not proposed	Not proposed

The METHONTOLOGY is developed within the ontology group at Universidad Politécnica de Madrid on the purpose of enabling a standard for the ontology development at the knowledge level. It depends on a life cycle with evolving prototypes (Corcho et al., 2003). Activities for the construction of ontology are gathered in three groups as: management activities, development activities and support activities. Details can be easily found out in the following figure (Figure 3.1) that shows the development process and life cycle of METHONTOLOGY (Gómez-Pérez et al., 2004).

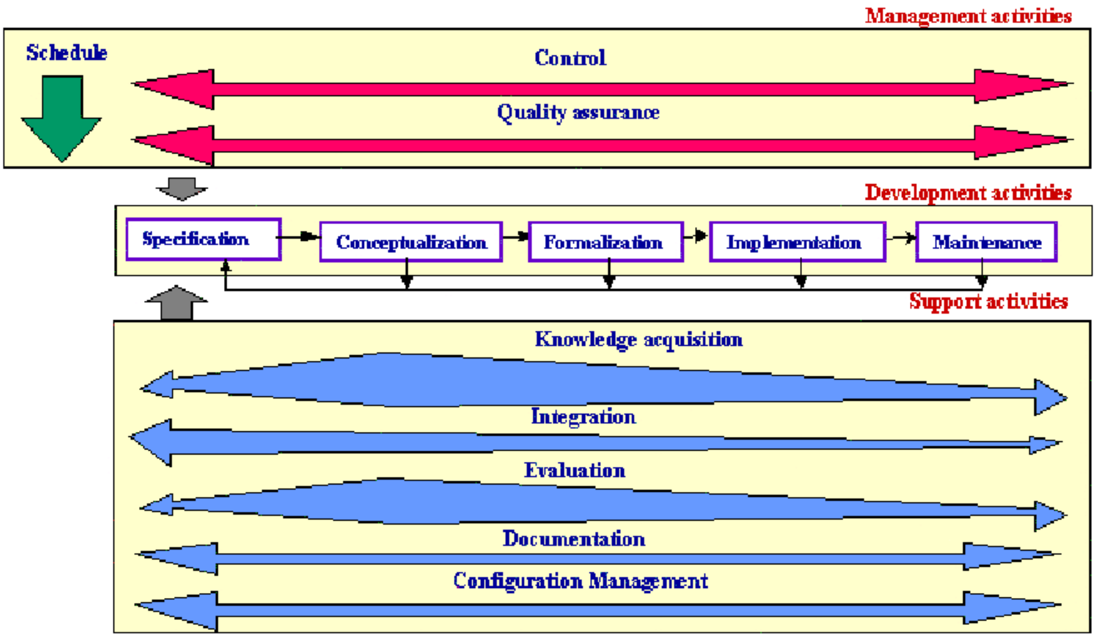


Figure 3.1: Activities in the ontology development proposed by METHONTOLOGY (Corcho et al., 2005; Gómez-Pérez et al., 2004)

The methodology starts with the schedule activity; which is also called as plan by Breitman et al. (2007), that stands for the identification and arrangement of all the tasks required with the consideration of time, resources and tools required for the completion of the activities. Subsequently, development activities start with the specification activity. At the same time with the specification activity, management activities (control and quality assurance) and support activities (knowledge acquisition, integration, evaluation, documentation and configuration management) also start and accompany the development activities (specification, conceptualization, formalization, implementation and maintenance) through the construction process (Gómez-Pérez et al., 2004).

Some of the activities that form the major part of ontology construction and support can be defined as follows:

1. **Specification:** Identification of the scope and goals of the ontology with the questioning of why the ontology is being built and who are its users (Breitman et al., 2007; Uschold and King, 1995).
2. **Conceptualization:** Gathered information through the knowledge acquisition activity is organized and transformed into a conceptual model. Gómez-Pérez et al. (2004) mention it as "*this (conceptualization) is like assembling a jigsaw puzzle with the pieces supplied by the knowledge acquisition activity*". So to develop this model, informal view of the domain is converted into a semi-formal type with the help of intermediate representations (IRs) such as tabular and graphical notations which are the forms that facilitate the denotation of the domain for domain experts and ontology developers. It forms an abstract and simplified view of the part of the world that is in concern and needed to be presented (Gruber, 1993b). Classes (concepts), properties (attributes) and relations between them are created for this purpose and these are assigned to take the ontology a step forward from the perception level of the domain to implementation level. This is an intermediate step between formal and natural language description. Besides tabular representations, graphical notations can also be preferable. Unified modeling language (UML) is suitable for such kind of representations and generally favored by authors. As it can be seen through the Figure 3.1, conceptualization activity is heavily related with the knowledge acquisition and evaluation activities which make their peak at conceptualization step. Because conceptualization consists of the data gathered and value of the data is important for the sake of ontology. This is why these three activities are indicated in relation and need to be taken into consideration (Breitman et al., 2007; Gómez-Pérez et al., 2004). Details with the tasks will be handled in the Chapter 4 within the information of development of the ontology.
3. **Formalization:** The created conceptual model is formalized in this step by a formal ontology representation model which could be description logic or frame-based model (Breitman et al., 2007). The semi-formal representation in

the previous step is totally formalized in this step. Representation of the complete model with UML class diagrams is favorable for formalization step.

4. **Integration:** As it is stated earlier in this section, some methodologies provide the reuse of existing ontologies and facilitate the studies by prevention of doing everything from scratch. METHONTOLOGY is one of the methodologies that provide integration activity between an existing ontology and the ontology that is under construction (Breitman et al., 2007).
5. **Implementation:** Formalized model is written by a machine-processable ontology language that provides the execution of the model in a computer (Breitman et al., 2007; Gómez-Pérez et al., 2004).
6. **Evaluation:** This step makes a technical judgment of the ontology and emphasizes the importance of verification and validation of the created ontology to demonstrate the quality, soundness and usefulness of the ontology. Competency questions or real world validations can be used for evaluation after construction of the ontology. Competency questions and various evaluation criteria are also used during construction phase of the ontology, however a final validation after the construction of the ontology is needed to ensure the reliability and complete the ontology (Breitman et al., 2007; Gómez-Pérez et al., 2004; Gruninger and Fox, 1995; Uschold and King, 1995). Details about validation process of the ontology will be handled in Chapter 5 under the heading of “Validation”.
7. **Documentation:** Proper documentation of the ontology provides the understandability of the ontology and eases the maintenance and reuse of it. So detailed description of the construction process is needed (Breitman et al., 2007; Uschold and King, 1995). All chapters of this study can be seen as already serving for this step.
8. **Maintenance:** Since the world has a changing nature, ontologies as an indication of a part of the world would also change. So updating the ontologies regularly would help the ontologies to protect their value and stay valid (Breitman et al., 2007). Since ontologies are created for information

sharing and open to updates, in case of its use it would be changed. This step can be seen as future work for this study.

This concludes the survey on methodologies and METHONTOLOGY. Details and usage of the methodology will be held in Chapter 4 under the heading of "Development of Ontology".

3.6 Tools and Languages for Ontology Development

With the increase in the usage of ontologies in recent years, creation of tools for construction and support of ontologies also increased. The first tool was the Ontolingua Server which is improved with the modules such as Webster (an equation solver), an Open Knowledge Base Connectivity (OKBC) server, Chimera (an ontology merging tool) and etc. Following the Ontolingua some of the other created ontology development tools are: Ontosaurus, WebOnto, Protégé, WebODE, OntoEdit, OILEd and DUET. Nowadays there are also many ontology-related tools, which are serving for other purposes rather than development of ontology such as; ontology merging, ontology translation between languages, ontology-based web page annotation, and etc. (Corcho et al., 2003). Most of the tools include properties as; editing and browsing ontologies, importing and exporting ontologies in different languages whereas some of them also enable these further properties as extensibility via plug-ins, integration of external resources, merging and mapping of ontologies, graphical editing and debugging capabilities for axioms/rules (Weiten, 2009). Among all of these numerous tools with different capabilities, Protégé will be used in this study.

Protégé is a frame-based tool, which uses OKBC knowledge model as basis for its knowledge model, created with two goals as: (1) providing interoperability with other knowledge representation systems and (2) creating a user-friendly and configurable knowledge-acquisition tool. Protégé is compatible with OKBC protocol that enables the interoperability among knowledge-representation systems, and provides an application programming interface (API) that helps to achieve the interoperability through a common query and construction interface for frame-based systems. So Protégé users can; not only import ontologies from other OKBC-compatible servers, but also export their ontologies to other OKBC knowledge servers.

As it is stated earlier; from the knowledge-model view, Protégé is frame-based. Frames constitute the building blocks of a knowledge base. Representation of a particular concept is organized as a frame and frames are seen as organized data structures. So with the help of frame-base; classes (concepts), slots (properties or attributes of classes), facets (properties of slots) and axioms (additional constraints) of an ontology can easily be defined in Protégé (Noy et al., 2000).

Protégé provides a free and open source ontology editor and knowledge-base framework, also enables fast modeling of the ontologies through construction and testing the semantic reasoning of the ontology (Elghamrawy et al., 2009). Moreover, extendibility of the Protégé capacity with various intended plug-ins provides a kind of freedom in the ontology design and implementation. These properties make Protégé preferred and since it is widely used, it has a large user-base that shows the reliability of the tool (Weiten, 2009).

Protégé is selected for the implementation of the ontology of this study because; besides its inclusion of frame-based operability that forms the ontology in this study, it is a widely used ontology editor with its open source facility and it presents variety of ontology visualization methods with its user friendly interface (Katifori et al., 2008). It is the one of the popular tools for ontology development with more than 50000 registered users in more than 100 countries worldwide. Also the high number of tutorials and various materials related with Protégé show the importance of this tool. Protégé enables two ways of ontology construction via Protégé-Frames and via Protégé-OWL editors (Breitman et al., 2007). So Protégé-Frames (with version 3.4.7) is selected for this study.

Conceptualization of the domain is needed to be written in an explicit and formal way with the use of an ontology language (Elghamrawy et al., 2009; Lima et al., 2005). To form the ontology, concepts should be formalized with taxonomies, instances, relations, functions and axioms through the ontology languages. At the beginning of 1990s ontologies were constructed with modeling techniques based on either frames or first order logic. Later on, various representation techniques and languages based on description logics are started to be used. Ontology languages can be categorized as traditional ontology languages and ontology markup languages. Traditional ontology languages are KIF (Knowledge Interchange Format), Ontolingua, LOOM (Lexical OWL Ontology Matcher), OCML (Operational Conceptual Modeling Language) and FLogic (Frame Logic). Ontology markup languages are SHOE (Simple HTML (HyperText Markup Language) Ontology Extensions), XML (Extensible Markup Language), XOL (Ontology Exchange Language), RDF (Resource Description Framework), RDF(S) (RDF Schema), OIL (Ontology Inference Layer), DAML+OIL (DARPA (Defense Advanced Research Projects Agency) Agent Markup Language + Ontology Inference Layer), OWL (Web Ontology Language), etc. (Breitman et al., 2007; Corcho et al., 2003; Gómez-Pérez, 2001; Gómez-Pérez et al., 2004). Details about languages are beyond the scope of this study, however related information is available in the study of Gómez-Pérez et al. (2004).

RDF language is selected from the available options of Protégé-Frames for the construction of the ontology of this study.

3.7 Examples of Ontologies

In this section, examples of ontologies and parts of ontologies will be presented with figures to depict more the information on ontologies.

A small detail about semantic web and ontologies concept is selected for the beginning to ease the basic understanding of the concept. As it is mentioned before, ontologies provide the machine-readable representation of the real world. Horrocks (2008) exemplifies the situation with this simple unstructured text: “Harry Potter has a pet named Hedwig”. When the sentence is in this form, it is impossible to get that

Harry Potter is a wizard and Hedwig is an owl for a software agent like search engine. However; when the information is structured in the objects and relations form (HarryPotter is the subject, hasPet is the predicate and Hedwig is the object for RDF language), data also gain meaning in the sight of machines. So, in case of a search about wizard or owl, Harry Potter or Hedwig are available to be retrieved as instances of these concepts. Graphical notation of the sentence is shown in the Figure 3.2.

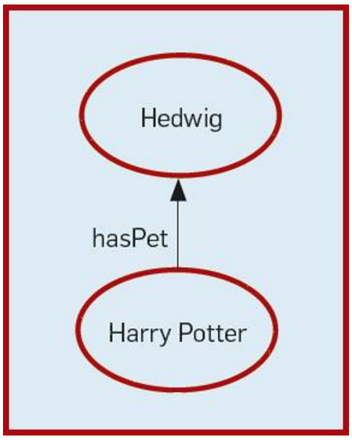


Figure 3.2: Example RDF Graph (adapted from Horrocks, 2008)

Ontologies are formed through objects and relations between those objects as it is the case in the previous example. All the information is aggregated through these small details that form the ontology. Once these concepts and relations are identified, they should be documented through tables and graphical notations to improve the understanding. Concept taxonomy, namely the concepts and taxonomic relations between concepts, can be represented by UML class diagrams (where tabular representation of concept taxonomy is also preferable). Tairas et al. (2008) present air traffic communication ontology that depicts the communication between responsible individuals of air traffic control at an airport specifically as ground controller, and the pilot of an aircraft. Taxonomic relations as inheritance relations (is-a relations showed by a hollow triangle on the tip of the solid line) and aggregation relations (with hollow tetragon on the tip of the solid line) between the concepts are represented with the information of attributes of the concepts. The related figure is presented below as Figure 3.3.

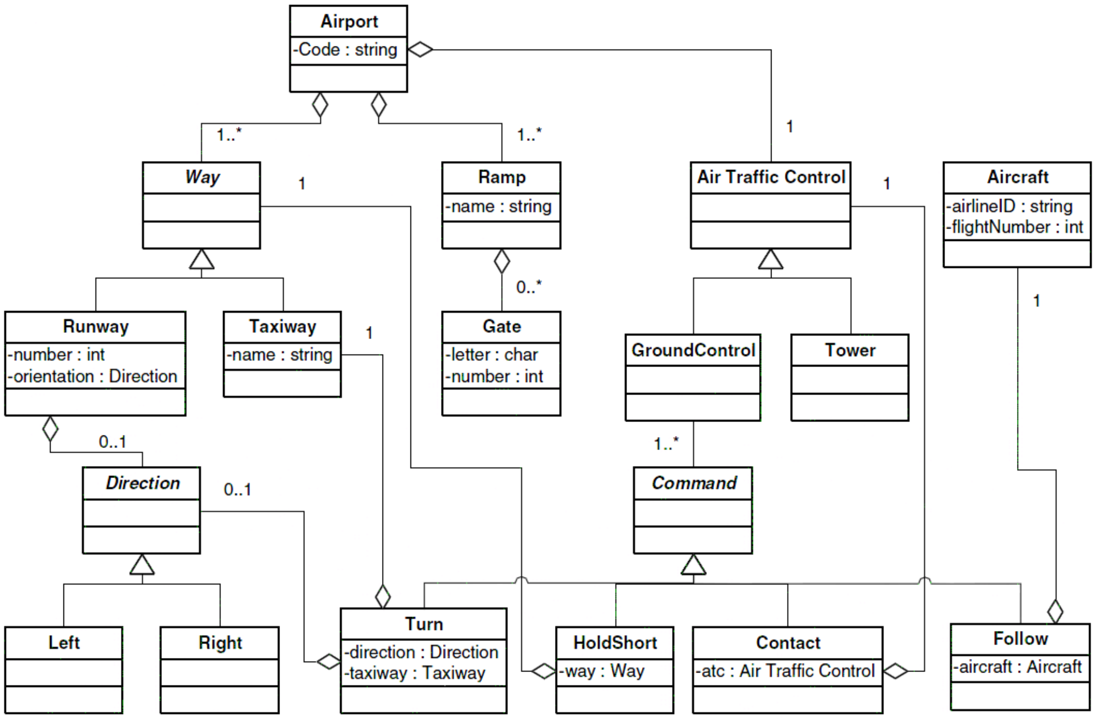


Figure 3.3: Conceptual class diagram of Air Traffic Communication Ontology (Tairas et al., 2008)

As ontologies give their developers freedom in identification of relations other than taxonomic relations, it is possible to define lots of relations as long as they are properly structured according to the design primitives. At this point, study of Sugumaran and Storey (2002), which is a partial ontology for the travel domain, is suitable to depict the graphical representation of various relations between concepts as in the following figure (Figure 3.4).

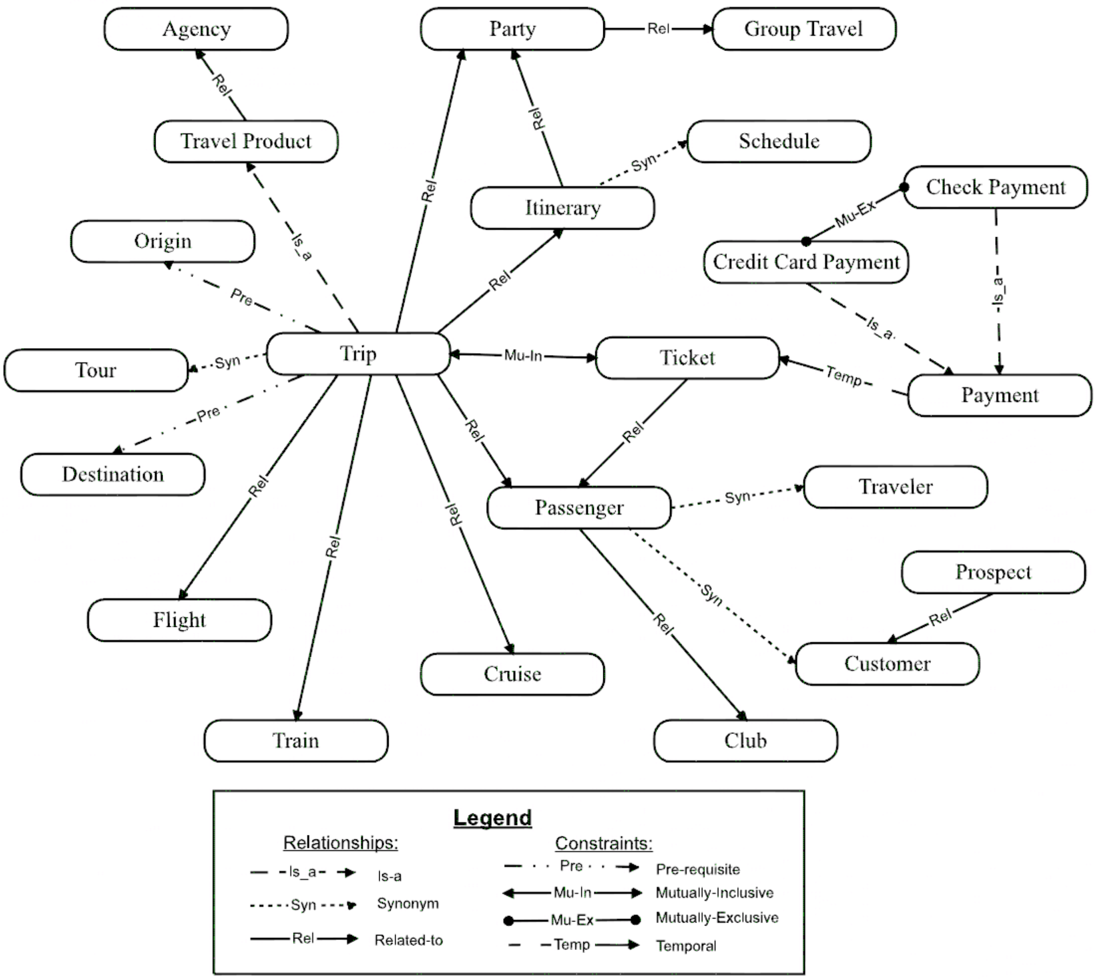


Figure 3.4: Partial travel domain ontology (Suguraman and Storey, 2002)

When it comes to the representation of a complete ontology model, study of Fidan et al. (2011) is selected. This ontology is aimed to serve for risk management area and associates risk-related concepts with cost overrun in a project. It is based on the idea of cost overrun is dependent on the risk sources that are affected by the vulnerability sources. The following figure (Figure 3.5) represents the model of the ontology in UML class diagram form with the information of main concepts with attributes and taxonomic and binary relations assigned between concepts.

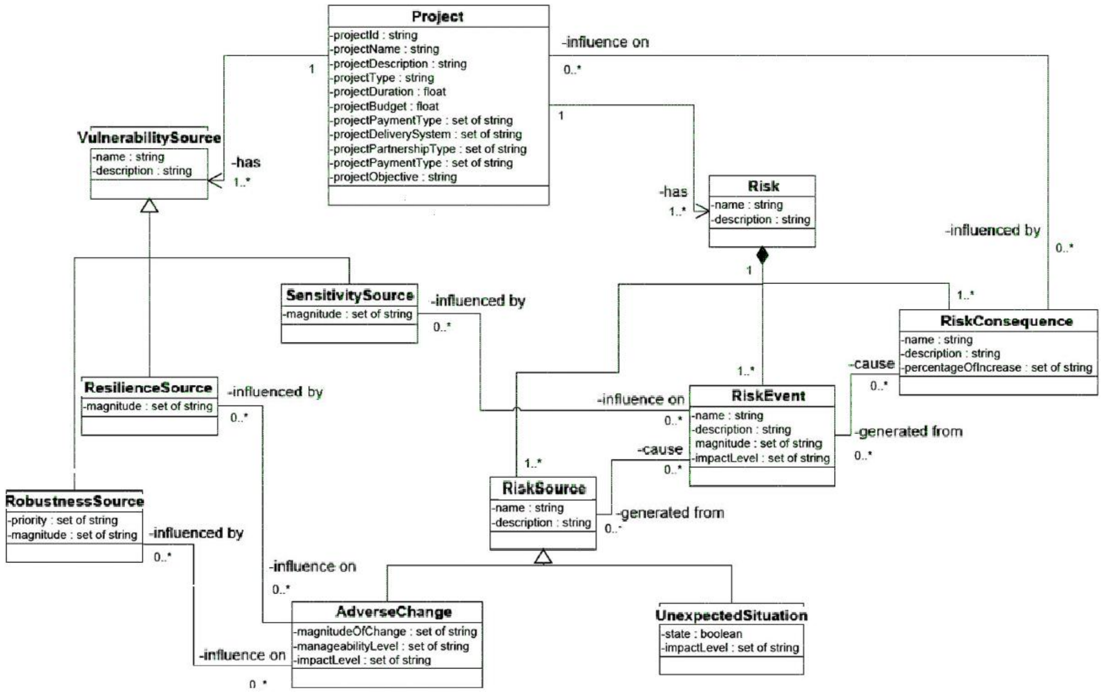


Figure 3.5: Data model for the risk and vulnerability ontology (adapted from Fidan et al., 2011)

There are lots of ontologies that serve for different purposes with differences in the amount and complexity of the data presented. Some ontologies are well-known due to their common purposes and huge content. The e-COGNOS (COnsistent knowledGe management across prOjects and between enterpriSes in the construction domain) ontology which is placed in a platform that also provides web services to support the management of ontology, user management and handling knowledge management requirements; is one of the ontologies of that kind that is worth to mention at this point. The e-COGNOS platform aims to encapsulate and manage the construction knowledge with its about 15000 concepts identified and classified in the taxonomy of the ontology. The following figure (Figure 3.6) presents the only higher level concepts in the e-COGNOS taxonomy (El-Diraby et al., 2005; Lima et al., 2005; Wang and Xue, 2008).

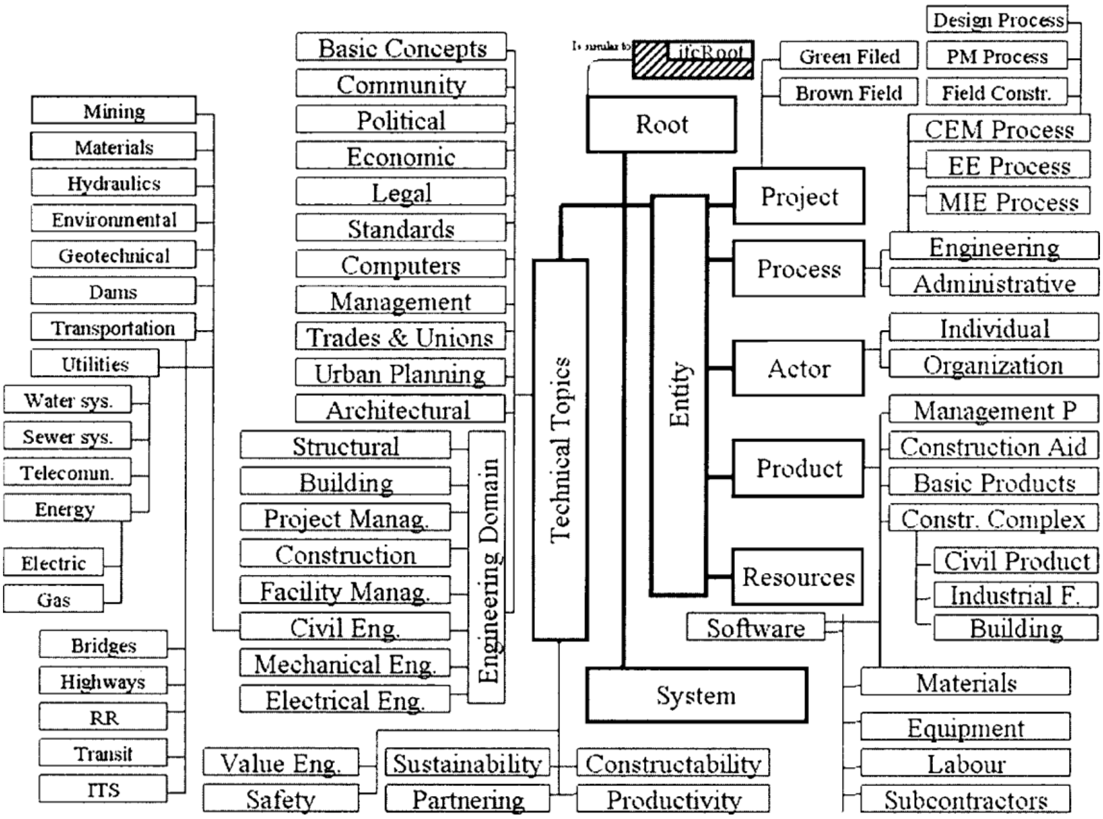


Figure 3.6: Higher level concepts in e-COGNOS taxonomy (El-Diraby et al., 2005)

The main concept that forms the skeleton of the e-COGNOS ontology is defined by Lima et al. (2005) as "*a group of Actors uses a set of Resources to produce a set of Products following certain Processes within a work environment (Related Domains) and according to certain conditions (Technical Topics)*". Detailed model of the ontology is available in their study however a simplified model by Wang and Xue (2008) is presented as in the following figure (Figure 3.7) to facilitate the realization. The basic concepts and corresponding relations of the e-COGNOS ontology are as follows.

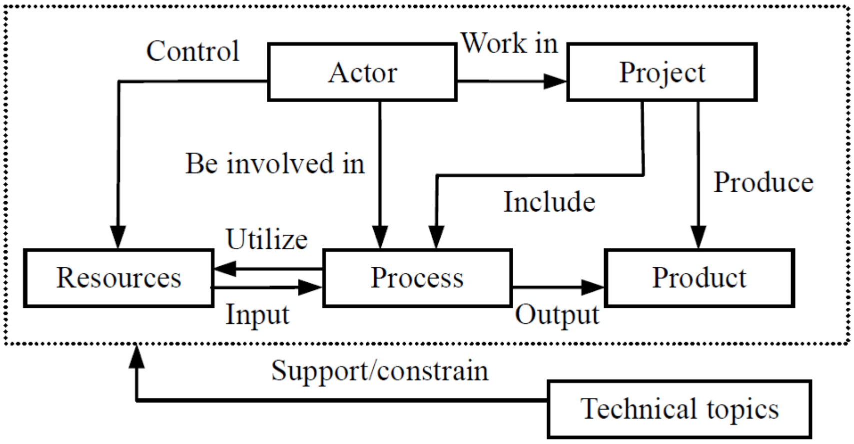


Figure 3.7: Higher level concepts and their relationship in e-COGNOS ontology (Wang and Xue, 2008)

This concludes the examples of ontologies and also the chapter of the literature review on ontology. Details about the ontology constructed in this study will be handled in the following chapters in light of the information presented throughout the previous chapters.

CHAPTER 4

DEVELOPMENT OF ONTOLOGY

This chapter presents the details of ontology development process through main steps of the methodology as; *specification*, *conceptualization*, *formalization*, *integration*, *evaluation and maintenance*, and *implementation*.

For development of the ontology, detailed literature review on delay analysis is carried out and main concepts of the subject are determined. According to their frequency of occurrence and importance of the concepts, main headings are determined as *delay, causes* of delay, *types* of delay, *responsibility* of delay, *impact* of delay, *claim* for impact of delay, *analysis* of delay and *prevention* of delay. Further concepts for delay analysis ontology are defined as *remedy* and *mitigation* that are related with impact of delay; *notice* that is related with mitigation (also with delay and claim); *parts*, *kinds*, *parties* and *result* that are related with claim; *dispute* and its *resolution* with *settlement* and *award* that are related with result of claim; *methodology steps*, *data*, *issues* and *techniques* that are related with analysis of delay; finally *selection criteria*, *advantages* and *disadvantages* that are related with techniques used for delay analysis. The basic ontological model is constructed through the fundamental rule of ontology construction as nouns in a sentence define the concepts of the ontology, whereas verbs constitute the relations of the ontology. This idea behind formed the basics of the ontology and the rest is structured and improved through a well-known methodology for ontology development.

As it is stated earlier in the previous chapter, there are many methodologies available for the development of ontologies. However there is not an ISO standard for the development of ontologies (Ceusters et al., 2005; Fidan, 2008). As a result of an investigation between a series of methodologies by Corcho et al. (2003), they state the METHONTOLOGY as the most mature approach between all. Thus, as it is mentioned previously in the chapter of literature review on ontology, METHONTOLOGY is used for the construction of the delay analysis ontology of this study.

Steps of the methodology are given in detail in the previous chapter as: specification, conceptualization, formalization, integration, implementation, evaluation, documentation and maintenance. These steps guided the construction of the ontology throughout the study. Simply, the defined main concepts are branched through their subcategories in forms of subclasses or instances according to the level of detail. Accordingly, an ontological model is created and presented in its formalized diagram. Finally, ontology is validated and implemented in an ontology construction program (Protégé). Following sections of this chapter present the usage of development activities of the methodology thoroughly in accordance with the details provided by Gómez-Pérez et al. (2004).

4.1 Specification

In this step scope and goals of the ontology are identified through competency questions of “why this ontology is being built?” and “who are its users?” (Breitman et al., 2007). To start with why it is being built, it can be deemed as a cure for one of the problems in construction sector. Construction delay is the major and common problem of construction sector. With the growth of the sector in recent years enhancement in the delay analysis processes did not work much because of the more complex state of the sector. Since any small wrong step taken in the analysis process causes greater disputes after delays, knowledge sharing in analysis of delay issue through an ontology is aimed in this study to enhance the analysis of delay issue by the integration of knowledge available on delay analysis in literature. In this way, the enhanced knowledge of the delay analysis issue may also serve as a checklist for prevention of delays during the preconstruction phase of the construction project. So; when it comes to its users, parties to a construction contract, experts on delay analysis and claims, and companies are thought to be main users of this delay analysis ontology. Companies may also use the ontology to create a database of delay that may provide enhancement in the delay issue and serve as a guide for the further delays that would be encountered. As it is mentioned, competency questions provide the limits of the ontology and make it to be reasonable. Further competency questions asked in this study are as follows:

- ✓ What is delay?
- ✓ What is delay analysis?
- ✓ What are the causes of delay?
- ✓ Who are responsible from delay?
- ✓ What should be done in case of a delay?
- ✓ What should be done for the prevention of delay?

In light of these questions main concepts and their subconcepts are determined through the literature review on analysis of delay by mainly focusing on type, cause and responsibility of delay with an analysis technique and proposed methodology steps for the technique. Also in case of a delay, mitigation of the delay should be taken into account first if it is possible, then accordingly analysis of the delay impact should be done and related remedy should be claimed for the preservation of rights. So this ontology is created from the point of a delay issue between an owner and a contractor including the possibility of an already submitted claim for the delay. However the ontology is also suitable for a case before claiming process and also may be used in claiming procedure. The focus is owner and the contractor in the ontology, however it is able to be used for any case between an employing party and a salaried party as contractor-subcontractor and subcontractor-subcontractor. Finally matters for prevention of delays are also presented to enhance the handling of delays.

4.2 Conceptualization

Conceptualization is the crucial step of the ontology development processes. It is the transformation of the gathered information in a conceptual model. This is why conceptualization activity is directly linked with the support activities of the methodology that are knowledge acquisition and evaluation. Literature review on delay analysis through web (namely papers) and books on construction delay analysis (Carnell, 2000; O'Brien, 1976; Trauner et al., 2009), claim management (Davenport, 1995; Thomas, 1993; Turner and Turner, 1999), ontologies and semantic web (Breitman et al., 2007; Davies et al., 2009; Gómez-Pérez et al., 2004) form the knowledge acquisition step of the methodology. Gathered information is evaluated and shaped to explicitly represent the real world knowledge.

For the extraction of knowledge through the available information, as it is the case in the study of Sugumaran and Storey (2002), basically the common and most frequently occurring terms are extracted. Accordingly with the help of the competency questions, the limits and purpose of the ontology formed the study. For the creation of the model, fundamental rule of the ontology construction as "*nouns of a sentence correspond to objects in an ontology, whereas verbs correspond to relations*" is used as a basis (Noy and McGuinness, 2001). Also, study of e-COGNOS ontology (Lima et al., 2005) gives the inspiration with the modeling base of: *"The basic ontological model of the e-COGNOS ontology is as follows: a group of Actors uses a set of Resources to produce a set of Products following certain Processes within a work environment (Related Domains) and according to certain conditions (Technical Topics)".* In this study concepts, which are words capitalized in first letters, are extracted from the definition of the case and basic ontological model is structured accordingly. So, concepts of delay analysis ontology are modeled with this basic information of the design process.

The basic ontological model of the delay analysis ontology: Ontology is aimed to be presented through sentences about delay that can be read through subconcepts to the core concept of "delay" in the main concepts level. "Causes of Delay", "Types of Delay", "Responsibility of Delay", "Claim for Impact of Delay", "Analysis of

Delay" and "Prevention of Delay" constitute the main parts of the ontology. Moreover, reading of the ontology is tried to be achieved by starting from subconcepts as:

- ✓ "*Selection Criteria* for *Techniques* used for *Analysis* of *Delay*"
- ✓ "*Notice* for *Mitigation* to reduce *Impact* of *Delay*"
- ✓ "*Award* through *Settlement* after *Resolution* of *Dispute* is-a *Result* of *Claim* for *Impact* of *Delay*"

Various sentences like these examples are available in the ontology. As it can be seen from the examples, italic words constitute the concepts of delay analysis ontology and the prepositions and verbs form the relations of the ontology. So, this forms the idea behind the delay analysis ontology.

With these basics of the ontology, details of the conceptualization process are presented in the following parts of this section. To provide a detailed understanding of conceptualization, the figure included by Corcho et al. (2005), which presents the tasks in conceptualization, could be seen through Figure 4.1. All of the steps are applied to form the delay analysis ontology in light of the figure (4.1) and examples, which are given in detail in the book, provided by Gómez-Pérez et al. (2004). As it is previously stated in the chapter of literature review on ontology of this study, tabular or graphical representation of the basics of the conceptual model is preferable for this step. So, tabular representations are selected for the most of the activities of the conceptualization step, whereas graphical representation by UML class diagrams is selected for the representation of concept relations.

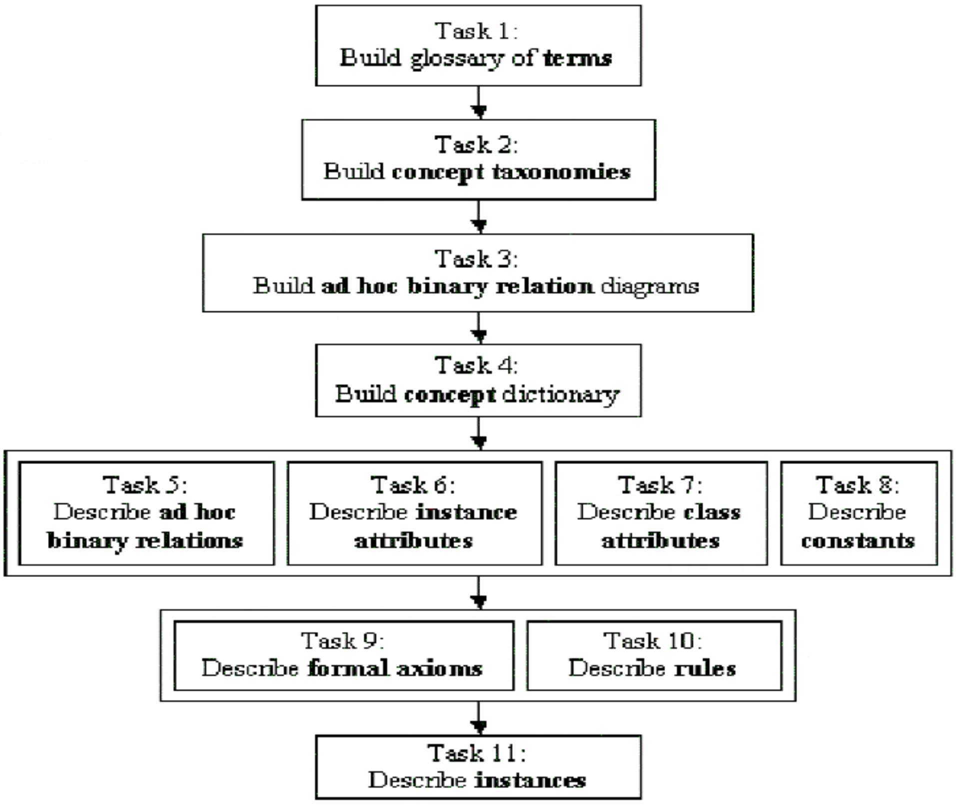


Figure 4.1: Tasks of the conceptualization activity according to METHONTOLOGY (adapted from Corcho et al., 2005)

4.2.1 Task 1: To Build Glossary of Terms

Building glossary of the terms means that indication of all the terms in domain that are needed to be defined such as; concepts, instances, attributes as properties of concepts, relations between concepts, etc. with the information synonyms and acronyms of the terms. While excessive document research is being done, the most important point is to be aware of synonyms; because repeated information is one of the leading faults when building ontologies. Since ontologies intended to serve the net information about a subject, any disorder caused by synonyms may reduce the quality of the ontology (Baxter et al., 2009). The synonyms of the terms are taken into consideration during the conceptualization step of the ontology, however Protégé-Frames does not allow directly loading of the data of synonyms and acronyms. So, synonyms and acronyms part of the table proposed is not used for this study. Concepts in the hierarchy as classes and subclasses, relations and instance attributes (there is no class attribute in the ontology) are presented in the table. However instances of the concepts are not presented in this table since they are already presented in italics in the tables of chapter of literature review on construction delay (Chapter 2). In addition to this, full list of the instances will be presented in the appendix in the light of creating instances step of the methodology. Following table (Table 4.1) represents the glossary of terms of delay analysis ontology as concepts, relations and instance attributes. Concepts are presented with stars (*) that show the levels of the subconcepts of the ontology to indicate hierarchy. Names of the concepts are assigned in the form of “NamesOfTheConcepts” as it is one of the stated forms in the study of Noy and McGuinness (2001). Accordingly relations and attributes are indicated in lower cases with an underscore (relations_with_underscore) between the words.

Table 4.1: Glossary of terms of the delay analysis ontology

Name	**Description**	**Type**
Delay	Core class representing the constructional delay.	Concept-Class
Causes	Class representing the causes of delay.	Concept-Class
*OwnerCauses	Subclass representing owner causes of delay.	Concept-Subclass
**DesignRelatedCauses	Subclass representing design related causes of owner causes of delay.	Concept-Subclass
**ConsultantCauses	Subclass representing consultant causes of owner causes of delay.	Concept-Subclass
**OwnersFinancialCauses	Subclass representing owner's financial causes of owner causes of delay.	Concept-Subclass
**OwnerGeneratedCauses	Subclass representing owner generated causes of owner causes of delay.	Concept-Subclass
**ContractRelatedCauses	Subclass representing contract related causes of owner causes of delay.	Concept-Subclass
**ContractualRelationshipRelatedCauses	Subclass representing contractual relationship related causes of owner causes of delay.	Concept-Subclass
*ContractorCauses	Subclass representing contractor causes of delay.	Concept-Subclass
**MaterialRelatedCauses	Subclass representing material related causes of contractor causes of delay.	Concept-Subclass

Table 4.1: Glossary of terms of the delay analysis ontology (continued)

Name	**Description**	**Type**
**EquipmentRelatedCauses	Subclass representing equipment related causes of contractor causes of delay.	Concept-Subclass
**LaborRelatedCauses	Subclass representing labor related causes of contractor causes of delay.	Concept-Subclass
**ContractorsFinancialCauses	Subclass representing contractor's financial causes of contractor causes of delay.	Concept-Subclass
**SubcontractorCauses	Subclass representing subcontractor causes of contractor causes of delay.	Concept-Subclass
**HealthAndSafetyRelatedCauses	Subclass representing health and safety related causes of contractor causes of delay.	Concept-Subclass
**SchedulingAndControllingRelatedCauses	Subclass representing scheduling and controlling related causes of contractor causes of delay.	Concept-Subclass
**ContractorGeneratedCauses	Subclass representing contractor generated causes of contractor causes of delay.	Concept-Subclass
*ExternalCauses	Subclass representing external causes of delay.	Concept-Subclass
**InclementWeatherCauses	Subclass representing inclement weather causes of external causes of delay.	Concept-Subclass
**EnvironmentalCauses	Subclass representing environmental causes of external causes of delay.	Concept-Subclass
**ForceMajeureCauses	Subclass representing force majeure causes of external causes of delay.	Concept-Subclass
***ActsOfGod	Subclass representing acts of god as force majeure causes of external causes of delay.	Concept-Subclass
****GeologicalDisasters	Subclass representing geological disasters as acts of god of force majeure causes of external causes of delay.	Concept-Subclass
****HydrologicalDisasters	Subclass representing hydrological disasters as acts of god of force majeure causes of external causes of delay.	Concept-Subclass
****MeteorologicalDisasters	Subclass representing meteorological disasters as acts of god of force majeure causes of external causes of delay.	Concept-Subclass
****HealthDisasters	Subclass representing health disasters as acts of god of force majeure causes of external causes of delay.	Concept-Subclass
****WildfiresAndBushfires	Subclass representing wildfires and bushfires as acts of god of force majeure causes of external causes of delay.	Concept-Subclass
***UnexpectedSituations	Subclass representing unexpected situations as force majeure causes of external causes of delay.	Concept-Subclass
**RulesAndRegulationsRelatedCauses	Subclass representing rules and regulations related causes of external causes of delay.	Concept-Subclass
**EconomicalCauses	Subclass representing economical causes of external causes of delay.	Concept-Subclass
**PoliticalCauses	Subclass representing political causes of external causes of delay.	Concept-Subclass
**SocialCauses	Subclass representing social causes of external causes of delay.	Concept-Subclass
**TechnologicalCauses	Subclass representing technological causes of external causes of delay.	Concept-Subclass
Types	Class representing the types of delay.	Concept-Class
*DelaysClassifiedByTheirOrigin	Subclass representing types of delays classified by their origin.	Concept-Subclass

Table 4.1: Glossary of terms of the delay analysis ontology (continued)

Name	**Description**	**Type**
*DelaysClassifiedByTheirTiming	Subclass representing types of delays classified by their timing.	Concept-Subclass
*DelaysClassifiedByTheirCompensability	Subclass representing types of delays classified by their compensability.	Concept-Subclass
*DelaysClassifiedByTheirContent	Subclass representing types of delays classified by their content.	Concept-Subclass
*DelaysClassifiedByTheirCriticality	Subclass representing types of delays classified by their criticality.	Concept-Subclass
Responsibility	Class representing the responsibility of delay.	Concept-Class
Impact	Class representing the impact of delay.	Concept-Class
*TimeOverrun	Subclass representing the time overrun impact of delay.	Concept-Subclass
*CostOverrun	Subclass representing the cost overrun impact of delay.	Concept-Subclass
**OwnersCosts	Subclass representing owner's costs due to delay.	Concept-Subclass
***OwnersDirectCosts	Subclass representing owner's direct costs due to delay.	Concept-Subclass
***OwnersIndirectCosts	Subclass representing owner's indirect costs due to delay.	Concept-Subclass
**ContractorsCosts	Subclass representing contractor's costs due to delay.	Concept-Subclass
***ContractorsDirectCosts	Subclass representing contractor's direct costs due to delay.	Concept-Subclass
****ExtendedandIncreasedFieldCosts	Subclass representing contractor's direct costs of extended and increased field costs due to delay.	Concept-Subclass
*****AdditionalLaborCosts	Subclass representing contractor's extended and increased field costs as additional labor costs due to delay.	Concept-Subclass
*****AdditionalMaterialCosts	Subclass representing contractor's extended and increased field costs as additional material costs due to delay.	Concept-Subclass
*****AdditionalEquipmentCosts	Subclass representing contractor's extended and increased field costs as additional equipment costs due to delay.	Concept-Subclass
*****ExtendedSiteOverheadCosts	Subclass representing contractor's extended and increased field costs as extended site overhead costs due to delay.	Concept-Subclass
****HomeOfficeOverheadCosts	Subclass representing contractor's direct costs of home office overhead costs due to delay.	Concept-Subclass
*****ExtendedHomeOfficeOverheadCosts	Subclass representing contractor's home office overhead costs as extended home office overhead costs due to delay.	Concept-Subclass
*****UnabsorbedHomeOfficeOverheadCosts	Subclass representing contractor's home office overhead costs as unabsorbed home office overhead costs due to delay.	Concept-Subclass
****LostProductivityCosts	Subclass representing contractor's direct costs of lost productivity costs due to delay.	Concept-Subclass

Table 4.1: Glossary of terms of the delay analysis ontology (continued)

Name	**Description**	**Type**
****AccelerationCosts	Subclass representing contractor's direct costs of acceleration costs due to delay.	Concept-Subclass
****CostsOfNoncriticalDelays	Subclass representing contractor's direct costs of costs of noncritical delays due to delay.	Concept-Subclass
****DisruptionCosts	Subclass representing contractor's direct costs of disruption costs due to delay.	Concept-Subclass
****ConsultingAndLegalCosts	Subclass representing contractor's direct costs of consulting and legal costs due to delay.	Concept-Subclass
****ExtendedTemporaryUtilityAndFacilityCosts	Subclass representing contractor's direct costs of extended temporary utility and facility costs due to delay.	Concept-Subclass
****ExtendedMaintenanceAndProtectionCosts	Subclass representing contractor's direct costs of extended maintenance and protection costs due to delay.	Concept-Subclass
****ExtendedWarrantyCosts	Subclass representing contractor's direct costs of extended warranty costs due to delay.	Concept-Subclass
****IncreasedBondCosts	Subclass representing contractor's direct costs of increased bond costs due to delay.	Concept-Subclass
****IncreasedFinancingCosts	Subclass representing contractor's direct costs of increased financing costs due to delay.	Concept-Subclass
****DemolitionCosts	Subclass representing contractor's direct costs of demolition costs due to delay.	Concept-Subclass
****WasteCostsOnAbandonedWork	Subclass representing contractor's direct costs of waste costs on abandoned work due to delay.	Concept-Subclass
***ContractorsIndirectCosts	Subclass representing contractor's indirect costs due to delay.	Concept-Subclass
*Disruption	Subclass representing the disruption impact of delay.	Concept-Subclass
*LostProductivity	Subclass representing the lost productivity impact of delay.	Concept-Subclass
*Acceleration	Subclass representing the acceleration impact of delay.	Concept-Subclass
*Dispute	Subclass representing the result of claim and dispute impact of delay.	Concept-Subclass
*TotalAbandonment	Subclass representing the total abandonment impact of delay.	Concept-Subclass
*ContractTermination	Subclass representing the contract termination impact of delay.	Concept-Subclass
Mitigation	Class representing the mitigation measures to reduce impact of delay.	Concept-Class
*ChangingTheWorkSequence	Subclass representing changing the work sequence as a mitigation measure.	Concept-Subclass
*AcceleratingTheWork	Subclass representing accelerating the work as a mitigation measure.	Concept-Subclass
*ChangingTheContract	Subclass representing changing the contract as a mitigation measure.	Concept-Subclass
*MakingImprovements	Subclass representing making improvements as a mitigation measure.	Concept-Subclass
Remedy	Class representing the remedy for impact of delay.	Concept-Class

Table 4.1: Glossary of terms of the delay analysis ontology (continued)

Name	**Description**	**Type**
Notice	Class representing the notice of a delay, mitigation or claim.	Concept-Class
Claim	Class representing the claiming procedure.	Concept-Class
Kinds	Class representing the kinds of claim.	Concept-Class
*VariationClaims	Subclass representing variation claims.	Concept-Subclass
*TimeRelatedClaims	Subclass representing time related claims.	Concept-Subclass
*QuantumMeuritClaims	Subclass representing quantum meurit claims.	Concept-Subclass
*ClaimsAfterTerminationByFrustration	Subclass representing claims after termination by frustration.	Concept-Subclass
*DefectiveWorkClaims	Subclass representing defective work claims.	Concept-Subclass
*LicensingAndBuildingClaims	Subclass representing licensing and building claims.	Concept-Subclass
*CounterClaims	Subclass representing counter-claims.	Concept-Subclass
Parties	Class representing the parties in claim.	Concept-Class
Parts	Class representing the parts of claim.	Concept-Class
*i.Introduction	Subclass representing introduction part of claim.	Concept-Subclass
*ii.SummaryOfFacts	Subclass representing summary of facts part of claim.	Concept-Subclass
*iii.BasisOfClaim	Subclass representing basis of claim part of claim.	Concept-Subclass
*iv.DetailsOfClaim	Subclass representing details of claim part of claim.	Concept-Subclass
*v.EvaluationOfClaim	Subclass representing evaluation of claim part of claim.	Concept-Subclass
*vi.StatementOfClaim	Subclass representing statement of claim part of claim.	Concept-Subclass
*vii.Appendices	Subclass representing appendices part of claim.	Concept-Subclass
Result	Class representing the result of claim.	Concept-Class
*Dispute	Subclass representing the result of claim and dispute impact of delay.	Concept-Subclass
*Settlement	Subclass representing the result of claim.	Concept-Subclass
Resolution	Class representing the resolution of dispute.	Concept-Class
*ResolutionByNegotiation	Subclass representing resolution of dispute by negotiation.	Concept-Subclass
*ResolutionByThirdParty	Subclass representing resolution of dispute by third party.	Concept-Subclass

Table 4.1: Glossary of terms of the delay analysis ontology (continued)

Name	Description	Type
**AlternativeDisputeResolution	Subclass representing resolution of dispute by alternative dispute resolution techniques.	Concept-Subclass
**Litigation	Subclass representing resolution of dispute by litigation.	Concept-Subclass
Award	Class representing the award of claim.	Concept-Class
Analysis	Class representing the analysis process of delay.	Concept-Class
Issues	Class representing issues relating to delay analysis.	Concept-Class
*FloatOwnershipIssue	Subclass representing float ownership issue relating to delay analysis.	Concept-Subclass
*SchedulingOptionsIssue	Subclass representing scheduling options issue relating to delay analysis.	Concept-Subclass
*ConcurrentDelaysIssue	Subclass representing concurrent delays issue relating to delay analysis.	Concept-Subclass
**DefinitionOfConcurrentDelaysIssue	Subclass representing definition of concurrent delays issue relating to delay analysis.	Concept-Subclass
**AnalysisOfConcurrentDelaysIssue	Subclass representing analysis of concurrent delays issue relating to delay analysis.	Concept-Subclass
*InterrelatedDelaysIssue	Subclass representing interrelated delays issue relating to delay analysis.	Concept-Subclass
*EarlyCompletionIssue	Subclass representing early completion issue relating to delay analysis.	Concept-Subclass
*DelaysAfterCompletionIssue	Subclass representing delays after completion issue relating to delay analysis.	Concept-Subclass
*ProlongationCostsIssue	Subclass representing prolongation costs issue relating to delay analysis.	Concept-Subclass
*PacingDelayIssue	Subclass representing pacing delay issue relating to delay analysis.	Concept-Subclass
*DrawbacksOfAnalysisTechniquesIssue	Subclass representing drawbacks of analysis techniques issue relating to delay analysis.	Concept-Subclass
*UsageOfAnalysisTechniqueIssue	Subclass representing usage of analysis techniques issue relating to delay analysis.	Concept-Subclass
Data	Class representing data used for delay analysis.	Concept-Class
*ContractDocuments	Subclass representing contract documents used for delay analysis.	Concept-Subclass
**MainContractDocuments	Subclass representing main contract documents as contract documents used for delay analysis.	Concept-Subclass
***Tender	Subclass representing tender as contract documents used for delay analysis.	Concept-Subclass
***ContractClauses	Subclass representing contract clauses as contract documents used for delay analysis.	Concept-Subclass
***ConditionsOfContract	Subclass representing conditions of contract as contract documents used for delay analysis.	Concept-Subclass
***SpecificationsAndDrawings	Subclass representing specifications and drawings as contract documents used for delay analysis.	Concept-Subclass
***BillsOfQuantities	Subclass representing bills of quantities as contract documents used for delay analysis.	Concept-Subclass

Table 4.1: Glossary of terms of the delay analysis ontology (continued)

Name	Description	Type
***DesignDrawings	Subclass representing design drawings as contract documents used for delay analysis.	Concept-Subclass
***MethodOfStatements	Subclass representing method of statements as contract documents used for delay analysis.	Concept-Subclass
***PlansAndProgrammes	Subclass representing plans and programmes as contract documents used for delay analysis.	Concept-Subclass
***Schedules	Subclass representing schedules as contract documents used for delay analysis.	Concept-Subclass
**SubcontractDocuments	Subclass representing subcontract documents as contract documents used for delay analysis.	Concept-Subclass
*PostContractDocuments	Subclass representing post-contract documents used for delay analysis.	Concept-Subclass
**MajorSchedules	Subclass representing major schedules as post-contract documents used for delay analysis.	Concept-Subclass
**ParticularSchedules	Subclass representing particular schedules as post-contract documents used for delay analysis.	Concept-Subclass
**UpdatedPlansAndProgrammes	Subclass representing updated plans and programmes as post-contract documents used for delay analysis.	Concept-Subclass
**Records	Subclass representing records as post-contract documents used for delay analysis.	Concept-Subclass
***Registers	Subclass representing registers as records of post-contract documents used for delay analysis.	Concept-Subclass
***Diaries	Subclass representing diaries as records of post-contract documents used for delay analysis.	Concept-Subclass
***Logs	Subclass representing logs as records of post-contract documents used for delay analysis.	Concept-Subclass
***SiteRecords	Subclass representing site records as records of post-contract documents used for delay analysis.	Concept-Subclass
***Reports	Subclass representing reports as records of post-contract documents used for delay analysis.	Concept-Subclass
***FormalSubmittals	Subclass representing formal submittals as records of post-contract documents used for delay analysis.	Concept-Subclass
***RecordsOfActualData	Subclass representing records of actual data as records of post-contract documents used for delay analysis.	Concept-Subclass
***RecordsOfAccountingData	Subclass representing records of accounting data as records of post-contract documents used for delay analysis.	Concept-Subclass
***MediaRecords	Subclass representing media records as records of post-contract documents used for delay analysis.	Concept-Subclass
***MinutesOfMeetings	Subclass representing minutes of meetings as records of post-contract documents used for delay analysis.	Concept-Subclass
***Notes	Subclass representing notes as records of post-contract documents used for delay analysis.	Concept-Subclass
***CorrespondenceData	Subclass representing correspondence data as records of post-contract documents used for delay analysis.	Concept-Subclass
***WitnessData	Subclass representing witness data as records of post-contract documents used for delay analysis.	Concept-Subclass
Techniques	Class representing techniques used for delay analysis.	Concept-Class
*StaticTechniques	Subclass representing static techniques used for delay analysis.	Concept-Subclass

Table 4.1: Glossary of terms of the delay analysis ontology (continued)

Name	**Description**	**Type**
*DynamicTechniques	Subclass representing dynamic techniques used for delay analysis.	Concept-Subclass
Advantages	Class representing advantages of techniques.	Concept-Class
*AdvantagesOfGlobalImpactTechnique	Subclass representing advantages of global impact technique.	Concept-Subclass
*AdvantagesOfNetImpactTechnique	Subclass representing advantages of net impact technique.	Concept-Subclass
*AdvantagesOfAsPlannedVsAsBuiltTechnique	Subclass representing advantages of as-planned vs as-built technique.	Concept-Subclass
*AdvantagesOfImpactedAsPlannedTechnique	Subclass representing advantages of impacted as-planned technique.	Concept-Subclass
*AdvantagesOfCollapsedAsBuiltTechnique	Subclass representing advantages of collapsed as-built technique.	Concept-Subclass
*AdvantagesOfWindowsAnalysisTechnique	Subclass representing advantages of windows analysis technique.	Concept-Subclass
*AdvantagesOfTimeImpactAnalysisTechnique	Subclass representing advantages of time impact analysis technique.	Concept-Subclass
Disadvantages	Class representing disadvantages of techniques.	Concept-Class
*DisadvantagesOfGlobalImpactTechnique	Subclass representing disadvantages of global impact technique.	Concept-Subclass
*DisadvantagesOfNetImpactTechnique	Subclass representing disadvantages of net impact technique.	Concept-Subclass
*DisadvantagesOfAsPlannedVsAsBuiltTechnique	Subclass representing disadvantages of as-planned vs as-built technique.	Concept-Subclass
*DisadvantagesOfImpactedAsPlannedTechnique	Subclass representing disadvantages of impacted as-planned technique.	Concept-Subclass
*DisadvantagesOfCollapsedAsBuiltTechnique	Subclass representing disadvantages of collapsed as-built technique.	Concept-Subclass
*DisadvantagesOfWindowsAnalysisTechnique	Subclass representing disadvantages of windows analysis technique.	Concept-Subclass
*DisadvantagesOfTimeImpactAnalysisTechnique	Subclass representing disadvantages of time impact analysis technique.	Concept-Subclass
SelectionCriteria	Class representing criteria for selection of techniques.	Concept-Class
*TimeOfAnalysis	Subclass representing time of analysis criterion for selection of techniques.	Concept-Subclass
*CapabilitiesOfTechniques	Subclass representing capabilities of techniques criterion for selection of techniques.	Concept-Subclass
*ScheduleTypeQuality	Subclass representing schedule type quality criterion for selection of techniques.	Concept-Subclass
*ScheduleUsed	Subclass representing schedule used criterion for selection of techniques.	Concept-Subclass
*AvailabilityOfData	Subclass representing availability of data criterion for selection of techniques.	Concept-Subclass
*TypeOfAnalysis	Subclass representing type of analysis criterion for selection of techniques.	Concept-Subclass
*NatureOfClaim	Subclass representing nature of claim criterion for selection of techniques.	Concept-Subclass

Table 4.1: Glossary of terms of the delay analysis ontology (continued)

Name	**Description**	**Type**
*AmountInClaim	Subclass representing amount in claim criterion for selection of techniques.	Concept-Subclass
*TimeCostEffortAllocatedForAnalysis	Subclass representing time/cost/effort allocated for analysis criterion for selection of techniques.	Concept-Subclass
*ProjectDurationScaleComplexity	Subclass representing project duration/scale/complexity criterion for selection of techniques.	Concept-Subclass
*AvailabilityOfExpertiseSoftware	Subclass representing availability of expertise/software criterion for selection of techniques.	Concept-Subclass
MethodologySteps	Class representing methodology steps for delay analysis.	Concept-Class
*i.TenderAndProgrammeAnalysis	Subclass representing tender and programme analysis as methodology steps for delay analysis.	Concept-Subclass
**i.GatherDataAvailable	Subclass representing gather data available step of tender and programme analysis for delay analysis.	Concept-Subclass
**ii.AnalyzeOriginalSchedule	Subclass representing analyze original schedule step of tender and programme analysis for delay analysis.	Concept-Subclass
**iii.DevelopAsBuiltSchedule	Subclass representing develop as-built schedule step of tender and programme analysis for delay analysis.	Concept-Subclass
**iv.AnalyzeAsBuiltSchedule	Subclass representing analyze as-built schedule step of tender and programme analysis for delay analysis.	Concept-Subclass
*ii.EventAnalysis	Subclass representing tender and programme analysis as methodology steps for delay analysis.	Concept-Subclass
**i.IdentifyDelayPeriod	Subclass representing identify delay period step of event analysis for delay analysis.	Concept-Subclass
**ii.AnalyzeCauseAndEffect	Subclass representing analyze cause and effect step of event analysis for delay analysis.	Concept-Subclass
**iii.IdentifyConcurrentDelays	Subclass representing identify concurrent delays step of event analysis for delay analysis.	Concept-Subclass
**iv.ApplyAnalysisTechnique	Subclass representing apply analysis technique step of event analysis for delay analysis.	Concept-Subclass
**v.AnalyzeClaim	Subclass representing analyze claim step of event analysis for delay analysis.	Concept-Subclass
**vi.CalculateCompensations	Subclass representing calculate compensations step of event analysis for delay analysis.	Concept-Subclass
**vii.PresentResults	Subclass representing present results step of event analysis for delay analysis.	Concept-Subclass
**viii.NegotiateClaim	Subclass representing negotiate claim step of event analysis for delay analysis.	Concept-Subclass
Prevention	Class representing prevention matters for delay.	Concept-Class
*PreventionDuringPlanning	Subclass representing prevention matters for delay during planning.	Concept-Subclass
**ContractRelatedPreventionMatters	Subclass representing contract related prevention matters for delay.	Concept-Subclass
**RiskRelatedPreventionMatters	Subclass representing risk related prevention matters for delay.	Concept-Subclass
**RelationsRelatedPreventionMatters	Subclass representing relations related prevention matters for delay.	Concept-Subclass
**ManagementRelatedPreventionMatters	Subclass representing management related prevention matters for delay.	Concept-Subclass

Table 4.1: Glossary of terms of the delay analysis ontology (continued)

Name	Description	Type
**SchedulingRelatedPrevention Matters	Subclass representing scheduling related prevention matters for delay.	Concept-Subclass
**PreventionMattersForComple xityOfWorks	Subclass representing prevention matters for delay for complexity of works.	Concept-Subclass
**ProjectDurationRelatedPreve ntionMatters	Subclass representing project duration related prevention matters for delay.	Concept-Subclass
**DesignRelatedPreventionMatt ers	Subclass representing design related prevention matters for delay.	Concept-Subclass
**ContractorRelatedPrevention Matters	Subclass representing contractor related prevention matters for delay.	Concept-Subclass
**SubcontractorRelatedPreventi onMatters	Subclass representing subcontractor related prevention matters for delay.	Concept-Subclass
*PreventionDuringConstruction	Subclass representing prevention matters for delay during construction.	Concept-Subclass
**ContractImplementationRelat edPreventionMatters	Subclass representing contract implementation related prevention matters for delay.	Concept-Subclass
**TrackingRelatedPreventionM atters	Subclass representing tracking related prevention matters for delay.	Concept-Subclass
**OwnerRelatedPreventionMatt ers	Subclass representing owner related prevention matters for delay.	Concept-Subclass
**ChangeRelatedPreventionMat ters	Subclass representing change related prevention matters for delay.	Concept-Subclass
**DelayResponseRelatedPreven tionMatters	Subclass representing delay response related prevention matters for delay.	Concept-Subclass
**ClaimingRelatedPreventionM atters	Subclass representing claiming related prevention matters for delay.	Concept-Subclass
**ClaimResponseRelatedPreven tionMatters	Subclass representing claim response related prevention matters for delay.	Concept-Subclass
*PreventionDuringAnalysis	Subclass representing prevention matters for delay during analysis.	Concept-Subclass
**PreventionMattersDuringAna lysis	Subclass representing prevention matters for delay during analysis.	Concept-Subclass
of	A relation that provides possession.	Relation
for	A relation that provides possession.	Relation
in	A relation that provides the possession for claim.	Relation
used_for	A relation that provides the possession for analysis.	Relation
relating_to	A relation that provides the possession for analysis.	Relation
to_reduce	A relation that provides the possession for impact.	Relation
after	A relation that provides the possession for resolution.	Relation
through	A relation that provides the possession for settlement.	Relation
focuses_on	A relation that provides the meaning importance.	Relation
takes_into_account	A relation that provides the meaning importance.	Relation
determines	A relation that provides the meaning of result.	Relation
also_used_in	A relation that provides the possession for resolution.	Relation
based_on	A relation that provides the possession for claim.	Relation
occurred_by	A relation that provides the connection between delays classified by their origin/compensability and causes of delay with the inverse relation of "originate".	Relation

Table 4.1: Glossary of terms of the delay analysis ontology (continued)

Name	Description	Type
originate	A relation that provides the connection between delays classified by their origin/compensability and causes of delay with the inverse relation of "occurred_by".	Relation
indicates_that	A relation that provides the connection between delays classified by their origin/compensability/timing and responsibility of delay with the inverse relation of "lead_to".	Relation
lead_to	A relation that provides the connection between delays classified by their origin/compensability/timing and responsibility of delay with the inverse relation of "indicates_that".	Relation
handled_in	A relation that provides the connection between delays classified by their compensability and contract clauses for delay.	Relation
contractor_claims	A relation that provides the connection between delays classified by their origin/compensability and remedy for delay.	Relation
owner_claims	A relation that provides the connection between delays classified by their origin/compensability and remedy for delay.	Relation
awarded_by	A relation that provides the connection between delays classified by their compensability and award for delay.	Relation
select	A relation that provides the guidance for the selectable delay analysis technique according to the selection criterion.	Relation
controlled_by	A relation that provides the connection between causes and prevention of delay with the inverse relation of "if_not_may_lead".	Relation
if_not_may_lead	A relation that provides the connection between causes and prevention of delay with the inverse relation of "controlled_by".	Relation
name	An instance attribute for representation of names of instances.	Instance Attribute

4.2.2 Task 2: To Build Concept Taxonomies

Concept hierarchy that forms the taxonomy is presented in this step (it is already partially presented in the previous step) to provide some level of meaning of the ontology through basic relations of taxonomy. Subconcepts of the concepts represent the hidden is-a relations of the taxonomy. For the formation of taxonomy, first the main concepts such as “Delay”, “Analysis”, “Causes”, “Types”, “Responsibility”, “Impact”, “Claim”, and “Prevention” are defined separately since they are not related with inheritance (is-a) relations. These concepts much more represent aggregation relations (part-of) through taxonomic relations. However, separately from plain aggregations, associations with availability of more flexible definitions are preferred as relations between these concepts. Further these concepts are either described with subconcepts or put aside to be loaded with instances. A top-down basis development process is followed up to create the taxonomy as it is stated in the study of Noy and McGuinness (2001). According to the level of the information, most of the concepts are reduced to the instance level with their following subconcepts. Some concepts are just left alone (“Notice”), whereas some concepts are aggregated with further concepts (“Analysis”, “Claim”). The full concept taxonomy of the ontology could be seen in the following table (Table 4.2). Each level in the taxonomy indicates the subconcept of the concept presented in the previous level.

Table 4.2: Concept taxonomy of classes in delay analysis ontology

Concept	**1st level**	**2nd level**	**3rd level**	**4th level**	**5th level**
Delay					
Causes					
	OwnerCauses				
		DesignRelatedCauses			
		ConsultantCauses			
		OwnersFinancialCauses			
		OwnerGeneratedCauses			
		ContractRelatedCauses			
		ContractualRelationshipRelatedCauses			
	ContractorCauses				
		MaterialRelatedCauses			
		EquipmentRelatedCauses			
		LaborRelatedCauses			
		ContractorsFinancialCauses			
		SubcontractorCauses			
		HealthAndSafetyRelatedCauses			
		SchedulingAndControllingRelatedCauses			
		ContractorGeneratedCauses			
	ExternalCauses				
		InclementWeatherCauses			
		EnvironmentalCauses			
		ForceMajeureCauses			
			ActsOfGod		

Table 4.2: Concept taxonomy of classes in delay analysis ontology (continued)

Concept	**1st level**	**2nd level**	**3rd level**	**4th level**	**5th level**
				GeologicalDisasters	
				HydrologicalDisasters	
				MeteorologicalDisasters	
				HealthDisasters	
				WildfiresAndBushfires	
			UnexpectedSituations		
		RulesAndRegulationsRelatedCauses			
		EconomicalCauses			
		PoliticalCauses			
		SocialCauses			
		TechnologicalCauses			
Types					
	DelaysClassifiedByTheirOrigin				
	DelaysClassifiedByTheirTiming				
	DelaysClassifiedByTheirCompensability				
	DelaysClassifiedByTheirContent				
	DelaysClassifiedByTheirCriticality				
Responsibility					
Impact					
	TimeOverrun				
	CostOverrun				
		OwnersCosts			
			OwnersDirectCosts		
			OwnersIndirectCosts		
		ContractorsCosts			
			ContractorsDirectCosts		
				ExtendedandIncreasedFieldCosts	
					AdditionalLaborCosts
					AdditionalMaterialCosts
					AdditionalEquipmentCosts
					ExtendedSiteOverheadCosts
				HomeOfficeOverheadCosts	
					ExtendedHomeOfficeOverheadCosts
					UnabsorbedHomeOfficeOverheadCosts
				LostProductivityCosts	
				AccelerationCosts	
				CostsOfNoncriticalDelays	
				DisruptionCosts	
				ConsultingAndLegalCosts	
				ExtendedTemporaryUtilityAndFacilityCosts	
				ExtendedMaintenanceAndProtectionCosts	
				ExtendedWarrantyCosts	
				IncreasedBondCosts	
				IncreasedFinancingCosts	
				DemolitionCosts	
				WasteCostsOnAbandonedWork	
			ContractorsIndirectCosts		
	Disruption				

Table 4.2: Concept taxonomy of classes in delay analysis ontology (continued)

Concept	1st level	2nd level	3rd level	4th level	5th level
	LostProductivity				
	Acceleration				
	Dispute				
	TotalAbandonment				
	ContractTermination				
Mitigation					
	ChangingTheWorkSequence				
	AcceleratingTheWork				
	ChangingTheContract				
	MakingImprovements				
Remedy					
Notice					
Claim					
Kinds					
	VariationClaims				
	TimeRelatedClaims				
	QuantumMeuritClaims				
	ClaimsAfterTerminationByFrustration				
	DefectiveWorkClaims				
	LicensingAndBuildingClaims				
	CounterClaims				
Parties					
Parts					
	i.Introduction				
	ii.SummaryOfFacts				
	iii.BasisOfClaim				
	iv.DetailsOfClaim				
	v.EvaluationOfClaim				
	vi.StatementOfClaim				
	vii.Appendices				
Result					
	Dispute				
	Settlement				
Resolution					
	ResolutionByNegotiation				
	ResolutionByThirdParty				
		AlternativeDisputeResolution			
		Litigation			
Award					
Analysis					
Issues					
	FloatOwnershipIssue				
	SchedulingOptionsIssue				
	ConcurrentDelaysIssue				
		DefinitionOfConcurrentDelaysIssue			
		AnalysisOfConcurrentDelaysIssue			
	InterrelatedDelaysIssue				
	EarlyCompletionIssue				

Table 4.2: Concept taxonomy of classes in delay analysis ontology (continued)

	DelaysAfterCompletionIssue		
	ProlongationCostsIssue		
	PacingDelayIssue		
	DrawbacksOfAnalysisTechniquesIssue		
	UsageOfAnalysisTechniqueIssue		
Data			
	ContractDocuments		
		MainContractDocuments	
			Tender
			ContractClauses
			ConditionsOfContract
			SpecificationsAndDrawings
			BillsOfQuantities
			DesignDrawings
			MethodOfStatements
			PlansAndProgrammes
			Schedules
		SubcontractDocuments	
	PostContractDocuments		
		MajorSchedules	
		ParticularSchedules	
		UpdatedPlansAndProgrammes	
		Records	
			Registers
			Diaries
			Logs
			SiteRecords
			Reports
			FormalSubmittals
			RecordsOfActualData
			RecordsOfAccountingData
			MediaRecords
			MinutesOfMeetings
			Notes
			CorrespondenceData
			WitnessData
Techniques			
	StaticTechniques		
	DynamicTechniques		
Advantages			
	AdvantagesOfGlobalImpactTechnique		
	AdvantagesOfNetImpactTechnique		
	AdvantagesOfAsPlannedVsAsBuiltTechnique		
	AdvantagesOfImpactedAsPlannedTechnique		
	AdvantagesOfCollapsedAsBuiltTechnique		
	AdvantagesOfWindowsAnalysisTechnique		
	AdvantagesOfTimeImpactAnalysisTechnique		
Disadvantages			

Table 4.2: Concept taxonomy of classes in delay analysis ontology (continued)

Concept	**1st level**	**2nd level**	**3rd level**	**4th level**	**5th level**
	DisadvantagesOfGlobalImpactTechnique				
	DisadvantagesOfNetImpactTechnique				
	DisadvantagesOfAsPlannedVsAsBuiltTechnique				
	DisadvantagesOfImpactedAsPlannedTechnique				
	DisadvantagesOfCollapsedAsBuiltTechnique				
	DisadvantagesOfWindowsAnalysisTechnique				
	DisadvantagesOfTimeImpactAnalysisTechnique				
SelectionCriteria					
	TimeOfAnalysis				
	CapabilitiesOfTechniques				
	ScheduleTypeQuality				
	ScheduleUsed				
	AvailabilityOfData				
	TypeOfAnalysis				
	NatureOfClaim				
	AmountInClaim				
	TimeCostEffortAllocatedForAnalysis				
	ProjectDurationScaleComplexity				
	AvailabilityOfExpertiseSoftware				
MethodologySteps					
	i.TenderAndProgrammeAnalysis				
		i.GatherDataAvailable			
		ii.AnalyzeOriginalSchedule			
		iii.DevelopAsBuiltSchedule			
		iv.AnalyzeAsBuiltSchedule			
	ii.EventAnalysis				
		i.IdentifyDelayPeriod			
		ii.AnalyzeCauseAndEffect			
		iii.IdentifyConcurrentDelays			
		iv.ApplyAnalysisTechnique			
		v.AnalyzeClaim			
		vi.CalculateCompensations			
		vii.PresentResults			
		viii.NegotiateClaim			
Prevention					
	PreventionDuringPlanning				
		ContractRelatedPreventionMatters			
		RiskRelatedPreventionMatters			
		RelationsRelatedPreventionMatters			
		ManagementRelatedPreventionMatters			
		SchedulingRelatedPreventionMatters			
		PreventionMattersForComplexityOfWorks			
		ProjectDurationRelatedPreventionMatters			
		DesignRelatedPreventionMatters			
		ContractorRelatedPreventionMatters			
		SubcontractorRelatedPreventionMatters			
	PreventionDuringConstruction				
		ContractImplementationRelatedPreventionMatters			

Table 4.2: Concept taxonomy of classes in delay analysis ontology (continued)

Concept	1st level	2nd level	3rd level	4th level	5th level
		TrackingRelatedPreventionMatters			
		OwnerRelatedPreventionMatters			
		ChangeRelatedPreventionMatters			
		DelayResponseRelatedPreventionMatters			
		ClaimingRelatedPreventionMatters			
		ClaimResponseRelatedPreventionMatters			
	PreventionDuringAnalysis				
		PreventionMattersDuringAnalysis			

4.2.3 Task 3: To Build Ad Hoc Binary Relation Diagrams

After the formation of taxonomy, more meaning is loaded on the ontology through ad hoc binary relations. UML class diagrams are used for representation of the ontology. Rather than representation of relations one by one as in the proposed methodology, total representation of the relations is preferred. Ad hoc binary relations are divided into two as binary relations between concepts and binary relations between instances of the concepts.

4.2.3.1 Binary Relations at Concepts Level

Binary relations between concepts are the main relations that provide the basis of the ontology. UML class diagram of the ontology with relations between concepts is presented in the following figure (Figure 4.2). Relations are represented in two colors (black and blue) to create clear view of the ontology. Only the relations between Dispute-Result and Settlement-Result are taxonomic is-a relations with hollow arrows in the end and the rest of the relations are associations through solid arrows with the relation names on. Details can be seen in the following figure (Figure 4.2).

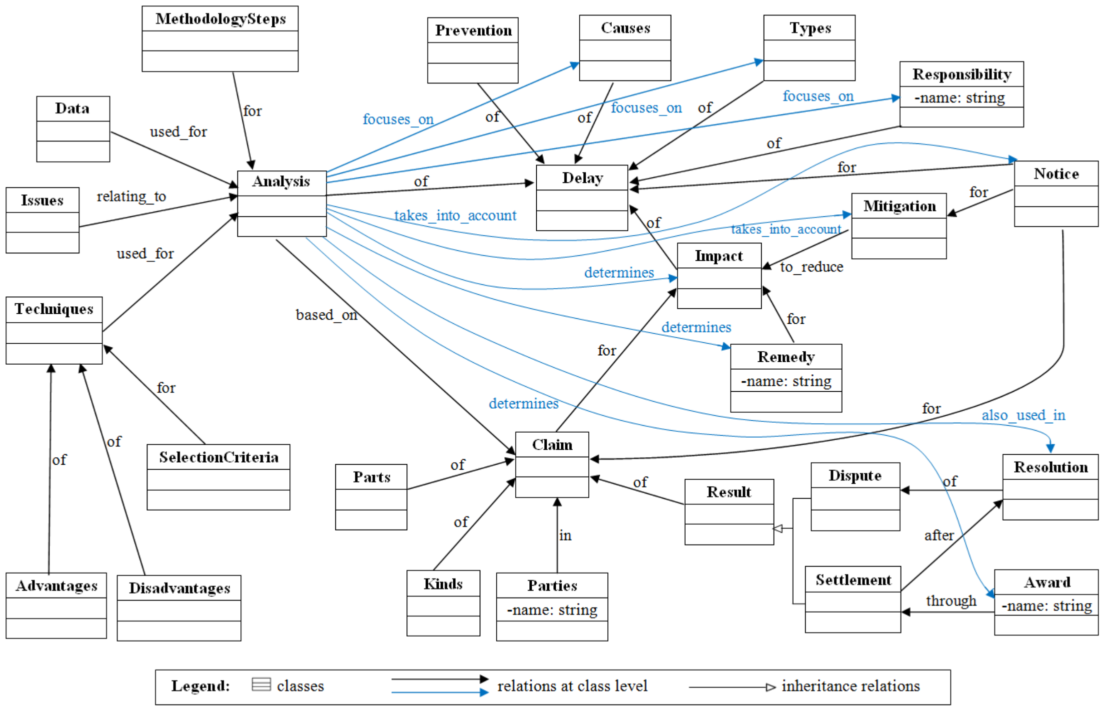


Figure 4.2: Relations between concepts of delay analysis ontology

4.2.3.2 Binary Relations at Instances Level

Binary relations also exist between instances of the concepts to provide further definitions in the ontology. Through the relations at instances level, matching between causes and types of delays, types and responsibilities of delays, types of delays and related contract clauses, types and remedy of delays, types and awards of delays, selection criteria and analysis techniques for delay, and finally causes and related prevention matters of delays are aimed to be achieved. Details including instances will be handled after assignment of instances in the further section. For this step UML class diagram of the ontology including the relations (which are assigned with the aim of relating instances of concepts) between concepts at instances level are presented (in red) in Figure 4.3. Actually, relations may be assigned to the subconcepts of the concepts, however relations are presented in the main concepts level in this figure. The details of the actual assignments of relations will be presented in the further task (Task 5) that is related with detail of relations. Also, the figure is simplified to prevent complexity by elimination of some associations of concepts level that are presented in previous figure (the blue ones). The complete figure will be available in expanded form in the further step of formalization.

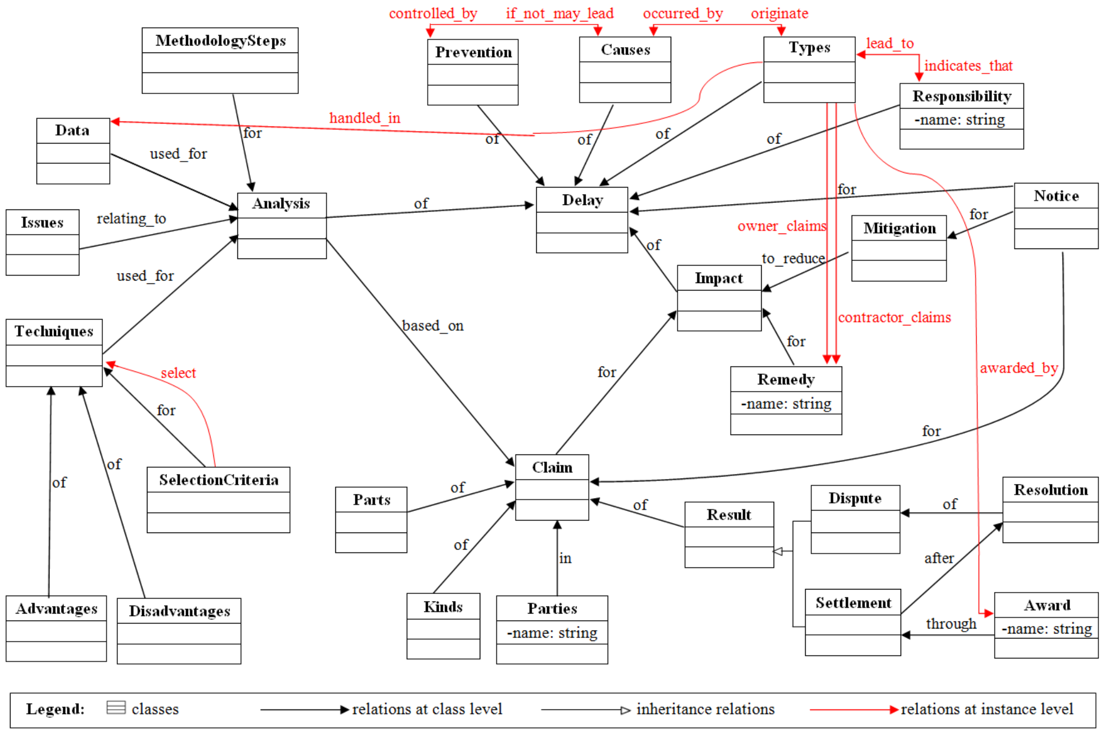


Figure 4.3: Relations between instances of delay analysis ontology

4.2.4 Task 4: To Build the Concept Dictionary

After creation of concept taxonomy and relations, concepts and relations should be matched and presented in a table to build the concept dictionary of the ontology (relations are matched only with source concepts in this step, target concepts will be held in the following section). In this step, also attributes (properties) of instances are presented. Since Protégé-Frames does not allow to change the names of instances, an attribute with name "name" and value type "string" is created and assigned to the concrete classes of the ontology, namely to the classes that have instances. Also, table sets a place for the attributes of classes, however only the instances have attributes and “name” attribute is assigned to the classes for their instances. A class attribute should be assigned only for qualification of classes rather than their instances (Gómez-Pérez et al., 1996). So; since there is no attributes assigned for classes, this part is discarded from the table. Instance attributes and relations of each concept of the taxonomy is represented together in a tabular form to certainly indicate which attribute or relation is in pair with which concept. Details can be seen in Table 4.3.

Table 4.3: Concept dictionary of delay analysis ontology

Concept name	**Instance attributes**	**Relations**
Causes		of
Types		of
Responsibility	name	of
		lead_to
Prevention		of
Impact		of
Analysis		of
		focuses_on
		takes_into_account
		determines
		also_used_in
		based_on
Claim		for
Kinds		of
Parts		of
Result		of
Resolution		of
Advantages		of
Disadvantages		of
Notice		for
Remedy	name	for
MethodologySteps		for
SelectionCriteria		for
		select
Mitigation		to_reduce
Parties	name	in
Data		used_for
Techniques		used_for
Issues		relating_to
Settlement		after
Award	name	through

Table 4.3: Concept dictionary of delay analysis ontology (continued)

Concept name	**Instance attributes**	**Relations**
OwnerCauses		controlled_by
		originate
DesignRelatedCauses	name	
ConsultantCauses	name	
OwnersFinancialCauses	name	
OwnerGeneratedCauses	name	
ContractRelatedCauses	name	
ContractualRelationshipRelatedCauses	name	
ContractorCauses		controlled_by
		originate
MaterialRelatedCauses	name	
EquipmentRelatedCauses	name	
LaborRelatedCauses	name	
ContractorsFinancialCauses	name	
SubcontractorCauses	name	
HealthAndSafetyRelatedCauses	name	
SchedulingAndControllingRelatedCauses	name	
ContractorGeneratedCauses	name	
ExternalCauses		controlled_by
		originate
InclementWeatherCauses	name	
EnvironmentalCauses	name	
GeologicalDisasters	name	
HydrologicalDisasters	name	
MeteorologicalDisasters	name	
HealthDisasters	name	
UnexpectedSituations	name	
RulesAndRegulationsRelatedCauses	name	
EconomicalCauses	name	
PoliticalCauses	name	
SocialCauses	name	
TechnologicalCauses	name	
DelaysClassifiedByTheirOrigin	name	occurred_by
		indicates_that
		owner_claims
		contractor_claims
DelaysClassifiedByTheirTiming	name	indicates_that
DelaysClassifiedByTheirCompensability	name	occurred_by
		indicates_that
		owner_claims
		contractor_claims
		awarded_by
		handled_in
DelaysClassifiedByTheirContent	name	
DelaysClassifiedByTheirCriticality	name	

Table 4.3: Concept dictionary of delay analysis ontology (continued)

Concept name	Instance attributes	Relations
Acceleration	name	
OwnersDirectCosts	name	
OwnersIndirectCosts	name	
LostProductivityCosts	name	
AccelerationCosts	name	
CostsOfNoncriticalDelays	name	
AdditionalLaborCosts	name	
AdditionalMaterialCosts	name	
AdditionalEquipmentCosts	name	
ExtendedSiteOverheadCosts	name	
ExtendedHomeOfficeOverheadCosts	name	
ContractorsIndirectCosts	name	
ChangingTheWorkSequence	name	
AcceleratingTheWork	name	
ChangingTheContract	name	
MakingImprovements	name	
VariationClaims	name	
TimeRelatedClaims	name	
QuantumMeuritClaims	name	
i.Introduction	name	
ii.SummaryOfFacts	name	
iii.BasisOfClaim	name	
iv.DetailsOfClaim	name	
v.EvaluationOfClaim	name	
vi.StatementOfClaim	name	
vii.Appendices	name	
ResolutionByNegotiation	name	
AlternativeDisputeResolution	name	
Litigation	name	
FloatOwnershipIssue	name	
SchedulingOptionsIssue	name	
DefinitionOfConcurrentDelaysIssue	name	
AnalysisOfConcurrentDelaysIssue	name	
DrawbacksOfAnalysisTechniquesIssue	name	
UsageOfAnalysisTechniqueIssue	name	
Tender	name	
ContractClauses	name	
Schedules	name	
MajorSchedules	name	
ParticularSchedules	name	
Registers	name	
Diaries	name	
Logs	name	
SiteRecords	name	
Reports	name	

Table 4.3: Concept dictionary of delay analysis ontology (continued)

Concept name	Instance attributes	Relations
FormalSubmittals	name	
RecordsOfActualData	name	
RecordsOfAccountingData	name	
MediaRecords	name	
Notes	name	
CorrespondenceData	name	
WitnessData	name	
StaticTechniques	name	
DynamicTechniques	name	
AdvantagesOfGlobalImpactTechnique	name	
AdvantagesOfNetImpactTechnique	name	
AdvantagesOfAsPlannedVsAsBuiltTechnique	name	
AdvantagesOfImpactedAsPlannedTechnique	name	
AdvantagesOfCollapsedAsBuiltTechnique	name	
AdvantagesOfWindowsAnalysisTechnique	name	
AdvantagesOfTimeImpactAnalysisTechnique	name	
DisadvantagesOfGlobalImpactTechnique	name	
DisadvantagesOfNetImpactTechnique	name	
DisadvantagesOfAsPlannedVsAsBuiltTechnique	name	
DisadvantagesOfImpactedAsPlannedTechnique	name	
DisadvantagesOfCollapsedAsBuiltTechnique	name	
DisadvantagesOfWindowsAnalysisTechnique	name	
DisadvantagesOfTimeImpactAnalysisTechnique	name	
TimeOfAnalysis	name	
CapabilitiesOfTechniques	name	
ScheduleTypeQuality	name	
ScheduleUsed	name	
AvailabilityOfData	name	
TypeOfAnalysis	name	
NatureOfClaim	name	
AmountInClaim	name	
TimeCostEffortAllocatedForAnalysis	name	
ProjectDurationScaleComplexity	name	
AvailabilityOfExpertiseSoftware	name	
i.GatherDataAvailable	name	
ii.AnalyzeOriginalSchedule	name	
iii.DevelopAsBuiltSchedule	name	
iv.AnalyzeAsBuiltSchedule	name	
i.IdentifyDelayPeriod	name	
ii.AnalyzeCauseAndEffect	name	
iii.IdentifyConcurrentDelays	name	
iv.ApplyAnalysisTechnique	name	
v.AnalyzeClaim	name	
vi.CalculateCompensations	name	
vii.PresentResults	name	

Table 4.3: Concept dictionary of delay analysis ontology (continued)

Concept name	Instance attributes	Relations
viii.NegotiateClaim	name	
PreventionDuringPlanning		if_not_may_lead
ContractRelatedPreventionMatters	name	
RiskRelatedPreventionMatters	name	
RelationsRelatedPreventionMatters	name	
ManagementRelatedPreventionMatters	name	
SchedulingRelatedPreventionMatters	name	
PreventionMattersForComplexityOfWorks	name	
ProjectDurationRelatedPreventionMatters	name	
DesignRelatedPreventionMatters	name	
ContractorRelatedPreventionMatters	name	
SubcontractorRelatedPreventionMatters	name	
PreventionDuringConstruction		if_not_may_lead
ContractImplementationRelatedPreventionMatters	name	
TrackingRelatedPreventionMatters	name	
OwnerRelatedPreventionMatters	name	
ChangeRelatedPreventionMatters	name	
DelayResponseRelatedPreventionMatters	name	
ClaimingRelatedPreventionMatters	name	
ClaimResponseRelatedPreventionMatters	name	
PreventionDuringAnalysis		if_not_may_lead
PreventionMattersDuringAnalysis	name	

4.2.5 Task 5: To Define Ad Hoc Binary Relations in Detail

All the previously figured relations are indicated in detail in tabular form with the information of source and target concepts, cardinalities and inverse relations. Since there are not mathematical properties of relations of the ontology, this part is discarded from the table. Details about relations are available in Table 4.4.

Table 4.4: Ad hoc binary relation table of delay analysis ontology

Relation name	Source concept	Source card.	Target concept	Inverse relation
of	Causes	single	Delay	null
of	Types	single	Delay	null
of	Responsibility	single	Delay	null

Table 4.4: Ad hoc binary relation table of delay analysis ontology (continued)

Relation name	Source concept	Source card.	Target concept	Inverse relation
of	Prevention	single	Delay	null
of	Impact	single	Delay	null
of	Analysis	single	Delay	null
of	Kinds	single	Claim	null
of	Parts	single	Claim	null
of	Result	single	Claim	null
of	Resolution	single	Dispute	null
of	Advantages	single	Techniques	null
of	Disadvantages	single	Techniques	null
for	Notice	single	Delay	null
for	Claim	single	Impact	null
for	Remedy	single	Impact	null
for	MethodologySteps	single	Analysis	null
for	SelectionCriteria	single	Techniques	null
for	Notice	single	Claim	null
for	Notice	single	Mitigation	null
in	Parties	single	Claim	null
used_for	Data	single	Analysis	null
used_for	Techniques	single	Analysis	null
relating_to	Issues	single	Analysis	null
to_reduce	Mitigation	single	Impact	null
after	Settlement	single	Resolution	null
through	Award	single	Settlement	null
focuses_on	Analysis	single	Causes	null
focuses_on	Analysis	single	Responsibility	null
focuses_on	Analysis	single	Types	null
takes_into_acc ount	Analysis	single	Notice	null
takes_into_acc ount	Analysis	single	Mitigation	null
determines	Analysis	single	Impact	null
determines	Analysis	single	Remedy	null
determines	Analysis	single	Award	null
also_used_in	Analysis	single	Resolution	null
based_on	Analysis	single	Claim	null
occurred_by	DelaysClassifiedByTheirOrigin DelaysClassifiedByTheirCompe nsability	single	ContractorCauses ExternalCauses OwnerCauses	originate
originate	ContractorCauses ExternalCauses OwnerCauses	single	DelaysClassifiedByTheirOrigin DelaysClassifiedByTheirCompen sability	occurred_by
indicates_that	DelaysClassifiedByTheirOrigin DelaysClassifiedByTheirCompe nsability DelaysClassifiedByTheirTiming	multiple	Responsibility	lead_to
lead_to	Responsibility	multiple	DelaysClassifiedByTheirOrigin DelaysClassifiedByTheirCompen sability DelaysClassifiedByTheirTiming	indicates_tha t

Table 4.4: Ad hoc binary relation table of delay analysis ontology (continued)

Relation name	Source concept	Source card.	Target concept	Inverse relation
handled_in	DelaysClassifiedByTheirCompensability	single	ContractClauses	null
contractor_claims	DelaysClassifiedByTheirOrigin DelaysClassifiedByTheirCompensability	multiple	Remedy	null
owner_claims	DelaysClassifiedByTheirOrigin DelaysClassifiedByTheirCompensability	single	Remedy	null
awarded_by	DelaysClassifiedByTheirCompensability	single	Award	null
select	SelectionCriteria	multiple	StaticTechniques DynamicTechniques	null
controlled_by	ContractorCauses ExternalCauses OwnerCauses	multiple	PreventionDuringPlanning PreventionDuringConstruction PreventionDuringAnalysis	if_not_may_lead
if_not_may_lead	PreventionDuringPlanning PreventionDuringConstruction PreventionDuringAnalysis	multiple	ContractorCauses ExternalCauses OwnerCauses	controlled_by

4.2.6 Task 6: To Define Instance Attributes in Detail

All the instance attributes are presented in tabular form in detail with the information of related concepts that attributes are created in, value types of attributes and cardinalities. Some parts of the table as; information of measurement units, precision and range of values are discarded since only value type of string is defined for instances. The following Table 4.5 presents the details about instance attributes.

Table 4.5: Instance attribute table of delay analysis ontology

Instance attribute name	Concept name	Value type	Cardinality
name	DesignRelatedCauses	String	single
name	ConsultantCauses	String	single
name	OwnersFinancialCauses	String	single
name	OwnerGeneratedCauses	String	single
name	ContractRelatedCauses	String	single
name	ContractualRelationshipRelatedCauses	String	single
name	MaterialRelatedCauses	String	single

Table 4.5: Instance attribute table of delay analysis ontology (continued)

Instance attribute name	Concept name	Value type	Cardinality
name	EquipmentRelatedCauses	String	single
name	LaborRelatedCauses	String	single
name	ContractorsFinancialCauses	String	single
name	SubcontractorCauses	String	single
name	HealthAndSafetyRelatedCauses	String	single
name	SchedulingAndControllingRelatedCauses	String	single
name	ContractorGeneratedCauses	String	single
name	InclementWeatherCauses	String	single
name	EnvironmentalCauses	String	single
name	GeologicalDisasters	String	single
name	HydrologicalDisasters	String	single
name	MeteorologicalDisasters	String	single
name	HealthDisasters	String	single
name	UnexpectedSituations	String	single
name	RulesAndRegulationsRelatedCauses	String	single
name	EconomicalCauses	String	single
name	PoliticalCauses	String	single
name	SocialCauses	String	single
name	TechnologicalCauses	String	single
name	DelaysClassifiedByTheirOrigin	String	single
name	DelaysClassifiedByTheirTiming	String	single
name	DelaysClassifiedByTheirCompensability	String	single
name	DelaysClassifiedByTheirContent	String	single
name	DelaysClassifiedByTheirCriticality	String	single
name	Responsibility	String	single
name	Remedy	String	single
name	Acceleration	String	single
name	OwnersDirectCosts	String	single
name	OwnersIndirectCosts	String	single
name	LostProductivityCosts	String	single
name	AccelerationCosts	String	single
name	CostsOfNoncriticalDelays	String	single
name	AdditionalLaborCosts	String	single
name	AdditionalMaterialCosts	String	single
name	AdditionalEquipmentCosts	String	single
name	ExtendedSiteOverheadCosts	String	single
name	ExtendedHomeOfficeOverheadCosts	String	single
name	ContractorsIndirectCosts	String	single
name	ChangingTheWorkSequence	String	single
name	AcceleratingTheWork	String	single
name	ChangingTheContract	String	single
name	MakingImprovements	String	single
name	VariationClaims	String	single
name	TimeRelatedClaims	String	single

Table 4.5: Instance attribute table of delay analysis ontology (continued)

Instance attribute name	Concept name	Value type	Cardinality
name	QuantumMeuritClaims	String	single
name	Parties	String	single
name	i.Introduction	String	single
name	ii.SummaryOfFacts	String	single
name	iii.BasisOfClaim	String	single
name	iv.DetailsOfClaim	String	single
name	v.EvaluationOfClaim	String	single
name	vi.StatementOfClaim	String	single
name	vii.Appendices	String	single
name	ResolutionByNegotiation	String	single
name	AlternativeDisputeResolution	String	single
name	Litigation	String	single
name	Award	String	single
name	FloatOwnershipIssue	String	single
name	SchedulingOptionsIssue	String	single
name	DefinitionOfConcurrentDelaysIssue	String	single
name	AnalysisOfConcurrentDelaysIssue	String	single
name	DrawbacksOfAnalysisTechniquesIssue	String	single
name	UsageOfAnalysisTechniqueIssue	String	single
name	Tender	String	single
name	ContractClauses	String	single
name	Schedules	String	single
name	MajorSchedules	String	single
name	ParticularSchedules	String	single
name	Registers	String	single
name	Diaries	String	single
name	Logs	String	single
name	SiteRecords	String	single
name	Reports	String	single
name	FormalSubmittals	String	single
name	RecordsOfActualData	String	single
name	RecordsOfAccountingData	String	single
name	MediaRecords	String	single
name	Notes	String	single
name	CorrespondenceData	String	single
name	WitnessData	String	single
name	StaticTechniques	String	single
name	DynamicTechniques	String	single
name	AdvantagesOfGlobalImpactTechnique	String	single
name	AdvantagesOfNetImpactTechnique	String	single
name	AdvantagesOfAsPlannedVsAsBuiltTechnique	String	single
name	AdvantagesOfImpactedAsPlannedTechnique	String	single
name	AdvantagesOfCollapsedAsBuiltTechnique	String	single
name	AdvantagesOfWindowsAnalysisTechnique	String	single

Table 4.5: Instance attribute table of delay analysis ontology (continued)

Instance attribute name	Concept name	Value type	Cardinality
name	AdvantagesOfTimeImpactAnalysisTechnique	String	single
name	DisadvantagesOfGlobalImpactTechnique	String	single
name	DisadvantagesOfNetImpactTechnique	String	single
name	DisadvantagesOfAsPlannedVsAsBuiltTechnique	String	single
name	DisadvantagesOfImpactedAsPlannedTechnique	String	single
name	DisadvantagesOfCollapsedAsBuiltTechnique	String	single
name	DisadvantagesOfWindowsAnalysisTechnique	String	single
name	DisadvantagesOfTimeImpactAnalysisTechnique	String	single
name	TimeOfAnalysis	String	single
name	CapabilitiesOfTechniques	String	single
name	ScheduleTypeQuality	String	single
name	ScheduleUsed	String	single
name	AvailabilityOfData	String	single
name	TypeOfAnalysis	String	single
name	NatureOfClaim	String	single
name	AmountInClaim	String	single
name	TimeCostEffortAllocatedForAnalysis	String	single
name	ProjectDurationScaleComplexity	String	single
name	AvailabilityOfExpertiseSoftware	String	single
name	i.GatherDataAvailable	String	single
name	ii.AnalyzeOriginalSchedule	String	single
name	iii.DevelopAsBuiltSchedule	String	single
name	iv.AnalyzeAsBuiltSchedule	String	single
name	i.IdentifyDelayPeriod	String	single
name	ii.AnalyzeCauseAndEffect	String	single
name	iii.IdentifyConcurrentDelays	String	single
name	iv.ApplyAnalysisTechnique	String	single
name	v.AnalyzeClaim	String	single
name	vi.CalculateCompensations	String	single
name	vii.PresentResults	String	single
name	viii.NegotiateClaim	String	single
name	ContractRelatedPreventionMatters	String	single
name	RiskRelatedPreventionMatters	String	single
name	RelationsRelatedPreventionMatters	String	single
name	ManagementRelatedPreventionMatters	String	single
name	SchedulingRelatedPreventionMatters	String	single
name	PreventionMattersForComplexityOfWorks	String	single
name	ProjectDurationRelatedPreventionMatters	String	single
name	DesignRelatedPreventionMatters	String	single
name	ContractorRelatedPreventionMatters	String	single
name	SubcontractorRelatedPreventionMatters	String	single
name	ContractImplementationRelatedPreventionMatters	String	single
name	TrackingRelatedPreventionMatters	String	single
name	OwnerRelatedPreventionMatters	String	single

Table 4.5: Instance attribute table of delay analysis ontology (continued)

Instance attribute name	Concept name	Value type	Cardinality
name	ChangeRelatedPreventionMatters	String	single
name	DelayResponseRelatedPreventionMatters	String	single
name	ClaimingRelatedPreventionMatters	String	single
name	ClaimResponseRelatedPreventionMatters	String	single
name	PreventionMattersDuringAnalysis	String	single

4.2.7 Task 7 – Task 10: Skipped

Since there are no class attributes, constants, axioms and rules defined in the delay analysis ontology; related steps of the methodology are skipped.

4.2.8 Task 11: To Define Instances

After the creation of concept model, instances of the concepts are defined and each instance is tabulated with its following concept and attribute. Values of attributes are discarded from the table by reason of the values are already names of the instances. Since the instances are presented in a way in the literature review on the construction delay chapter of the ontology, only a representative piece of instance table with its randomly selected instances is presented in Table 4.6. However, the full list of instances defined is available in Appendix A.

Table 4.6: Instance table of the delay analysis ontology (continued in Appendix A)

Instance name	Concept name	Attribute
Insufficient data collection, survey and site investigation prior to design	DesignRelatedCauses	name
Unclear and inadequate details in drawings	DesignRelatedCauses	name
Delay in performing inspection and testing by consultant	ConsultantCauses	name
Delay in approving major changes in the scope of work by consultant	ConsultantCauses	name

Table 4.6: Instance table of the delay analysis ontology (continued in Appendix A) (continued)

Instance name	Concept name	Attribute
Failure to give timely orders/instructions for work by owner	OwnerGeneratedCauses	name
Inadequate information and supervision by the owner	OwnerGeneratedCauses	name
Poor communication and coordination by contractor with other parties	ContractorGeneratedCauses	name
Inclement weather effect on construction activities	InclementWeatherCauses	name
Unexpected foundation conditions encountered in the field	EnvironmentalCauses	name
Excusable compensable delays	DelaysClassifiedByTheirCompensability	name
Excusable non-compensable delays	DelaysClassifiedByTheirCompensability	name
Additional direct labor cost	AdditionalLaborCosts	name
Additional idle labor cost	AdditionalLaborCosts	name
Increasing manpower	AcceleratingTheWork	name
Acceleration claims	VariationClaims	name
Actual date of commencement and practical completion	ii.SummaryOfFacts	name
Common law provisions	iii.BasisOfClaim	name
Arbitration	AlternativeDisputeResolution	name
Extension of time	Award	name
Liquidated damages	Award	name
That occur at the same time: Concurrent delay	DefinitionOfConcurrentDelaysIssue	name
Fair rule	AnalysisOfConcurrentDelaysIssue	name
Geological report	Tender	name
Time is of the essence clause	ContractClauses	name
As-planned schedule: the original schedule	MajorSchedules	name
Tape recordings	MediaRecords	name
i.As-planned vs as-built technique	DynamicTechniques	name
ii.Impacted as-planned technique	DynamicTechniques	name
Contemporaneous analysis of delays is possible	AdvantagesOfTimeImpact AnalysisTechnique	name
Concurrent delays not recognized	DisadvantagesOfGlobalImpactTechnique	name
Compare actual resources utilized with planned ones.	iv.AnalyzeAsBuiltSchedule	name
Identify and analyze delay disruption periods.	i.IdentifyDelayPeriod	name
Analyze cause and effect of specific issues.	ii.AnalyzeCauseAndEffect	name
Standard forms of contract should be used, as both parties are generally familiar with the obligations assumed by each party.	ContractRelatedPrevention Matters	name
Design changes should be adequately highlighted and updated on all relevant project documentations (e.g. drawings, specifications, reports, etc.).	ChangeRelatedPreventionMatters	name
Proper design reviews and audits should be established.	DesignRelatedPreventionMatters	name

After installation process of the instances, previously prepared relations at the instance level are assigned between the instances. The following table (Table 4.7) indicates the details of information stored through these relations. Matching between types of delay and with corresponding causes, responsibilities, remedies, awards and contract clauses is done through relations between instances. Also, selection of the analysis technique according to the presented criteria and matching between causes and related prevention matters are achieved through these relations. Since details of "Selection Criteria for Techniques" and similarly, "Causes" and corresponding "Prevention Matters" are handled in detail in the literature review on construction delay section, they will not be presented in this table.

Table 4.7: Table of details of relations at instances level

Relations between Types (Origin) and Causes of Delay					
Relation name	**Source concept**	**Source card.**	**Target concept**	**Value type**	**Inverse relation**
occurred_ by	DelaysClassifiedByTheir Origin DelaysClassifiedByTheir Compensability	single	ContractorCauses OwnerCauses ExternalCauses	class	originate
ContractorCauses		<---occurred_by--------originate--->		Contractor caused delays	
ExternalCauses		<---occurred_by--------originate--->		Third party caused delays	
OwnerCauses		<---occurred_by--------originate--->		Owner caused delays	
Relations between Types (Compensability) and Causes of Delay					
Relation name	**Source concept**	**Source card.**	**Target concept**	**Value type**	**Inverse relation**
originate	ContractorCauses OwnerCauses ExternalCauses	single	DelaysClassifiedByTheir Origin DelaysClassifiedByTheir Compensability	instance	occurred_by
ContractorCauses		<---occurred_by--------originate--->		Non-excusable delays	
ExternalCauses		<---occurred_by--------originate--->		Excusable compensable delays	
OwnerCauses		<---occurred_by--------originate--->		Excusable non-compensable delays	

Table 4.7: Table of details of relations at instances level (continued)

Relations between Types (Compensability) and Responsibilities of Delay

Relation name	Source concept	Source card.	Target concept	Value type	Inverse relation
indicates_ that	DelaysClassifiedByTheir Origin DelaysClassifiedByTheir Compensability DelaysClassifiedByTheirT iming	multiple	Responsibility	instance	lead_to

Excusable compensable delays	<---lead_to--------indicates_that--->	Owner (or his agents) responsible
Excusable non-compensable delays	<---lead_to--------indicates_that--->	Neither contractual party responsible
Non-excusable delays	<---lead_to--------indicates_that--->	Contractor (or his subcontractors) responsible

Relations between Types (Origin/Timing) and Responsibilities of Delay

Relation name	Source concept	Source card.	Target concept	Value type	Inverse relation
lead_to	Responsibility	multiple	DelaysClassifiedByTheir Origin DelaysClassifiedByTheir Compensability DelaysClassifiedByTheir Timing	instance	indicates_that

Contractor caused delays	<---lead_to--------indicates_that--->	Contractor (or his subcontractors) responsible
Owner caused delays	<---lead_to--------indicates_that--->	Owner (or his agents) responsible
Third party caused delays	<---lead_to--------indicates_that--->	Neither contractual party responsible
Concurrent delays	<---lead_to--------indicates_that--->	Both contractual parties responsible
		Contractor (or his subcontractors) responsible
		Owner (or his agents) responsible
		Neither contractual party responsible

Relations between Types (Compensability) and Related Contract Clauses of Delay

Relation name	Source concept	Source card.	Target concept	Value type	Inverse relation
handled_i n	DelaysClassifiedByTheir Compensability	single	ContractClasues	instance	null

Excusable compensable delays	--------handled_in--->	Exculpatory clauses: No damages for delay clause
Excusable non-compensable delays	--------handled_in--->	Force majeure clauses
Non-excusable delays	--------handled_in--->	Liquidated damages clause

Table 4.7: Table of details of relations at instances level (continued)

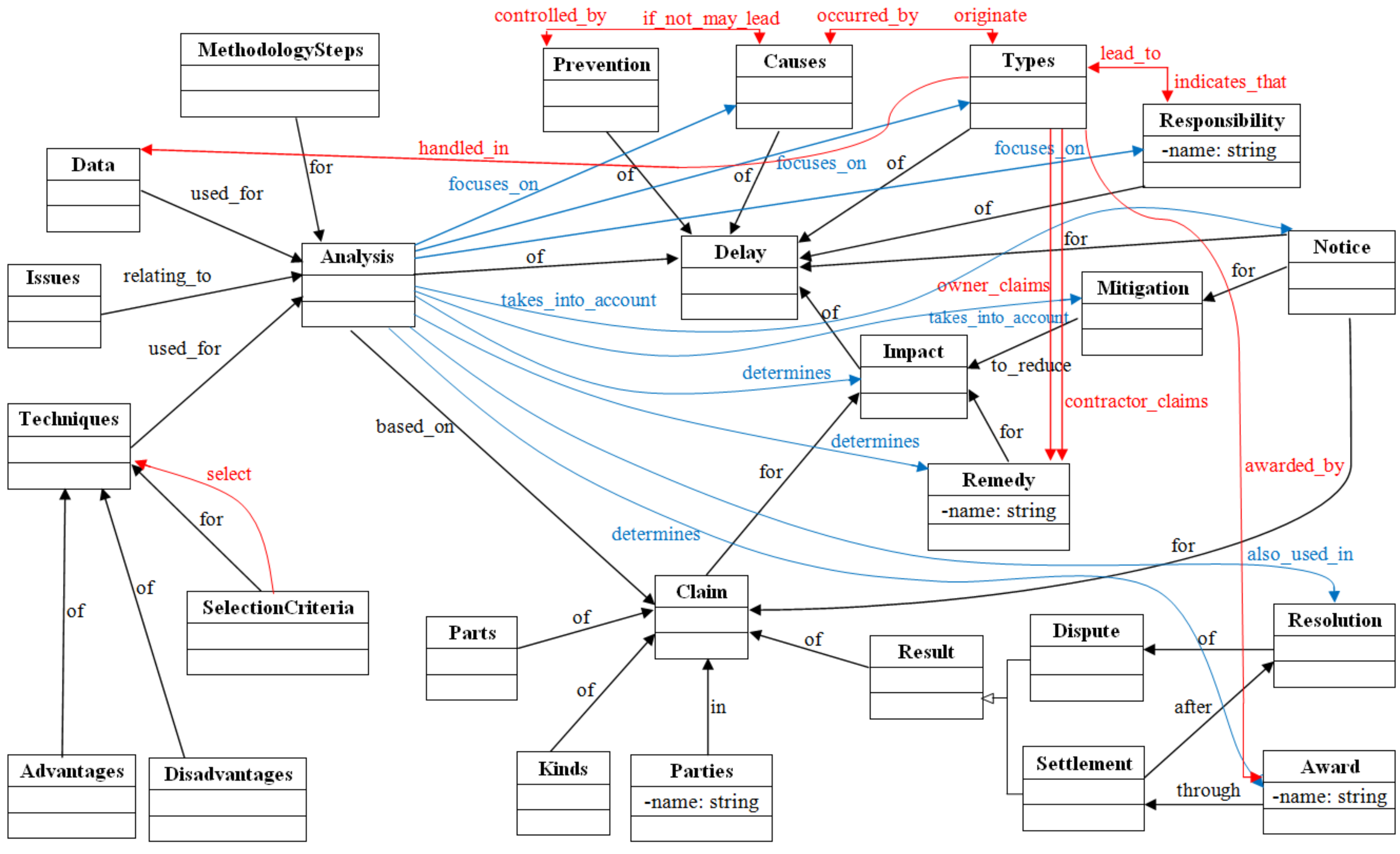
Relations between Types (Origin/Compensability) and Contractor's Remedy of Delay					
Relation name	**Source concept**	**Source card.**	**Target concept**	**Value type**	**Inverse relation**
contractor_claims	DelaysClassifiedByTheirOrigin DelaysClassifiedByTheirCompensability	multiple	Remedy	instance	null
Excusable compensable delays		--------contractor_claims--->		Time compensation	
				Cost compensation	
Excusable non-compensable delays		--------contractor_claims--->		Time compensation	
Owner caused delays		--------contractor_claims--->		Time compensation	
				Cost compensation	
Third party caused delays		--------contractor_claims--->		Time compensation	
Relations between Types (Origin/Compensability) and Owner's Remedy of Delay					
Relation name	**Source concept**	**Source card.**	**Target concept**	**Value type**	**Inverse relation**
owner_claims	DelaysClassifiedByTheirOrigin DelaysClassifiedByTheirCompensability	single	Remedy	instance	null
Non-excusable delays		--------owner_claims--->		Cost compensation	
Contractor caused delays		--------owner_claims--->		Cost compensation	
Relations between Types (Compensability) and Award of Delay					
Relation name	**Source concept**	**Source card.**	**Target concept**	**Value type**	**Inverse relation**
awarded_by	DelaysClassifiedByTheirCompensability	single	Award	instance	null
Excusable compensable delays		--------awarded_by--->		Extension of time + Cost compensation to contractor	
Excusable non-compensable delays		--------awarded_by--->		Extension of time	
Non-excusable delays		--------awarded_by--->		Liquidated damages	
Relations between Selection Criteria and Related Analysis Technique of Delay					
Relation name	**Source concept**	**Source card.**	**Target concept**	**Value type**	**Inverse relation**
select	SelectionCriteria	multiple	StaticTechniques DynamicTechniques	instance	null
Selection criterion		--------select--->		Analysis technique	
Since this section is presented in the literature review on construction delay in detail (in section 2.8.3.3), it will not be handled again.					

Table 4.7: Table of details of relations at instances level (continued)

Relations between Causes and Related Prevention Matters of Delay					
Relation name	**Source concept**	**Source card.**	**Target concept**	**Value type**	**Inverse relation**
controlled_by	ContractorCauses OwnerCauses ExternalCauses	multiple	PreventionDuringPlanning PreventionDuringConstruction PreventionDuringAnalysis	instance	if_not_may_lead
if_not_may_lead	PreventionDuringPlanning PreventionDuringConstruction PreventionDuringAnalysis	multiple	ContractorCauses OwnerCauses ExternalCauses	instance	controlled_by
Causes		<---if_not_may_lead--------controlled_by--->		Prevention Matters	
Since this section is presented in the literature review on construction delay in detail (in section 2.11.2), it will not be handled again.					

4.3 Formalization

Formalization step is the description of the ontology in a formal language like description logic or frame-based models. For the representation of the model, UML class diagrams can be used as they are used for the static representation of an application and easy to understand with their standard graphical representation. In this method, classes that describe the concepts are presented in rectangles divided into three with the information of name, attributes and operations (operations are not used in ontologies so this part is left empty). Attribute description and their values may also be represented in that division. Relationships between the classes (both taxonomic and ad hoc ones) are represented through solid lines indicating the type of the relations. Taxonomic relations (generalization/is-a, aggregation/part-of, instance-of etc.) end up with a characteristic form whereas, other binary relations are solid arrows (association) with the information of the relation name typed along (Gómez-Pérez et al., 2004; Lee et al., 2005a; Purchase et al., 2001). Since this ontology is a frame-based model, it may easily be represented through UML class diagrams. So, representation by UML class diagrams is selected for representation of the complete ontological model of this study. UML class diagrams are also preferred to present relations in the conceptualization step of the ontology. So, formalization step is partially carried out in the conceptualization step of the ontology. However, only the following figure (Figure 4.4) forms the complete formalized representation of the delay analysis ontology. In this figure, main concepts of the ontology (with their attribute information as long as it is identified) are presented through their relations (taxonomic is-a relations and associations).



Legend: classes; relations at class level; inheritance relations; relations at instance level

Figure 4.4: Complete model of delay analysis ontology

4.4 Integration

Integration step is the usage of a previously created ontology to ease the development process. However, since there is no available ontology related to the delay analysis, integration step is not applicable for this study.

4.5 Evaluation and Maintenance

Evaluation step is a continuous supportive activity during development process of an ontology. It is totally taken into consideration and it perfectly guided formation of the ontology during its construction process as it is proposed. Also, a created ontology may be evaluated before its reuse in another study. So, a final evaluation step is performed before the implementation step to include the possible changes after evaluation of the ontology. In addition to this, maintenance step constitutes the last step of the development process of the ontology with its indication of need to update the ontology after its creation and during its life time. Accordingly; to meet these two objectives, validation of the ontology through three case studies is made by expert reports on claim analysis. Details about the evaluation process are handled separately under following chapter (Chapter 5) with the heading of "Validation". Thus, a last evaluation and an initial update of the ontology are made as a first step of maintenance period of the ontology.

4.6 Implementation

Implementation step is the process of loading of the ontology in an ontology construction program. Protégé-Frames with the version of "Protégé-3.4.7" is used in this study for this purpose. Accordingly, RDF language is selected for the ontology files. A view from the Protégé-Frames can be seen in the following figure (Figure 4.5).

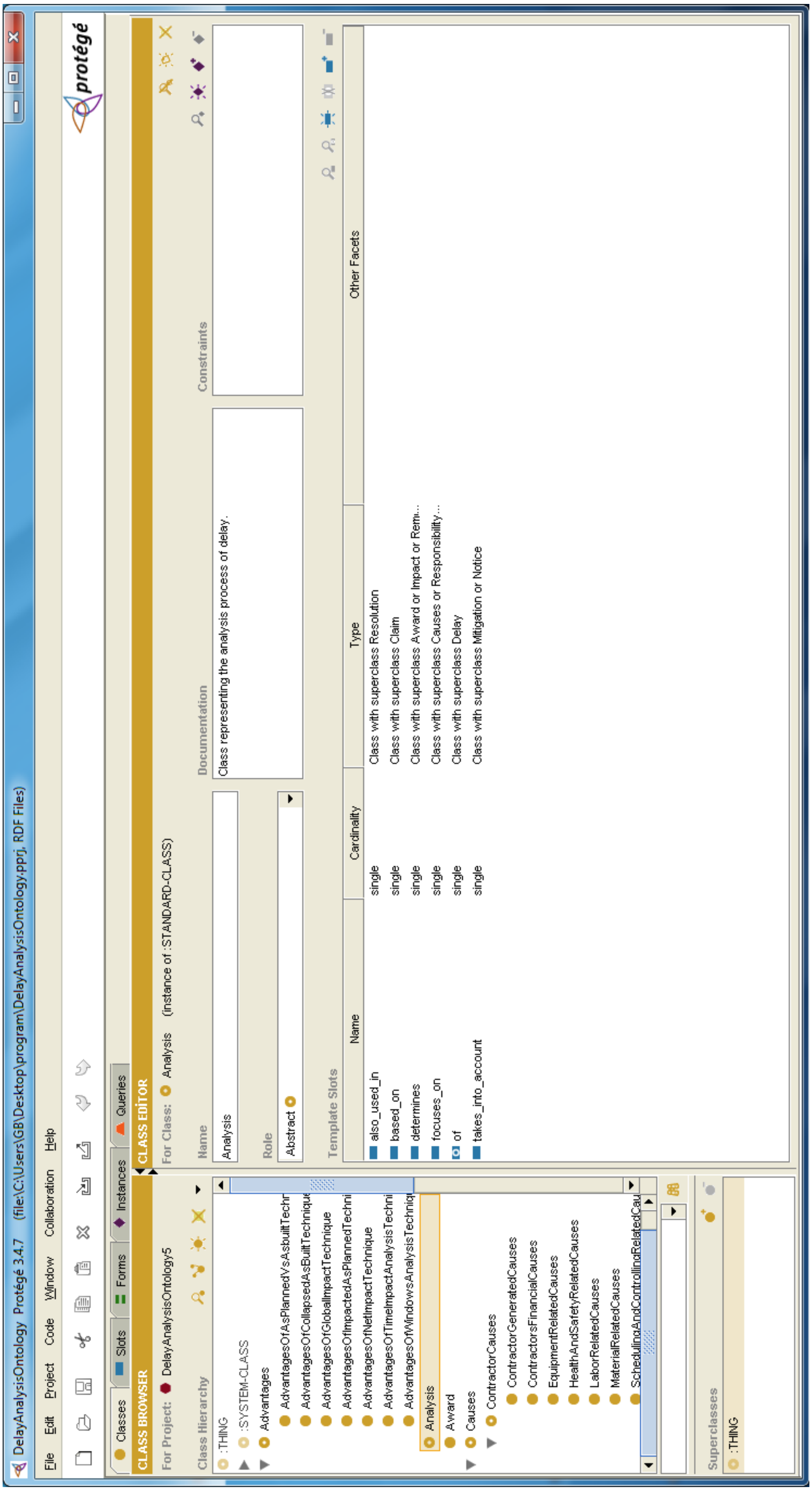


Figure 4.5: View from Protégé-Frames

CHAPTER 5

VALIDATION

This chapter presents the validation process of the ontology through a brief *introductory information* and the *three case studies* following that with the *conclusion to validation*.

5.1 Introduction to Validation

Evaluation of ontologies is a vital step that is needed to be made in the life time of an ontology. Evaluation during the whole construction process of the ontology not only guides the process, but also brings the quality and provides the creation of the ontology that meets the essential need. Moreover; continuing on evaluation of the ontologies, namely evaluations made after the construction process depict the reliability of the ontology. Since ontologies are constructed on the purpose of knowledge sharing and reuse; just like any other resource that would be used in knowledge systems, evaluation of the content before publishing and usage is important. So, developers of the ontologies should go through an evaluation process that would be most suitable for their ontology after the completion of construction process. As the ontologies evolve with time, maintenance period of an ontology also requires evaluations with their usage and updates to keep the ontology valid (Corcho et al., 2003; Gómez-Pérez, 2001; Gómez-Pérez et al., 2004).

As it is previously mentioned in the methodologies for ontology construction section of this study, there are no certain guidelines for the construction of ontologies. Every construction team presented their own procedures for development processes. Afterwards, some reliable methods arose between all and gained popularity. Same situation is also observed with evaluation processes of ontologies. Gruninger and Fox (1995) present one of the initial evaluation studies as competency questions that undertake the queries helping the construction of the ontology. These questions clarify what is needed and how it should be presented. Competency questions can also be used for the evaluation of created ontologies before usage. There are some design and evaluation criteria again used in both construction and usage periods of ontologies. Gruber’s (1993b) previously mentioned five design criteria are; clarity, coherence, extendibility, minimal encoding bias and minimal ontological commitment. Gómez-Pérez (1996) identifies the criteria as; consistency, completeness, conciseness, expandability and sensitiveness. Similarly, Fox and Grüninger (1997) present evaluation criteria based on investigation of ontology characteristics such as; functional completeness, generality, efficiency, perspicuity, precision/granularity and minimality. These characteristics of the ontology provide the basic considerations that should be taken into account when constructing ontologies. They are also the ones that give the first impression about the reliability of a created ontology. In addition to ontology characteristics, Gómez-Pérez (1996) presents evaluation criteria for taxonomic knowledge in frame-based ontologies in the groups of inconsistency, incompleteness and redundancy. Possible errors (circularity errors, partition errors, semantic errors, grammatical errors, etc.) are presented in this study to help the construction and evaluation processes of the ontologies.

There are also ontology evaluation tools published with different capabilities. However; since they are specific in nature, they can be considered to be beyond the scope of this study. Moreover; since most of the developers have some work on evaluation of ontologies, there are various techniques presented on this purpose. Still most of them have limited content that makes them ontology-specific; there is no universal technique available for evaluation of ontologies. Detailed investigation of techniques can be found in the study of Tartir et al. (2010). In addition to that, further information on evaluation of ontologies is available in the study of Vrandečić (2010).

Gómez-Pérez (1996) explains the ontology evaluation issue as the judgment on the conformity of the ontology to the intended use and reality of the world according to a frame of reference. Evaluation procedure consists of two phases as ontology verification and ontology validation. These two phases distinguish the evaluation processes like verification phase for the ontology under construction and validation phase for the created ontology. They are defined as (Gómez-Pérez et al., 2004):

> ***Ontology Verification*** *refers to building the ontology correctly, that is, ensuring that its definitions implement correctly the ontology requirements and competency questions, or function correctly in the real world.*
>
> ***Ontology Validation*** *refers to whether the ontology definitions really model the real world for which the ontology was created. The goal is to prove that the world model (if it exists and is known) is compliant with the world modeled formally.*

When it comes to the ontology of this study; in the grand scheme of things, since it is constructed with a methodology (METHONTOLOGY) that indicates evaluation step as a continuous step during the construction of the ontology, verification of the ontology was in concern from the beginning to the end of the construction process. Competency questions are used in the specification step of the methodology. According to the basics of the methodology, all the data are built through the literature review on delay analysis. Also the evaluation criteria presented by different researchers (Fox and Grüninger, 1997; Gómez-Pérez, 1996; Gruber, 1993b) light the way for the construction of the ontology, and are taken into consideration as far as possible. Objectivity is tried to be provided to prevent ambiguity and inconsistent definitions are not included in the ontology. Also, the created ontology is open to update with its common representation system and has only the common definitions of the subject, so does not limit its users when its usage is in question. Moreover; for the implementation of the ontology, a reliable tool (Protégé) is used that would form an anticipated ontology skeleton. To sum up, in a kind of way evaluation of the ontology during construction phase, namely verification of the ontology is made. Since the ontology is totally based on literature review and its possible users would be the companies, demonstration of compliance of the ontology with real world becomes essential. So, validation of the ontology is the primary concern in the evaluation of the ontology in this study. On this purpose; between previously presented options for validation (expert interviews, case studies, comparative analysis of industry documents and competency questions), the validation of the ontology through case studies is selected. Details of the validation process are available in the following section.

5.2 Case Studies

The ontology is constructed on the primary purpose of information sharing in delay analysis issue. From the daily life point of view, companies would be its principal users through computers in the claim management issue and such. Companies generally face with this common problem, delay, and various factors that cause the delay also make the analysis of the delay difficult. So, each party to the contract come up with their own claims about the situation and dispute arises. At this point, parties usually make appeal to neutral experts for the resolution of dispute. Experts make in-depth research on the cases and make analysis of delay accordingly. In the light of these, in the validation process, expert reports are used as case studies to demonstrate the compliance of this literature review based ontology to the real world.

Each expert report is read several times and main concepts of the reports are retrieved as it is the case in ontology development. First concepts in the reports are highlighted, then all these concepts (sometimes complete sentences) are transferred into a comparison table as “phrases in report” and their corresponding phrases are searched in the created ontology. Concepts that imply the previously remarked information in the ontology are not taken into account second time, but some concepts in sentences are handled twice or more in a single report not to ruin the integrity of the direct phrases of the report. Phrases of the report are totally kept in quotation marks, whereas only concepts in the ontology are presented in quotation marks. To specify the place of the concept in the ontology, upper concepts defined are also included. For the inclusion of information of relations in the ontology; the word "under" is used to refer taxonomic relations between concepts, whereas the demonstration "-association_name-" is used for the associations (namely binary relations). So, "phrases in ontology" are indicated in path forms such as: "concept" under "concept" -association- "concept". Corresponding phrases in the ontology are matched with the underlined concepts in the report. Sometimes one concept in the report is matched with several concepts of the ontology. Phrases of the ontology are presented according to the appearing order of concepts in the phrase of the report. Thus comparison of the real world with the provided ontology is made through these case studies. Details about the case studies are presented in the following sections.

5.2.1 Project A: Power Plant Project in Bulgaria

A Bulgarian based company has awarded a contract for the replacement of its power station's existing boiler. Furthermore; contractor has engaged a subcontractor who is responsible from the fabrication, delivery and erection of the boiler steel structure including also the erection of the boiler. So, contractor and subcontractor made contracts as Steel Structure Fabrication Contract, Steel Structure Erection Contract, and Boiler Erection Contract for the works and also Supplementary Agreement which is an umbrella agreement for the coordination of contracts.

Later on, delays occurred and contractor issued a termination notice for the termination of Steel Structure Erection Contract and the Boiler Erection Contract. As a response to this notice subcontractor filed a request for arbitration with the claim of termination decision was wrong.

The works contracted to subcontractor mainly include the fabrication of structural steel at its factory located at Gerede-Turkey, followed by the delivery of fabricated material to the project site and finally erection of the steel structure including the erection of boiler pressure parts and also lifting of the steam drum. Besides, all design drawings have to be prepared and submitted by contractor to subcontractor within the contractually specified dates. Network diagram of activities with the corresponding responsibilities can be seen from the following figure (Figure 5.1).

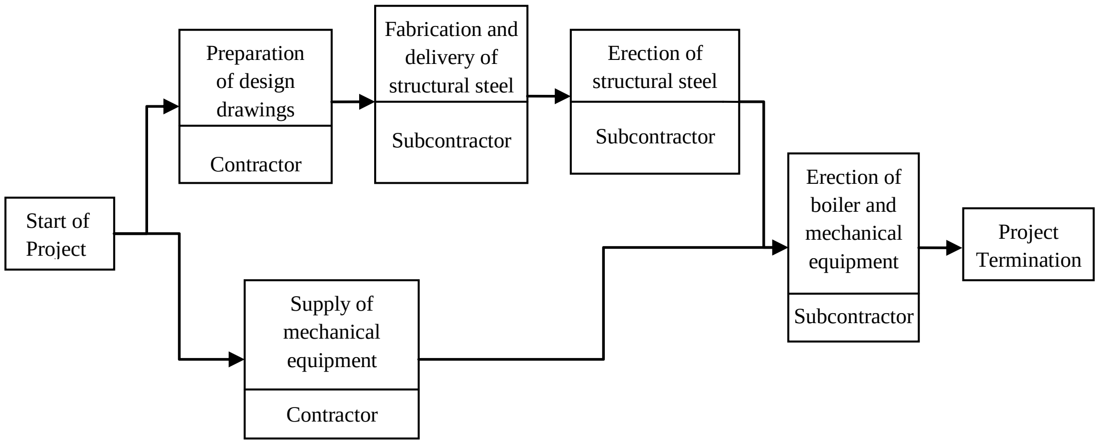


Figure 5.1: Activities and responsible parties in the project

With this introductory information, the project can be named as a small-scale project with low technological complexity for the subcontracting company when the volume of works and total budget are considered. However, the project site has limited accessibility that increases construction complexity since it is confined from three of its sides with the existing buildings. The physical boundaries and working conditions prevailing at the construction site display unique characteristics which should be taken into account during planning and delay analysis.

For the analysis of delay, there is a conflicting report previously presented which holds the subcontractor responsible for the delays. This report indicates that subcontractor generally failed to fulfill its contractual steel structure fabrication, delivery and erection responsibilities in accordance with his contractual requirements. Report also mentions that contractor failed to deliver the design drawings at the project issue dates as stipulated in the contract, however it claims that the late deliveries were not controlling the delay to the execution of the project. So, subcontractor is found directly responsible for the delay.

However, current experts find flaws in the previous report since it is not based upon factual data and not presenting sound methodology for analysis of the case. Major findings of the main expert report are; dominant causes of the delay are contractor’s inability to submit design drawings and materials on time and sending frequent revisions to already submitted drawings, even if poor management, coordination and resource allocation of subcontractor have an effect on the delay. Thus, originally contractor is found responsible for the delay.

Further details about the report and comparison of the report with the ontology are presented in the following table (Table 5.1). Concepts in the expert report are extracted and the corresponding concepts in the ontology are matched in this table. Since the ontology is based on owner-contractor relationship and report has a contractor-subcontractor point of view; contractor in the report refers to owner in the ontology, whereas subcontractor refers to contractor in the ontology. Here are some examples of this process through direct quotations from the report where matching phrases of the ontology are given in parenthesis:

Phrase 1, Findings of previous report: *“The reasons of this delay* (“Causes”) *are subcontractor’s actions* (“Contractor (or his subcontractors) responsible”) *which are; inability to acquire sufficient quantities of raw materials* (“Unavailability of materials on site on time”), *other projects were given available shop space* (“Poor/Inappropriate procurement method/programming of construction material”) *and inadequate project management* (“Unsuitable management structure and style of contractor”) *and planning* (“Poor project planning and scheduling by contractor”).*”*

Phrase 2, Findings of main report: *“However, there may be other disruptions* (“Disruption”) *and concurrent delays* (“Concurrent delays”) *that are under the control of either* (“Owner (or his agents) responsible”) (“Contractor (or his subcontractors) responsible”), *both* (“Both contractual parties responsible”) *or none of the parties* (“Neither contractual party responsible”) *that are not included in the* *delay analysis* ("Analysis"). *Poor management* ("Unsuitable management structure and style of contractor"), *coordination* ("Poor communication and coordination by contractor with other parties") *and resource allocation* (-The term will be added-) *by subcontractor could also decreased productivity* ("Lost Productivity") ("Lost productivity costs") *of works and resulted in delays, however, it is believed that inability of contractor* ("Owner (or his agents) responsible") *to submit design drawings* ("Failure on the part of the owner to review and approve design documents, schedules, and material on time") *and materials on time* ("Problems/Delays in materials, labor or goods that are in responsibility of the owner") *and sending frequent revisions to already submitted drawings* ("Excessive scope changes and constructive changed orders") *are the "initial" and "dominant"* (-The term will be added-) *causes of delay* ("Causes") *leading to delay in the forthcoming activities and consequently, in project completion* ("Critical delays: Delay to completion")."

These two phrases and rest of the phrases compared are presented in the following table (Table 5.1). The most occurring terms in the report and the general information are handled in the part "General Terms and Information in the Report". In addition to this, documents used through analysis of the delay are presented in the "Documents used for Analysis in the Report" part of the table. "Findings of the Previous Expert Report" and "Pitfalls of the Previous Expert Report" are presented respectively. Finally table is completed with the last part and main part which is "Findings of the Current Expert Report".

Table 5.1: Comparison table for Case Study A

General Terms and Information in the Report	
Phrase in the Report	**Phrase in the Ontology**
"analysis of delays"	"Analysis" -of- "Delay"
"consequences of delays"	"Impact" -of- "Delay"
"impacts of delays"	"Impact" -of- "Delay"
"claim"	"Claim" -for- "Impact" -of- "Delay"
"dispute"	"Dispute" -is-a- "Result" -of- "Claim" -for- "Impact" -of- "Delay"

Table 5.1: Comparison table for Case Study A (continued)

<table>
<tr><th colspan="2">General Terms and Information in the Report (continued)</th></tr>
<tr><th>Phrase in the Report</th><th>Phrase in the Ontology</th></tr>
<tr><td>"arbitration"</td><td>"Arbitration" under "Alternative Dispute Resolution" under "Resolution By Third Party" under "Resolution" -of- "Dispute" -is-a- "Result" -of- "Claim" -for- "Impact" -of- "Delay"</td></tr>
<tr><td>"disruption"</td><td>"Disruption" under "Impact" -of- "Delay"</td></tr>
<tr><td>"parties"</td><td>"Parties" -in- "Claim" -for- "Impact" -of- "Delay"</td></tr>
<tr><td>"claimant"</td><td>"Claimant" under "Parties" -in- "Claim" -for- "Impact" -of- "Delay"</td></tr>
<tr><td>"respondent"</td><td>"Responsible" under "Parties" -in- "Claim" -for- "Impact" -of- "Delay"</td></tr>
<tr><td>"project documentation"</td><td>"Data" -used_for- "Analysis" -of- "Delay"</td></tr>
<tr><td>"network analysis"</td><td>"Dynamic Techniques" under "Techniques" -used_for- "Analysis" -of- "Delay"</td></tr>
<tr><td>"window analysis"</td><td>"Window analysis technique (/Snapshot/Current period analysis (CPA))" under "Dynamic Techniques" under "Techniques" -used_for- "Analysis" -of- "Delay"</td></tr>
<tr><td>"critical path method (CPM) or critical path analysis"</td><td>"Dynamic Techniques" under "Techniques" -used_for- "Analysis" -of- "Delay"</td></tr>
<tr><td>"schedule analysis"</td><td>"Analyze Original Schedule" under "Tender and Programme Analysis" under "Methodology Steps" -for- "Analysis" -of- "Delay"</td></tr>
<tr><td>"small-scale project"</td><td>"Short duration project/Small contract values: Simple techniques" under "Project Duration/Scale/Complexity" under "Selection Criteria" -for- "Techniques" -used_for- "Analysis" -of- "Delay"</td></tr>
<tr><td>"...subcontractor is only responsible from..."</td><td>"Contractor (or his subcontractors) responsible" under "Responsibility" -of- "Delay"</td></tr>
<tr><td>"...executives were interviewed..."</td><td>"The statements of the personnel involved in the project" under "Witness Data" under "Records" under "Post-contract Documents" under "Data" -used_for- "Analysis" -of- "Delay"</td></tr>
<tr><td>"Subcontractor has signed a contract with “...” for the hiring of a tower crane."</td><td>"Subcontract Documents" under "Contract Documents" under "Data" -used_for- "Analysis" -of- "Delay"</td></tr>
<tr><td>"delays in the project completion"</td><td>"Critical delays: Delay to completion" under "Delays Classified By Their Criticality" under "Types" -of- "Delay"</td></tr>
<tr><td rowspan="2">"“Delay” is the situation where works take longer than originally intended. “Disruption” by contrast refers to the situation where the works are rendered more difficult by some act of hindrance or prevention."</td><td>"Delay"</td></tr>
<tr><td>"Disruption" under "Impact" -of- "Delay"</td></tr>
<tr><td rowspan="2">"...identify the sources of delay, their consequences and overall impact on the project..."</td><td>"Causes" -of- "Delay</td></tr>
<tr><td>"Impact" -of- "Delay"</td></tr>
</table>

Table 5.1: Comparison table for Case Study A (continued)

General Terms and Information in the Report (continued)	
Phrase in the Report	**Phrase in the Ontology**
"...causation and responsibility analysis to identify the causes of delays..."	"Responsibility" -of- "Delay"
	"Causes" -of- "Delay"
"Delays in construction projects can lead to different consequences such as late completion, acceleration, productivity loss, cost overrun and even contract termination."	"Impact" -of- "Delay"
	"Time Overrun" under "Impact" -of- "Delay"
	"Acceleration" under "Impact" -of- "Delay"
	"Lost Productivity" under "Impact" -of- "Delay"
	"Cost Overrun" under "Impact" -of- "Delay"
	"Contract Termination" under "Impact" -of- "Delay"
"Some of the schedule delay analysis methods are listed as follows: Global Impact Technique, As-planned versus As-built Method, Impact As-planned Method, and Time Impact Method."	"Techniques" -used_for- "Analysis" -of- "Delay"
	"Global impact technique (Bar chart analysis)" under "Static Techniques" under "Techniques" -used_for- "Analysis" -of- "Delay"
	"As-planned vs as-built technique" under "Dynamic Techniques" under "Techniques" -used_for- "Analysis" -of- "Delay"
	"Impacted as-planned technique" under "Dynamic Techniques" under "Techniques" -used_for- "Analysis" -of- "Delay"
	"Time impact analysis technique (/Fragnet)" under "Dynamic Techniques" under "Techniques" - used_for- "Analysis" -of- "Delay"
"There are various schedule delay analysis methods, which method to use depends on availability of information, scheduling options (network-based or bar charts) and existence of different type of schedules (as-planned, as-built, updates, adjusted)."	"Availability of Data: (information/factual material/records available)" under "Selection Criteria" -for- "Techniques" -used_for- "Analysis" -of- "Delay"
	"Schedule Type/Quality" under "Selection Criteria" -for- "Techniques" -used_for- "Analysis" -of- "Delay"
	"CPM network schedules/Large project" under "Schedule Type/Quality" under "Selection Criteria" -for- "Techniques" -used_for- "Analysis" -of- "Delay"
	"Bar chart schedules/Small project" under "Schedule Type/Quality" under "Selection Criteria" -for- "Techniques" -used_for- "Analysis" -of- "Delay"
	"Schedule Used" under "Selection Criteria" -for- "Techniques" -used_for- "Analysis" -of- "Delay"
	"As-planned schedule: the original schedule" under "Major Schedules" under "Post-contract Documents" under "Data" -used_for- "Analysis" -of- "Delay"
	"As-built schedule: actual/final adjusted schedule" under "Major Schedules" under "Post-contract Documents" under "Data" -used_for- "Analysis" -of- "Delay"
	"Adjusted/Updated schedule: schedule depicting impacts by changes on as-planned schedule" under "Major Schedules" under "Post-contract Documents" under "Data" -used_for- "Analysis" -of- "Delay"

Table 5.1: Comparison table for Case Study A (continued)

Documents Used for Analysis in the Report	
Phrase in the Report	**Phrase in the Ontology**
"contracts"	"Contract Documents" under "Data" -used_for- "Analysis" -of- "Delay"
"contract termination date"	"Termination clauses: Termination for default and Termination for convenience" under "Contract Clauses" under "Main Contract Documents" under " Contract Documents" under "Data" -used_for- "Analysis" -of- "Delay"
"completion guarantee dates in the contract"	"Dates for commencement and completion" under "Introduction" under "Parts" -of- "Claim" -for- "Impact" -of- "Delay"
"termination notice"	"Notices and other formal documents" under "Formal Submittals" under "Records" under "Post-contract Documents" under "Data" -used_for- "Analysis" -of- "Delay"
"statement of delay"	"Statement of Claim" under "Parts" -of- "Claim" -for- "Impact" -of- "Delay"
"statement for defense/counterclaim"	"Statement of Claim" under "Parts" -of- "Claim" -for- "Impact" -of- "Delay"
	"Counter-claims" under "Kinds" -of- "Claim" -for- "Impact" -of- "Delay"
"request for arbitration"	"Notices and other formal documents" under "Formal Submittals" under "Records" under "Post-contract Documents" under "Data" -used_for- "Analysis" -of- "Delay"
"site photographs"	"Dated photographs of the site at large or of special pieces of work" under "Media Records" under "Records" under "Post-contract Documents" under "Data" -used_for- "Analysis" -of- "Delay"
"correspondence"	"Correspondence Data" under "Records" under "Post-contract Documents" under "Data" -used_for- "Analysis" -of- "Delay"
"email correspondence"	"Correspondence by e-mails" under "Correspondence Data" under "Records" under "Post-contract Documents" under "Data" -used_for- "Analysis" -of- "Delay"
"fax messages"	(-The term will be added-)
"site meeting"	"Minutes of Meetings" under "Records" under "Post-contract Documents" under "Data" -used_for- "Analysis" -of- "Delay"
"interviews with executives"	"Interviews" under "Witness Data" under "Records" under "Post-contract Documents" under "Data" -used_for- "Analysis" -of- "Delay"
	"The statements of the personnel involved in the project" under "Witness Data" under "Records" under "Post-contract Documents" under "Data" -used_for- "Analysis" -of- "Delay"
"general layout plan"	"Plans and Programmes" under "Main Contract Documents" under "Contract Documents" under "Data" -used_for- "Analysis" -of- "Delay"

Table 5.1: Comparison table for Case Study A (continued)

Documents Used for Analysis in the Report (continued)	
Phrase in the Report	**Phrase in the Ontology**
"preliminary site plan"	"Plans and Programmes" under "Main Contract Documents" under "Contract Documents" under "Data" -used_for- "Analysis" -of- "Delay"
"design drawings"	"Design Drawings" under "Main Contract Documents" under "Contract Documents" under "Data" -used_for- "Analysis" -of- "Delay"
"submitted and revised drawings"	"Drawing register: details of amendments and revisions made to plans" under "Registers" under "Records" under "Post-contract Documents" under "Data" -used_for- "Analysis" -of- "Delay"
"schedule of project"	"Major Schedules" under "Post-contract Documents" under "Data" -used_for- "Analysis" -of- "Delay"
"actual durations"	"As-built schedule: actual/final adjusted schedule" under "Major Schedules" under "Post-contract Documents" under "Data" -used_for- "Analysis" -of- "Delay"
"actual submission dates"	"As-built schedule: actual/final adjusted schedule" under "Major Schedules" under "Post-contract Documents" under "Data" -used_for- "Analysis" -of- "Delay"
"project construction reports"	"Construction progress reports diary" under "Diaries" under "Records" under "Post-contract Documents" under "Data" -used_for- "Analysis" -of- "Delay"
"project records"	"Records" under "Post-contract Documents" under "Data" -used_for- "Analysis" -of- "Delay"
"expert report"	"Expert witness statements" under "Witness Data" under "Records" under "Post-contract Documents" under "Data" -used_for- "Analysis" -of- "Delay"
"instruction to subcontractor"	"Instructions issued by architect" under "Formal Submittals" under "Records" under "Post-contract Documents" under "Data" -used_for- "Analysis" -of- "Delay"
Findings of the Previous Expert Report	
Phrase in the Report	**Phrase in the Ontology**
"Subcontractor generally failed to fulfill its contractual steel structure fabrication, delivery and erection responsibilities in accordance with its contractual requirements."	"Nonadherence to contract conditions by contractor" under "Contractor Generated Causes" under "Contractor Causes" under "Causes" -of- "Delay"
	"Delay in manufacturing special building materials" under "Material Related Causes" under "Contractor Causes" under "Causes" -of- "Delay"
	"Delay in delivery of materials" under "Material Related Causes" under "Contractor Causes" under "Causes" -of- "Delay"
"Contractor also failed to deliver the design drawings at the project issue dates as stipulated in the contract, the late deliveries were not controlling the delay to the execution of the project."	"Failure on the part of the owner to review and approve design documents, schedules, and material on time" under "Owner Generated Causes" under "Owner Causes" under "Causes" -of- "Delay"
	"Non-critical delays: Delay to progress" under "Delays Classified By Their Criticality" under "Types" -of- "Delay"

Table 5.1: Comparison table for Case Study A (continued)

<table>
<tr><th colspan="2">Findings of the Previous Expert Report (continued)</th></tr>
<tr><th>Phrase in the Report</th><th>Phrase in the Ontology</th></tr>
<tr><td rowspan="4">"Subcontractor was found directly responsible for approximately 20 weeks or 140 calendar days of delay."</td><td>"Contractor (or his subcontractors) responsible" under "Responsibility" -of- "Delay"</td></tr>
<tr><td>"Contractor caused delays" under "Delays Classified By Their Origin" under "Types" -of- "Delay"</td></tr>
<tr><td>"Non-excusable delays" under "Delays Classified By Their Compensability" under "Types" -of- "Delay"</td></tr>
<tr><td>"Critical delays: Delay to completion" under "Delays Classified By Their Criticality" under "Types" -of- "Delay"</td></tr>
<tr><td rowspan="3">"...steel price escalation..."</td><td>"Inflation/Escalation of prices" under "Economical Causes" under "External Causes" under "Causes" -of- "Delay"</td></tr>
<tr><td>"Changes in materials prices in unit-priced contracts" under "Owner's Financial Causes" under "Owner Causes" under "Causes" -of- "Delay"</td></tr>
<tr><td>"Changes in materials prices in fixed-priced contracts" under "Material Related Causes" under "Contractor Causes" under "Causes" -of- "Delay"</td></tr>
<tr><td>"...subcontractor would not have been able to progress the fabrication any further."</td><td>"Nonadherence to contract conditions by contractor" under "Contractor Generated Causes" under "Contractor Causes" under "Causes" -of- "Delay"</td></tr>
<tr><td rowspan="3">"Subcontractor failed to erect the steel structure in an efficient and effective manner, despite the fact that it had on site more than sufficient amounts of steel structure material."</td><td>"Inappropriate/Inadequate/misuse of material" under "Material Related Causes" under "Contractor Causes" under "Causes" -of- "Delay"</td></tr>
<tr><td>"Low productivity/efficiency level of labors" under "Labor Related Causes" under "Contractor Causes" under "Causes" -of- "Delay"</td></tr>
<tr><td>"Low contractor productivity" under "Contractor Generated Causes" under "Contractor Causes" under "Causes" -of- "Delay"</td></tr>
<tr><td>"Allocation of resources to other projects by subcontractor: "raw materials that were needed for the Project were utilized by subcontractor to fulfill obligations to other clients and projects.""</td><td>"Poor/Inappropriate procurement method/programming of construction materials" under "Material Related Causes" under "Contractor Causes" under "Causes" -of- "Delay"</td></tr>
<tr><td rowspan="2">"...very frequent revisions that render the manufacturing process..."</td><td>"Design changes/modifications by owner or his agent during construction" under "Design Related Causes" under "Owner Causes" under "Causes" -of- "Delay"</td></tr>
<tr><td>"Excessive scope changes and constructive changed orders" under "Design Related Causes" under "Owner Causes" under "Causes" -of- "Delay"</td></tr>
<tr><td rowspan="3">"Reasons of low productivity: Factors include, dilution of supervision, reassignment of manpower, crew size inefficiency, learning curve and overtime."</td><td>"Low productivity/efficiency level of labors" under "Labor Related Causes" under "Contractor Causes" under "Causes" -of- "Delay"</td></tr>
<tr><td>"Poor labor supervision" under "Contractor Generated Causes" under "Contractor Causes" under "Causes" -of- "Delay"</td></tr>
<tr><td>"Excessive turnover in contractor's staff" under "Contractor Generated Causes" under "Contractor Causes" under "Causes" -of- "Delay"</td></tr>
</table>

Table 5.1: Comparison table for Case Study A (continued)

Findings of the Previous Expert Report (continued)	
Phrase in the Report	**Phrase in the Ontology**
"Reasons of low productivity: Factors include, dilution of supervision, reassignment of manpower, crew size inefficiency, learning curve and overtime."	"Frequent change of subcontractors (because of their inefficient work)" under "Subcontractor Causes" under "Contractor Causes" under "Causes" -of- "Delay"
	"Staff turnover" under "Lost productivity costs" under "Contractor's Direct Costs" under "Contractor's Costs" under "Cost Overrun" under "Impact" -of- "Delay"
	"Poor distribution of labor" under "Labor Related Causes" under "Contractor Causes" under "Causes" -of- "Delay"
	"Changes in manpower levels and distribution" under "Lost productivity costs" under "Contractor's Direct Costs" under "Contractor's Costs" under "Cost Overrun" under "Impact" -of- "Delay"
	"Loss of learning curve" under "Lost productivity costs" under "Contractor's Direct Costs" under "Contractor's Costs" under "Cost Overrun" under "Impact" -of- "Delay"
	"Too much overtime for labor" under "Labor Related Causes" under "Contractor Causes" under "Causes" -of- "Delay"
	"Severe overtime and shifts" under "Labor Related Causes" under "Contractor Causes" under "Causes" -of- "Delay"
"...any delay occurred due to the absence of a tower crane and operator..."	"Unavailabilty of equipment and tool on site" under "Equipment Related Causes" under "Contractor Causes" under "Causes" -of- "Delay"
	"Lack of high-technology mechanical equipment/Outdated equipment" under "Equipment Related Causes" under "Contractor Causes" under "Causes" -of- "Delay"
	"Inadequate skill of equipment-operator" under "Equipment Related Causes" under "Contractor Causes" under "Causes" -of- "Delay"
	"Unavailability of site labors" under "Labors Related Causes" under "Contractor Causes" under "Causes" -of- "Delay"
"The reasons of this delay are subcontractor's actions which are; inability to acquire sufficient quantities of raw materials, other projects were given available shop space and inadequate project management and planning."	"Causes" -of- "Delay"
	"Contractor (or his subcontractors) responsible" under "Responsibility" -of- "Delay"
	"Unavailability of materials on site on time" under "Material Related Causes" under "Contractor Causes" under "Causes" -of- "Delay"
	"Poor/Inappropriate procurement method/programming of construction materials" under "Material Related Causes" under "Contractor Causes" under "Causes" -of- "Delay"
	"Unsuitable management structure and style of contractor" under "Contractor Generated Causes" under "Contractor Causes" under "Causes" -of- "Delay"
	"Poor project planning and scheduling by contractor" under "Scheduling and Controlling Related Causes" under "Contractor Causes" under "Causes" -of- "Delay"

Table 5.1: Comparison table for Case Study A (continued)

Pitfalls of the Previous Expert Report	
Phrase in the Report	**Phrase in the Ontology**
"Report is one-sided as it mainly assesses the delays that may be attributed to subcontractor and ignores the impact of any delays and/or disruptions that are under the responsibility of contractor."	"The analyst should focus on determining the source and magnitude of all critical project delays without regard to the party responsible to achieve an objective analysis." under "Prevention Matters During Analysis" under "Prevention During Analysis" under "Prevention" -of- "Delay"
	"Contractor (or his subcontractors) responsible" under "Responsibility" -of- "Delay"
	"Owner (or his agents) responsible" under "Responsibility" -of- "Delay"
"Lack of a detailed schedule analysis...there is no network or critical path analysis that accompany the report."	"The delay analysis should rely on the contemporaneous project schedules as the basis of analysis to create objectivity as much as possible." under "Prevention Matters During Analysis" under "Prevention During Analysis" under "Prevention" -of- "Delay"
"...but fails to integrate physical constraints (such as construction method due to restricted site area) and relations between erection activities and the other activities."	"As with creating and updating schedule, an analyst must have a familiarity with scheduling terminology and be able to accurately interpret the data and results displayed by the schedule." under "Tracking Related Prevention Matters" under "Prevention During Construction" under "Prevention" -of- "Delay"
"Inadequate methodology of the report..."	"Parties might negotiate and agree on methodologies, techniques, and procedure for assessing and resolving different aspects of delay and disruption claims." under "Contract Related Prevention Matters" under "Prevention During Planning" under "Prevention" -of- "Delay"
	"Methodology Steps" -for- "Analysis" -of- "Delay"
"It is not clear how it is decided that “sufficient” work was available to start erection without considering the type of steel elements, sequence of work and quality of submitted drawings."	"Proper, complete and consistent contract documents, work details, drawings and specifications have to be ready and provided before commencement of work." under "Contract Related Prevention Matters" under "Prevention During Planning" under "Prevention" -of- "Delay"
"Unsupported arguments and criticisms to subcontractor that has no factual evidence..."	"Clear agreement on procedure for gathering and keeping records and rules of evidence for claims is needed." under "Contract Related Prevention Matters" under "Prevention During Planning" under "Prevention" -of- "Delay"
"Report carried out this investigation based on the (wrong) assumption that “the weight of steel elements specified at certain dates is an indicator of % completion of the task”."	"Being capable of appropriate use of the methodologies with multidisciplinary knowledge, understanding, and skills, particularly in the areas of scheduling, construction methods, estimating, costing, construction law, and information technology tools." under "Scheduling Related Prevention Matters" under "Prevention During Planning" under "Prevention" -of- "Delay"
"Report is untrue which is premised on unsupported technical data without considering the technical characteristics of the available tower crane."	"Being capable of appropriate use of the methodologies with multidisciplinary knowledge, understanding, and skills, particularly in the areas of scheduling, construction methods, estimating, costing, construction law, and information technology tools." under "Scheduling Related Prevention Matters" under "Prevention During Planning" under "Prevention" -of- "Delay"
"This issue creates a severe concern about the objectivity and validity of the results concluded in the report."	"Contemporaneous project schedules and updating should be used to keep the analysis objective and reliable." under "Tracking Related Prevention Matters" under "Prevention During Construction" under "Prevention" -of- "Delay"

Table 5.1: Comparison table for Case Study A (continued)

Findings of the Current Expert Report	
Phrase in the Report	**Phrase in the Ontology**
"Subcontractor filed a request for arbitration...with the consideration that this Termination Notice is wrongful."	"Notices and other formal documents" under "Formal Submittals" under "Records" under "Post-contract Documents" under "Data" -used_for- "Analysis" -of- "Delay"
	"Suspension of work or wrongful termination by owner" under "Owner Generated Causes" under "Owner Causes" under "Causes" -of- "Delay"
"technological complexity"	"Technological complexity" under "Technological" under "External" under "Causes" -of- "Delay"
"The project site has limited accessibility as it is confined from three of its sides with the existing buildings which increases construction complexity."	"Restricted access to the site/Poor site access and availability" under "Owner Generated Causes" under "Owner Causes" under "Causes" -of- "Delay"
	"Site investigation" under "Witness Data" under "Records" under "Post-contract Documents" under "Data" -used_for- "Analysis" -of- "Delay"
	"Complexity of works" under "Scheduling and Controlling Related Causes" under "Contractor Causes" under "Causes" -of- "Delay"
"physical working conditions"	"Unforeseen site conditions" under "Environmental Causes" under "External Causes" under "Causes" -of- "Delay"
	"Unforeseen ground conditions (rock, acid, sediment basin)" under "Environmental Causes" under "External Causes" under "Causes" -of- "Delay"
	"Unexpected foundation conditions encountered in the field" under "Environmental Causes" under "External Causes" under "Causes" -of- "Delay"
	"Unexpected subsurface conditions (geological problems/water table problems, etc.)" under "Environmental Causes" under "External Causes" under "Causes" -of- "Delay"
"The as-planned schedule (shown in blue) and as-built-schedule (shown in red) are compared."	"Compare actual dates, duration, and logic with original ones by superimposing the schedules in CPM." under "Analyze As-Built Schedule" under "Tender and Programme Analysis" under "Methodology Steps" -for- "Analysis" -of- "Delay"
	"Calculate actual production rates and compare with original ones." under "Analyze As-Built Schedule" under "Tender and Programme Analysis" under "Methodology Steps" -for- "Analysis" -of- "Delay"
	"Compare actual resources utilized with planned ones." under "Analyze As-Built Schedule" under "Tender and Programme Analysis" under "Methodology Steps" -for- "Analysis" -of- "Delay"
"...this constraint is very optimistic as at least a couple of days (lag time) should be necessary..."	"Creation of the schedule too optimistic" under "Scheduling and Controlling Related Causes" under "Contractor Causes" under "Causes" of "Delay"

Table 5.1: Comparison table for Case Study A (continued)

Findings of the Current Expert Report (continued)	
Phrase in the Report	**Phrase in the Ontology**
"...as-planned schedule was constructed based on the assumption that "erection of Tier 3 does not depend on lifting of silos" although the silos (together with their supporting structures) should be placed on Tier 2 and a certain part of Tier 3 could not be erected before silos are placed. It is also clear that, erection works at Tier 3 cannot be completed before all silos are placed. Contractual erection dates were determined neglecting this relationship between especially the coal silos, Tier 2 and Tier 3. Due to the fact that there are existing buildings at 3 sides of the erection area, it would be physically impossible to locate the coal silos in place, if Tier 3 was erected."	"Analyze contractor's original CPM schedule (determine appropriateness: is it realistic and reasonable?)." under "Analyze Original Schedule" under "Tender and Programme Analysis" under "Methodology Steps" -for- "Analysis" -of- "Delay"
"During delay analysis; the progress of work starting from the design, fabrication, delivery and erection of steel structure has been investigated as these activities should be completed to allow for lifting and placement of the drum, which is necessary for erection of the boiler. Thus, in this report, the impact of disruptions on the completion date of steam drum lifting is considered as an appropriate indicator of amount of delay."	"Identify what caused the delay." under "Analyze Cause and Effect" under "Event Analysis" under "Methodology Steps" -for- "Analysis" -of- "Delay"
"Manufacturer has the right to postpone the fabrication activities till the submission date of all the drawings and wait till the end of revisions and reschedule fabrication plans to minimize idle time and optimize the usage of space and human resources considering multiple projects."	"Pacing delays" under "Delays Classified By Their Timing" under "Types" -of- "Delay"
"Even if both parties complied with their responsibilities before the "lifting of coal silos", subcontractor had to wait for the completion of the erection of Tier 3 because lifting of coal silos was delayed by 72 days due to late delivery of silos by contractor."	"Pacing Delay Issue" under "Issues" -relating_to- "Analysis"-of- "Delay"
"Contractor also failed to submit drawings free from mistakes."	"Mistakes and discrepancies in design documents" under "Design Related Causes" under "Owner Causes" under "Causes" -of- "Delay"
"Within this context; it is interesting to note that, although there was no contractual relation between subcontractor and the design team, these two parties established direct contact with each other and communicated in order to find technical solutions to design problems being encountered."	"Improvement of communications between parties" under "Making Improvements" under "Mitigation" -to_reduce- "Impact" -of- "Delay"
"...very frequent revisions jeopardized the material procurement and fabrication process ..."	"Increased risk (Loss of float and Increased sensitivity to further delays)" under "Contractor's Indirect Costs" under "Contractor's Costs" under "Cost Overrun" under "Impact" -of- "Delay"
	"Serial delays" under "Delays Classified By Their Timing" under "Types" -of- "Delay"

Table 5.1: Comparison table for Case Study A (continued)

Findings of the Current Expert Report (continued)	
Phrase in the Report	**Phrase in the Ontology**
"Manufacturing process cannot be controlled and planned any more, which further triggers controlling, coordination, communication and management problems."	"Serial delays" under "Delays Classified By Their Timing" under "Types" -of- "Delay"
	"Ineffective control of the project progress by the contractor/Inadequate progress review" under "Scheduling and Controlling Related Causes" under "Contractor Causes" under "Causes" -of- "Delay"
	"Poor communication and coordination by contractor with other parties" under "Contractor Generated Causes" under "Contractor Causes" under "Causes" -of- "Delay"
	"Poor contract management by contractor" under "Contractor Generated Causes" under "Contractor Causes" under "Causes" -of- "Delay"
	"Poor site management/inspection and supervision by contractor" under "Contractor Generated Causes" under "Contractor Causes" under "Causes" -of- "Delay"
	"Poor subcontract management" under "Contractor Generated Causes" under "Contractor Causes" under "Causes" -of- "Delay"
"Due to the chaotic working environment created by contractor, as-planned schedule could not be followed and even re-planning became impossible."	"Changing the Work Sequence" under "Mitigation" -to_reduce- "Impact" -of- "Delay"
"Sudden revisions were made by contractor and subcontractor was never informed about the progress."	"Poor communication and coordination by owner with other parties" under "Contractual Relationship Related Causes" under "Owner Causes" under "Causes" -of- "Delay"
"...3 members became utterly unusable and had to be re-manufactured resulting in additional cost and time."	"Changes in material types and specifications during construction" under "Design Related Causes" under "Owner Causes" under "Causes" -of- "Delay"
	"Rework due to defective material" under "Material Related Causes" under "Contractor Causes" under "Causes" -of- "Delay"
	"Cost Overrun" under "Impact" -of- "Delay"
	"Time Overrun" under "Impact" -of- "Delay"
"Delay in the delivery of material under the responsibility of contractor..."	"Problems/Delays in materials, labor or goods that are in responsibility of the owner" under "Owner Generated Causes" under "Owner Causes" under "Causes" -of- "Delay"
"Other sources of low productivity which are not under the responsibility of subcontractor such as acceleration, weather conditions, disruptions due to change in the work sequence etc...."	"Acceleration costs" under "Contractor's Direct Costs" under "Contractor's Costs" under "Cost Overrun" under "Impact" -of- "Delay"
	"Shifts in the construction season" under "Lost productivity costs" under "Contractor's Direct Costs" under "Contractor's Costs" under "Cost Overrun" under "Impact" -of- "Delay"
	"Resequencing of work" under "Lost productivity costs" under "Contractor's Direct Costs" under "Contractor's Costs" under "Cost Overrun" under "Impact" -of- "Delay"

Table 5.1: Comparison table for Case Study A (continued)

Findings of the Current Expert Report (continued)	
Phrase in the Report	**Phrase in the Ontology**
"...(matters) which should be taken into account during planning and delay analysis..."	"Prevention During Planning" under "Prevention" -of- "Delay"
	"Prevention During Analysis" under "Prevention" -of- "Delay"
"Physical conditions are explored in detail, before attempting to conduct any delay analysis."	"Contractor should properly inspect and examine the site and its surroundings in detail and to satisfy himself before submitting his tender and signing the contract" under "Contract" under "During planning" under "Prevention" -of- "Delay"
"In the contract; the submission dates of design drawings were determined."	"Clear agreement on drawing and delivery process with schedule (between contractors and consultants) for preparation, submittal and approval of drawings is needed." under "Contract Related Prevention Matters" under "Prevention During Planning" under "Prevention" -of- "Delay"
"The as-planned schedule is updated considering this constraint."	"Design changes should be adequately highlighted and updated on all relevant project documentations (e.g. drawings, specifications, reports, etc.)" under "Change Related Prevention Matters" under "Prevention During Construction" under "Prevention" -of- "Delay"
	"If the analyst notes serious errors in the logic of the schedule, he or she should consider not accepting the contractor's schedule as a valid tool to measure the delays." under "Prevention Matters During Analysis" under "Prevention During Analysis" under "Prevention" -of- "Delay"
"...“lifting of coal gallery/conveyor” becomes critical and any delay regarding this activity delays drum lifting."	"Adequate update to preserve dynamic nature of the schedules" under "Usage of Analysis Technique Issue" under "Issues" -relating_to- "Analysis" of "Delay"
"Subcontractor decided to carry out erection works in parallel to accelerate the project and did not wait for the final issue date of design drawings to start erection."	"Allowing more of the critical work to occur at the same time" under "Changing the Work Sequence" under "Mitigation" -to_reduce- "Impact" -of- "Delay"
	"Changing the method of construction" under "Changing the Contract" under "Mitigation" -to_reduce- "Impact" -of- "Delay"
"Although it was contractor's responsibility to collect the design drawings from designer and then, submit them to subcontractor; due to contractor's poor management and coordination, all drawing submissions were made by designer to subcontractor."	"Work imposed that is not part of the contract by owner" under "Contract Related Causes" under "Owner Causes" under "Causes" -of- "Delay"
	"Poor contract management by consultant" under "Consultant Causes" under "Owner Causes" under "Causes" -of- "Delay"
	"Poor communication and coordination by owner with other parties" under "Contractual Relationship Related Causes" under "Owner Causes" under "Causes" -of- "Delay"

Table 5.1: Comparison table for Case Study A (continued)

Findings of the Current Expert Report (continued)	
Phrase in the Report	**Phrase in the Ontology**
"...force majeure events that are beyond the reasonable control of either party which prevents or impedes the due performance of the contract. "Exceptionally severe weather conditions or the consequences thereof" is listed among force majeure events."	"Force Majeure Causes" under "External Causes" under "Causes" -of- "Delay"
	"Neither contractual party responsible" under "Responsibility" -of- "Delay"
	"Third party caused delays" under "Delays Classified By Their Origin" under "Types" -of- "Delay"
	"Excusable non-compensable delays" under "Delays Classified By Their Compensability" under "Types" -of- "Delay"
	"Inclement Weather Causes" under "External Causes" under "Causes" -of- "Delay"
"...especially high wind significantly affected the productivity of erection process and led to idle time."	"Wind effect on construction activities" under "Inclement Weather Causes" under "External Causes" under "Causes" -of- "Delay"
	"Additional idle labor cost" under "Additional Labor Costs" under "Extended and Increased Field Costs" under "Contractor's Direct Costs" under "Contractor's Costs" under "Cost Overrun" under "Impact" -of- "Delay"
	"Additional standing/idle time" under "Additional Equipment Costs" under "Extended and Increased Field Costs" under "Contractor's Direct Costs" under "Contractor's Costs" under "Cost Overrun" under "Impact" -of- "Delay"
"...the steam drum lifting activity could have been significantly affected from strong wind and snow."	"Wind effect on construction activities" under "Inclement Weather Causes" under "External Causes" under "Causes" -of- "Delay"
	"Snow effect on construction activities" under "Inclement Weather Causes" under "External Causes" under "Causes" -of- "Delay"
"...regarding the lifting of coal gallery is a very late decision which was the outcome of a major engineering and planning mistake. Thus, the negative impact of this lifting activity on time schedule was solely due to poor planning, management and coordination of contractor and should be considered among the main reasons of delay affecting drum lifting."	"Slow decision making by designers" under "Design Related Causes" under "Owner Causes" under "Causes" -of- "Delay"
	"Delayed and slow supervision in making decisions" under "Consultant Causes" under "Owner Causes" under "Causes" -of- "Delay"
	"Slowness in decision making process by owner" under "Contractual Relationship Related Causes" under "Owner Causes" under "Causes" -of- "Delay"
	"Errors and omissions in design documents and defective specifications" under "Design Related Causes" under "Owner Causes" under "Causes" -of- "Delay"
	"Incomplete/Defective/Poor design drawings, specifications or documents" under "Design Related Causes" under "Owner Causes" under "Causes" -of- "Delay"
	"Poor contract management by consultant" under "Consultant Causes" under "Owner Causes" under "Causes" -of- "Delay"
	"Insufficient communication between the owner and designer in design phase" under "Design Related Causes" under "Owner Causes" under "Causes" -of- "Delay"
	"Poor communication and coordination by owner with other parties" under "Contractual Relationship Related Causes" under "Owner Causes" under "Causes" -of- "Delay"

Table 5.1: Comparison table for Case Study A (continued)

Findings of the Current Expert Report (continued)	
Phrase in the Report	**Phrase in the Ontology**
"However, there may be other disruptions and concurrent delays that are under the control of either, both or none of the parties that are not included in the delay analysis. Poor management, coordination and resource allocation by subcontractor could also decreased productivity of works and resulted in delays, however, it is believed that inability of contractor to submit design drawings and materials on time and sending frequent revisions to already submitted drawings are the "initial" and "dominant" causes of delay leading to delay in the forthcoming activities and consequently, in project completion."	"Disruption" under "Impact" -of- "Delay"
	"Concurrent delays" under "Delays Classified By Their Timing" under "Types" -of- "Delay"
	"Owner (or his agents) responsible" under "Responsibility" -of- "Delay"
	"Contractor (or his subcontractors) responsible" under "Responsibility" -of- "Delay"
	"Both contractual parties responsible" under "Responsibility" -of- "Delay"
	"Neither contractual party responsible" under "Responsibility" -of- "Delay"
	"Analysis" -of- "Delay"
	"Unsuitable management structure and style of contractor" under "Contractor Generated Causes" under "Contractor Causes" under "Causes" -of- "Delay"
	"Poor communication and coordination by contractor with other parties" under "Contractor Generated Causes" under "Contractor Causes" under "Causes" -of- "Delay"
	(-The term will be added-)
	"Lost Productivity" under "Impact" -of- "Delay"
	"Lost Productivity Costs" under "Contractor's Direct Costs" under "Contractor's Costs" under "Cost Overrun" under "Impact" -of- "Delay"
	"Owner (or his agents) responsible" under "Responsibility" -of- "Delay"
	"Failure on the part of the owner to review and approve design documents, schedules, and material on time" under "Owner Generated Causes" under "Owner Causes" under "Causes" -of- "Delay"
	"Problems/Delays in materials, labor or goods that are in responsibility of the owner" under "Owner Generated Causes" under "Owner Causes" under "Causes" -of- "Delay"
	"Excessive scope changes and constructive changed orders" under "Design Related Causes" under "Owner Causes" under "Causes" -of- "Delay"
	(-The term will be added-)
	"Causes" -of- "Delay
	"Critical delays: Delay to completion" under "Delays Classified By Their Criticality" under "Types" -of- "Delay"
"...shifted the remaining erection activities of subcontractor to a period during which adverse weather conditions were experienced."	"Shifts in the construction season" under "Lost productivity costs" under "Contractor's Direct Costs" under "Contractor's Costs" under "Cost Overrun" under "Impact" -of- "Delay"
"Late issuance and approval of grating drawings is another failure of contractor that caused delay in the project."	"Long waiting time for approval of drawings" under "Design Related Causes" under "Owner Causes" under "Causes" -of- "Delay"

Table 5.1: Comparison table for Case Study A (continued)

Findings of the Current Expert Report (continued)	
Phrase in the Report	**Phrase in the Ontology**
"Failure to deliver the erection site free from obstacles..."	"Restricted access to the site/Poor site access and availability" under "Owner Generated Causes" under "Owner Causes" under "Causes" -of- "Delay"
"...subcontractor changed the sequence of erection so that erecting of tiers can be carried out in parallel to accelerate the work."	"Changing the Work Sequence" under "Mitigation" -to_reduce- "Impact" -of- "Delay"
"...delay shall not be attributed either parties' failures..."	"Neither contractual party responsible" under "Responsibility" -of- "Delay"

Amendments through the Case Project A: The corresponding phrase for the "fax messages", which is used in the section of documents revised for the analysis in the expert report, does not exist in the ontology. It could be referred with the term "Correspondence Data" of the ontology, however when the detail presented in the ontology with the terms under that concept such as; "Correspondence by e-mails", "Correspondence by letters" and "Notes of conversations" and "Notes of telephone calls" are considered, it is more suitable to add the term "fax messages" in the ontology. So the term is added as "Correspondence by fax messages" to its location ("Correspondence by fax messages" under "Correspondence Data" under "Records" under "Post-contract Documents" under "Data" -used_for- "Analysis" -of- "Delay") with its reference as Case Project A. In addition to that, a term that directly meets the "poor resource allocation by subcontractor" of the expert report is not available in the ontology. There are more specific terms available on the resource allocation issue; however inclusion of the generalized version as "Poor resource allocation by contractor" is needed. Accordingly the term is added to the ontology ("Poor resource allocation by contractor" under "Contractor Generated Causes" under "Contractor Causes" under "Causes" -of- "Delay"). Finally, for the analysis of concurrent delays "initial and dominant cause approach" is used in the report. Concurrent delays are handled in the "issues in the analysis of delay" part of the ontology. But this "Concurrent delays issue" term in the ontology only focuses on the confusion in the definition of concurrent delays. Since there is still a debate on the analysis of concurrent delays, an issue as “Analysis of concurrent delays” is also suitable to be added. So to match the “initial and dominant cause approach” of the report, “Analysis of concurrent delays” concept is added with “Easy rule” and “Fair rule” subconcepts (where the “fair rule” corresponds to the “initial and dominant cause approach”) to its location in the ontology as a subconcept of “Concurrent Delays Issue” (“Analysis of concurrent delays issue” under “Concurrent Delays Issue” under “Issues” -relating_to- “Analysis” -of- “Delay”). Accordingly, since the previous “Concurrent delays Issue” is changed as a main concept, its constricted version as “Definition of concurrent delays issue” to emphasize its essential meaning in the ontology is put under its previous version as “Concurrent delays issue”. The other concepts within the ontology are found enough to match the remaining concepts of the expert report.

5.2.2 Project B: Fast Tram Project in Poland

Contractor of the Fast Tram Project requests assessment of the delays occurred in the construction of the project. There is not much detail on the project in the expert report, so outline of the report is shared as introductory information for this case.

Expert first of all gives the list of the documents that are submitted for review and following that, shares the list of issues causing delays. Accordingly, detailed analysis of delays starts with the investigation of the schedule especially in terms of logic behind the activities; namely relations of the activities, and assigned durations to the corresponding activities. Detailed calculations on durations are presented through the multiplication of calculated amount of the work with the average work output (productivity). Then delays are analyzed with the required schedule updates. At the end of the report, it is found out that the delays are beyond the control of the contractor, so contractor is irresponsible for the delays.

Details of the comparison of the report and the ontology are presented through the comparison table (Table 5.2). The details of the matching process of the concepts may be laid out through the sample quotations from the report, such as:

Phrase 1: *“First three of the above mentioned points (causes of delay)* (“Causes”) *are analyzed* (“Analysis”) *by forming time schedules* (“Adjusted/Updated schedule: schedule depicting impacts by changes on as-planned schedule”). *The question asked is whether these delays are on the critical path that affects the Time for Completion or not* (“Critical delays: Delay to completion”) (“Identify and analyze concurrent delays.”)*.”*

Phrase 2: *“It is beyond doubt that the works would consume more financial resources and time during winter* (“Shifts in the construction season”). *Whether or not the Contractor should be entitled to time extension* (“Extension of Time”) *for the period due to the delay caused is a contractual issue* (“Extension of time clause”) *rather than technical.”*

The full list of the phrases compared is presented in the following table (Table 5.2). The documents listed in the report are presented as “Documents Used for Analysis in the Report”, whereas factors of delays are handled under heading of “Causes of Delays Presented in the Report”. Finally; the rest of the information, namely main concepts about analysis are depicted in “Phrases from Analysis Part of the Report”.

Table 5.2: Comparison table for Case Study B

Documents Used for Analysis in the Report	
Phrase in the Report	**Phrase in the Ontology**
"Contract"	"Contract Documents" under "Data" -used_for- "Analysis" -of- "Delay"
"Clarification of the Tender of the Project, which is an attachment to the Contract"	"Tender" under "Main Contract Documents" under "Contract Documents" under "Data" -used_for- "Analysis" -of- "Delay"
"Tender calculation files"	"Tender" under "Main Contract Documents" under "Contract Documents" under "Data" -used_for- "Analysis" -of- "Delay"
	"Bills of quantities" under "Main Contract Documents" under "Data" -used_for- "Analysis" -of- "Delay"
"Work schedule in Addendum 2"	"Schedules" under "Main Contract Documents" under "Contract Documents" under "Data" -used_for- "Analysis" -of- "Delay"
"Overall work program"	"Plans and programmes" under "Main Contract Documents" under "Contract Documents" under "Data" -used_for- "Analysis" -of- "Delay"

Table 5.2: Comparison table for Case Study B (continued)

Documents Used for Analysis in the Report (continued)	
Phrase in the Report	**Phrase in the Ontology**
"Monthly work schedules submitted to owner"	"Adjusted/Updated schedule: schedule depicting impacts by changes on as-planned schedule" under "Major Schedules" under "Post-contract Documents" under "Data" -used_for- "Analysis" -of- "Delay"
"Site log books"	"Daily logs" under "Logs" under "Records" under "Post-Contract Documents" under "Data" -used_for- "Analysis" -of- "Delay"
"Detailed Inventory of Existing Greenery"	(-The term will be added-)
"Monthly Progress Reports"	"Construction progress reports diary" under "Diaries" under "Records" under "Post-contract Documents" under "Data" -used_for- "Analysis" -of- "Delay"
	"Weekly and monthly reports" under "Reports" under "Records" under "Post-contract Documents" under "Data" -used_for- "Analysis" -of- "Delay"
"Design drawings"	"Design Drawings" under "Main Contract Documents" under "Contract Documents" under "Data" -used_for- "Analysis" -of- "Delay"
"Contractor's Determination of the Value of the Work Done"	"Cost and value of work executed each month (for the project)" under "Records of Accounting Data" under "Records" under "Post-contract Documents" under "Data" -used_for- "Analysis" -of- "Delay"
"Correspondence between the Parties"	"Correspondence between parties to the contract" under "Correspondence Data" under "Records" under "Post-contract Documents" under "Data" -used_for- "Analysis" -of- "Delay"
"Statement of Claim"	"Claims' log" under "Logs" under "Records" under "Post-contract Documents" under "Data" -used_for- "Analysis" -of- "Delay" "Statement of Claim" under "Parts" -of- "Claim" -for- "Impact" -of- "Delay"
"Reply to the Statement of Claim"	
"Reply on Main Claim and Full Statement of Defense on Counterclaim"	
"Rejoinder on Claim and Reply on Counterclaim"	
"Rejoinder on Counterclaim"	
"As seen from the <u>correspondence</u> and the <u>minutes of meetings</u>..."	"Correspondence Data" under "Records" under "Post-contract Documents" under "Data" -used_for- "Analysis" -of- "Delay"
	"Minutes of Meetings" under "Records" under "Post-contract Documents" under "Data" -used_for- "Analysis" -of- "Delay"
"...foreseen neither in the <u>geological report</u> nor in the <u>contract documents</u>."	(-The term will be added-)
	"Contract Documents" under "Data" -used_for- "Analysis" -of- "Delay"

Causes of Delays Presented in the Report	
Phrase in the Report	**Phrase in the Ontology**
"the Employer's delay in obtaining tree-cutting permits"	"Obtaining permits/approvals from the municipality/different government authorities" under "Rules and Regulations Related Causes" under "External Causes" under "Causes" -of- "Delay"

Table 5.2: Comparison table for Case Study B (continued)

Causes of Delays Presented in the Report (continued)	
Phrase in the Report	**Phrase in the Ontology**
"the Engineer's instructions relating to Variation 1"	"Change orders by owner during construction/Owner initiated variations" under "Design Related Causes" under "Owner Causes" under "Causes" -of- "Delay"
"the Engineer's instruction for Variation regarding the West Ventilation Shaft"	
"the change in the application of material on the T1 Tunnel walls"	"Changes in material types and specifications during construction" under "Design Related Causes" under "Owner Causes" under "Causes" -of- "Delay"
"the Engineer's instruction that Contractor use another water-stop material"	
"the change in season in which construction works were to be carried out, as a result of the Engineer's instructions for Variations"	"Shifts in the construction season" under "Lost productivity costs" under "Contractor's Direct Costs" under "Contractor's Costs" under "Cost Overrun" under "Impact" -of- "Delay"
	"Serial delays" under "Delays Classified By Their Timing" under "Types" -of- "Delay"
"the Engineer's instruction that the Contractor use additional water-stop material not required by the Contract for the contraction and expansion joints"	"Work imposed that is not part of the contract by owner" under "Contract Related Causes" under "Owner Causes" under "Causes" -of- "Delay"
"the Employer's failure to certify the Contractor's monthly statements"	"Delays in contractors' progress payments (of completed work) by owner" under "Financial Causes" under "Owner Causes" under "Causes" -of- "Delay"
"unforeseeable poor ground conditions in Area 2"	"Unforeseen ground conditions (rock, acid, sediment basin)" under "Environmental Causes" under "External Causes" under "Causes" -of- "Delay"
Phrases from Analysis Part of the Report	
Phrase in the Report	**Phrase in the Ontology**
"...effect of these delays..."	"Impact" -of- "Delay"
"...list of <u>issues causing delays</u> <u>related to the time for completion..."</u>	"Causes" -of- "Delay"
	"Critical delays: Delay to completion" under "Delays Classified By Their Criticality" under "Types" -of- "Delay"
"...the need to <u>accelerate the work</u>..."	"Accelerating the Work" under "Mitigation" -to_reduce- "Impact" -of- "Delay"
"Contractor does not actually <u>claim</u> the corresponding extensions in full..."	"Claim" -for- "Impact" -of- "Delay"
"<u>Claimant</u> uses another material..."	"Claimant" under "Parties" -in- "Claim" -for- "Impact" -of- "Delay"
"...but the delays cease to <u>be in the critical path</u> when the <u>delays in obtaining tree cutting permits</u> <u>blocked the excavation and further activities</u> until the end of July..."	"Critical delays: Delay to completion" under "Delays Classified By Their Criticality" under "Types" -of- "Delay"
	"Obtaining permits/approvals from the municipality/different government authorities" under "Rules and Regulations Related Causes" under "External Causes" under "Causes" -of- "Delay"
	"Serial delays" under "Delays Classified By Their Timing" under "Types" -of- "Delay"

Table 5.2: Comparison table for Case Study B (continued)

Phrases from Analysis Part of the Report (continued)	
Phrase in the Report	**Phrase in the Ontology**
"First three of the above mentioned points (causes of delay) are analyzed by forming time schedules. The question asked is whether these delays are on the critical path that affects the Time for Completion or not."	"Causes" -of- "Delay"
	"Analysis" -of- "Delay"
	"Adjusted/Updated schedule: schedule depicting impacts by changes on as-planned schedule" under "Major Schedules" under "Post-contract Documents" under "Data" -used_for- "Analysis" -of- "Delay"
	"Critical delays: Delay to completion" under "Delays Classified By Their Criticality" under "Types" -of- "Delay"
	"Identify and analyze concurrent delays." under "Identify Concurrent Delays" under "Event Analysis" under "Methodology Steps" -for- "Analysis" -of- "Delay"
"Time schedule analysis focusing on the overall volumes of work items and the average approximate work outputs..."	"Analyze contractor's original CPM schedule (determine appropriateness: is it realistic and reasonable?)." under "Analyze Original Schedule" under "Tender and Programme Analysis" under "Methodology Steps" -for- "Analysis" -of- "Delay"
	"Examine the planned production rate of activities through parameters of duration and amount of work accomplished in that duration." under "Analyze Original Schedule" under "Tender and Programme Analysis" under "Methodology Steps" -for- "Analysis" -of- "Delay"
"Taking into account the method of excavation, the interrelations between excavation stages are estimated as follows..."	"Examine the logic utilized to interrelate various activities (examine logical relationships and lead-lag factors between activities)." under "Analyze Original Schedule" under "Tender and Programme Analysis" under "Methodology Steps" -for- "Analysis" -of- "Delay"
"...a proper resource leveling is ensured..."	"Examine the project resources' utilization." under "Analyze Original Schedule" under "Tender and Programme Analysis" under "Methodology Steps" -for- "Analysis" -of- "Delay"
"The Gant chart, which is prepared for the previous issues, is extended to include the analysis of the third issue of delay..."	"Gantt charts/Bar chart schedules" under "Schedules" under "Main Contract Documents" under "Contract Documents" under "Data" -used_for- "Analysis" -of- "Delay"
	"Adjusted/Updated schedule: schedule depicting impacts by changes on as-planned schedule" under "Major Schedules" under "Post-contract Documents" under "Data" -used_for- "Analysis" -of- "Delay"
"The amount of resources is assumed taking into consideration the limited access to the area and the limited available working space of the area."	"Site congestion" under "Lost Productivity Costs" under "Contractor's Direct Costs" under "Contractor's Costs" under "Cost Overrun" under "Impact" -of- "Delay"
"...due to these delays, which are not attributable to the Contractor, makes..."	"Owner (or his agents) responsible" under "Responsibility" -of- "Delay"
	"Owner caused delays" under "Delays Classified By Their Origin" under "Types" -of- "Delay"
	"Neither contractual party responsible" under "Responsibility" -of- "Delay"
	"Third party caused delays" under "Delays Classified By Their Origin" under "Types" -of- "Delay"

Table 5.2: Comparison table for Case Study B (continued)

Phrases from Analysis Part of the Report (continued)	
Phrase in the Report	**Phrase in the Ontology**
"This means that the resources actually allocated was far more than the resources foreseen during the tendering stage. But due to other obstacles causing delays, this acceleration could not result in an early finish of the Works."	"Increasing manpower" under "Accelerating the Work" under "Mitigation" -to_reduce- "Impact" -of- "Delay"
	"Adding equipment" under "Accelerating the Work" under "Mitigation" -to_reduce- "Impact" -of- "Delay"
	"Causes" -of- "Delay"
	"Accelerating the Work" under "Mitigation" -to_reduce- "Impact" -of- "Delay"
"...the Contractor compensated for almost all of these delays..."	"Excusable compensable delays" under "Delays Classified By Their Compensability" under "Types" -of- "Delay"
	"Owner caused delays" under "Delays Classified By Their Origin" under "Types" -of- "Delay"
"It is beyond doubt that the works would consume more financial resources and time during winter. Whether or not the Contractor should be entitled to time extension for the period due to the delay caused is a contractual issue rather than technical."	"Shifts in the construction season" under "Lost productivity costs" under "Contractor's Direct Costs" under "Contractor's Costs" under "Cost Overrun" under "Impact" -of- "Delay"
	"Extension of time" under "Award" -through- "Settlement" -is-a- "Result" -of- "Claim" -for- "Impact" -of- "Delay"
	"Extension of time clause" under "Contract Clauses" under "Main Contract Documents" under "Contract Documents" under "Data" -used_for- "Analysis" -of- "Delay"
"...it is noted that the effect of winter conditions is well reported in the site logs..."	"Weather reports diary" under "Diaries" under "Records" under "Post-contract Documents" under "Data" -used_for- "Analysis" -of- "Delay"
	"Records of weather conditions and its effect on progress" under "Site Records" under "Records" under "Post-contract Documents" under "Data" -used_for- "Analysis" -of- "Delay"
	"Maintaining proper job records on a timely manner is needed." under "Tracking Related Prevention Matters" under "Prevention During Construction" under "Prevention" -of- "Delay"
	"Daily logs" under "Logs" under "Records" under "Post-contract Documents" under "Data" -used_for- "Analysis" -of- "Delay"
"As a result, the Contractor should be entitled to time extension for the period of the related delay."	"Extension of time" under "Award" -through- "Settlement" -is-a- "Result" -of- "Claim" -for- "Impact" -of- "Delay"
"...it has been determined that the new concrete mix design prepared by the Contractor in accordance with the Engineer's instruction was both submitted to the Engineer for approval and was approved by the Engineer on the same day with the instruction. However, the Engineer cancelled its approval for the new mix design by its letter dated... Upon this cancellation, the Contractor submitted its second proposal for the mix design which was approved by the Engineer on..."	"Waiting time for sample materials approval" under "Consultant Causes" under "Owner Causes" under "Causes" -of- "Delay"

Table 5.2: Comparison table for Case Study B (continued)

Phrases from Analysis Part of the Report (continued)	
Phrase in the Report	**Phrase in the Ontology**
"...it appears that the Contractor had to stay idle during the period between..."	"Additional idle labor cost" under "Additional Labor Costs" under "Extended and Increased Field Costs" under "Contractor's Direct Costs" under "Contractor's Costs" under "Cost Overrun" under "Impact" -of- "Delay"
	"Additional standing/idle time" under "Additional Equipment Costs" under "Extended and Increased Field Costs" under "Contractor's Direct Costs" under "Contractor's Costs" under "Cost Overrun" under "Impact" -of- "Delay"

Amendments through the Case Project B: "Detailed Inventory of Existing Greenery" term in the expert report recalls the site investigation report by contractor before commencement of the works. This meaning is implied in the “Prevention” part of the ontology on side of the contractor. Also, “Site investigation” term is included in the documents used for the analysis of the ontology as a research on site for the general situation before analysis. However, this term does not meet the exact meaning of the report at the tender stage, whereas the expression in the prevention part does not present a “document” in the ontology. So, the term “Site report” is added to the documents part of the ontology as a subconcept of “Tender” (“Site report” under “Tender” under “Main Contract Documents” under “Contract Documents” under “Data” -used_for- “Analysis” -of- “Delay”). Similarly the term “geological report” of the expert report is missing in the ontology and become more significant after the inclusion of term “Site report”. Thus “Geological report” is also added as a subconcept of “Tender” to complete the detail of information at that level (“Geological report” under “Tender” under “Main Contract Documents” under “Contract documents” under “Data” -used_for- “Analysis” -of- “Delay”). The rest of the terms in the expert report find their corresponding phrases in the ontology.

5.2.3 Project C: Campus Building Project in Turkey

Dispute arises between Contractor (joint venture) and Owner of a campus building project in Turkey in a contract with 420 days of duration; and upon the counterclaim by contractor, the parties take the case to arbitration. Commission of the arbitration decides to refer to the experts for the technical issues that cause the dispute. So, this expert report consists of the questions asked by the commission of arbitration and the corresponding replies from the commission of experts. Experts review the available documentations provided and make a site investigation with the participation of the parties to the contract and accordingly present their analysis results.

Here are some examples from the quotations of the report. However, since the report is in Turkish, translated forms of the quotations are presented.

Phrase 1: *"Obtaining building permits: Contractor informs the Engineer* ("Notice") *about the delay due to obtaining building permits* ("Building permits approval process") *is not in their (contractor's) responsibility* ("Owner (or his agents) responsible") ("Neither contractual party responsible") *and claims* ("Claim") *the required extension of time* ("Extension of time claim"). *Engineer approves the contractor's claim* ("Settlement") *and with the consent of owner 17 days of extension* ("Extension of time") *is awarded* ("Award") *to contractor and the new contract completion date* ("Current completion date") ("Practical completion/Substantial completion and initial certificate") *is determined* ("Update and reanalyze the network: specify the project is ahead or behind the schedule at delay date.") ("Adjusted/Updated schedule: schedule depicting impacts by changes on as-planned schedule")*"*

Phrase 2: *"The calculated extension of time* ("Extension of time") *due to the reasons* ("Causes") *presented, should also be added* ("Updated schedule") *to the planned completion date* ("Dates for commencement and completion"). *Then according to the actual practical completion date* ("Actual date of commencement and practical completion") ("As-built schedule: actual/final adjusted schedule") *of the project the difference between the revised completion dates* ("Current completion date")

("Adjusted/Updated schedule: schedule depicting impacts by changes on as-planned schedule") *should be taken as* *liquidated damages* ("Liquidated Damages") ("Liquidated damages") *from the contractor."*

The full list of the phrases compared is presented in the following table (Table 5.3). Basic terms in the report are gathered under the heading of "General Terms in the Report". Documents mentioned in the report are presented as "Documents Used for Analysis in the Report". Last, the details of analysis are given through explanations of causes of delays in the part of "Analysis of Causes in the Report".

Table 5.3: Comparison table for Case Study C

General Terms in the Report	
Phrase in the Report (translated from Turkish)	**Phrase in the Ontology**
"dispute"	"Dispute" -is-a- "Result" -of- "Claim" -for- "Impact" -of- "Delay"
"counterclaim"	"Claim" -for- "Impact" -of- "Delay"
"arbitration"	"Arbitration" under "Alternative Dispute Resolution" under "Resolution By Third Party" under "Resolution" -of- "Dispute" -is-a- "Result" -of- "Claim" -for- "Impact" -of- "Delay"
"Dispute Review Expert"	"Expert determination/Neutral evaluation" under "Alternative Dispute Resolution" under "Resolution By Third Party" under "Resolution" -of- "Dispute" -is-a- "Result" -of- "Claim" -for- "Impact" -of- "Delay"
Documents Used for Analysis in the Report	
Phrase in the Report (translated from Turkish)	**Phrase in the Ontology**
"contract"	"Contract Documents" under "Data" -used_for- "Analysis" -of- "Delay"
"duration of contract"	"Contract performance period: Commencement of contract time (Contract award and Notice to proceed) and Contract completion" under "Contract Clauses" under "Main Contract Documents" under " Contract Documents" under "Data" -used_for- "Analysis" -of- "Delay"
	"Dates for commencement and completion" under "Introduction" under "Parts" of "Claim" -for- "Impact" -of- "Delay"
"completion date"	"Current completion date" under "Details of Claim" under "Parts" -of- "Claim" -for- "Impact" -of- "Delay"
"site investigation"	"Site investigation" under "Witness Data" under "Records" under "Post-contract Documents" under "Data" -used_for- "Analysis" -of- "Delay"

Table 5.3: Comparison table for Case Study C (continued)

Documents Used for Analysis in the Report (continued)	
Phrase in the Report (translated from Turkish)	**Phrase in the Ontology**
"bill of quantities estimate"	"Bills of quantities" under "Main Contract Documents" under "Data" -used_for- "Analysis" -of- "Delay"
"technical specification"	"Specifications and Drawings" under "Main Contract Documents" under "Data" -used_for- "Analysis" -of- "Delay"
"unit prices in bid"	"Tender" under "Main Contract Documents" under "Data" -used_for- "Analysis" -of- "Delay"
"details"	"Drawing register: details of amendments and revisions made to plans" under "Registers" under "Records" under "Post-contract Documents" under "Data" -used_for- "Analysis" -of- "Delay"
"correspondence"	"Correspondence Data" under "Records" under "Post-contract Documents" under "Data" -used_for- "Analysis" -of- "Delay"
"architectural project"	"Design Drawings" under "Main Contract Documents" under "Contract Documents" under "Data" -used_for- "Analysis" -of- "Delay"
"As-Built Project"	"As-built schedule: actual/final adjusted schedule" under "Major Schedules" under "Post-contract Documents" under "Data" -used_for- "Analysis" -of- "Delay"
Analysis of Causes in the Report	
Phrase in the Report (translated from Turkish)	**Phrase in the Ontology**
"In case of an extra or additional work, conditions of contract with 44.1a clause, allow contractor to be granted to extension of time."	"Extra work claims" under "Variation Claims" under "Kinds" -of- "Claim" -for- "Impact" -of- "Delay"
	"Conditions of Contract" under "Main Contract Documents" under "Contract Documents" under "Data" -used_for- "Analysis" -of- "Delay"
	"Contract Clauses" under "Main Contract Documents" under "Contract Documents" under "Data" -used_for- "Analysis" -of- "Delay"
	"Extension of time" under "Award" -through- "Settlement" -is-a- "Result" -of- "Claim" -for- "Impact" -of- "Delay"
"Claiming of the expenses between practical completion date and final completion date from the owner is disapproved."	"Quantum Meurit Claims" under "Kinds" -of- "Claim" -for- "Impact" -of- "Delay"
	"Practical completion/Substantial completion and initial certificate" under "Contract Clauses" under "Main Contract Documents" under "Contract Documents" under "Data" -used_for- "Analysis" -of- "Delay"
	"Final completion and certificate" under "Contract Clauses" under "Main Contract Documents" under "Contract Documents" under "Data" -used_for- "Analysis" -of- "Delay"

Table 5.3: Comparison table for Case Study C (continued)

Analysis of Causes in the Report (continued)	
Phrase in the Report (translated from Turkish)	**Phrase in the Ontology**
"Obtaining building permits: Contractor informs the Engineer about the delay due to obtaining building permits is not in their (contractor's) responsibility and claims the required extension of time. Engineer approves the contractor's claim and with the consent of owner 17 days of extension is awarded to contractor and the new contract completion date is determined."	"Notice" -for- "Claim"-for- "Impact" -of- "Delay"
	"Building permits approval process" under "Rules and Regulations Related Causes" under "External Causes" under "Causes" -of- "Delay"
	"Owner (or his agents) responsible" under "Responsibility" -of- "Delay"
	"Neither contractual party responsible" under "Responsibility" -of- "Delay"
	"Claim" -for- "Impact" -of- "Delay"
	"Extension of time claim" under "Time Related Claims" under "Kinds" -of- "Claim" -for- "Impact" -of- "Delay"
	"Settlement" -is-a- "Result" -of- "Claim" -for- "Impact" -of- "Delay"
	"Extension of time" under "Award" -through- "Settlement" -is-a- "Result" -of- "Claim" -for- "Impact" -of- "Delay"
	"Award" -through- "Settlement" -is-a- "Result" -of- "Claim" -for- "Impact" -of- "Delay"
	"Current completion date" under "Details of Claim" under "Parts" -of- "Claim" -for- "Impact" -of- "Delay"
	"Practical completion/Substantial completion and initial certificate" under "Contract Clauses" under "Main Contract Documents" under "Contract Documents" under "Data" -used_for- "Analysis" -of- "Delay"
	"Update and reanalyze the network: specify the project is ahead or behind the schedule at delay date." under "Apply Analysis Technique" under "Event Analysis" under "Methodology Steps" for "Analysis" -of- "Delay"
	"Adjusted/Updated schedule: schedule depicting impacts by changes on as-planned schedule" under "Major Schedules" under "Post-contract Documents" under "Data" -used_for- "Analysis" -of- "Delay"
"Ground enrichment: Review of available documents reveals that, contractor informs the Engineer about the differences between geo-technical report and ground; and adds that 0.60m of extra excavation and crushed stone backfill is required for ground enrichment. Contractor informs the Engineer about depth of the excavation, the backfill material and the corresponding cost however does not claim any extension of time. So no extension of time should be given to contractor."	"Data" -used_for- "Analysis" -of- "Delay"
	"Notice" -for- "Delay"
	"Unforeseen ground conditions (rock, acid, sediment basin)" under "Environmental Causes" under "External Causes" under "Causes" -of- "Delay"
	"Claim" -for- "Impact" -of- "Delay"
	"Extension of time claim" under "Time Related Claims" under "Kinds" -of- "Claim" -for- "Impact" -of- "Delay"
	"Extension of time" under "Award" -through- "Settlement" -is-a- "Result" -of- "Claim" -for- "Impact" -of- "Delay"

Table 5.3: Comparison table for Case Study C (continued)

Analysis of Causes in the Report (continued)	
Phrase in the Report (translated from Turkish)	**Phrase in the Ontology**
"Isolation of pipe: Review of available documents reveals that, contractor requests on date from consultant to clarify the isolation system for heating and cooling system and according to the contract clauses presents the engineer alternative materials with corresponding prices. Later on again on date, according to the contract clauses, contractor gives the notice of potential delay due to the selection of material to the Engineer. However decision of the owner and the engineer is given to contractor late and the corresponding extension of time should be given to contractor."	"Data" -used_for- "Analysis" -of- "Delay"
	"Request for information (RFI) log" under "Logs" under "Records" under "Post-contract Documents" under "Data" -used_for- "Analysis" -of- "Delay"
	"Contract document clarification (CDC) log" under "Logs" under "Records" under "Post-contract Documents" under "Data" -used_for- "Analysis" -of- "Delay"
	"Slow response by the consultant engineer to contractor inquiries" under "Consultant Causes" under "Owner Causes" under "Causes" -of- "Delay"
	"Contract Clauses" under "Main Contract Documents" under " Contract Documents" under "Data" -used_for- "Analysis" -of- "Delay"
	"Notice" -for- "Delay"
	"Waiting time for sample materials approval" under "Consultant Causes" under "Owner Causes" under "Causes" -of- "Delay"
	"Extension of time" under "Award" -through- "Settlement" -is-a- "Result" -of- "Claim" -for- "Impact" -of- "Delay"
"Selection of facade windows"	(same with the isolation of pipe case)
"Selection of carpet: Review of available documents reveals that, contractor fails to present the material samples to owner in time according to the contract. Since there is nothing in owner's responsibility, there is no need for an extension of time."	"Data" -used for- "Analysis" -of- "Delay"
	"Late procurement of materials" under "Material Related Causes" under "Contractor Causes" under "Causes" -of- "Delay"
	"Contract Clauses" under "Main Contract Documents" under "Contract Documents" under "Data" -used_for- "Analysis" -of- "Delay"
	"Contractor (or his subcontractors) responsible" under "Responsibility" -of- "Delay"
	"Extension of time" under "Award" -through- "Settlement" -is-a- "Result" -of- "Claim" -for- "Impact" -of- "Delay"
"Selection of fire-resistant laminated doors"	(same with the selection of carpet case)

Table 5.3: Comparison table for Case Study C (continued)

Analysis of Causes in the Report (continued)	
Phrase in the Report (translated from Turkish)	**Phrase in the Ontology**
"The calculated extension of time due to the reasons presented should also be added to the planned completion date. Then according to the actual practical completion date of the project the difference between the revised completion date should be taken as liquidated damages from the contractor."	"Extension of time" under "Award" -through- "Settlement" -is-a- "Result" -of- "Claim" -for- "Impact" -of- "Delay"
	"Causes" -of- "Delay
	"Dates for commencement and completion" under "Introduction" under "Parts" of "Claim" -for- "Impact" -of- "Delay"
	"Actual date of commencement and practical completion" under "Summary of Facts" under "Parts" of "Claim" -for- "Impact" -of- "Delay"
	"As-built schedule: actual/final adjusted schedule" under "Major Schedules" under "Post-contract Documents" under "Data" -used_for- "Analysis" -of- "Delay"
	"Current completion date" under "Details of Claim" under "Parts" -of- "Claim" -for- "Impact" -of- "Delay"
	"Adjusted/Updated schedule: schedule depicting impacts by changes on as-planned schedule" under "Major Schedules" under "Post-contract Documents" under "Data" -used_for- "Analysis" -of- "Delay"
	"Liquidated Damages" under "Owner's Costs" under "Cost Overrun" under "Impact" -of- "Delay"
	"Liquidated damages" under "Award" -through- "Settlement" -is-a- "Result" -of- "Claim" -for- "Impact" -of- "Delay"

Amendments through the Case Project C: Since all the factors in the report are able to be matched with concepts of the ontology, no amendment is needed after the investigation of Case Project C.

5.3 Conclusion to Validation

As a conclusion to the validation of the ontology, it can be said that all the cases presented match with the ontology. So from the practical use of the ontology point, the ontology could be used as a checkpoint for prevention of delays before the commencement of the works for each case. At least, possible causes of delay could be taken into consideration and preventive actions could be taken in the planning stage. Similarly, more strong contracts could be established through guidance of the created ontology. Moreover, parties to the dispute of each case may also use the ontology to store the information of their cases for their company databases.

In conclusion; with the validation process, usability of the ontology with three real world cases is checked, and also an initial update of the ontology is made through the amendments after investigation of cases. This process can be seen also as the first step of the maintenance period of the ontology.

CHAPTER 6

CONCLUSION AND FUTURE WORK

The study is concluded through this chapter by presentation of *brief summary* of the study with the information of *limitations of the study* and related *possible future work* to overcome the limitations and to provide the study to stay up-to-date.

6.1 Summary

Delay is the common problem of the construction sector. With the progression of construction industry; competition in the sector and complexity of the projects increased. So; achieving construction projects in time, namely production of successful projects became a challenging issue. Despite all the prevention measures taken in pre-construction period, delays may still occur in life time of the project. Once delay occurs; unless it is mitigated or analyzed correctly, it can easily cause further problems such as dispute and further delays that stir the things up and make the resolution more difficult. For this reason; sound knowledge in delay analysis issue, and accordingly, proper and timely analysis of delays are required. At this point, ontologies are ready to come into action to provide the knowledge sharing and usage processes of the delay analysis issue. Common and widespread understanding of the delay analysis issue would help the planning process and provide to build the project on a solid basis. Knowledge in concept of delay and delay analysis would also ease the handling and analysis of problems after occurrence of a delay. The created delay analysis ontology may assist the risk and claim management processes and help to promote the prevention of delays with the increased perception of the delay and delay analysis issues. There are various studies for delay analysis based on various methods available in the literature. Since this ontology provides a part of an unified form of the information available in literature, a database or a decision support system (DSS) based on this ontology may be helpful in planning and management of projects. It may provide a basis for establishment of such database or decision support system for the companies that would ease the usage of the stored information from past projects for further projects. The database or decision support system may help in organizational decision-making processes on delay and delay analysis problems of the company. It may guide project participants in critical points and also improve the information on the issue by providing learning from the projects and sharing of knowledge. At least, previously made mistakes would be prevented or if not prevented would be handled sensibly. So in short, aim and objective of the study is stated as to develop a delay analysis ontology:

(1) to integrate the information on delay analysis available in literature
(2) to provide easy sharing of the knowledge
(3) to help risk management process by serving as a checklist that may increase the possibility of prevention of delays
(4) to help the delay analysis process that forms the basis of claim management and
(5) to form a basis for delay analysis databases or decision support systems for companies

On this purpose, literature review on construction delay and delay analysis is carried out. Most mentioned terms in the survey constituted the concepts of the ontology of delay analysis domain. Each class that is under investigation in ontology is tried to be searched through different available sources and these sources are merged to represent the knowledge in one unit. The fundamental rule of the ontology construction provides the definition of the ontology in sentences with nouns describing concepts and verbs referring to relations between concepts. This rule forms the basis of the ontology and main concepts of the ontology are identified as *delay*, *types*, *causes*, *responsibility*, *impact*, *mitigation*, *analysis*, *claim*, *notice* and finally *prevention* of delay with also their subcategories. Relations among these concepts form the sentential nature of the ontology. The gathered information is presented in form of taxonomies to ease the realization and use. Details of the ontology are structured on this basis through the methodology named METHONTOLOGY. All the detailed information in the ontology first presented in tables and figures by force of the procedure of the methodology. Later on, the model is totally formalized with the creation of concept model of the ontology through UML class diagrams. Validation of the ontology is made through three case studies of expert reports for claim management. Since claim management and delay analysis are interpenetrating issues, evaluation of the ontology is made through its usage area as claim issues. Concepts in claim analysis indicate that the ontology has enough concepts to match the expert reports. Some amendments through expert reports are made and the ontology is updated accordingly. So, it is seen that the ontology is suitable for the real world expert reports presented. Risk analysis and claim analysis for the presented cases could be done easily with the guidance of the created delay analysis ontology. Finally; ontology is written in a formal ontology language with the help of ontology implementation tool that is named as named Protégé, and left ready for the usage.

6.2 Limitations of the Study

As a major limitation of the study, knowledge acquisition process can be reported since it is solely based on literature review. In addition to that, this ontology is based on the primary purpose of knowledge sharing and lacks part for company specific information as it stands. For the use of ontology as a database or a decision support system by companies as it is stated, it needs to be structured to a convenient form according to the intended use of companies. As a final limitation, ontology is validated through three case studies and more case studies could help more to improve the created ontology. Improvements through case studies may show that the ontology is suitable for the handled cases and help enhancement of the extent of the ontology at the best. However, enhancement would be gotten by validation through case studies is subjected to a limit. Actual validation of the ontology would be provided by the reliable results got from its active usage through databases or decision support systems that would be established by companies for delay analysis.

6.3 Suggestions for Future Work

For future work, the ontology may be enhanced with various knowledge elicitation techniques such as information retrieval from analysis of case studies, interviews of experts, questionnaires and etc. In addition, this ontology may form a base in delay analysis issue and guide any other study of different purposes that would increase the knowledge variety. New ontologies may be formed with improvements on this ontology or as a primary facility of ontologies; integration and reuse of this ontology in different studies may be provided. Also as another facility of the ontologies, this ontology may be easily adapted to be used in a probable study in software engineering. Accordingly, adaptation of the ontology to a company specific database or a decision support system for delay issue may be made and the ontology may be structured to be used by companies in risk and claim management processes. Finally through the usage of the ontology, deficiencies may be defined and ontology may be updated accordingly to overcome the possible problems that may be encountered. Any other enhancement activity on the ontology may be anticipated to provide the ontology to stay up-to-date through its serving life.

REFERENCES

[1] Abdul-Malak, M. A. U., El-Saadi, M. M. H., and Abou-Zeid, M. G. (2002). "Process model for administrating construction claims", *Journal of Management in Engineering*, 18(2), 84-94. doi: 10.1061/(ASCE)0742-597X(2002)18:2(84)

[2] Abdul-Rahman, H., Berawi, M. A., Berawi, A. R., Mohamed, O., Othman, M., and Yahya, I. A. (2006). "Delay mitigation in the Malaysian construction industry", *Journal of Construction Engineering and Management*, 132(2), 125-133. doi: 10.1061/(ASCE)0733-9364(2006)132:2(125)

[3] Abdul-Rahman, H., Yahya, I. A., Berawi, M. A., and Wah, L. W. (2008). "Conceptual delay mitigation model using a project learning approach in practice", *Construction Management and Economics*, 26, 15-27. doi: 10.1080/01446190701744350

[4] Adhikari, I., Kim, S.-Y., and Lee, Y.-D. (2006). "Selection of appropriate schedule delay analysis method: Analytical Hierarchy Process (AHP)", *Proceedings of PICMET 2006*, Istanbul, Turkey.

[5] Aibinu, A. A. (2009). "Avoiding and mitigating delay and disruption claims conflict: Role of precontract negotiation", *Journal of Legal Affairs and Dispute Resolution in Engineering and Construction*, 1(1), 47-58. doi: 10.1061/(ASCE)1943-4162(2009)1:1(47)

[6] Aibinu, A. A., and Jagboro, G. O. (2002). "The effects of construction delays on project delivery in Nigerian construction industry", *International Journal of Project Management*, 20, 593-599.

[7] Aibinu, A. A., and Odeyinka, H. A. (2006). "Construction delays and their causative factors in Nigeria", *Journal of Construction Engineering and Management*, 132(7), 667-677. doi: 10.1061/(ASCE)0733-9364(2006)132:7(667)

[8] Al-Gahtani, K. S. (2006). "A comprehensive construction delay analysis technique - Enhanced with a float ownership concept", Ph. D. Thesis, State University of New York at Buffalo.

[9] Al-Khalil, M. I., and Al-Ghafly, M. A. (1999). "Important causes of delays in public utility projects in Saudi Arabia", *Construction Management and Economics*, 5(17), 647-655.

[10] Al-Kharashi, A., and Skitmore, M. (2009). "Causes of delays in Saudi Arabian public sector construction projects", *Construction Management and Economics*, 27, 3-23. doi: 10.1080/01446190802541457

[11] Al-Momani, A. H. (2000). "Construction delay: a quantitative analysis", *International Journal of Project Management*, 18, 51-59.

[12] Al-Saggaf, H. A. (1998). "The five commandments of construction project delay analysis", *Cost Engineering*, 40(4), 37-41.

[13] Alaghbari, W., Kadir, M. R. A., Salim, A., and Ernawati. (2007). "The significant factors causing delay of building construction projects in Malaysia", *Engineering, Construction and Architectural Management*, 14(2), 192-206. doi: 10.1108/09699980710731308

[14] Alkass, S., Mazerolle, M., and Harris, F. (1996). "Construction delay analysis techniques", *Construction Management and Economics*, 14, 375-394.

[15] Alkass, S., Mazerolle, M., Tribaldos, E., and Harris, F. (1995). "Computer aided construction delay analysis and claims preparation", *Construction Management and Economics*, 13, 335-352.

[16] Alnuaimi, A. S., Taha, R. A., Mohsin, M. A., and Al-Harthi, A. S. (2010). “Causes, effects, benefits, and remedies of change orders on public construction projects in Oman”, *Journal of Construction Engineering and Management*, 136-5. doi: 10.1061/(ASCE)CO.1943-7862.0000154

[17] Alway Associates. (2003). “Retrospective delay analysis techniques”, http://www.alway-associates.co.uk/legal-update/article.asp?id=14 retrieved on June 8, 2010.

[18] Alwi, S., and Hampson, K. (2003). “Identifying the important causes of delays in building construction projects”, *Proceedings of the 9th East Asia-Pacific Conference on Structural Engineering and Construction*, Bali, Indonesia.

[19] Aoude, H. S. (1996). “Computerized construction delay management system”, Ph. D. Thesis, Polytechnic University.

[20] Arditi, R. D., Akan, G. T., and Gurdamar, S. (1985). “Reasons for delays in public projects in Turkey”, *Construction Management and Economics*, 3, 171-181.

[21] Arditi, D., and Patel, B. K. (1989). “Impact analysis of owner-directed acceleration”, *Journal of Construction Engineering and Management*, 115(1), 144-157.

[22] Arditi, D., and Pattanakitchamroon, T. (2006). “Selecting a delay analysis method in resolving construction claims”, *International Journal of Project Management*, 24, 145-155. doi:10.1016/j.ijproman.2005.08.005

[23] Arditi, D., and Pattanakitchamroon, T. (2008). “Analysis methods in time-based claims”, *Journal of Construction Engineering and Management*, 134(4), 242-252. doi: 10.1061/(ASCE)0733-9364(2008)134:4(242)

[24] Assaf, S. A., and Al-Hejji, S. (2006). “Causes of delay in large construction projects”, *International Journal of Project Management*, 24, 349-357. doi: 10.1016/j.ijproman.2005.11.010

[25] Assaf, S. A., Al-Khalil, M., and Al-Hazmi, M. (1995). “Causes of delay in large building construction projects”, *Journal of Management in Engineering*, 11(2), 45-50.

[26] Babel, D. (2004). “Construction claims: Is there a way to avoid them?”, *Proceedings of Cement Industry Technical Conference, 2004, IEEE-IAS/PCA*, 93-101.

[27] Badman, J. (2007). “Extension of time claims”, *Construction Week, Arabian Business Publishing Ltd*. http://www.arabianbusiness.com/504174-extension-of-time-claims?ln=en retrieved on October 28, 2010.

[28] Battikha, M. (1994). “A computer integrated system for construction delay analysis: Time and impact costs”, M. Sc. Thesis, Concordia University.

[29] Baxter, D., Klimt, B., Grobelnik, M., Schneider, D., Witbrock, M., and Mladenić, D. (2009). “Capturing document semantics for ontology generation and document summarization”, in Davies, J., Grobelnik, M., and Mladenić, D., “Semantic Knowledge Management: Integrating Ontology Management, Knowledge Discovery, and Human Language Technologies”, *Berlin / Heidelberg: Springer-Verlag*.

[30] Benson, R. W. (2006). “Key issues for the construction industry and the economy”, *MidMarket Advantage*, Fall, 16-18.

[31] Bernaras, A., Laresgoiti, I., and Corera, J. (1996). “Building and reusing ontologies for electrical network applications”, *Proceedings of European Conference on Artificial Intelligence (ECAI’96),* Budapest, Hungary, 298-302.

[32] Berners-Lee, T., Hendler, J., and Lassila, O. (2001). “The semantic web”, *Scientific American*, 284(5), 34-43.

[33] Beşoğul, E. (2006). “Reasons of delays in steel construction projects: An application of a delay analysis methodology”, M. Sc. Thesis, Middle East Technical University, Ankara, Turkey.

[34] Bodenreider, O., Mitchell, J. A., and McCray, A. T. (2003). "Biomedical ontologies", *Proceedings of Pacific Symposium on Biocomputing (PSB)*, Stanford University, Stanford, California, 562–564.

[35] Bordoli, D. W., and Baldwin, A. N. (1998). "A methodology for assessing construction project delays", *Construction Management and Economics*, 16, 327-337.

[36] Borst, W. N. (1997). "Construction of engineering ontologies for knowledge sharing and reuse", Ph. D. Thesis, University of Twente, Enschede, NL.

[37] Bouaud, J., Bachimont, B., Charlet, J., and Zweigenbaum, P. (1995). "Methodological principles for structuring an ontology", *Proceedings of lJCAI-95 Workshop on Basic Ontological Issues in Knowledge Sharing*, Montreal, Quebec, Canada.

[38] Braimah, N. (2008). "An investigation into the use of construction delay and disruption analysis methodologies", Ph. D. Thesis, University of Wolverhampton.

[39] Braimah, N., and Ndekugri, I. (2008). "Factors influencing the selection of delay analysis methodologies", *International Journal of Project Management*, 26, 789-799. doi: 10.1016/j.ijproman.2007.09.001

[40] Braimah, N., and Ndekugri, I. (2009). "Consultants' perceptions on construction delay analysis methodologies", *Journal of Construction Engineering and Management*, 135(12), 1279-1288. doi: 10.1061/(ASCE)CO.1943-7862.0000096

[41] Bramble, B. B., and Callahan, M. T. (2001). "Construction delay claims", *New York: Aspen Publishers.*

[42] Breitman, K., and do Prado Leite, J. C. S. (2003). "Ontology as a requirement engineering product", *Proceedings of the 11th IEEE International Requirements Engineering Conference*, Monterey Bay, California, USA, 309-319.

[43] Breitman, K. K., Casanova, M. A., and Truszkowski, W. (2007). "Semantic Web: Concepts, Technologies and Applications", *Springer-Verlag London Limited.*

[44] Bubshait, A. A., and Cunningham, M. J. (1998). "Comparison of delay analysis methodologies", *Journal of Construction Engineering and Management*, 124(4), 315-322.

[45] Carmichael, S., and Murray, M. (2006). "Record keeping for contemporaneous delay analysis: a model for effective event management", *Construction Management and Economics*, 24(10), 1007-1018. doi: 10.1080/01446190500521207

[46] Carnell, N. J. (2000). "Causation and Delay in Construction Disputes", *Oxford, U.K: Blackwell Science Ltd.*

[47] Ceusters, W., Smith, B., and Goldberg, L. (2005) "A terminological and ontological analysis of the NCI Thesaurus", *Methods of Information in Medicine*, 44, 498-507.

[48] Chan, D. W. M., and Kumaraswamy, M. M. (1997). "A comparative study of causes of time overruns in Hong Kong construction projects", *International Journal of Project Management*, 15(1), 55-63.

[49] Chan, E. H. W., and Suen, H. C. H. (2005a). "Dispute resolution management for international construction projects in China", *Management Decision*, 43(4), 589-602. doi: 10.1108/00251740510593576

[50] Chan, E. H. W., and Suen, H. C. H. (2005b). "Disputes and dispute resolution systems in sino-foreign joint venture construction projects in China", *Journal of Professional Issues in Engineering Education and Practice*, 131(2), 141-148. doi: 10.1061/(ASCE)1052-3928(2005)131:2(141)

[51] Chandrasekaran, B., and Josephson, J. R. (1997). "The ontology of tasks and methods", *AAAI Technical Report SS-97-06*, 9-16.

[52] Chandrasekaran, B., Josephson, J. R., and Benjamins, V. R. (1999). "What are ontologies, and why do we need them?", *IEEE Intelligent Systems*, 14(1), 20-26.

[53] Cheung, S.-O., and Suen, H. C. H. (2002). "A multi-attribute utility model for dispute resolution strategy selection", *Construction Management and Economics*, 20(7), 557-568.

[54] Cheung, S.-O., Suen, H. C. H., and Lam, T.-I. (2002). "Fundamentals of alternative dispute resolution processes in construction", *Journal of Construction Engineering and Management*, 128(5), 409-417. doi: 10.1061/(ASCE)0733-9364(2002)128:5(409)

[55] Chong, H. Y., and Rosli, M. Z. (2009). "The behaviour of dispute resolution methods in Malaysian construction industry", *Proceedings of IEEE International Conference on Industrial Engineering and Engineering Management (IEEM 2009)*, Hong Kong.

[56] Chuen, T. S. (n.d.). "EOT and loss and expense claim", Widnell Ltd. http://www.docstoc.com/docs/44089812/EOT-and-Loss-and-Expense-Claim retrieved on October 28, 2010.

[57] Coertse, N. (2011). "Assessing delays: the impacted as-planned method compared to the time-impact analysis method", MDA Consulting, Creamer Media Reporter. http://www.polity.org.za/article/assessing-delays-the-impacted-as-planned-method-compared-to-the-time-impact-analysis-method-2011-03-03 retrieved on June 15, 2011.

[58] Conlin, J., and Retik, A. (1997). "The applicability of project management software and advanced IT techniques in construction delays mitigation", *International Journal of Project Management*, 15(2), 107-120.

[59] Corcho, O., Fernández-López, M., and Gómez-Pérez, A. (2003). "Methodologies, tools and languages for building ontologies. Where is their meeting point?", *Data & Knowledge Engineering*, 46, 41-64. doi: 10.1016/S0169-023X(02)00195-7

[60] Corcho, O., Fernández-López, M., Gómez-Pérez, A., and López-Cima, A. (2005). “Building legal ontologies with METHONTOLOGY and WebODE”, in Benjamins, R., Casanovas, P., Breuker, J., and Gangemi, A. (ed.s), "Law and the Semantic Web", *Springer-Verlag*, 142-157.

[61] Crowley, L. G., Zech, W. C., Bailey, C., and Gujar, P. (2008). “Liquidated damages: Review of current state of the practice”, *Journal of Professional Issues in Engineering Education and Practice*, 134(4), 383-390. doi: 10.1061/(ASCE)1052-3928(2008)134:4(383)

[62] Cui, D.-H., Yao, L., and Yang, R. (2010). “An algorithm for improving Shapley Value Method for time claim in concurrent delay”, *Proceedings of 2010 International Conference on Logistics Systems and Intelligent Management (ICLSIM)*, Harbin, People's Republic of China.

[63] Davenport, P. (1995). “Construction Claims”, *Sydney, Australia: Federation Press.*

[64] Davies, J., Grobelnik, M., and Mladenić, D. (2009). “Semantic Knowledge Management: Integrating Ontology Management, Knowledge Discovery, and Human Language Technologies”, *Berlin / Heidelberg: Springer-Verlag*.

[65] De Le Garza, J. M., and Vorster, M. C. (1991). “Total float traded as commodity”, *Journal of Construction Engineering and Management*, 117(4), 716-727.

[66] Diekmann, J. E., and Girard, M. J. (1995). “Are contract disputes predictable?”, *Journal of Construction Engineering and Management*, 121(4), 355-363.

[67] Diekmann, J. E., and Kim, M. P. (1992). “SuperChange: Expert system for analysis of change claims”, *Journal of Construction Engineering and Management*, 118(2), 399-411.

[68] Diekmann, J. E., and Nelson, M. C. (1985). “Construction claims: frequency and severity”, *Journal of Construction Engineering and Management*, 111(1), 74-81.

[69] Doyle, J. (2005). “Concurrent delays in contracts”, Doyles Construction Lawyers, Australia.

[70] Egan, J. (1998). “Rethinking construction: Report of the construction task force”, *London: HMSO*.

[71] Ehsan, N., Alam, M., Mirza, E., and Ishaque, A. (2010). “Risk Management in construction industry”, *Proceedings of 3rd IEEE International Conference on Computer Science and Information Technology (IEEE ICCSIT 2010),* Vol.9, 16-21, Chengdu, China.

[72] El-Diraby, T. A., Lima, C., and Feis, B. (2005). “Domain Taxonomy for Construction Concepts: Toward a Formal Ontology for Construction Knowledge”, *Journal of Computing in Civil Engineering*, 19(4), 394-406. doi: 10.1061/(ASCE)0887-3801(2005)19:4(394)

[73] El-Diraby, T. A., and Zhang, J. (2006). “A semantic framework to support corporate memory management in building construction”, *Automation in Construction*, 15, 504-521. doi:10.1016/j.autcon.2005.07.005

[74] El-Razek, M. E. A., Bassioni, H. A., and Mobarak, A. M. (2008). “Causes of delay in building construction projects in Egypt”, *Journal of Construction Engineering and Management*, 134(11), 831-841. doi: 10.1061/(ASCE)0733-9364(2008)134:11(831)

[75] Elghamrawy, T., Boukamp, F., and Kim, H.-S. (2009). “Ontology-based, semi-automatic framework for storing and retrieving on-site construction problem information – An RFID-based case study”, *Proceedings of the 2009 Construction Research Congress*, Seattle, WA, 457-466.

[76] Euzenat, J. (1996). “Corporate memory through cooperative creation of knowledge bases and hyper-documents”, *Proceedings of 10th Knowledge Acquisition for Knowledge-Based Systems Workshop (KAW96)*, Banff, Alberta, Canada.

[77] Faridi, A. S., and El-Sayegh, S. M. (2006). "Significant factors causing delay in the UAE construction industry", *Construction Management and Economics*, 24(11), 1167-1176. doi: 10.1080/01446190600827033

[78] Farrow, T. (2007). "Developments in the analysis of extensions of time", *Journal of Professional Issues in Engineering Education and Practice*, 133(3), 218-228. doi: 10.1061/(ASCE)1052-3928(2007)133:3(218)

[79] Fenn, P., Lowe, D., and Speck, C. (1997). "Conflict and dispute in construction", *Construction Management and Economics*, 15(6), 513-518. doi: 10.1080/014461997372719

[80] Fidan, G. (2008). "A risk and vulnerability ontology for construction projects", M. Sc. Thesis, Middle East Technical University, Ankara, Turkey.

[81] Fidan, G., Dikmen, I., Tanyer, A. M., and Birgonul, M. T. (2011). "Ontology for relating risk and vulnerability with cost overrun in international projects", *Journal of Computing in Civil Engineering*, 25(4), 1-16. doi: 10.1061/(ASCE)CP.1943-5487.0000090.

[82] Finke, M. R. (1999). "Window analyses of compensable delays", *Journal of Construction Engineering and Management*, 125(2), 96-100.

[83] Force majeure. (n.d). In *Wikipedia*. http://en.wikipedia.org/wiki/Force_majeure retrieved on February 23, 2011.

[84] Fox, M. S., and Grüninger, M. (1997). "On ontologies and enterprise modelling", *Proceedings of the International Conference on Enterprise Integration Modelling Technology97*, Springer-Verlag.

[85] Frimpong, Y., Oluwoye, J., and Crawford, L. (2003). "Causes of delay and cost overruns in construction of groundwater projects in a developing countries; Ghana as a case study", *International Journal of Project Management*, 21, 321-326. doi: 10.1016/S0263-7863(02)00055-8

[86] Gómez-Pérez, A. (1996). "Towards a framework to verify knowledge sharing technology", *Expert Systems with Applications,* 11(4), 519-529.

[87] Gómez-Pérez, A. (2001). "Evaluation of ontologies", *International Journal of Intelligent Systems,* 16, 391-409.

[88] Gómez-Pérez, A., and Benjamins, V. R. (1999). "Overview of knowledge sharing and reuse components: Ontologies and problem-solving methods", *Proceedings of IJCAI-99 workshop on Ontologies and Problem-Solving Methods (KRR5),* Stockholm, Sweden, 1-15.

[89] Gómez-Pérez, A., Fernández-López, M., and Corcho O. (2004). "Ontological Engineering", *USA: Springer-Verlag London Limited.*

[90] Gómez-Pérez, A., Fernández-López, M., and de Vicente, A. (1996). "Towards a method to conceptualize domain ontologies", *Proceedings of ECAI96 Workshop on Ontological Engineering,* Budapest, 41-51.

[91] Gruber, T. R. (1993a) "A translation approach to portable ontology specifications", *Knowledge Acquisition,* 5, 199-220.

[92] Gruber, T. R. (1993b). "Toward principles for the design of ontologies used for knowledge sharing", *International Journal Human-Computer Studies,* 43, 907-928.

[93] Gruninger, M., and Fox, M. S. (1995). "Methodology for the design and evaluation of ontologies", *Proceedings of Workshop on Basic Ontological Issues in Knowledge Sharing,* Montreal, Canada.

[94] Guarino, N. (1994). "The ontological level", in Casati, R., Smith, B., and White, G. (ed.s), "Philosophy and the Cognitive Sciences", *Vienna: Hölder-Pichler-Tempsky.*

[95] Guarino, N., Carrara, M., and Giaretta, P. (1995). "Ontologies and knowledge bases: Towards a terminological clarification", in: Mars N. (ed.s), "Towards Very Large Knowledge Bases, Knowledge Building and Knowledge Sharing", *Amsterdam: IOS Press,* 25-32.

[96] Harris, R. A., and Scott, S. (2001). “UK practice in dealing with claims for delay”, *Engineering, Construction and Architectural Management*, 8, 317-324.

[97] Hegazy, T., Elbeltagi, E., and Zhang, K. (2005). “Keeping better site records using intelligent bar charts”, *Journal of Construction Engineering and Management*, 131(5), 513-521. doi: 10.1061/(ASCE)0733-9364(2005)131:5(513)

[98] Hegazy, T., and Zhang, K. (2005). “Daily windows delay analysis”, *Journal of Construction Engineering and Management*, 131(5), 505-512. doi: 10.1061/(ASCE)0733-9364(2005)131:5(505)

[99] Hendler, J. (2001). “Agents and the semantic web”, *IEEE Intelligent Systems & Their Applications*, 16(2), 30-37.

[100] Horrocks, I. (2003). “An example OWL ontology”, ISCW 2003 tutorial. http://www.cs.man.ac.uk/~horrocks/ISWC2003/Tutorial/examples.pdf retrieved on March 14, 2011.

[101] Horrocks, I. (2008). “Ontologies and the semantic web”, *Communications of the ACM*, 51(12), 58-67. doi: 10.1145/1409360.1409377

[102] Hoshino, K. P., Brown, R. B., Ciccarelli, J. J., Costa, G. R., Dennis, M. S., Douglas, E. E., Farrocco, P. J., Hymes, S. J., Livengood, J. C., Nagata, M. F., Ottesen, J. L., Peters, T. F., Pickavance, K., Popescu, A. I., Ramirez, J. F., Sanders, M. C., Sato, T., Schumacher, L. L., Seals, R., Winter, R. M., and Zack, J. G. (2007). “Forensic Schedule Analysis”, TCM Framework: 6.4 - Forensic Performance Assessment, AACE International Recommended Practice No. 29R-03, *AACE International, Inc*.

[103] Householder, J. L., and Rutland, H. E. (1990). “Who owns float?”, *Journal of Construction Engineering and Management*, 116(1), 130-133.

[104] Ibbs, W., and Nguyen, L. D. (2007). “Schedule analysis under the effect of resource allocation”, *Journal of Construction Engineering and Management*, 133(2), 131-138. doi: 10.1061/(ASCE)0733-9364(2007)133:2(131)

[105] Ibbs, W., Nguyen, L. D., and Simonian, L. (2011). "Concurrent delays and apportionment of damages", *Journal of Construction Engineering and Management*, 137(2), 119-126. doi: 10.1061/(ASCE)CO.1943-7862.0000259

[106] Iwamatsu, J., Akiyama, T., and Endo, K. (2008). "Construction claims and disputes and the business culture of construction in Japan", *Journal of Professional Issues in Engineering Education and Practice*, 134(1), 119-127. doi: 10.1061/(ASCE)1052-3928(2008)134:1(119)

[107] Iyer, K. C., Chaphalkar, N. B., and Joshi, G. A. (2008). "Understanding time delay disputes in construction contracts", *International Journal of Project Management*, 26, 174-184. doi:10.1016/j.ijproman.2007.05.002

[108] Jaafari, A. (1984). "Criticism of CPM for project planning analysis", *Journal of Construction Engineering and Management*, 110(2), 222-233.

[109] Jannadia, M. O., Assaf, S., Bubshait, A. A., and Naji, A. (2000). "Contractual methods for dispute avoidance and resolution (DAR)", *International Journal of Project Management*, 18, 41-49.

[110] Jenz, D. E. (2003). "Business process ontologies: Frequently asked questions", Jenz & Partner GmbH, Germany. http://www.bptrends.com/publicationfiles/09-03%20WP%20BP%20Ontologies%20FAQ%20Jenz.pdf retrieved on February 8, 2011.

[111] Jergeas, G. F., and Hartman, F. T. (1994). "Contractors' construction-claims avoidance", *Journal of Construction Engineering and Management*, 120(3), 553-560.

[112] Jones, D. (2006). "Construction project dispute resolution: Options for effective dispute avoidance and management", *Journal of Professional Issues in Engineering Education and Practice*, 132(3), 225-235. doi:10.1061/(ASCE)1052-3928(2006)132:3(225)

[113] Josephson, P.-E., and Hammarlund, Y. (1999). “The causes and costs of defects in construction: A study of seven building projects”, *Automation in Construction,* 8, 681-687.

[114] Kaliba, C., Muya, M., and Mumba, K. (2009). “Cost escalation and schedule delays in road construction projects in Zambia”, *International Journal of Project Management,* 27, 522-531. doi: 10.1016/j.ijproman.2008.07.003

[115] Kaming, P. F., Olomolaiye, P. O., Holt, G. D., and Harris, F. C. (1997). “Factors influencing construction time and cost overruns on high-rise projects in Indonesia”, *Construction Management and Economics,* 15(1), 83-94. doi: 10.1080/014461997373132

[116] Kao, C.-K., and Yang, J.-B. (2009). “Comparison of windows-based delay analysis methods”, *International Journal of Project Management*, 27, 408-418. doi: 10.1016/j.ijproman.2008.05.016

[117] Kartam, S. (1999). “Generic methodology for analyzing delay claims”, *Journal of Construction Engineering and Management*, 125(6), 409-419.

[118] Katifori, A., Vassilakis, C., Daradimos, I., Lepouras, G., Ioannidis, Y., Dix, A., Poggi, A., and Catarci, T. (2008). “Personal ontology creation and visualization for a personal interaction management system”, *Proceedings of PIM, CHI 2008*.

[119] Kim, Y., Kim, K., and Shin, D. (2005). “Delay analysis method using delay section”, *Journal of Construction Engineering and Management*, 131(11), 1155-1164. doi: 10.1061/(ASCE)0733-9364(2005)131:11(1155)

[120] Koolwijk, J. S. J. (2006). “Alternative dispute resolution methods used in alliance contracts”, *Journal of Professional Issues in Engineering Education and Practice*, 132(1), 44-47. doi: 10.1061/(ASCE)1052-3928(2006)132:1(44)

[121] Koushki, P. A., Al-Rashid, K., and Kartam, N. (2005). “Delays and cost increases in the construction of private residential projects in Kuwait”, *Construction Management and Economics,* 23, 285-294. doi: 10.1080/0144619042000326710

[122] Kraiem, Z. M., and Diekmann, J. E. (1987). "Concurrent delays in construction projects", *Journal of Construction Engineering and Management*, 113(4), 591-602.

[123] Kumaraswamy, M. M., and Chan, D. W. M. (1998). "Contributors to construction delays", *Construction Management and Economics*, 16(1), 17-29. doi: 10.1080/014461998372556

[124] Kumaraswamy, M. M., and Yogeswaran, K. (1998). "Significant sources of construction claims", *International Construction Law Review*, 15(1), 144-160.

[125] Lammari, N., and Métais, E. (2004). "Building and maintaining ontologies: a set of algorithms", *Data & Knowledge Engineering*, 48, 155-176. doi: 10.1016/S0169-023X(03)00103-4

[126] Larkin, C. (n.d.). "To go retrospective, or to go prospective & The sophisticated methods of delay analysis available", *Construction Week, Construction Management Guide*. http://www.cmguide.org/archives/4 retrieved on January 10, 2011.

[127] Latham, M. (1994). "Constructing the team", *London: HMSO*.

[128] Lee, T., Lee, I., Lee, S., Lee, S., Kim, D., Chun, J., Lee, H., and Shim, J. (2006). "Building an operational product ontology system", *Electronic Commerce Research and Applications*, 5, 16-28. doi: 10.1016/j.elerap.2005.08.005

[129] Lee, H.-S., Ryu, H.-G., Yu, J.-H., and Kim, J.-J. (2005b). "Method for calculating schedule delay considering lost productivity", *Journal of Construction Engineering and Management*, 131(11), 1147-1154.

[130] Lee, C., Wang, H., and Chang, M. (2005a). "Ontology-based fuzzy decision agent and its application to meeting scheduling support system", in Halgamuge, S. K., and Wang, L. (ed.s), "Classification and Clustering for Knowledge Discovery", *Berlin / Heidelberg / New York: Springer-Verlag*.

[131] Leishman, D. M. (1991). "Protecting engineer against construction delay claims: NDC", *Journal of Management in Engineering*, 7(3), 314-333.

[132] Lenat, D. B., and Guha, R. V. (1990). “Building Large Knowledge-Based Systems: Representation and Inference in the Cyc Project”, *Boston: Addison-Wesley*.

[133] Lima, C., El-Diraby, T., and Stephens, J. (2005). “Ontology-based optimisation of knowledge management in e-construction”, *ITcon*, 10, 305-327.

[134] Lo, T. Y., Fung, I. W. H., and Tung, K. C. F. (2006). “Construction delays in Hong Kong civil engineering projects”, *Journal of Construction Engineering and Management*, 132(6), 636-649. doi: 10.1061/(ASCE)0733-9364(2006)132:6(636)

[135] Long, R. J., Avalon, A., and Rider, R. J. (2011). “Long International’s schedule and delay analysis methodologies”, Long International, Inc. www.long-intl.com/schedule.pdf retrieved on July 17, 2011.

[136] Long, N. D., Ogunlana, S., Quang, T., and Lam, K. C. (2004). “Large construction projects in developing countries: a case study from Vietnam”, *International Journal of Project Management*, 22(7), 553-561.

[137] Longley, N., and De Witt, T. (2006). “Extension of time claims in Hong Kong”, Tanner De Witt Solicitors. http://www.scribd.com/doc/27748188/Extension-of-Time-Claims-in-Hong-Kong retrieved on October 28, 2010.

[138] Love, P., Davis, P., Ellis, J., and Cheung, S. O. (2010). “Dispute causation: Identification of pathogenic influences in construction”, *Engineering, Construction and Architectural Management*, 17(4), 404-423. doi: 10.1108/09699981011056592

[139] Majid, M. Z. A., and McCaffer, R. (1998). ‘‘Factors of non-excusable delays that influence contractors’ performance’’, *Journal of Management in Engineering*, 14(3), 42-49. doi:10.1061/(ASCE)0742-597X(1998)14:3(42)

[140] Marcus, S. D. (1988). “Goals and objectives for alternative dispute resolution”, *Journal of Performance of Constructed Facilities*, 2(1), 2-8.

[141] Mbabazi, A., Hegazy, T., and Saccomanno, F. (2005). “Modified but-for method for delay analysis”, *Journal of Construction Engineering and Management*, 131(10), 1142-1144. doi: 10.1061/(ASCE)0733-9364(2005)131:10(1142)

[142] McDonald, P. R., and Baldwin, G. C. (1989). "Builder's and contractor's handbook of construction claims", *Englewood Cliffs, New Jersey, USA: Prentice Hall*.

[143] McGuinness, D. L. (2002). "Ontologies come of age", in Fensel, D., Hendler, J., Lieberman, H., and Wahlster, W. (ed.s), "Spinning the semantic web: bringing the world wide web to its full potential", *Boston, MA: MIT Press*.

[144] Menesi, W. (2007). "Construction delay analysis under multiple baseline updates", M. Sc. Thesis, University of Waterloo.

[145] Mezher, T. M., and Tawil, W. (1998). "Causes of delays in the construction industry in Lebanon", *Engineering, Construction and Architectural Management*, 5(3), 252-260.

[146] Mitropoulos, P., and Howell, G. (2001). "Model for understanding, preventing, and resolving project disputes", *Journal of Construction Engineering and Management*, 127(3), 223-231.

[147] Mladenić, D., Grobelnik, M., Fortuna, B., and Grčar, M. (2009). "Knowledge discovery for semantic web", in Davies, J., Grobelnik, M., and Mladenić, D., "Semantic Knowledge Management: Integrating Ontology Management, Knowledge Discovery, and Human Language Technologies", *Berlin / Heidelberg: Springer-Verlag*.

[148] Natural disaster. (n.d). In *Wikipedia*. http://en.wikipedia.org/wiki/Natural_disaster retrieved on February 23, 2011.

[149] Ndekugri, I., Braimah, N., and Gameson, R. (2008). "Delay analysis within construction contracting organizations", *Journal of Construction Engineering and Management*, 134(9), 692-700.

[150] Neches, R., Fikes, R. E., Finin, T., Gruber, T. R., Senator, T., and Swartout, W. R. (1991). "Enabling technology for knowledge sharing", *AI Magazine*, 12(3), 36-56.

[151] Nguyen, L. D. (2007). “The dynamics of float, logic, resource allocation, and delay timing in forensic schedule analysis and construction delay claims”, Ph. D. Thesis, University of California, Berkeley.

[152] Niesse, D. P. (2004). “Determining after-the-fact time-related damages caused by changes”, *Journal of Professional Issues in Engineering Education and Practice*, 130(1), 46-49. doi:10.1061/(ASCE)1052-3928(2004)130:1(46)

[153] Noy, N. F. (2004). “Semantic integration: A survey of ontology-based approaches”, *SIGMOD Record*, 33(4), 65-70.

[154] Noy, N. F., Fergerson, R. W., and Musen, M. A. (2000). “The knowledge model of Protégé-2000: combining interoperability and flexibility”, *Proceedings of 2nd International Conference on Knowledge Engineering and Knowledge Management (EKAW'2000)*, Juan-les-Pins, France.

[155] Noy, N. F., and McGuinness, D. L. (2001). “Ontology development 101 - a guide to creating your first ontology”, *KSL Technical Report*, Stanford University, Stanford, CA, USA.

[156] O'Brien, J. J. (1976). “Construction delay: Responsibilities, risks, and litigation”, *Boston: Cahners Books International*.

[157] Odeh, A. M., and Battaineh, H. T. (2002). “Causes of construction delay: Traditional contracts”, *International Journal of Project Management*, 20, 67-73.

[158] Olawale, Y. A., and Sun, M. (2010). “Cost and time control of construction projects: Inhibiting factors and mitigating measures in practice”, *Construction Management and Economics*, 28(5), 509-526. doi: 10.1080/01446191003674519

[159] Oliveros, A. V. O. (2002). “A fuzzy logic approach for daily site recording, schedule delay monitoring and progress forecasting”, M. Sc. Thesis, University of Alberta.

[160] Ontology. (n.d). In *Wikipedia*. http://en.wikipedia.org/wiki/Ontology retrieved on July 17, 2011.

[161] Özdemir, M. (2010). "A probabilistic schedule delay analysis in construction projects by using fuzzy logic incorporated with relative importance index (RII) method", M. Sc. Thesis, Middle East Technical University, Ankara, Turkey.

[162] Palles-Clark, R. (2006). "The requirements for an extension of time claim", Brewer Consulting, UK. http://www.brewerconsulting.co.uk/cases/CJ0608CL.htm retrieved on October 28, 2010.

[163] Pandit, A., and Zhu, Y. (2007). "An ontology-based approach to support decision-making for the design of ETO (Engineer-To-Order) products", *Automation in Construction*, 16, 759-770. doi:10.1016/j.autcon.2007.02.003

[164] Patrick, A. E., Beaumont, D. R., Brookie, T. L., Kirsh, H. J., Tarullo, M. D., and Spencer, K. S. (2010). "Termination clauses in construction contracts", excerpted from "The Annotated Construction Law Glossary", Forum on the Construction Industry, American Bar Association, USA. http://www2.americanbar.org/publishing/bookbriefsblog/Lists/Posts/Post.aspx?ID=189 retrieved on 22 September, 2011.

[165] Peters, T. (2003). "Dissecting the doctrine of concurrent delay", PinnacleOne Institute, Los Angeles, USA.

[166] Peurifoy, R. L., and Ledbetter, W. B. (1985). "Construction planning equipment and methods", *New York: McGraw-Hill Company Inc.*

[167] Popescu-Kohler, A. I. (1998). "Improvements to construction delay analysis techniques", Ph. D. Thesis, The University of Texas at Austin.

[168] Poulin, D. M. (2008). "Abandoning the construction project", *The Construction Lawyer*, Summer 2008, 48-52 and 66-67. http://www.pepehazard.com/images/dyn/publications/pdf/PoulinConstructionLaw08.pdf retrieved on September 22, 2011.

[169] Purchase, H. C., Colpoys, L., McGill, M., Carrington, D., and Britton, C. (2001). “UML class diagram syntax: an empirical study of comprehension”, *Proceedings of Australian Symposium on Information Visualisation*, Sydney, Australia, 113-120.

[170] Rezgui, Y. (2006). “Ontology-centered knowledge management using information retrieval techniques”, *Journal of Computing in Civil Engineering*, 20(4), 261-270. doi: 10.1061/(ASCE)0887-3801(2006)20:4(261)

[171] Rider, R. J., and Long, R. J. (2009). “Analysis of concurrent/pacing delay”, Long International Inc., Colorado.

[172] Rubin, R. A., Guy, S. D., Maevis, A. C., and Fairweather, V. (1983). “Construction claims: analysis, presentation and defense”, *New York: Van Nostrand Reinhold*.

[173] Rubin, R. A., and Quintas, B. V. (2003). “Alternative dispute resolution in U.S. public works: Proposed model”, *Journal of Professional Issues in Engineering Education and Practice*, 129(2), 80-83. doi: 10.1061/(ASCE)1052-3928(2003)129:2(80)

[174] Sağlam, Ö. (2009). “İnşaat projelerinde gecikme analizi”, Yüksek Lisans Tezi, İstanbul Teknik Üniversitesi, İstanbul, Türkiye.

[175] Sakka, Z. I., and El-Sayegh, S. M. (2007). “Float consumption impact on cost and schedule in the construction industry”, *Journal of Construction Engineering and Management*, 133(2), 124-130. doi: 10.1061/(ASCE)0733-9364(2007)133:2(124)

[176] Sambasivan, M., and Soon, Y. W. (2007). “Causes and effects of delays in Malaysian construction industry”, *International Journal of Project Management*, 25, 517-526. doi: 10.1016/j.ijproman.2006.11.007

[177] Sarıkaya, Ö. (2010). “Causes of delay in and their effects on construction projects in Turkey”, M. Sc. Thesis, Boğaziçi University, Istanbul, Turkey.

[178] Scott, S., and Harris, R. A. (2004). "United Kingdom construction claims: Views of professionals", *Journal of Construction Engineering and Management*, 130(5), 734-741. doi: 10.1061/(ASCE)0733-9364(2004)130:5(734)

[179] Scott, S., Harris, R. A., and Greenwood, D. (2004). "Assessing the new United Kingdom Protocol for dealing with delay and disruption", *Journal of Professional Issues in Engineering Education and Practice*, 130(1), 50-59. doi: 10.1061/(ASCE)1052-3928(2004)130:1(50)

[180] Semple, C., Hartman, F. T., and Jergeas, G. (1994). "Construction claims and disputes: Causes and cost/time overruns", *Journal of Construction Engineering and Management*, 120(4), 785-795.

[181] Sgarlata, M. A., and Brasco, C. J. (2004). "Successful claims resolution through an understanding of the law governing allocation of risk for delay and disruption", CM eJOURNAL, *Construction Management Association of America*.

[182] Shangguan, J., Yan, Y., Liu, H., Wang, G., and Zhao, B. (2009). "Role assignment and cooperation of ontology and object-oriented principle in construction of digital product model", *Tsinghua Science and Technology*, 14(S1), 71-76.

[183] Shi, J. J., Cheung, S. O., and Arditi, D. (2001). "Construction delay computation method", *Journal of Construction Engineering and Management*, 127(1), 60-65.

[184] Soon, T. K. (2010). "Dispute resolution in relation to delay of construction project", M. Sc. Thesis, Universiti Teknologi Malaysia.

[185] Soucar, J. (n.d.). "Construction delay analysis methods", Forensis Group, http://www.forensisgroup.com/forensisforum/construction-delay-analysis-methods retrieved on January 10, 2011.

[186] Staab, S., Schnurr, H.-P., Studer, R., and Sure, Y. (2001). "Knowledge processes and ontologies", *IEEE Intelligent Systems*, 16(1), 26-34.

[187] Stumpf, G. R. (2000). “Schedule delay analysis”, *Cost Engineering*, 42(7), 32-43.

[188] Sugumaran, V., and Storey, V. C. (2002). “Ontologies for conceptual modeling: their creation, use, and management”, *Data and Knowledge Engineering*, 42(3), 251-271.

[189] Sun, M., and Meng, X. (2009). “Taxonomy for change causes and effects in construction projects”, *International Journal of Project Management*, 27, 560-572. doi: 10.1016/j.ijproman.2008.10.005

[190] Swartout, B., Ramesh, P., Knight, K., and Russ, T. (1997). “Toward distributed use of large-scale ontologies”, *Proceedings of AAAI Symposium on Ontological Engineering*, Stanford University, California.

[191] Sweis, G., Sweis, R., Hammad, A. A., and Shboul, A. (2008). “Delays in construction projects: The case of Jordan”, *International Journal of Project Management*, 26, 665-674. doi: 10.1016/j.ijproman.2007.09.009

[192] Tairas, R., Mernik, M., and Gray, J. (2008). “Using ontologies in the domain analysis of domain-specific languages”, *Proceedings of Workshop on Transforming and Weaving Ontologies and Model Driven Engineering*, Toulouse, France.

[193] Tait, J. N. (2008). “Briefing: Alternative dispute resolution techniques”, Institution of Civil Engineers, *Management, Procurement and Law*, 161, 91-92. doi: 10.1680/mpal.2008.161.3.91

[194] Tartir, S., Arpinar, I. B., and Sheth, A. P. (2010). “Ontological evaluation and validation”, in Poli, R., Healy, M., and Kameas, A., “Theory and Applications of Ontology: Computer Applications”, *Dordrecht / Heidelberg / London / New York: Springer*.

[195] Tazelaar, F., and Snijders, C. (2010). "Dispute resolution and litigation in the construction industry. Evidence on conflicts and conflict resolution in The Netherlands and Germany", *Journal of Purchasing & Supply Management*, 16, 221-229. doi: 10.1016/j.pursup.2010.08.003

[196] Thomas, R. (1993). "Construction Contract Claims", *London: Macmillan Press Ltd.*

[197] Thomas, H. R., and Messner, J. I. (2003). "No-damages-for-delay clause: Evaluating contract delay risk", *Journal of Professional Issues in Engineering Education and Practice*, 129(4), 257-262. doi: 10.1061/(ASCE)1052-3928(2003)129:4(257)

[198] Tieder, J. B. (2008). "Methods of delay analysis and how they are viewed by the United States legal system", Society of Construction Law, *Proceedings of International Construction Law Conference*, London, England.

[199] Toor, S.-U.-R., and Ogunlana, S. O. (2008). "Problems causing delays in major construction projects in Thailand", *Construction Management and Economics*, 26, 395-408. doi: 10.1080/01446190801905406

[200] Trauner, T. J., Manginelli, W. A., Lowe, J. S., Nagata, M. F., and Furniss, B. J. (2009). "Construction Delays: Understanding them clearly, analyzing them correctly", *USA: Elsevier Inc.*

[201] Treacy, T. B. (1995). "Use of alternative dispute resolution in the construction industry", *Journal of Management in Engineering*, 11(1), 58-63.

[202] Tserng, H. P., Yin, S. Y. L., Dzeng, R. J., Wou, B., Tsai, M. D., and Chen, W. Y. (2009). "A study of ontology-based risk management framework of construction projects through project life cycle", *Automation in Construction*, 18, 994-1008. doi:10.1016/j.autcon.2009.05.005

[203] Turner, D. F., and Turner, A. (1999). "Building Contract Claims and Disputes", *Edinburgh Gate, Harlow, Essex, England: Addison Wesley Longman Limited.*

[204] Ugwu, O. O., Anumba, C. J., and Thorpe, A. (2005). "Ontological foundations for agent support in constructability assessment of steel structures - a case study", *Automation in Construction*, 14, 99-114. doi:10.1016/j.autcon.2004.08.009

[205] UNDP. (2000). "General Conditions of Contract for Civil Works", http://www.bb.undp.org/uploads/file/pdfs/general/Procurement%20-%20General%20Terms%20%20Conditions%20Civil%20Works.pdf retrieved on September 5, 2010.

[206] Uschold, M., and Jasper, R. (1999). "A framework for understanding and classifying ontology applications", *Proceedings of IJCAI-99 Workshop on Ontologies and Problem-Solving Methods*, Stockholm.

[207] Uschold, M., and King, M. (1995). "Towards a methodology for building ontologies", *Proceedings of IJCAI-95 Workshop on Basic Ontological Issues in Knowledge Sharing*, Montreal.

[208] Van Inwagen, P. (2010). "Metaphysics", *The Stanford Encyclopedia of Philosophy*. http://plato.stanford.edu/archives/fall2010/entries/metaphysics/ retrieved on July 17, 2011.

[209] Vorster, M. C. (1993). "Dispute prevention and resolution: alternative dispute resolution in construction with emphasis on dispute review boards." *CII Source Document,* Construction Industry Institute, University Of Texas, Austin.

[210] Vrandečić, D. (2010). "Ontology evaluation", Ph. D. Thesis, Karlsruhe Institute of Technology (KIT).

[211] Wang, C. C., and Xue, D. (2008). "Using domain ontology in a semantic blogging system for construction professionals", *Tsinghua Science and Technology,* 13(S1), 279-285.

[212] Wei, K. S. (2010). “Causes, effects, and methods of minimizing delays in construction projects”, Bachelor of Civil Engineering, Universiti Teknologi Malaysia.

[213] Weiten, M. (2009). “OntoSTUDIO as a ontology engineering environment”, in Davies, J., Grobelnik, M., and Mladenić, D., “Semantic Knowledge Management: Integrating Ontology Management, Knowledge Discovery, and Human Language Technologies”, *Berlin / Heidelberg: Springer-Verlag*.

[214] Wild, S. E. (2006). “Webster’s New World Law Dictionary”, *New Jersey, USA: Wiley Publishing, Inc.* http://law.yourdictionary.com/time-is-of-the-essence retrieved on August 30, 2010.

[215] Williams, T. (2003). “Assessing extension of time delays on major projects”, *International Journal of Project Management*, 21, 19-26.

[216] Williams, T., Ackermann, F., and Eden, C. (2003). “Structuring a delay and disruption claim: An application of cause-mapping and system dynamics”, *European Journal of Operational Research*, 148, 192-204. doi:10.1016/S0377-2217(02)00372-7

[217] Winter, J., Bayfield, R., Brough, P., Caletka, A., Douglas, J., Johnson, P., Jordan, S., Nash, S., Pickavance, K., Pragnell, J., and Richards, D. (2002). “Delay and Disruption Protocol”, *Society of Construction Law*.

[218] Xiao, H., and Proverbs, D. (2003). “Factors influencing contractor performance: an international investigation”, *Engineering, Construction and Architectural Management*, 10(5), 322-332.

[219] Yang, J.-B., and Kao, C.-K. (2009). “Review of delay analysis methods: A process-based comparison”, *The Open Construction and Building Technology Journal*, 3, 81-89.

[220] Yang, J.-B., and Wei, P.-R. (2010). "Causes of delay in the planning and design phases for construction projects", *Journal of Architectural Engineering*, 16(2), 80-83. doi: 10.1061/(ASCE)1076-0431(2010)16:2(80)

[221] Yates, J. K. (1993). "Construction decision support system for delay analysis", *Journal of Construction Engineering and Management*, 119(2), 226-244.

[222] Yates, J. K., and Epstein, A. (2006). "Avoiding and minimizing construction delay claim disputes in relational contracting", *Journal of Professional Issues in Engineering Education and Practice*, 132(2), 168-179. doi: 10.1061/(ASCE)1052-3928(2006)132:2(168)

[223] Yates, J. K., and Smith, J. A. (2007). "Global legal issues for engineers and constructors", *Journal of Professional Issues in Engineering Education and Practice*, 133(3), 199-209. doi: 10.1061/(ASCE)1052-3928(2007)133:3(199)

[224] Yogeswaran, K., Kumaraswamy, M. M., and Miller, D. R. A. (1998). "Claims for extensions of time in civil engineering projects", *Construction Management and Economics*, 16, 283-293. doi: 10.1080/014461998372312

[225] Zack, J. G. (1993). ""Claimsmanship": Current perspective", *Journal of Construction Engineering and Management*, 119(3), 480-497.

[226] Zack, J. G. (2000). "Pacing delays - The practical effect", *Cost Engineering*, 42(7), 23-28.

[227] Zack, J. G. (2006). "Delay and delay analysis: Isn't it simple?", AACE International RP/FSA Project, *Proceedings of 1st ICEC & IPMA Global Congress on Project Management*, Ljubljana, Slovenia.1

[228] Zaneldin, E. K. (2006). "Construction claims in United Arab Emirates: Types, causes, and frequency", *International Journal of Project Management*, 24, 453-459. doi:10.1016/j.ijproman.2006.02.006

APPENDIX A

INSTANCE TABLE OF THE DELAY ANALYSIS ONTOLOGY

Table A.1: Instance table of the delay analysis ontology

Instance name	**Concept name**	**Attribute**
Insufficient data collection, survey and site investigation prior to design	DesignRelatedCauses	name
Unclear and inadequate details in drawings	DesignRelatedCauses	name
Incomplete/Defective/Poor design drawings, specifications or documents	DesignRelatedCauses	name
Inaccurate estimates - errors or omissions in quantity estimating/inaccurate bills of quantities	DesignRelatedCauses	name
Errors and omissions in design documents and defective specifications	DesignRelatedCauses	name
Inaccurate design information	DesignRelatedCauses	name
Inaccurate design documentation	DesignRelatedCauses	name
Disagreements on design specifications	DesignRelatedCauses	name
Lack of standardization in design	DesignRelatedCauses	name
Citation of inadequate specification	DesignRelatedCauses	name
Design errors made by designers	DesignRelatedCauses	name
Mistakes and discrepancies in design documents	DesignRelatedCauses	name
Inconsistency between drawings and site conditions	DesignRelatedCauses	name
Complexity of project design	DesignRelatedCauses	name
Inadequate design-team experience	DesignRelatedCauses	name
Insufficient training of designers	DesignRelatedCauses	name
Non-use of advanced engineering design software tool	DesignRelatedCauses	name
Delays in design information	DesignRelatedCauses	name
Change orders by owner during construction/Owner initiated variations	DesignRelatedCauses	name
Necessary changes/variations of works	DesignRelatedCauses	name
Design changes/modifications by owner or his agent during construction	DesignRelatedCauses	name
Design changes in respond to site conditions	DesignRelatedCauses	name
Design changes due to poor brief, errors and omissions	DesignRelatedCauses	name
Changes in material types and specifications during construction	DesignRelatedCauses	name

Table A.1: Instance table of the delay analysis ontology (continued)

Instance name	Concept name	Attribute
Change orders by deficiency design	DesignRelatedCauses	name
Excessive scope changes and constructive changed orders	DesignRelatedCauses	name
Delay in issuance of change orders by the owner	DesignRelatedCauses	name
Improper or delayed change orders	DesignRelatedCauses	name
Changes in owner’s requirements	DesignRelatedCauses	name
Long waiting time for approval of drawings	DesignRelatedCauses	name
Long waiting time for approval of test samples and materials	DesignRelatedCauses	name
Late in revising and approving design documents by owner	DesignRelatedCauses	name
Slow drawing revision and distribution	DesignRelatedCauses	name
Poor quality of design - wrong/improper/impractical design	DesignRelatedCauses	name
Low constructability of design	DesignRelatedCauses	name
Over-design increasing the overall cost	DesignRelatedCauses	name
Poor communication and coordination between designers	DesignRelatedCauses	name
Insufficient communication between the owner and designer in design phase	DesignRelatedCauses	name
Misunderstanding of owner's requirements by design engineer	DesignRelatedCauses	name
Slow decision making by designers	DesignRelatedCauses	name
Slow information delivery between designers	DesignRelatedCauses	name
Slow correction of design errors	DesignRelatedCauses	name
Lack of involvement of design team during construction stage	DesignRelatedCauses	name
Delay in performing inspection and testing by consultant	ConsultantCauses	name
Delay in approving major changes in the scope of work by consultant	ConsultantCauses	name
Late in reviewing and approving design documents by consultant	ConsultantCauses	name
Waiting time for sample materials approval	ConsultantCauses	name
Waiting time for site inspection and approval of quality control tests or results by consultant	ConsultantCauses	name
Slow preparation and approval of shop drawings by consultant	ConsultantCauses	name
Slow preparation of scheduling networks and revisions by consultant while construction is in progress	ConsultantCauses	name
Poor inspection and testing procedure used in project by consultant	ConsultantCauses	name
Poor contract management by consultant	ConsultantCauses	name
Poor quality assurance and quality control by consultant	ConsultantCauses	name
Inflexibility (rigidity) of consultant	ConsultantCauses	name
Lack of experience on the part of the consultant	ConsultantCauses	name
Lack of experience on the part of the consultant’s site staff (managerial and supervisory personnel)	ConsultantCauses	name
Absence of consultant’s site staff	ConsultantCauses	name
Conflicts between consultant and design engineer	ConsultantCauses	name

Table A.1: Instance table of the delay analysis ontology (continued)

Instance name	Concept name	Attribute
Poor communication and coordination by consultant with other parties	ConsultantCauses	name
Poor information dissemination/provision by consultant	ConsultantCauses	name
Late preparation of interim valuation by consultant	ConsultantCauses	name
Late valuation of variation works by consultant	ConsultantCauses	name
Delayed and slow supervision in making decisions	ConsultantCauses	name
Delay in the approval of contractor submissions by the consultant engineer	ConsultantCauses	name
Late issuance of instruction by the consultant engineer	ConsultantCauses	name
Slow response by the consultant engineer regarding testing and inspection	ConsultantCauses	name
Slow response by the consultant engineer to contractor inquiries	ConsultantCauses	name
Inaccurate site investigation by consultant	ConsultantCauses	name
Poor site management and supervision by consultant	ConsultantCauses	name
Inadequate project management assistance by consultant	ConsultantCauses	name
Replacement of key personnel by consultant	ConsultantCauses	name
Improper selection of subsequent consultants	ConsultantCauses	name
Problems due to company organization of consultant	ConsultantCauses	name
Fraud by consultant	ConsultantCauses	name
Delays in contractor's progress payments (of completed work) by owner	OwnersFinancialCauses	name
Problems with partial payments during construction	OwnersFinancialCauses	name
Owner’s cash flow problem	OwnersFinancialCauses	name
Payment delays by owner	OwnersFinancialCauses	name
Poor project financing by owner	OwnersFinancialCauses	name
Failure to fund the project on time	OwnersFinancialCauses	name
Funding changes, i.e., shortage of funding	OwnersFinancialCauses	name
Financial problems (delayed payments, financial difficulties, and economic problems)	OwnersFinancialCauses	name
Lack of finance to complete the work by the owner	OwnersFinancialCauses	name
Non-payment of contractor claim	OwnersFinancialCauses	name
Financial constraints faced by the owner	OwnersFinancialCauses	name
Changes in material prices in unit-priced contracts	OwnersFinancialCauses	name
Selecting the type of project bidding and award (negotiation, lowest bidder, etc.)	OwnerGeneratedCauses	name
Lack of clear bidding process/Exceptionally low bids	OwnerGeneratedCauses	name
Insufficient time for bid preparation	OwnerGeneratedCauses	name
Selecting the type of construction contract/project delivery system (Turnkey, design-build, general contracting, construction only,.)	OwnerGeneratedCauses	name
Selection of inappropriate contract type	OwnerGeneratedCauses	name
Selection of inappropriate type of main construction	OwnerGeneratedCauses	name
Imbalance in the risk allocation by owner	OwnerGeneratedCauses	name
Inappropriate contractor or consultant selection	OwnerGeneratedCauses	name
Improper project feasibility study	OwnerGeneratedCauses	name
Delay in site preparation and delivery	OwnerGeneratedCauses	name

Table A.1: Instance table of the delay analysis ontology (continued)

Instance name	Concept name	Attribute
Difficulty in site acquisition/Failure to provide property	OwnerGeneratedCauses	name
Restricted access to the site/Poor site access and availability	OwnerGeneratedCauses	name
Failure of the employer over ingress and egress	OwnerGeneratedCauses	name
Failure of the employer to provide right of way	OwnerGeneratedCauses	name
Problems/Delays in materials, labor or goods that are in responsibility of the owner	OwnerGeneratedCauses	name
Lack of working knowledge of owner	OwnerGeneratedCauses	name
Lack of experience of owner in construction projects	OwnerGeneratedCauses	name
Lack of capable owner’s representative	OwnerGeneratedCauses	name
Failure on the part of the owner to review and approve design documents, schedules, and material on time	OwnerGeneratedCauses	name
Failure on the part of the owner to properly coordinate multiple contractors	OwnerGeneratedCauses	name
Unrealistic time/cost/quality targets/expectations and requirements by owner	OwnerGeneratedCauses	name
Unrealistic information expectations by owner	OwnerGeneratedCauses	name
Confusing and ambiguous requirements by owner	OwnerGeneratedCauses	name
Slow responses from the owner's organization	OwnerGeneratedCauses	name
Change in scope of work or in construction detail	OwnerGeneratedCauses	name
Introduction of major changes in requirements	OwnerGeneratedCauses	name
Failure to give timely orders/instructions for work by owner	OwnerGeneratedCauses	name
Inadequate information and supervision by the owner	OwnerGeneratedCauses	name
Interference by other prime contractors working for the owner	OwnerGeneratedCauses	name
Nonadherence to contract conditions by owner	OwnerGeneratedCauses	name
Suspension of work or wrongful termination by owner	OwnerGeneratedCauses	name
Insufficient or ill-integrated basic project data that is needed to be provided by owner	OwnerGeneratedCauses	name
Mistakes and discrepancies in contract documents due to owner	ContractRelatedCauses	name
Inadequate contract administration	ContractRelatedCauses	name
Incomplete/erroneous contract documentation	ContractRelatedCauses	name
Inadequate definitions/contract clauses in contract	ContractRelatedCauses	name
Disagreements on contract clauses	ContractRelatedCauses	name
Poor interpretation of contract clauses	ContractRelatedCauses	name
Inappropriate contract form	ContractRelatedCauses	name
Poor knowledge of local statues	ContractRelatedCauses	name
Poor scope definition	ContractRelatedCauses	name
Poor contract familiarity/Owner's contracting procedures	ContractRelatedCauses	name
Contract and specification interpretation disagreement	ContractRelatedCauses	name
Poor contract interpretation	ContractRelatedCauses	name
Ineffective delay penalties in contract	ContractRelatedCauses	name
Unavailability of financial incentives for contractor for finishing ahead of schedule in contract	ContractRelatedCauses	name
Unrealistic contract duration imposed by owner	ContractRelatedCauses	name

Table A.1: Instance table of the delay analysis ontology (continued)

Instance name	**Concept name**	**Attribute**
Work imposed that is not part of the contract by owner	ContractRelatedCauses	name
Owner’s late contract award	ContractRelatedCauses	name
Contract modifications (replacement and addition of new work to the project and change in specifications)	ContractRelatedCauses	name
Owner's personality and characteristics	ContractualRelationshipRelatedCauses	name
Owner's interference/Unnecessary interference by the owner	ContractualRelationshipRelatedCauses	name
Uncooperative owner	ContractualRelationshipRelatedCauses	name
Excessive bureaucracy by owner's administration	ContractualRelationshipRelatedCauses	name
Slowness in decision making process by owner	ContractualRelationshipRelatedCauses	name
Conflicts between joint-ownership of the project	ContractualRelationshipRelatedCauses	name
Conflicts between owner and other parties (contractor)	ContractualRelationshipRelatedCauses	name
Faulty negotiations and obtaining of contracts	ContractualRelationshipRelatedCauses	name
Poor communication and coordination by owner with other parties (construction parties and government authorities)	ContractualRelationshipRelatedCauses	name
Inappropriate overall structure linking all parties in project	ContractualRelationshipRelatedCauses	name
Lack of communication and coordination between the parties involved in construction	ContractualRelationshipRelatedCauses	name
Low speed of decision making involving all project teams	ContractualRelationshipRelatedCauses	name
Low speed of decision making within each project team	ContractualRelationshipRelatedCauses	name
Slow information flow between project team members	ContractualRelationshipRelatedCauses	name
Replacement of key personnel by owner	ContractualRelationshipRelatedCauses	name
High turnover in owner's technical personnel	ContractualRelationshipRelatedCauses	name
Negotiation by knowledgeable people	ContractualRelationshipRelatedCauses	name
Delay in the settlement of contractor claims by the owner	ContractualRelationshipRelatedCauses	name
Delay in delivery of materials	MaterialRelatedCauses	name
Poorly scheduled delivery of material to site	MaterialRelatedCauses	name
Delay in manufacturing special building materials	MaterialRelatedCauses	name
Problems due to imported materials and plant items	MaterialRelatedCauses	name
Problems due to proportion of off-site prefabrication	MaterialRelatedCauses	name
Late procurement of materials	MaterialRelatedCauses	name
Poor/Inappropriate procurement method/programming of construction materials	MaterialRelatedCauses	name
Unavailability of materials on site on time	MaterialRelatedCauses	name

Table A.1: Instance table of the delay analysis ontology (continued)

Instance name	Concept name	Attribute
Inappropriate/Inadequate use (misuse) of material	MaterialRelatedCauses	name
Poor material handling on site	MaterialRelatedCauses	name
Improper tools for materials	MaterialRelatedCauses	name
Poor quality of materials	MaterialRelatedCauses	name
Poor storage of material	MaterialRelatedCauses	name
Damage of sorted materials while they are needed urgently	MaterialRelatedCauses	name
Unforeseen material damages	MaterialRelatedCauses	name
Noncompliance of material to specifications	MaterialRelatedCauses	name
Rework due to defective material	MaterialRelatedCauses	name
Rejected material	MaterialRelatedCauses	name
Unreliable material suppliers	MaterialRelatedCauses	name
Changes in materials prices in fixed-priced contracts	MaterialRelatedCauses	name
Changes in materials specifications	MaterialRelatedCauses	name
Shortage of construction materials in market	MaterialRelatedCauses	name
Equipment breakdown/failure and maintenance problem	EquipmentRelatedCauses	name
Unavailability of equipment and tool on site	EquipmentRelatedCauses	name
Shortage of construction equipment and tools in market	EquipmentRelatedCauses	name
Inadequate skill of equipment-operator	EquipmentRelatedCauses	name
Low productivity and efficiency of equipment	EquipmentRelatedCauses	name
Failure to provide sufficient equipment	EquipmentRelatedCauses	name
Lack of high-technology mechanical equipment/Outdated equipment	EquipmentRelatedCauses	name
Poor/Wrong selection of equipment/Improper equipment	EquipmentRelatedCauses	name
Inadequate/Insufficient/Ineffective equipment used for the works	EquipmentRelatedCauses	name
Equipment delivery problem	EquipmentRelatedCauses	name
Deficiencies in equipment allocation	EquipmentRelatedCauses	name
Slow mobilization of equipment	EquipmentRelatedCauses	name
Rejected equipment	EquipmentRelatedCauses	name
Unavailability of site labors	LaborRelatedCauses	name
Unqualified/Inadequate experienced labor	LaborRelatedCauses	name
Low skilled manpower/Unskilled labor	LaborRelatedCauses	name
Low productivity/efficiency level of labors	LaborRelatedCauses	name
Weak motivation and morale of labors	LaborRelatedCauses	name
Poor workmanship	LaborRelatedCauses	name
Unavailability of technical professionals in the contractor's organization	LaborRelatedCauses	name
Poor distribution of labor	LaborRelatedCauses	name
Slow mobilization of labor	LaborRelatedCauses	name
Too much overtime for labor	LaborRelatedCauses	name
Severe overtime and shifts	LaborRelatedCauses	name
Absenteeism problems of labor	LaborRelatedCauses	name
Labor and management relations	LaborRelatedCauses	name
Problems due to nationality of labors	LaborRelatedCauses	name
Personal conflicts among labors	LaborRelatedCauses	name

Table A.1: Instance table of the delay analysis ontology (continued)

Instance name	Concept name	Attribute
Labor injuries	LaborRelatedCauses	name
Unavailability of skilled/qualified labor/craft	LaborRelatedCauses	name
Unavailability of local labor	LaborRelatedCauses	name
Non-cooperation from labor unions	LaborRelatedCauses	name
Difficulties in financing project by contractor	ContractorsFinancialCauses	name
Late payment to subcontractor by the main contractor	ContractorsFinancialCauses	name
Contractor's financial problems	ContractorsFinancialCauses	name
Problems in cash flow management	ContractorsFinancialCauses	name
Contractor's financial obligations	ContractorsFinancialCauses	name
Poor subcontracting (system)	SubcontractorCauses	name
Delays in subcontractor's work/Delay caused by subcontractor	SubcontractorCauses	name
Lack of subcontractor's skills	SubcontractorCauses	name
Lack of subcontractor's experience	SubcontractorCauses	name
Unreliable subcontractors	SubcontractorCauses	name
Poor performance of subcontractors and nominated suppliers	SubcontractorCauses	name
Bankruptcy by subcontractor or supplier	SubcontractorCauses	name
Subcontractor's financial difficulties	SubcontractorCauses	name
Poor communication and coordination by subcontractor with contractor/other parties	SubcontractorCauses	name
Frequent change of subcontractors (because of their inefficient work)	SubcontractorCauses	name
Time spent to find appropriate subcontractors for each task	SubcontractorCauses	name
Conflicts between different subcontractors' schedules in execution of project	SubcontractorCauses	name
Subcontractor interference	SubcontractorCauses	name
Interference with other trades (trade stacking)	SubcontractorCauses	name
Slow mobilization by subcontractor	SubcontractorCauses	name
Rework due to subcontractor	SubcontractorCauses	name
Accident during construction	HealthAndSafetyRelatedCauses	name
Unsafe practices during construction	HealthAndSafetyRelatedCauses	name
Damage to structure	HealthAndSafetyRelatedCauses	name
Problems due to site safety considerations/Poor safety conditions	HealthAndSafetyRelatedCauses	name
Problems due to site security considerations	HealthAndSafetyRelatedCauses	name
Problems due to site restrictions	HealthAndSafetyRelatedCauses	name
Lateness in safety facilities reinforcement	HealthAndSafetyRelatedCauses	name
Loose safety rules and regulations within the contractor's organization	HealthAndSafetyRelatedCauses	name

Table A.1: Instance table of the delay analysis ontology (continued)

Instance name	**Concept name**	**Attribute**
Safety rules and regulations are not followed within the contractor's organization	HealthAndSafetyRelatedCauses	name
Problems due to site pollution and noise	HealthAndSafetyRelatedCauses	name
Environmental protection and mitigation costs	HealthAndSafetyRelatedCauses	name
Theft/Vandalism inside the site	HealthAndSafetyRelatedCauses	name
Creation of the schedule too optimistic	SchedulingAndControllingRelatedCauses	name
Overestimation of the labor productivity	SchedulingAndControllingRelatedCauses	name
More work exists than planned	SchedulingAndControllingRelatedCauses	name
Lack of database in estimating activity duration and resources	SchedulingAndControllingRelatedCauses	name
Inaccurate estimate of materials, labor output, equipment production rates	SchedulingAndControllingRelatedCauses	name
Inaccurate evaluation of projects time/duration	SchedulingAndControllingRelatedCauses	name
Improper or wrong cost estimation	SchedulingAndControllingRelatedCauses	name
Nonuse of appropriate software for scheduling and controlling	SchedulingAndControllingRelatedCauses	name
Contractors' planning and scheduling problems	SchedulingAndControllingRelatedCauses	name
Unrealistic project schedule	SchedulingAndControllingRelatedCauses	name
Poor judgment and experience of involved people in estimating time and resources	SchedulingAndControllingRelatedCauses	name
Lack of experiences in project management & scheduling process	SchedulingAndControllingRelatedCauses	name
Lack of experiences and information preparing in price quotation	SchedulingAndControllingRelatedCauses	name
Lack of training personnel and management support to model the construction operation	SchedulingAndControllingRelatedCauses	name
Unavailability of the construction/project management group for the project	SchedulingAndControllingRelatedCauses	name
Unavailability of managerial and supervisory personnel	SchedulingAndControllingRelatedCauses	name
Improper technical study by the contractor during the bidding stage	SchedulingAndControllingRelatedCauses	name
Inadequate early planning of the project	SchedulingAndControllingRelatedCauses	name
Unreasonable or unpractical initial plan	SchedulingAndControllingRelatedCauses	name
Insufficient or ill-integrated basic project data that is needed to be provided by contractor	SchedulingAndControllingRelatedCauses	name
Poor project planning and scheduling by contractor	SchedulingAndControllingRelatedCauses	name

Table A.1: Instance table of the delay analysis ontology (continued)

Instance name	Concept name	Attribute
Ineffective control of the project progress by the contractor/Inadequate progress review	SchedulingAndControllingRelatedCauses	name
Poor quality of site documentation	SchedulingAndControllingRelatedCauses	name
Inefficient work breakdown structure	SchedulingAndControllingRelatedCauses	name
Problems with timelines of project information	SchedulingAndControllingRelatedCauses	name
Staffing problems (overstaffing/understaffing)	SchedulingAndControllingRelatedCauses	name
Transportation problems	SchedulingAndControllingRelatedCauses	name
Overcrowded work area/Congestion	SchedulingAndControllingRelatedCauses	name
Complexity of works	SchedulingAndControllingRelatedCauses	name
Using obsolete technology	SchedulingAndControllingRelatedCauses	name
Large number of participants of project	SchedulingAndControllingRelatedCauses	name
Involvement of several foreign designers and contractors	SchedulingAndControllingRelatedCauses	name
Conflicts between contractor and other parties (consultant and owner)	ContractorGeneratedCauses	name
Poor communication and coordination by contractor with other parties	ContractorGeneratedCauses	name
Lack of consultation of contractor/project manager with owner	ContractorGeneratedCauses	name
Lack of proper training and experience of contractor/project manager	ContractorGeneratedCauses	name
Poor/Inadequate contractor experience/Inexperienced contractor	ContractorGeneratedCauses	name
Contractor's lack of geographical experience	ContractorGeneratedCauses	name
Contractor's lack of project type experience	ContractorGeneratedCauses	name
Unsuitable leadership style of construction/project manager	ContractorGeneratedCauses	name
Unsuitable management structure and style of contractor	ContractorGeneratedCauses	name
Nonutilization of professional construction/contractual management	ContractorGeneratedCauses	name
Inadequate managerial skills/Inadequate site/project management skills	ContractorGeneratedCauses	name
Lack of responsibility of contractor/project manager	ContractorGeneratedCauses	name
Lack of authority of contractor/project/site manager	ContractorGeneratedCauses	name
Unreasonable risk allocation by contractor	ContractorGeneratedCauses	name
Poor contract management by contractor	ContractorGeneratedCauses	name
Poor subcontract management	ContractorGeneratedCauses	name
Poor site management/inspection and supervision by contractor	ContractorGeneratedCauses	name
Poor site management and slow site clearance	ContractorGeneratedCauses	name

Table A.1: Instance table of the delay analysis ontology (continued)

Instance name	Concept name	Attribute
Poor labor supervision	ContractorGeneratedCauses	name
Poor control of site resource allocation/Lack of available resources	ContractorGeneratedCauses	name
Poor resource allocation by contractor	ContractorGeneratedCauses	name
Delay of field survey by contractor	ContractorGeneratedCauses	name
Inefficient quality assurance and quality control	ContractorGeneratedCauses	name
Poor site layout	ContractorGeneratedCauses	name
Poor site storage capacity	ContractorGeneratedCauses	name
Poor logistic control by contractor	ContractorGeneratedCauses	name
Poor trade coordination	ContractorGeneratedCauses	name
Contractor's deficiencies in planning and scheduling at preconstruction stage	ContractorGeneratedCauses	name
Improper construction methods/techniques implemented by contractor	ContractorGeneratedCauses	name
Inadequate contractor's work	ContractorGeneratedCauses	name
Mistakes in soil investigation	ContractorGeneratedCauses	name
Poor qualification of the contractor's technical staff/Incompetent technical staff assigned to the project	ContractorGeneratedCauses	name
Incompetent project team	ContractorGeneratedCauses	name
Excessive turnover in contractor's staff	ContractorGeneratedCauses	name
Replacement of key personnel by contractor	ContractorGeneratedCauses	name
Lack of site contractor’s staff	ContractorGeneratedCauses	name
Contractor's failure to coordinate the work, i.e., deficient planning, scheduling, and supervision	ContractorGeneratedCauses	name
Failure to utilize tools to manage the project symmetrically by contractor/project manager	ContractorGeneratedCauses	name
Inadequate instructions by contractor	ContractorGeneratedCauses	name
Lack of timely decisions and corrective actions by contractor/project manager	ContractorGeneratedCauses	name
Slow response by contractor/project manager	ContractorGeneratedCauses	name
Low contractor productivity	ContractorGeneratedCauses	name
Construction mistakes and defective work	ContractorGeneratedCauses	name
Errors committed during field construction on site	ContractorGeneratedCauses	name
Rework due to errors during construction	ContractorGeneratedCauses	name
Delay in site mobilization	ContractorGeneratedCauses	name
Delay in preparation of contractor submissions	ContractorGeneratedCauses	name
Mistakes and discrepancies in contract documents due to contractor	ContractorGeneratedCauses	name
Nonadherence to contract conditions by contractor	ContractorGeneratedCauses	name
Risk and uncertainty associated with projects	ContractorGeneratedCauses	name
Non-familiarity of contractor with local regulations	ContractorGeneratedCauses	name
Ineffective contractor head office involvement in the project	ContractorGeneratedCauses	name
Problems due to company organization of contractor	ContractorGeneratedCauses	name
Internal company problems of contractor	ContractorGeneratedCauses	name
Ill defined duties and responsibilities by contractor's company organization	ContractorGeneratedCauses	name

Table A.1: Instance table of the delay analysis ontology (continued)

Instance name	**Concept name**	**Attribute**
Inadequate decision making mechanism of contractor's company organization	ContractorGeneratedCauses	name
Lack of contractor's administrative personnel	ContractorGeneratedCauses	name
Problems due to other work on hold	ContractorGeneratedCauses	name
Project fraud and corruption	ContractorGeneratedCauses	name
Fraud by contractor	ContractorGeneratedCauses	name
Opportunistic behavior of contractor	ContractorGeneratedCauses	name
Hot weather effect on construction activities	InclementWeatherCauses	name
Humidity effect on construction activities	InclementWeatherCauses	name
Inclement weather effect on construction activities	InclementWeatherCauses	name
Wind effect on construction activities	InclementWeatherCauses	name
Rain effect on construction activities	InclementWeatherCauses	name
Snow effect on construction activities	InclementWeatherCauses	name
Freezing effect on construction activities	InclementWeatherCauses	name
Unexpected foundation conditions encountered in the field	EnvironmentalCauses	name
Unexpected subsurface conditions (geological problems/water table problems, etc.)	EnvironmentalCauses	name
Unforeseen site conditions	EnvironmentalCauses	name
Unforeseen ground conditions (rock, acid, sediment basin)	EnvironmentalCauses	name
Delay in providing services from utilities (such as water, electricity)	EnvironmentalCauses	name
Unavailability of utilities on site (such as, water, electricity, telephone, etc.)	EnvironmentalCauses	name
Lack of temporary facilities on site (buildings, phones, electricity, etc.)	EnvironmentalCauses	name
External work due to public agencies (roads, utilities and public services)	EnvironmentalCauses	name
Difficulties in obtaining energy (electricity, fuel)	EnvironmentalCauses	name
Transportation delays beyond control	EnvironmentalCauses	name
Locational project restrictions	EnvironmentalCauses	name
Interferences of existing utilities	EnvironmentalCauses	name
Unanticipated utilities	EnvironmentalCauses	name
Work damaged by others	EnvironmentalCauses	name
Noise level too high	EnvironmentalCauses	name
Environmental issues	EnvironmentalCauses	name
Avalanches	GeologicalDisasters	name
Earthquakes	GeologicalDisasters	name
Landslides	GeologicalDisasters	name
Volcanic eruptions	GeologicalDisasters	name
Floods	HydrologicalDisasters	name
Limnic eruptions	HydrologicalDisasters	name
Tsunamis	HydrologicalDisasters	name
Blizzards	MeteorologicalDisasters	name
Cyclones	MeteorologicalDisasters	name
Droughts	MeteorologicalDisasters	name

Table A.1: Instance table of the delay analysis ontology (continued)

Instance name	**Concept name**	**Attribute**
Hurricanes	MeteorologicalDisasters	name
Tornadoes	MeteorologicalDisasters	name
Storms	MeteorologicalDisasters	name
Epidemics	HealthDisasters	name
Famines	HealthDisasters	name
Nationalization	UnexpectedSituations	name
Government sanction	UnexpectedSituations	name
Blockage	UnexpectedSituations	name
Embargo	UnexpectedSituations	name
Labor dispute	UnexpectedSituations	name
Strike	UnexpectedSituations	name
Lockout or interruption or failure of electricity or telephone service	UnexpectedSituations	name
War	UnexpectedSituations	name
Invasion	UnexpectedSituations	name
Act of foreign/public enemies	UnexpectedSituations	name
Hostilities	UnexpectedSituations	name
Civil war	UnexpectedSituations	name
Rebellion	UnexpectedSituations	name
Revolution	UnexpectedSituations	name
Insurrection	UnexpectedSituations	name
Military or usurped power or confiscation	UnexpectedSituations	name
Terrorism or threat of terrorism	UnexpectedSituations	name
Theft/Vandalism outside of the site	UnexpectedSituations	name
Obtaining permits/approvals from the municipality/different government authorities	RulesAndRegulationsRelated Causes	name
Obtaining (working) permits for laborers	RulesAndRegulationsRelated Causes	name
Obtaining transportation permit	RulesAndRegulationsRelated Causes	name
Building permits approval process	RulesAndRegulationsRelated Causes	name
Problems related to using of building codes in design of projects	RulesAndRegulationsRelated Causes	name
Delay in performing final inspection and certification by a third party	RulesAndRegulationsRelated Causes	name
Environmental concerns and restrictions	RulesAndRegulationsRelated Causes	name
Traffic control regulation and restriction at job site	RulesAndRegulationsRelated Causes	name
Conservation restrictions	RulesAndRegulationsRelated Causes	name
Restricted use of labor	RulesAndRegulationsRelated Causes	name
Limitation of working hours	RulesAndRegulationsRelated Causes	name
Prevention of contractor's resource	RulesAndRegulationsRelated Causes	name

Table A.1: Instance table of the delay analysis ontology (continued)

Instance name	**Concept name**	**Attribute**
Inability to obtain labor, goods or materials (shortage through statutory action)	RulesAndRegulationsRelated Causes	name
Work in pursuance of a body's statutory obligations	RulesAndRegulationsRelated Causes	name
Legal issues arising due to local government rules and regulations	RulesAndRegulationsRelated Causes	name
Lack of cooperation from local authorities	RulesAndRegulationsRelated Causes	name
Difficulties in obtaining construction licenses	RulesAndRegulationsRelated Causes	name
Government actions and inactions regarding ordinances, construction law, and etc.	RulesAndRegulationsRelated Causes	name
Changes in government regulations and laws	RulesAndRegulationsRelated Causes	name
Worker's compensation board shutdown	RulesAndRegulationsRelated Causes	name
Acts of government (sovereign or contractual)	RulesAndRegulationsRelated Causes	name
Acts of another contractor in performance of a government contract	RulesAndRegulationsRelated Causes	name
Quarantine restrictions	RulesAndRegulationsRelated Causes	name
Freight embargoes	RulesAndRegulationsRelated Causes	name
Local government pressures	RulesAndRegulationsRelated Causes	name
Economic development cycle and its impact on demand	EconomicalCauses	name
Inflation impact on material, equipment and labor price fluctuation	EconomicalCauses	name
Market competition	EconomicalCauses	name
Inflation/Escalation of prices	EconomicalCauses	name
Price/Financial fluctuations	EconomicalCauses	name
Fluctuation of currency/exchange rate	EconomicalCauses	name
Unstable interest rate	EconomicalCauses	name
Poor economic conditions (currency, inflation rate, etc.)	EconomicalCauses	name
Unforeseeable financial and economic crises	EconomicalCauses	name
Prices of some materials shooting up or the constructed project being devalued	EconomicalCauses	name
Changes in government policies (environmental protection, sustainability, waste recycle, brown field use, etc.)	PoliticalCauses	name
Changes in legislations on employment, and working conditions	PoliticalCauses	name
Political pressure	PoliticalCauses	name
Weak regulation and control	PoliticalCauses	name
Government regulations	PoliticalCauses	name
Demography change and its impact on labor demand and supply	SocialCauses	name
Skill shortage on certain trades	SocialCauses	name

Table A.1: Instance table of the delay analysis ontology (continued)

Instance name	**Concept name**	**Attribute**
Problems with neighboring community	SocialCauses	name
Problems with local residents	SocialCauses	name
Effect of cultural factors	SocialCauses	name
Civil commotion/disturbances	SocialCauses	name
Effects of other organizations	SocialCauses	name
Social and cultural factors	SocialCauses	name
Problems with new materials	TechnologicalCauses	name
Problems with new construction methods	TechnologicalCauses	name
Technological complexity	TechnologicalCauses	name
Technical challenges	TechnologicalCauses	name
Owner caused delays	DelaysClassifiedByTheirOrigin	name
Contractor caused delays	DelaysClassifiedByTheirOrigin	name
Third party caused delays	DelaysClassifiedByTheirOrigin	name
Independent/Classic delays	DelaysClassifiedByTheirTiming	name
Concurrent delays	DelaysClassifiedByTheirTiming	name
Serial delays	DelaysClassifiedByTheirTiming	name
Pacing delays	DelaysClassifiedByTheirTiming	name
Excusable compensable delays	DelaysClassifiedByTheirCompensability	name
Excusable non-compensable delays	DelaysClassifiedByTheirCompensability	name
Non-excusable delays	DelaysClassifiedByTheirCompensability	name
Date delays	DelaysClassifiedByTheirContent	name
Total delays	DelaysClassifiedByTheirContent	name
Extended delays	DelaysClassifiedByTheirContent	name
Additional delays	DelaysClassifiedByTheirContent	name
Sequence delays	DelaysClassifiedByTheirContent	name
Progress delays	DelaysClassifiedByTheirContent	name
Critical delays: Delay to completion	DelaysClassifiedByTheirCriticality	name
Non-critical delays: Delay to progress	DelaysClassifiedByTheirCriticality	name
Owner (or his agents) responsible	Responsibility	name
Contractor (or his subcontractors) responsible	Responsibility	name
Neither contractual party responsible	Responsibility	name

Table A.1: Instance table of the delay analysis ontology (continued)

Instance name	**Concept name**	**Attribute**
Both contractual parties responsible	Responsibility	name
Constructive acceleration	Acceleration	name
Directive acceleration	Acceleration	name
Loss of key resources (staffing and equipment)	OwnersDirectCosts	name
Reduction of shareholder equity	OwnersDirectCosts	name
Costs for the owner's staff	OwnersDirectCosts	name
Costs for additional design services	OwnersDirectCosts	name
Cost for project inspection	OwnersDirectCosts	name
Costs for maintaining current facilities	OwnersDirectCosts	name
Costs for additional rentals	OwnersDirectCosts	name
Costs for additional storage	OwnersDirectCosts	name
Governmental fines and penalties	OwnersDirectCosts	name
Temporary lodging costs	OwnersDirectCosts	name
Additional moving expense	OwnersDirectCosts	name
Increased financing costs	OwnersDirectCosts	name
Extra inflation or fluctuation costs	OwnersDirectCosts	name
Extended overhead costs	OwnersDirectCosts	name
Escalation costs	OwnersDirectCosts	name
Missed market penetration	OwnersDirectCosts	name
Interest charges	OwnersDirectCosts	name
Claims by follow-on contractors	OwnersDirectCosts	name
Claims by third parties	OwnersDirectCosts	name
Extended warranties	OwnersDirectCosts	name
Loss of income/revenue/profit	OwnersIndirectCosts	name
Lost rents	OwnersIndirectCosts	name
Costs to the public for not having the facility	OwnersIndirectCosts	name
Loss of rhythm	LostProductivityCosts	name
Lower morale	LostProductivityCosts	name
Schedule compression	LostProductivityCosts	name
Resequencing of work	LostProductivityCosts	name
Trade stacking	LostProductivityCosts	name
Staff turnover	LostProductivityCosts	name
Team changes	LostProductivityCosts	name
Less qualified labor	LostProductivityCosts	name
Loss of learning curve	LostProductivityCosts	name
Site congestion	LostProductivityCosts	name
Poor safety conditions	LostProductivityCosts	name
Poor coordination	LostProductivityCosts	name
Shifts in the construction season	LostProductivityCosts	name
Unavailability of resources	LostProductivityCosts	name
Changes in manpower levels and distribution	LostProductivityCosts	name
Additional manpower	LostProductivityCosts	name
Erratic staffing	LostProductivityCosts	name
Variations in preferred/optimum crew size	LostProductivityCosts	name
Multiple-shift work	LostProductivityCosts	name

Table A.1: Instance table of the delay analysis ontology (continued)

Instance name	**Concept name**	**Attribute**
Unbalanced gangs	LostProductivityCosts	name
Additional material costs due to acceleration	AccelerationCosts	name
Additional equipment costs due to acceleration	AccelerationCosts	name
Labor premiums for acceleration	AccelerationCosts	name
Inefficiency due to acceleration	AccelerationCosts	name
Miscellaneous expenses due to acceleration	AccelerationCosts	name
Escalation of labor costs due to noncritical delay	CostsOfNoncriticalDelays	name
Additional material costs due to noncritical delay	CostsOfNoncriticalDelays	name
Additional equipment costs due to noncritical delay	CostsOfNoncriticalDelays	name
Additional supervision for noncritical delay	CostsOfNoncriticalDelays	name
Inefficiency due to noncritical delay	CostsOfNoncriticalDelays	name
Escalation of labor cost	AdditionalLaborCosts	name
Additional direct labor cost	AdditionalLaborCosts	name
Additional idle labor cost	AdditionalLaborCosts	name
Additional union supervisory personnel cost	AdditionalLaborCosts	name
Escalation of material cost	AdditionalMaterialCosts	name
Deterioration in conditions of material	AdditionalMaterialCosts	name
Additional material storage costs	AdditionalMaterialCosts	name
Escalation of equipment cost	AdditionalEquipmentCosts	name
Additional working/productive time	AdditionalEquipmentCosts	name
Additional standing/idle time	AdditionalEquipmentCosts	name
Extra cost for replacement of unavailable equipment	AdditionalEquipmentCosts	name
Costs of bringing to site and commissioning	AdditionalEquipmentCosts	name
Costs of dismantling and removing from site	AdditionalEquipmentCosts	name
Site preliminaries	ExtendedSiteOverheadCosts	name
Site infrastructure	ExtendedSiteOverheadCosts	name
Connecting and mobilizing utilities	ExtendedSiteOverheadCosts	name
General site equipment	ExtendedSiteOverheadCosts	name
Cranes	ExtendedSiteOverheadCosts	name
Providing a jobsite office	ExtendedSiteOverheadCosts	name
Supervising the project	ExtendedSiteOverheadCosts	name
Mobilization/Demobilization costs	ExtendedSiteOverheadCosts	name
Rent	ExtendedHomeOfficeOverheadCosts	name
Utilities	ExtendedHomeOfficeOverheadCosts	name
Furnishings	ExtendedHomeOfficeOverheadCosts	name
Office equipment	ExtendedHomeOfficeOverheadCosts	name
Executive staff	ExtendedHomeOfficeOverheadCosts	name
Support and clerical staff not assigned to the field	ExtendedHomeOfficeOverheadCosts	name
Estimators and schedulers not assigned to the field	ExtendedHomeOfficeOverheadCosts	name

Table A.1: Instance table of the delay analysis ontology (continued)

Instance name	Concept name	Attribute
Mortgage costs	ExtendedHomeOfficeOverheadCosts	name
Real estate taxes	ExtendedHomeOfficeOverheadCosts	name
Non-project-related bond or insurance expenses	ExtendedHomeOfficeOverheadCosts	name
Depreciation of equipment and other assets	ExtendedHomeOfficeOverheadCosts	name
Office supplies (paper, staples, etc.)	ExtendedHomeOfficeOverheadCosts	name
Advertising	ExtendedHomeOfficeOverheadCosts	name
Marketing	ExtendedHomeOfficeOverheadCosts	name
Interest	ExtendedHomeOfficeOverheadCosts	name
Accounting and data processing	ExtendedHomeOfficeOverheadCosts	name
Professional fees and registrations	ExtendedHomeOfficeOverheadCosts	name
Loss of profits, bonuses or opportunity costs (on the delayed project / on other projects)	ContractorsIndirectCosts	name
Destruction of business	ContractorsIndirectCosts	name
Increased risk (Loss of float and Increased sensitivity to further delays)	ContractorsIndirectCosts	name
Quality damages	ContractorsIndirectCosts	name
Quality degradation	ContractorsIndirectCosts	name
Damage to reputation	ContractorsIndirectCosts	name
Deleting some work items	ChangingTheWorkSequence	name
Allowing more of the critical work to occur at the same time	ChangingTheWorkSequence	name
Increasing manpower	AcceleratingTheWork	name
Adding equipment	AcceleratingTheWork	name
Expediting the delivery of materials	AcceleratingTheWork	name
Working outside planned working hours	AcceleratingTheWork	name
Extra shifting	AcceleratingTheWork	name
Improving conditions e.g. providing temporary heat	AcceleratingTheWork	name
Changing the materials used	ChangingTheContract	name
Changing the method of construction	ChangingTheContract	name
Relaxing the contract restrictions	ChangingTheContract	name
Asking for a change in design	ChangingTheContract	name
Improvement of productivity	MakingImprovements	name
Improvement of communications between parties	MakingImprovements	name
Conducting work methods improvement studies	MakingImprovements	name
Asking for more site meetings with all functional groups	MakingImprovements	name
Asking top management for more executive authorities to project manager	MakingImprovements	name
Protection of uncompleted work	MakingImprovements	name

Table A.1: Instance table of the delay analysis ontology (continued)

Instance name	**Concept name**	**Attribute**
Timely and reasonable reprocurement	MakingImprovements	name
Timely changing or cancellation of purchase orders	MakingImprovements	name
Extra work claims	VariationClaims	name
Different site conditions claims/Latent condition claims	VariationClaims	name
Acceleration claims	VariationClaims	name
Interest claim	VariationClaims	name
Extension of time claim	TimeRelatedClaims	name
Liquidated damages claim	TimeRelatedClaims	name
Prolongation claim	TimeRelatedClaims	name
Global/Composite/Rolled-up/Ambit claim	TimeRelatedClaims	name
Disruption/Loss of productivity claim	TimeRelatedClaims	name
Total cost claim	QuantumMeuritClaims	name
Contractual quantum meurit (Quantum meurit under contract)	QuantumMeuritClaims	name
Restitutionary quantum meurit (Quantum meurit on unjust enrichment)	QuantumMeuritClaims	name
Claimant	Parties	name
Responsible	Parties	name
Date of the claim	i.Introduction	name
Names of the parties	i.Introduction	name
Addresses of the parties	i.Introduction	name
Contract name	i.Introduction	name
Contract number	i.Introduction	name
Contract sum	i.Introduction	name
The form of contract and any amendments thereto	i.Introduction	name
Details of tender and acceptance	i.Introduction	name
Dates for commencement and completion	i.Introduction	name
Phased completion (if applicable)	i.Introduction	name
Description of the works	i.Introduction	name
The programme	i.Introduction	name
Liquidated damages for delay	i.Introduction	name
Actual date of commencement and practical completion	ii.SummaryOfFacts	name
Actual dates of sectional or partial completion (if applicable)	ii.SummaryOfFacts	name
Summary of applications for extensions of time	ii.SummaryOfFacts	name
Extensions of time awarded	ii.SummaryOfFacts	name
Summary of claims submitted	ii.SummaryOfFacts	name
Final account and claims assessed (if any)	ii.SummaryOfFacts	name
Amount of latest certificate and retention	ii.SummaryOfFacts	name
Payments received	ii.SummaryOfFacts	name
Liquidated damages deducted (if applicable)	ii.SummaryOfFacts	name
Contract provisions relied upon	iii.BasisOfClaim	name
Common law provisions	iii.BasisOfClaim	name
Contractual analysis	iii.BasisOfClaim	name
Contractual entitlement	iii.BasisOfClaim	name
Contractual compliance	iii.BasisOfClaim	name

Table A.1: Instance table of the delay analysis ontology (continued)

Instance name	Concept name	Attribute
Explanation of the basis of the claim	iii.BasisOfClaim	name
Key dates	iv.DetailsOfClaim	name
The date of delay commenced	iv.DetailsOfClaim	name
The date of notice of delay	iv.DetailsOfClaim	name
Identification of the notices served and relied upon	iv.DetailsOfClaim	name
Description of events	iv.DetailsOfClaim	name
Description of causes and effects	iv.DetailsOfClaim	name
Explanation of the differing item already required by contract	iv.DetailsOfClaim	name
References to relevant documents and specific contract clauses that apply	iv.DetailsOfClaim	name
Narrative of history of effects	iv.DetailsOfClaim	name
Distinguish causes and effects as EOT and financial effect	iv.DetailsOfClaim	name
A detailed breakdown of damages with supporting information	iv.DetailsOfClaim	name
Analysis of the schedule showing the effect on schedule	iv.DetailsOfClaim	name
Applicable details - public holidays etc.	iv.DetailsOfClaim	name
Current completion date	iv.DetailsOfClaim	name
An explanation of liability of the claim	iv.DetailsOfClaim	name
Summary of records and particulars	iv.DetailsOfClaim	name
Extensive use of schedules	iv.DetailsOfClaim	name
Programmes	iv.DetailsOfClaim	name
Diagrammatic illustration	iv.DetailsOfClaim	name
Tables	iv.DetailsOfClaim	name
Details of calculation of additional costs ascertained	v.EvaluationOfClaim	name
Statement setting out the claimant's alleged entitlements and relief	vi.StatementOfClaim	name
Copies of all documents	vii.Appendices	name
(Negotiated settlement/Amicable negotiation/Direct negotiation)	ResolutionByNegotiation	name
Expert determination/Neutral evaluation	AlternativeDisputeResolution	name
Private judging/Rent a judge	AlternativeDisputeResolution	name
Executive tribunal	AlternativeDisputeResolution	name
Adjudication	AlternativeDisputeResolution	name
Conciliation	AlternativeDisputeResolution	name
Mediation	AlternativeDisputeResolution	name
Facilitation	AlternativeDisputeResolution	name
Minitrial	AlternativeDisputeResolution	name
Arbitration	AlternativeDisputeResolution	name
Dispute review boards	AlternativeDisputeResolution	name
Dispute resolution adviser	AlternativeDisputeResolution	name
Med-arb	AlternativeDisputeResolution	name
(Lawsuit/Legal Trial)	Litigation	name
Extension of time	Award	name
Liquidated damages	Award	name

Table A.1: Instance table of the delay analysis ontology (continued)

Instance name	Concept name	Attribute
Cost compensation to contractor	Award	name
Extension of time + Cost compensation to contractor	Award	name
The float belongs to the project: whoever "gets to it first"	FloatOwnershipIssue	name
The float belongs to the contractor	FloatOwnershipIssue	name
The float belongs to either party so long as it is reasonably utilized	FloatOwnershipIssue	name
Retained logic vs Progress override	SchedulingOptionsIssue	name
Theories of critical path (Longest path theory/Float theory)	SchedulingOptionsIssue	name
Use of multiple calendars	SchedulingOptionsIssue	name
Use of constraint/mandatory functions	SchedulingOptionsIssue	name
Use of unconventional logic - start to finish	SchedulingOptionsIssue	name
Use of long or negative lag times	SchedulingOptionsIssue	name
That occur at the same time: Concurrent delay	DefinitionOfConcurrentDelaysIssue	name
That occur sequentially but effects felt at the same time: Sequential Delays with Concurrency effect	DefinitionOfConcurrentDelaysIssue	name
Easy rule	AnalysisOfConcurrentDelaysIssue	name
Fair rule	AnalysisOfConcurrentDelaysIssue	name
Inability to identify the progress of the project at the time the delay occurred	DrawbacksOfAnalysisTechniquesIssue	name
Inability to identify the changing/dynamic nature of the critical path	DrawbacksOfAnalysisTechniquesIssue	name
Inability to identify mitigation/acceleration/the effects of action taken to minimize potential delays	DrawbacksOfAnalysisTechniquesIssue	name
Inability to identify the effects of time shortened activities	DrawbacksOfAnalysisTechniquesIssue	name
Inability to identify the effect of early completion	DrawbacksOfAnalysisTechniquesIssue	name
Inability to identify the effects of inter-dependence of delays	DrawbacksOfAnalysisTechniquesIssue	name
Inability to identify concurrency	DrawbacksOfAnalysisTechniquesIssue	name
Inability to identify resequencing of programme	DrawbacksOfAnalysisTechniquesIssue	name
Inability to identify redistribution of resources	DrawbacksOfAnalysisTechniquesIssue	name
Adequate update to preserve dynamic nature of the schedules	UsageOfAnalysisTechniqueIssue	name
Adequate selection of the window size/the fragnet itself	UsageOfAnalysisTechniqueIssue	name
Inadequate consideration of baseline changes along the project	UsageOfAnalysisTechniqueIssue	name
No consideration of resource (over-)allocation in delay analysis	UsageOfAnalysisTechniqueIssue	name
Site report	Tender	name
Geological report	Tender	name

Table A.1: Instance table of the delay analysis ontology (continued)

Instance name	**Concept name**	**Attribute**
Time is of the essence clause	ContractClauses	name
Contract performance period: Commencement of contract time (Contract award and Notice to proceed) and Contract completion	ContractClauses	name
Interim milestones clause	ContractClauses	name
Practical completion/Substantial completion and initial certificate	ContractClauses	name
Defects liability period clause	ContractClauses	name
Final completion and certificate	ContractClauses	name
Early occupancy clause	ContractClauses	name
Exclusion clauses	ContractClauses	name
Notice provisions: Time of notice, Notice procedures, Actual notice, Oral notice, Prejudice and Waiver	ContractClauses	name
Scheduling provisions	ContractClauses	name
Ownership of float clauses	ContractClauses	name
Records clause/Clauses for documentation	ContractClauses	name
Coordination clauses	ContractClauses	name
Changes clause/Variation clause	ContractClauses	name
Differing site conditions clause: Type1/Type2 conditions, Site inspection, Schedule extensions, Recovery of costs and Disclaimers	ContractClauses	name
Force majeure clauses	ContractClauses	name
Exculpatory clauses: No damages for delay clause	ContractClauses	name
Suspension of work clause	ContractClauses	name
Termination clauses: Termination for default and Termination for convenience	ContractClauses	name
Extension of time clause	ContractClauses	name
Delay damages clauses/Loss and expense clause	ContractClauses	name
Liquidated damages clause	ContractClauses	name
Valuation clause	ContractClauses	name
Bonus or incentive clauses/Early completion clause	ContractClauses	name
Clauses related to claims	ContractClauses	name
Disputes clause	ContractClauses	name
Narrative schedules	Schedules	name
Gantt charts/Bar chart schedules	Schedules	name
Linear scheduling/Lobscheduling	Schedules	name
CPM scheduling	Schedules	name
As-planned schedule: the original schedule	MajorSchedules	name
Adjusted/Updated schedule: schedule depicting impacts by changes on as-planned schedule	MajorSchedules	name
As-built schedule: actual/final adjusted schedule	MajorSchedules	name
Entitlement schedule: impacted as-planned schedules/collapsed as-built schedules	MajorSchedules	name
As-projected schedule: schedule created for the remainder of the project	MajorSchedules	name
Schedule of resources to comply with the original and each revision	ParticularSchedules	name

Table A.1: Instance table of the delay analysis ontology (continued)

Instance name	**Concept name**	**Attribute**
Schedule of anticipated plant output	ParticularSchedules	name
Schedule of anticipated productivity for various activities	ParticularSchedules	name
Schedule of anticipated overtime (and the costs thereof) in order to comply with the original and each revision	ParticularSchedules	name
Schedule showing required access dates	ParticularSchedules	name
Schedule of design freeze dates	ParticularSchedules	name
Schedule of information release	ParticularSchedules	name
Further descriptive schedules necessary for use	ParticularSchedules	name
Drawing register: details of amendments and revisions made to plans	Registers	name
Risk register	Registers	name
Project records/reports diary	Diaries	name
Site/Field reports diary	Diaries	name
Construction progress reports diary	Diaries	name
Weather reports diary	Diaries	name
Temperature reports diary	Diaries	name
Resource assignments and allocation reports diary	Diaries	name
Labor records diary	Diaries	name
Foremen reports diary	Diaries	name
Equipment records diary	Diaries	name
Material records diary	Diaries	name
Personal diaries	Diaries	name
Diaries of key staff	Diaries	name
Simple appointment diaries kept by those involved in the project	Diaries	name
Daily logs	Logs	name
Submittal logs	Logs	name
Request for information (RFI) log	Logs	name
Contract document clarification (CDC) log	Logs	name
Potential cost/schedule (PCI) incidents log	Logs	name
Change order log	Logs	name
Claims' log	Logs	name
Time sheets for field labor	SiteRecords	name
Transmission sheets	SiteRecords	name
Punch lists	SiteRecords	name
Purchase orders with suppliers	SiteRecords	name
Materials invoices/receipts	SiteRecords	name
Delivery records of equipment and materials	SiteRecords	name
Wage sheets/Payroll records	SiteRecords	name
Records of resource data and costs	SiteRecords	name
Pay requests	SiteRecords	name
Plant records	SiteRecords	name
Records of supervision and inspection	SiteRecords	name
Records of weather conditions and its effect on progress	SiteRecords	name
Area release forms	SiteRecords	name
System turnover packages	SiteRecords	name

Table A.1: Instance table of the delay analysis ontology (continued)

Instance name	Concept name	Attribute
Labor productivity reports	Reports	name
Material receiving reports (MRRs)	Reports	name
Equipment utilization reports	Reports	name
Daily inspection reports (DIR)	Reports	name
Contractor caused disruption (CCD) report	Reports	name
Cost reporting data	Reports	name
Weekly and monthly reports	Reports	name
CPM reports with narrative with each updating	Reports	name
Quality control reports	Reports	name
Accident and site safety report	Reports	name
Occurrence reports	Reports	name
Reports on special aspects which have arisen	Reports	name
Instructions issued by architect	FormalSubmittals	name
Directions issued by the contractor	FormalSubmittals	name
Confirmations of oral instructions or directions	FormalSubmittals	name
Notices and other formal documents	FormalSubmittals	name
Change order forms	FormalSubmittals	name
Files on delays and disturbance	FormalSubmittals	name
Files on time extensions	FormalSubmittals	name
Architect's certificates for payment	FormalSubmittals	name
Architect's certificates especially on matters other than payment	FormalSubmittals	name
Interim valuations in support of architect's certificates for payment	FormalSubmittals	name
Records of actual resources	RecordsOfActualData	name
Records of actual plant output on key activities	RecordsOfActualData	name
Records of actual productivity on key activities	RecordsOfActualData	name
Records of actual cash flow	RecordsOfActualData	name
Records of actual overtime worked and the costs thereof	RecordsOfActualData	name
Cost and value of work executed each month (for the project)	RecordsOfAccountingData	name
Cost and value of work executed each month for all projects (company turnover)	RecordsOfAccountingData	name
Allowance for overheads and profit in the tender sum	RecordsOfAccountingData	name
Cost of head office overheads each month (quarterly or yearly if not monthly basis)	RecordsOfAccountingData	name
Profit (or loss) made by the company for each accounting period	RecordsOfAccountingData	name
Cash flow forecast based on the original and each revision	RecordsOfAccountingData	name
Statements prepared for the calculation of fluctuations on the traditional basis	RecordsOfAccountingData	name
Progress payment applications and certificates	RecordsOfAccountingData	name
Dated photographs of the site at large or of special pieces of work	MediaRecords	name
Video records showing sequence and method of working	MediaRecords	name
Tape recordings	MediaRecords	name

Table A.1: Instance table of the delay analysis ontology (continued)

Instance name	Concept name	Attribute
Computer records	MediaRecords	name
Memos to the file	Notes	name
Individual and private compositions	Notes	name
General correspondence	CorrespondenceData	name
Project correspondence	CorrespondenceData	name
Job site correspondence	CorrespondenceData	name
Correspondence between parties to the contract	CorrespondenceData	name
Correspondence between members of the professional team	CorrespondenceData	name
Correspondence with subcontractors and consultants	CorrespondenceData	name
Correspondence with statutory undertakers	CorrespondenceData	name
Correspondence with third parties	CorrespondenceData	name
Correspondence by e-mails	CorrespondenceData	name
Correspondence by letters	CorrespondenceData	name
Correspondence by fax messages	CorrespondenceData	name
Notes of telephone calls	CorrespondenceData	name
Notes of conversations	CorrespondenceData	name
Personal observation by the owner's field team and CPM consultant	WitnessData	name
The statements of the personnel involved in the project	WitnessData	name
Expert witness statements	WitnessData	name
Site investigation	WitnessData	name
Interviews	WitnessData	name
i.Entropy technique	StaticTechniques	name
ii.Scatter diagram technique	StaticTechniques	name
iii.S-curve technique/Dollar to time relationship/Technique based on dollars	StaticTechniques	name
iv.Global impact technique (Bar chart analysis)	StaticTechniques	name
v.Net impact technique (Bar chart analysis)	StaticTechniques	name
i.As-planned vs as-built technique	DynamicTechniques	name
ii.Impacted as-planned technique	DynamicTechniques	name
iii.Collapsed as-built technique (/But for) (Unit subtractive/Gross subtractive)	DynamicTechniques	name
iv.Window analysis technique (/Snapshot/Current period analysis (CPA))	DynamicTechniques	name
v.Time impact analysis technique (/Fragnet)	DynamicTechniques	name
Simple	AdvantagesOfGlobalImpactTechnique	name
Inexpensive	AdvantagesOfGlobalImpactTechnique	name
Easy to understand and use	AdvantagesOfGlobalImpactTechnique	name
No need to detailed as-built information	AdvantagesOfGlobalImpactTechnique	name
Easy when detailed calculations not possible	AdvantagesOfGlobalImpactTechnique	name

Table A.1: Instance table of the delay analysis ontology (continued)

Instance name	**Concept name**	**Attribute**
Simple	AdvantagesOfNetImpactTechnique	name
Inexpensive	AdvantagesOfNetImpactTechnique	name
Easy to understand and use	AdvantagesOfNetImpactTechnique	name
No need to detailed as-built information	AdvantagesOfNetImpactTechnique	name
Partial refinement in concurrent issue	AdvantagesOfNetImpactTechnique	name
Simple	AdvantagesOfAsPlannedVsAsBuiltTechnique	name
Inexpensive	AdvantagesOfAsPlannedVsAsBuiltTechnique	name
Easy to understand and use	AdvantagesOfAsPlannedVsAsBuiltTechnique	name
No need for networked schedule	AdvantagesOfAsPlannedVsAsBuiltTechnique	name
Not much requirement to adjusted schedule	AdvantagesOfAsPlannedVsAsBuiltTechnique	name
As-planned and as-built schedules are both taken into consideration	AdvantagesOfAsPlannedVsAsBuiltTechnique	name
Simple	AdvantagesOfImpactedAsPlannedTechnique	name
Easy to understand and use	AdvantagesOfImpactedAsPlannedTechnique	name
No need an as-built schedule	AdvantagesOfImpactedAsPlannedTechnique	name
Not much requirement to adjusted schedule	AdvantagesOfImpactedAsPlannedTechnique	name
Simple	AdvantagesOfCollapsedAsBuiltTechnique	name
Inexpensive	AdvantagesOfCollapsedAsBuiltTechnique	name
Easy to understand and use	AdvantagesOfCollapsedAsBuiltTechnique	name
Incurs less time and effort	AdvantagesOfCollapsedAsBuiltTechnique	name
Factual information based less theoretical	AdvantagesOfCollapsedAsBuiltTechnique	name
Uses only one schedule	AdvantagesOfCollapsedAsBuiltTechnique	name
No requirement to as-planned schedule	AdvantagesOfCollapsedAsBuiltTechnique	name
Results with good accuracy	AdvantagesOfCollapsedAsBuiltTechnique	name
Concurrent delays recognized	AdvantagesOfWindowsAnalysisTechnique	name
Ability to scrutinize delay types	AdvantagesOfWindowsAnalysisTechnique	name

Table A.1: Instance table of the delay analysis ontology (continued)

Instance name	Concept name	Attribute
Effect of each delay in CPM is recognized	AdvantagesOfWindowsAnalysisTechnique	name
Ability to take care of the dynamic nature of critical path	AdvantagesOfWindowsAnalysisTechnique	name
Assess mitigation	AdvantagesOfWindowsAnalysisTechnique	name
Consider actual progress and revised programs	AdvantagesOfWindowsAnalysisTechnique	name
Most credible and reliable results	AdvantagesOfTimeImpactAnalysisTechnique	name
Dynamic nature of CPM is recognized	AdvantagesOfTimeImpactAnalysisTechnique	name
Ability to scrutinize delay types	AdvantagesOfTimeImpactAnalysisTechnique	name
Ability to assess consumption of float	AdvantagesOfTimeImpactAnalysisTechnique	name
Concurrent delays recognized	AdvantagesOfTimeImpactAnalysisTechnique	name
Acceleration recognized	AdvantagesOfTimeImpactAnalysisTechnique	name
Resequencing recognized	AdvantagesOfTimeImpactAnalysisTechnique	name
Disruption recognized	AdvantagesOfTimeImpactAnalysisTechnique	name
Effect of particular delay in CPM is taken into consideration	AdvantagesOfTimeImpactAnalysisTechnique	name
Recommended by Society for Computers and Law (SCL)	AdvantagesOfTimeImpactAnalysisTechnique	name
Consider actual progress and revised programs	AdvantagesOfTimeImpactAnalysisTechnique	name
Planned schedule is taken into consideration	AdvantagesOfTimeImpactAnalysisTechnique	name
Contemporaneous analysis of delays is possible	AdvantagesOfTimeImpactAnalysisTechnique	name
Concurrent delays not recognized	DisadvantagesOfGlobalImpactTechnique	name
Not scrutinize delay types	DisadvantagesOfGlobalImpactTechnique	name
Not demonstrate cause and effect	DisadvantagesOfGlobalImpactTechnique	name
Failure to consider the dynamic nature of critical path	DisadvantagesOfGlobalImpactTechnique	name
Ignores reality	DisadvantagesOfGlobalImpactTechnique	name
Overestimates total delay	DisadvantagesOfGlobalImpactTechnique	name
Concurrent delays not recognized	DisadvantagesOfNetImpactTechnique	name
Not scrutinize delay types	DisadvantagesOfNetImpactTechnique	name

Table A.1: Instance table of the delay analysis ontology (continued)

Instance name	Concept name	Attribute
Not demonstrate cause and effect	DisadvantagesOfNetImpactTechnique	name
Failure to consider the dynamic nature of critical path	DisadvantagesOfNetImpactTechnique	name
No network so no true effect on completion	DisadvantagesOfNetImpactTechnique	name
Acceleration not recognized	DisadvantagesOfNetImpactTechnique	name
Disruption not recognized	DisadvantagesOfNetImpactTechnique	name
Not much reliable	DisadvantagesOfAsPlannedVsAsBuiltTechnique	name
Not dealing events separately	DisadvantagesOfAsPlannedVsAsBuiltTechnique	name
Lacks systematic procedure	DisadvantagesOfAsPlannedVsAsBuiltTechnique	name
Failure to consider the dynamic nature of critical path	DisadvantagesOfAsPlannedVsAsBuiltTechnique	name
Not scrutinize delay types (depends)	DisadvantagesOfAsPlannedVsAsBuiltTechnique	name
Not demonstrate cause and effect	DisadvantagesOfAsPlannedVsAsBuiltTechnique	name
Concurrent delays not recognized (depends)	DisadvantagesOfAsPlannedVsAsBuiltTechnique	name
Redistribution of resources not recognized	DisadvantagesOfAsPlannedVsAsBuiltTechnique	name
Resequencing of work not recognized	DisadvantagesOfAsPlannedVsAsBuiltTechnique	name
Mitigation not recognized	DisadvantagesOfAsPlannedVsAsBuiltTechnique	name
Acceleration not recognized (depends)	DisadvantagesOfAsPlannedVsAsBuiltTechnique	name
Need for as-planned and as-built schedules	DisadvantagesOfAsPlannedVsAsBuiltTechnique	name
Inability to deal with complex delay situations	DisadvantagesOfAsPlannedVsAsBuiltTechnique	name
Used only retrospectively	DisadvantagesOfAsPlannedVsAsBuiltTechnique	name
Very theoretical method	DisadvantagesOfImpactedAsPlannedTechnique	name
Relies heavily on the planned schedule not the actual work performed	DisadvantagesOfImpactedAsPlannedTechnique	name
Assumption of that the planned construction sequence remains valid	DisadvantagesOfImpactedAsPlannedTechnique	name
Ignores actual as-built schedule	DisadvantagesOfImpactedAsPlannedTechnique	name
Ignores the changes to programme logic	DisadvantagesOfImpactedAsPlannedTechnique	name
Concurrent delays not recognized	DisadvantagesOfImpactedAsPlannedTechnique	name

Table A.1: Instance table of the delay analysis ontology (continued)

Instance name	**Concept name**	**Attribute**
Acceleration not recognized	DisadvantagesOfImpactedAs PlannedTechnique	name
Resequencing not recognized	DisadvantagesOfImpactedAs PlannedTechnique	name
Failure to consider the dynamic nature of critical path	DisadvantagesOfImpactedAs PlannedTechnique	name
Inability to deal with complex delay situations	DisadvantagesOfImpactedAs PlannedTechnique	name
Highly subjective	DisadvantagesOfCollapsedAs BuiltTechnique	name
Failure to consider the dynamic nature of critical path	DisadvantagesOfCollapsedAs BuiltTechnique	name
Concurrent delays not recognized	DisadvantagesOfCollapsedAs BuiltTechnique	name
Resequencing not recognized	DisadvantagesOfCollapsedAs BuiltTechnique	name
Redistribution of resources not recognized	DisadvantagesOfCollapsedAs BuiltTechnique	name
Acceleration not recognized	DisadvantagesOfCollapsedAs BuiltTechnique	name
Mitigation not recognized	DisadvantagesOfCollapsedAs BuiltTechnique	name
Changes not recognized	DisadvantagesOfCollapsedAs BuiltTechnique	name
Great deal effort in identifying the as-built critical path	DisadvantagesOfCollapsedAs BuiltTechnique	name
Accuracy depend on the quality of the information based	DisadvantagesOfCollapsedAs BuiltTechnique	name
Depends on as-built schedule only	DisadvantagesOfCollapsedAs BuiltTechnique	name
Ignores the as-planned schedule	DisadvantagesOfCollapsedAs BuiltTechnique	name
Expensive	DisadvantagesOfWindowsAn alysisTechnique	name
Considerable time and effort is required	DisadvantagesOfWindowsAn alysisTechnique	name
Ambiguity in concurrent delays due to selection of period	DisadvantagesOfWindowsAn alysisTechnique	name
No mechanism for time shortened activities	DisadvantagesOfWindowsAn alysisTechnique	name
Detailed project records are needed	DisadvantagesOfWindowsAn alysisTechnique	name
Expensive	DisadvantagesOfTimeImpact AnalysisTechnique	name
Difficult to understand	DisadvantagesOfTimeImpact AnalysisTechnique	name
Takes time and effort	DisadvantagesOfTimeImpact AnalysisTechnique	name
Requires large amount of information	DisadvantagesOfTimeImpact AnalysisTechnique	name

Table A.1: Instance table of the delay analysis ontology (continued)

Instance name	**Concept name**	**Attribute**
Need to have good accurate documentation on site	DisadvantagesOfTimeImpact AnalysisTechnique	name
Hindsight: retrospective analysis/actual delays	TimeOfAnalysis	name
Real time: contemporaneous analysis/potential delays	TimeOfAnalysis	name
Foresight: prospective analysis/potential delays	TimeOfAnalysis	name
Float consumption/Critical path	CapabilitiesOfTechniques	name
Concurrent delay	CapabilitiesOfTechniques	name
Resequencing/Changes	CapabilitiesOfTechniques	name
Dynamic nature of CPM	CapabilitiesOfTechniques	name
Acceleration	CapabilitiesOfTechniques	name
Bar chart schedules/Small project	ScheduleTypeQuality	name
CPM network schedules/Large project	ScheduleTypeQuality	name
As-planned schedule	ScheduleUsed	name
As-built schedule	ScheduleUsed	name
Contemporaneous schedules	ScheduleUsed	name
Adjusted schedules	ScheduleUsed	name
Fragnets	ScheduleUsed	name
Only as-built records	AvailabilityOfData	name
Only networked as-planned programme	AvailabilityOfData	name
Only bar chart and no CPM	AvailabilityOfData	name
No planned network programme and no as-built records	AvailabilityOfData	name
Good as-planned network programme and no update/no as-built records	AvailabilityOfData	name
No/poor as-planned programme - Little scheduling information and good as-built records	AvailabilityOfData	name
Networked/Unnetworked as-planned programme and networked/unnetworked as-built programme	AvailabilityOfData	name
Updated as-planned programme and little/no information on network logic	AvailabilityOfData	name
Unnetworked as-planned programme and as-built records	AvailabilityOfData	name
Networked as-planned and not updated	AvailabilityOfData	name
Networked as-planned programme and as-built records	AvailabilityOfData	name
Networked as-planned and updated networked as-planned	AvailabilityOfData	name
Observative	TypeOfAnalysis	name
Additive	TypeOfAnalysis	name
Subtractive	TypeOfAnalysis	name
Only justification of time: Extension of time/Entitlement-based (theoretical) techniques	NatureOfClaim	name
Also for recovery of money/reimbursement of loss and expense: Compensation/Actual-based techniques	NatureOfClaim	name
Moderate	AmountInClaim	name
High	AmountInClaim	name
Low	TimeCostEffortAllocatedFor Analysis	name
Moderate	TimeCostEffortAllocatedFor Analysis	name

Table A.1: Instance table of the delay analysis ontology (continued)

Instance name	Concept name	Attribute
High	TimeCostEffortAllocatedForAnalysis	name
Short duration project/Small contract values: Simple techniques	ProjectDurationScaleComplexity	name
Long duration project/High contract values: Sophisticated techniques	ProjectDurationScaleComplexity	name
Inexperienced staff: Simple techniques	AvailabilityOfExpertiseSoftware	name
Experienced staff/Specialized approach: Sophisticated techniques	AvailabilityOfExpertiseSoftware	name
Get acquainted with all project documents.	i.GatherDataAvailable	name
Understand contractor submitted claim (if exists).	i.GatherDataAvailable	name
Analyze contractor's original CPM schedule (determine appropriateness: is it realistic and reasonable?).	ii.AnalyzeOriginalSchedule	name
Examine the level of detail in work breakdown structure (WBS).	ii.AnalyzeOriginalSchedule	name
Examine the logic utilized to interrelate various activities (examine logical relationships and lead-lag factors between activities).	ii.AnalyzeOriginalSchedule	name
Examine the durations imposed to activities.	ii.AnalyzeOriginalSchedule	name
Examine the planned production rate of activities through parameters of duration and amount of work accomplished in that duration.	ii.AnalyzeOriginalSchedule	name
Examine the project resources' utilization.	ii.AnalyzeOriginalSchedule	name
Develop project's as-built schedule (ABS) (if not provided).	iii.DevelopAsBuiltSchedule	name
Summarize daily inspection reports to serve as foundation.	iii.DevelopAsBuiltSchedule	name
Plot daily inspection reports (DIR) summary sheets.	iii.DevelopAsBuiltSchedule	name
Develop various levels of detail for ABS.	iii.DevelopAsBuiltSchedule	name
Compare actual dates, duration, and logic with original ones by superimposing the schedules in CPM.	iv.AnalyzeAsBuiltSchedule	name
Calculate actual production rates and compare with original ones.	iv.AnalyzeAsBuiltSchedule	name
Compare actual resources utilized with planned ones.	iv.AnalyzeAsBuiltSchedule	name
Identify and analyze delay disruption periods.	i.IdentifyDelayPeriod	name
Identify when the delay occurred.	i.IdentifyDelayPeriod	name
Identify how long the delay lasted.	i.IdentifyDelayPeriod	name
Identify what notice was given formal or informal.	i.IdentifyDelayPeriod	name
Analyze cause and effect of specific issues.	ii.AnalyzeCauseAndEffect	name
Identify which activity the delay affected.	ii.AnalyzeCauseAndEffect	name
Identify what caused the delay.	ii.AnalyzeCauseAndEffect	name
Identify who was responsible for the act or omission that caused the delay.	ii.AnalyzeCauseAndEffect	name
Identify which particular day or days the delay affected and to what extent.	ii.AnalyzeCauseAndEffect	name
Identify and analyze concurrent delays.	iii.IdentifyConcurrentDelays	name
Apply adequate technique for analyzing delay claims: contemporaneous period analysis technique (CPAT).	iv.ApplyAnalysisTechnique	name

Table A.1: Instance table of the delay analysis ontology (continued)

Instance name	Concept name	Attribute
Identify and classify the first relevant event.	iv.ApplyAnalysisTechnique	name
Identify progress at that delay date.	iv.ApplyAnalysisTechnique	name
Update and reanalyze the network: specify the project is ahead or behind the schedule at delay date.	iv.ApplyAnalysisTechnique	name
Simulate the first relevant event and reanalyze the network: specify the potential delay.	iv.ApplyAnalysisTechnique	name
Consider mitigating action.	iv.ApplyAnalysisTechnique	name
Consider the effect of omissions.	iv.ApplyAnalysisTechnique	name
Apply the same procedure for subsequent relevant events.	iv.ApplyAnalysisTechnique	name
Analyze and evaluate the contractor submitted claim (if applicable).	v.AnalyzeClaim	name
Summarize various analyses to calculate compensations of time or cost.	vi.CalculateCompensations	name
Present the results with a tally of category of delays and corresponding completion dates.	vii.PresentResults	name
Conduct effective meetings to discuss, negotiate, and settle claims.	viii.NegotiateClaim	name
Standard forms of contract should be used, as both parties are generally familiar with the obligations assumed by each party.	ContractRelatedPreventionMatters	name
Special contracting provisions and practices that have been used successfully on past projects should be used.	ContractRelatedPreventionMatters	name
Proper production of contract documentation and reasonable interpretation of the contract should be achieved.	ContractRelatedPreventionMatters	name
Proper, complete and consistent contract documents, work details, drawings and specifications have to be ready and provided before commencement of work.	ContractRelatedPreventionMatters	name
Clarity, common sense, and precision in the drafting of contract language with no ambiguity should be provided.	ContractRelatedPreventionMatters	name
Adequate time should be provided to plan and develop the contract documentation.	ContractRelatedPreventionMatters	name
Accurate initial cost estimates should be provided in the contract documentation.	ContractRelatedPreventionMatters	name
Detailed examination and acceptance of tender focused on pricing and programme is needed.	ContractRelatedPreventionMatters	name
Owner should make sure that adequate provision has been allowed in tender prices for the fulfillment of statutory and contractual responsibilities.	ContractRelatedPreventionMatters	name
The contract should be read several times before signing it to understand any unclear clauses.	ContractRelatedPreventionMatters	name
The quality of documentation that is produced should be improved, initially by adhering to policies and procedures, especially those embedded within quality assurance.	ContractRelatedPreventionMatters	name
Attention should be paid to contract details, such as making sure the language versions of the contract are consistent with each other.	ContractRelatedPreventionMatters	name

Table A.1: Instance table of the delay analysis ontology (continued)

Instance name	**Concept name**	**Attribute**
There should be single point responsibility for managing and coordinating the documentation process.	ContractRelatedPreventionMatters	name
Before signing of contract clear analysis of needings should be determined by both parties.	ContractRelatedPreventionMatters	name
Providing a third party to read contract documents before the bidding stage is needed.	ContractRelatedPreventionMatters	name
The contract details should be studied by a lawyer before signing or entering into an agreement.	ContractRelatedPreventionMatters	name
Adopting a new approach to contract award procedure by giving less weight to prices and more weight to the capabilities and past performance of contractors is needed.	ContractRelatedPreventionMatters	name
Owner should reject exceptionally low bids which have not taken proper account of the risks involved.	ContractRelatedPreventionMatters	name
Instead of competitive tendering use of negotiated or selective tendering with a policy whereby contractors openly present their margins and how they priced the project relies trust and cooperation between parties.	ContractRelatedPreventionMatters	name
Reliable contractor's tender policy should be provided.	ContractRelatedPreventionMatters	name
Adopting new approaches to contracting such as design-build and construction management (CM) types of contracts is needed.	ContractRelatedPreventionMatters	name
Greater consideration should be given to procurement method selection/contracting.	ContractRelatedPreventionMatters	name
Partnering should be introduced as a new form of contract to develop cooperative and problem solving attitudes on projects through a risk-sharing philosophy and by establishing trust among partners.	ContractRelatedPreventionMatters	name
Clear agreement on the period of notice to commence for mobilization is needed.	ContractRelatedPreventionMatters	name
Clear agreement on the timetables of information and other requirements is needed.	ContractRelatedPreventionMatters	name
Proper site handing over and possession provided by proper recording especially for the dates and chorology of events of the site handing over is needed.	ContractRelatedPreventionMatters	name
Complete definition of scope from inception to completion and mutually understanding is needed.	ContractRelatedPreventionMatters	name
Insuring the sufficiency of drawings and specifications by strengthening the language and content of clauses by including comprehensive scheduling provisions and voiding unrealistic performances is needed.	ContractRelatedPreventionMatters	name
Owners should incorporate requirements for scheduling and schedule control in the contract documents.	ContractRelatedPreventionMatters	name
Clear agreement on drawing and delivery process with schedule (between contractors and consultants) for preparation, submittal and approval of drawings is needed.	ContractRelatedPreventionMatters	name
Realistic and agreed-upon time schedules by all parties should be established.	ContractRelatedPreventionMatters	name

Table A.1: Instance table of the delay analysis ontology (continued)

Instance name	Concept name	Attribute
Clear agreement on software for preparation of program is needed.	ContractRelatedPreventionMatters	name
Clear agreement on options of scheduling tool like decision of scheduling logic mode to be used as retained logic or progress override is needed.	ContractRelatedPreventionMatters	name
Clear agreement on the factors of various issues of delay analysis is needed.	ContractRelatedPreventionMatters	name
Clear agreement on the procedure for maintaining and updating the program is needed.	ContractRelatedPreventionMatters	name
Clear agreement on ownership of float is needed.	ContractRelatedPreventionMatters	name
Clear agreement on treatment of concurrent delays is needed.	ContractRelatedPreventionMatters	name
Clear agreement on procedure for gathering and keeping records and rules of evidence for claims is needed.	ContractRelatedPreventionMatters	name
Clear provisions on approval of the works should be provided.	ContractRelatedPreventionMatters	name
Clear provisions on variations and provisional sums should be provided.	ContractRelatedPreventionMatters	name
Clear provisions on problems with site possession, access, ground and other conditions is needed.	ContractRelatedPreventionMatters	name
Clear provisions on certificates and payment are needed: agreements on how payments are paid, when they are paid, and in which currency, etc.	ContractRelatedPreventionMatters	name
Exact terms of performance standards should be specified.	ContractRelatedPreventionMatters	name
The contract should include a change order provision and provide a proper mechanism for processing and evaluating change orders.	ContractRelatedPreventionMatters	name
Care should be taken by the owner on the scheduling clauses, change orders, and delay damages clauses.	ContractRelatedPreventionMatters	name
If the contract is rampant with exculpatory language, especially in the area of no-damages-for-delay, the contractor should carefully consider accepting the risks involved because some projects are not worth the risk of bidding.	ContractRelatedPreventionMatters	name
Reasonable time frame for notice should be considered in contract, given the opportunity for parties to ensure that work can be altered or accomplish as required by notice given.	ContractRelatedPreventionMatters	name
Clear agreement on notice provisions in contract documents, including how, when, and to whom notice of problems must be given.	ContractRelatedPreventionMatters	name
Clear agreement on method of dispute resolution that has the confidence of all parties with the dispute resolution clause is needed.	ContractRelatedPreventionMatters	name
Parties might negotiate and agree on methodologies, techniques, and procedure for assessing and resolving different aspects of delay and disruption claims.	ContractRelatedPreventionMatters	name
Establishment of proactive claims management in contract is needed.	ContractRelatedPreventionMatters	name

Table A.1: Instance table of the delay analysis ontology (continued)

Instance name	Concept name	Attribute
Establishing time limits for the filing of claims by the contractor should be considered.	ContractRelatedPreventionMatters	name
Clear agreement on acceleration procedure and its compensation is needed.	ContractRelatedPreventionMatters	name
Clear agreement on claim for payment of interest on compensation is needed - the rate of interest and the circumstances in which it will be paid.	ContractRelatedPreventionMatters	name
Clear agreement on cost of preparing claims is needed - whether claimable or not.	ContractRelatedPreventionMatters	name
Enforcing liquidated damage clauses and offering incentives for early completion is needed.	ContractRelatedPreventionMatters	name
Including provision of adequate compensation to contractors and consultants is needed.	ContractRelatedPreventionMatters	name
Contractor should properly inspect and examine the site and its surroundings in detail and to satisfy himself before submitting his tender and signing the contract.	ContractRelatedPreventionMatters	name
Contractor shall be fully responsible for the review of the engineering design and details of the works and shall inform the employer of any mistakes or incorrectness in such design and details which would affect the works.	ContractRelatedPreventionMatters	name
Once the time for the completion was made to be essence and fixed in the contract, parties should make sure that they were actually bonded to the contract to provide timely delivery of project.	ContractRelatedPreventionMatters	name
Clear description of assessment on final certificate and claim for work done is needed.	ContractRelatedPreventionMatters	name
Control of subcontracting on quality, programme, design and price should be established.	ContractRelatedPreventionMatters	name
Risk assessment should be conducted to identify areas of potential problems and to establish proactive management of risk.	RiskRelatedPreventionMatters	name
A realistic risk assessment should be devised by consulting experts for reliable sources.	RiskRelatedPreventionMatters	name
More than media sources or immediate partners should be used to evaluate the risks, and always there should be a contingency plan for an emergency.	RiskRelatedPreventionMatters	name
Adequate contingency allowance should be used for potential additional costs in areas of uncertainty.	RiskRelatedPreventionMatters	name
Owners should exercise robust change control/risk mitigation plan, with particular emphasis on comprehensive project planning and risk assessment at the projects from their outset.	RiskRelatedPreventionMatters	name
Achieving a more equitable/fair allocation of risks between contracting parties should be provided.	RiskRelatedPreventionMatters	name
Allocation of risks to the parties that can best control it is needed to increase the integrity and acceptance of the contract and to have positive impact on parties' relationships.	RiskRelatedPreventionMatters	name
A risk register is needed in place for the project as early as possible (e.g. from tender stage).	RiskRelatedPreventionMatters	name

Table A.1: Instance table of the delay analysis ontology (continued)

Instance name	Concept name	Attribute
Proper identification, allocation and management of risks should be provided.	RiskRelatedPreventionMatters	name
Cost and/or time implication should be assigned to all identified risks on the risk register whenever possible.	RiskRelatedPreventionMatters	name
The risk register should be ensured to be open to all relevant members of the project team.	RiskRelatedPreventionMatters	name
A strategy already developed is needed to solve each of the identified risks in case they come to fruition.	RiskRelatedPreventionMatters	name
A risk workshop should be conducted involving all relevant project parties at the outset of the project in order to identify potential risks.	RiskRelatedPreventionMatters	name
Encouraging, emphasizing and striving for a risk sharing regime should be provided when possible (it may aid in buttressing partnership and openness among the project parties).	RiskRelatedPreventionMatters	name
Risks should not be used to mask project problems or deficiencies in planning.	RiskRelatedPreventionMatters	name
Looking out for opportunities is needed to improve cost and time performance during risk analysis.	RiskRelatedPreventionMatters	name
Project participants should be familiar with significant causes of delays and plan to avoid or at least mitigate their impact on project success.	RiskRelatedPreventionMatters	name
Developing human resource management is needed to help improve labor skills and productivity.	RelationsRelatedPreventionMatters	name
Behavioral assessment of project team members should be made.	RelationsRelatedPreventionMatters	name
Having a sound understanding of the staff's personality type is needed - their emotional intelligence and how they are able to cope with the pressures associated with their role in the specific project.	RelationsRelatedPreventionMatters	name
Development of an emotionally intelligent team that is able to stimulate creativity and solve problems that arise during design and construction to manage conflict more effectively and resolve issues through negotiation should be provided.	RelationsRelatedPreventionMatters	name
Relations at multiple levels - senior management and project level - should be promoted.	RelationsRelatedPreventionMatters	name
Teambuilding should be conducted to develop common project goals and processes, and discuss interests and expectations.	RelationsRelatedPreventionMatters	name
Joint training in negotiations and problem-solving should be set up.	RelationsRelatedPreventionMatters	name
The sharing of knowledge through the establishment of inter-organizational communities of practice would encourage joint problem solving and possibly reduce the incidence of conflict between parties.	RelationsRelatedPreventionMatters	name
Owners should ensure appropriate allocation of responsibilities among project participants and enforce a clear accountability structure within their own organization.	RelationsRelatedPreventionMatters	name

Table A.1: Instance table of the delay analysis ontology (continued)

Instance name	**Concept name**	**Attribute**
The role and responsibility of respective parties should be understood clearly before the commencement of project whether is in the main contract or subcontract work.	RelationsRelatedPreventionMatters	name
The roles of superintendent officer, either the architect or engineer, should be given full control authorization for his execution of work; immediate instruction can be obtained in fast way to expedite of work progress.	RelationsRelatedPreventionMatters	name
Problem solving ability should be increased with processes and policies that promote fast decision making at the project level.	RelationsRelatedPreventionMatters	name
Owner should devise ways to improve the authority structure and decision-making mechanism in their organizations.	RelationsRelatedPreventionMatters	name
Everyone in the project should be kept informed about actions of each other during the project.	RelationsRelatedPreventionMatters	name
Establishment of good faith cooperation between the parties is needed.	RelationsRelatedPreventionMatters	name
Project participants should establish and maintain open lines of communication.	RelationsRelatedPreventionMatters	name
The communication of plans should be improved from planners to users (e.g., have meetings to discuss work scope in detail with contractors).	RelationsRelatedPreventionMatters	name
More frequent site meetings should be held between the parties, in order to verify that the works are progressing normally and are executed in accordance with the contract.	RelationsRelatedPreventionMatters	name
Continuous involvement of stakeholders in constructive dialogue should be provided.	RelationsRelatedPreventionMatters	name
Constructability reviews should be conducted to reduce the interaction between operations during the different stages of the project.	RelationsRelatedPreventionMatters	name
Owners should develop a better understanding of the different facets of the construction delivery process, set clear project requirements and maintain close involvement in project implementation.	RelationsRelatedPreventionMatters	name
Value engineering should be used and constructability should be implemented during the different stages of the project.	RelationsRelatedPreventionMatters	name
Continuous work-training programs should be established for personnel to update their knowledge and be familiar with project management techniques and processes and have effective and efficient performances.	RelationsRelatedPreventionMatters	name
Employers, consultants and contractors should adopt a proactive approach in resolving claims and disputes by providing proper training and relevant resources to ensure effective implementation.	RelationsRelatedPreventionMatters	name
Developing a crack skill qualification framework is needed in order to provide career paths for tradesmen.	RelationsRelatedPreventionMatters	name

Table A.1: Instance table of the delay analysis ontology (continued)

Instance name	**Concept name**	**Attribute**
Top management of owners should drive improvements in safety performance through proper procurement and contractual arrangements.	RelationsRelatedPreventionMatters	name
Owners and project teams should secure teamwork, good practice and commitment from all parties at a project level through a jointly developed project pact.	RelationsRelatedPreventionMatters	name
Owners should prohibit total subletting and exercise tighter control over the performance and management of subcontractors.	RelationsRelatedPreventionMatters	name
Reliable production management process should be established to improve the reliability of workflow.	RelationsRelatedPreventionMatters	name
Application of various project management techniques have to be made from the conception to the completion stage, which include managing various risks associated with the project in its every stage.	ManagementRelatedPreventionMatters	name
Skillful and determined management are required both before and during construction to handle the threats and challenges that lead to claims.	ManagementRelatedPreventionMatters	name
An effective disciplinary mechanism should be developed to tackle non-performers by sharing information among owners on the performance of their consultants and contractors.	ManagementRelatedPreventionMatters	name
All team members should be paid realistic level of fees for the work they undertake.	ManagementRelatedPreventionMatters	name
Selection of contractors and consultants should be done with great attention.	ManagementRelatedPreventionMatters	name
The selected contractor must have sufficient experience, technical capability, financial capability, and sufficient manpower to execute the project.	ManagementRelatedPreventionMatters	name
Contractors should make sure that their company organization is compatible with the size and type of the job they undertake.	ManagementRelatedPreventionMatters	name
Owners should agree with subcontractors in light of contractors.	ManagementRelatedPreventionMatters	name
Assignment of experienced managers and superintendents/site supervisors with strong cooperative skills and attitudes is needed.	ManagementRelatedPreventionMatters	name
Hiring of an independent supervising engineer is needed to monitor the progress of the work and ensure timely delivery of materials.	ManagementRelatedPreventionMatters	name
Owners, consultants and contractors should ensure that they have the right personnel with the right qualifications to manage their projects.	ManagementRelatedPreventionMatters	name
All construction stakeholders (owner, consultants, designers and contractors) should form an independent commission for performance evaluation.	ManagementRelatedPreventionMatters	name
Proper site management and (monitoring) supervision should be established.	ManagementRelatedPreventionMatters	name
All project participants should recognize that conflicts are inevitable and the conflict management is a needed to produce a good working environment.	ManagementRelatedPreventionMatters	name

Table A.1: Instance table of the delay analysis ontology (continued)

Instance name	Concept name	Attribute
Improved intelligence on market conditions should be provided.	ManagementRelatedPreventionMatters	name
Up-to-date technology utilization should be established.	ManagementRelatedPreventionMatters	name
Using of proper and modern construction equipment is required.	ManagementRelatedPreventionMatters	name
Appropriate funding levels should always be determined at the planning stage of the project so that regular payment should be paid to all parties.	ManagementRelatedPreventionMatters	name
Adequate and available source of finance should be ensured.	ManagementRelatedPreventionMatters	name
Attention should be paid not to deal with insolvent partners.	ManagementRelatedPreventionMatters	name
Owners must insure the works and people.	ManagementRelatedPreventionMatters	name
Proper planning, scheduling, documenting and coordination of works by contractor during planning are needed.	SchedulingRelatedPreventionMatters	name
A realistic project schedule should be established that secures the involvement and agreement of all project participants should be prepared and routinely updated and maintained.	SchedulingRelatedPreventionMatters	name
A preconstruction planning of project tasks and resource needs should be performed.	SchedulingRelatedPreventionMatters	name
Contractor should provide a properly organized labor and material histograms with a resource schedule.	SchedulingRelatedPreventionMatters	name
Contractor should properly identify the dates that he is likely to require certain information from owner/architect.	SchedulingRelatedPreventionMatters	name
A strategy on how to deal with tighter scheduling requirements should be established.	SchedulingRelatedPreventionMatters	name
Being capable of appropriate use of the methodologies is needed with multidisciplinary knowledge, understanding, and skills, particularly in the areas of scheduling, construction methods, estimating, costing, construction law, and information technology tools.	SchedulingRelatedPreventionMatters	name
A well-trained construction manager must not only understand the benefits and shortcomings of each approach, but also why a particular approach may or may not be well suited for analyzing the delay encountered.	SchedulingRelatedPreventionMatters	name
Proper understanding of the problems and adequate use of management tools is needed.	SchedulingRelatedPreventionMatters	name
The project manager must be aware of the different scheduling capabilities and options for each software tool.	SchedulingRelatedPreventionMatters	name
Proper training in the use of any software is essential.	SchedulingRelatedPreventionMatters	name
Critical-path-method scheduling, cost control and productivity analysis should be used to monitor progress and detect any change in productivity and/or cost.	SchedulingRelatedPreventionMatters	name

Table A.1: Instance table of the delay analysis ontology (continued)

Instance name	**Concept name**	**Attribute**
Breaking the project down into manageable chunks is needed.	PreventionMattersForComplexityOfWorks	name
Making sure the project is properly understood before embarking on it is needed.	PreventionMattersForComplexityOfWorks	name
Detailed review of the information relating to the work before embarking on it is needed.	PreventionMattersForComplexityOfWorks	name
A project execution plan should be developed for the work before starting on it.	PreventionMattersForComplexityOfWorks	name
Having enough resources to deal with the complexity is needed.	PreventionMattersForComplexityOfWorks	name
Allocating to the project experienced personnel that have handled similar type of complexity in the past is needed.	PreventionMattersForComplexityOfWorks	name
Incorporating longer lead-in time/sufficient time for complex works or phases of the project is required.	PreventionMattersForComplexityOfWorks	name
Ensuring as much design as possible is done for the complex work or project before commencing is needed.	PreventionMattersForComplexityOfWorks	name
Ensuring adequate coordination of design and activities preceding and following the complex work is required.	PreventionMattersForComplexityOfWorks	name
Calling in specialists to advise and contribute to the planning and management of complex works/projects should be provided.	PreventionMattersForComplexityOfWorks	name
Utilizing in-house expertise for the management of complex projects is needed.	PreventionMattersForComplexityOfWorks	name
Conducting workshops and brainstorming session to generate ideas and for problem-solving before and during the complex work/project is needed.	PreventionMattersForComplexityOfWorks	name
Overlaying a risk analysis process specifically for a complex phase or activity in a project is required.	PreventionMattersForComplexityOfWorks	name
One team should run with the complex work/project from beginning to the end where possible and practical.	PreventionMattersForComplexityOfWorks	name
One should think holistically when planning a complex project by considering logistics, interfaces, etc. e.g. having a preconstruction services department that will not only plan the project but take a holistic look at the project rather than just having planning department as customary.	PreventionMattersForComplexityOfWorks	name
Subcontractors should be ensured with the capability to deal with the complexity is procured for the project when needed.	PreventionMattersForComplexityOfWorks	name
Getting as much information on the complex part of the project and sequence all activities is required.	PreventionMattersForComplexityOfWorks	name
Ensuring every element of the design has an aspect on the programme and using 4D modeling to show how the work will be built (i.e. have a plan and test it to see how it works) is advised.	PreventionMattersForComplexityOfWorks	name
When a complex project is broken down into manageable chunks, one should clearly understand how the complexities interact with each other.	PreventionMattersForComplexityOfWorks	name
Building in the risk of delay and higher cost allowances for complex projects is needed.	PreventionMattersForComplexityOfWorks	name

Table A.1: Instance table of the delay analysis ontology (continued)

Instance name	**Concept name**	**Attribute**
Ensuring the project planner is well trained in the construction process is required.	ProjectDurationRelatedPreventionMatters	name
Preparation of the project programme with input from the construction site management/ production team is required.	ProjectDurationRelatedPreventionMatters	name
The programme should be developed using science based methods augmented by experience and not relying on gut feeling alone.	ProjectDurationRelatedPreventionMatters	name
Owner should be educated and advised on alternative if an unachievable/unrealistic project timescale is stipulated.	ProjectDurationRelatedPreventionMatters	name
Owners who are unwilling to yield to professional advice must have the courage to refuse unrealistic project timescale.	ProjectDurationRelatedPreventionMatters	name
Developing the project programme of works using experienced planners that have appreciation of the various construction disciplines is needed.	ProjectDurationRelatedPreventionMatters	name
A process mapping exercise should be conducted to validate the time allocated to a project.	ProjectDurationRelatedPreventionMatters	name
Enough time should be allocated during tender planning for the proper development of the project programme.	ProjectDurationRelatedPreventionMatters	name
One should make sure when possible that the programme is developed by or in conjunction with someone that is experienced in the relevant type of project.	ProjectDurationRelatedPreventionMatters	name
One should make sure the programme is built up from the first principle using metrics of how long typical activities take rather than using assessment only (ensuring that the time allocated to activities is quantifiable).	ProjectDurationRelatedPreventionMatters	name
Proper design reviews and audits should be established.	DesignRelatedPreventionMatters	name
The overall project schedule should be ensured that it includes adequate time for all parties to perform their work, including design phase, bid phase and contract duration.	DesignRelatedPreventionMatters	name
Comprehensive and complete design preparation at the right time should be provided.	DesignRelatedPreventionMatters	name
Reasonable time for the design team should be allowed to produce clear and complete design and documentation.	DesignRelatedPreventionMatters	name
Owners should allow sufficient time for proper consideration of all relevant factors of a project and to mobilize the necessary resources to deliver projects.	DesignRelatedPreventionMatters	name
Owners must make sure that sufficient time, money and effort are allocated to the feasibility study and design process.	DesignRelatedPreventionMatters	name
Owners should consult with knowledgeable advisors to determine a reasonable duration to specify in the contract documents.	DesignRelatedPreventionMatters	name

Table A.1: Instance table of the delay analysis ontology (continued)

Instance name	Concept name	Attribute
Designers should analyze in a careful, detailed manner to determine the time required to perform the work considering the project, the site, the weather, and so forth.	DesignRelatedPreventionMatters	name
Involvement of contractor earlier in the design process is needed to resolve planning issues that occur on-site.	DesignRelatedPreventionMatters	name
Owners and stakeholders (e.g. end-users) need to be kept constantly informed and integrated within the design process.	DesignRelatedPreventionMatters	name
Efficient quality control techniques and mechanisms that can be used during the design process to minimize errors, mismatches, and discrepancies in contact documents must be established.	DesignRelatedPreventionMatters	name
Clear distinction between a design change and a design development should be made at the outset of a project.	DesignRelatedPreventionMatters	name
The cause of a design change should be always determined.	DesignRelatedPreventionMatters	name
Determination of the provision of the design change within the building contract is required.	DesignRelatedPreventionMatters	name
Identification of potential design changes as a risk and devising a strategy for managing the risk is needed especially in design and build projects.	DesignRelatedPreventionMatters	name
The project should be designed in great detail at the outset whenever possible.	DesignRelatedPreventionMatters	name
Change management procedure should be agreed and put in place before the commencement of projects (incorporating this into the contract if possible).	DesignRelatedPreventionMatters	name
Open discussion by the relevant project party should be provided before the project start about how design changes will be managed and incorporating this into the contract if possible.	DesignRelatedPreventionMatters	name
Contractors need to act early to obtain permits and approvals from the different government agencies.	ContractorRelatedPreventionMatters	name
Contractors must plan their work properly and provide the entire schedule to the owners.	ContractorRelatedPreventionMatters	name
Contractor should assess the time allowed by the contract to determine if enough time is provided to perform the work without the use of extraordinary resources.	ContractorRelatedPreventionMatters	name
Contractors must include in its bid the cost for additional effort (such as overtime) required to meet the contract completion date.	ContractorRelatedPreventionMatters	name
Contractors should approach every contract with the intent of early completion.	ContractorRelatedPreventionMatters	name
Contractors must make sure they have a sound financial backing.	ContractorRelatedPreventionMatters	name
Appropriate construction methods should be selected by contractor.	ContractorRelatedPreventionMatters	name
Contractor should provide a proper method statement showing the construction technique.	ContractorRelatedPreventionMatters	name
Effective and efficient material procurement systems should be established within projects by contractors.	ContractorRelatedPreventionMatters	name

Table A.1: Instance table of the delay analysis ontology (continued)

Instance name	**Concept name**	**Attribute**
Thorough resource planning and development of the project concept is needed by contractors.	ContractorRelatedPrevention Matters	name
Contractors need to give awareness on level of labor's skill, supervisor's ability to coordinate the project, quality of equipment and material used in order to minimize the problems.	ContractorRelatedPrevention Matters	name
Contractors should be aware of stock control problems with materials and should consider using more effective material scheduling techniques.	ContractorRelatedPrevention Matters	name
Subcontractors should clearly communicate to the general contractor the time and schedule to which the bid applies.	SubcontractorRelatedPreventi onMatters	name
Subcontractors should seriously consider whether to bid on contracts with extensive exculpatory (general contractor protective) language or not.	SubcontractorRelatedPreventi onMatters	name
Properly directing the subcontractor is needed to ensure that they know what is expected of them in relation to the project.	SubcontractorRelatedPreventi onMatters	name
Developing a good working relationship with subcontractors is essential.	SubcontractorRelatedPreventi onMatters	name
A system for early identification of non-performance in subcontract works/packages should be put in place in order to nip it in the bud as soon as possible.	SubcontractorRelatedPreventi onMatters	name
Performance measurements should be utilized to monitor the output/performance of subcontractors on their work package.	SubcontractorRelatedPreventi onMatters	name
A committed supply chain that can be used should be ensured.	SubcontractorRelatedPreventi onMatters	name
A process in place is needed that mutually allows non-performing subcontractors to be removed from the supply chain.	SubcontractorRelatedPreventi onMatters	name
A partnering/collaborative relationship with the subcontractor should be ensured (this may ensure the subcontractor gives a better than normal service).	SubcontractorRelatedPreventi onMatters	name
A progress-performance-payment rule in the subcontract should be incorporated where possible, e.g. that stipulates a certain amount can only be earned/paid when certain requirements have been met/a stage has been achieved in the project.	SubcontractorRelatedPreventi onMatters	name
A stringent process is needed in place for selecting subcontractors into the supply chain.	SubcontractorRelatedPreventi onMatters	name
Subcontractors doing major/critical part of the project should be involved with the internal planning process, i.e. early involvement of relevant subcontractors, e.g. at pre-tender stage in order to advise on design before having cost and time implications (early engagement).	SubcontractorRelatedPreventi onMatters	name
A prompt system of payment to subcontractors for jobs that have been done should be ensured (this boosts morale and may prevent financial difficulty by subcontractor).	SubcontractorRelatedPreventi onMatters	name

Table A.1: Instance table of the delay analysis ontology (continued)

Instance name	Concept name	Attribute
Relationship and communicating at management/board level of the subcontractors' companies should be built.	SubcontractorRelatedPreventionMatters	name
Holding significant retention on serial non-performing subcontractors is needed as it may serve as a deterrent/be used to remedy any non-performance issue that may occur.	SubcontractorRelatedPreventionMatters	name
Reduction of the retention is advisable for trusted and the best performing subcontractors.	SubcontractorRelatedPreventionMatters	name
Finding and understanding the root cause of any non-performance and working with the subcontractor is needed to see how to be of help.	SubcontractorRelatedPreventionMatters	name
Going through the different layers of the subcontractor's management is needed to ensure that a nonperformance situation is improved.	SubcontractorRelatedPreventionMatters	name
The selection of the cheapest subcontractor should be avoided if there is doubt on performance track record.	SubcontractorRelatedPreventionMatters	name
Taking time to understand the implementation strategy a subcontractor intends to adopt for a subcontract package and ensuring it fits well with the cost and time performance requirements of the project is needed.	SubcontractorRelatedPreventionMatters	name
One should make sure subcontractors are allocated adequate time to complete subcontract work packages.	SubcontractorRelatedPreventionMatters	name
Seeing the benefits in having a small but quality closely knit supply chain that is well known rather than having a large supply chain where subcontractors are hardly known is required.	SubcontractorRelatedPreventionMatters	name
Sharing with individual subcontractors their evaluations and reviewing their weaknesses with them so that they can improve on it going forward is advisable.	SubcontractorRelatedPreventionMatters	name
One should have knowledge of the best projects the company's subcontractors are best able to undertake and allocate these to them and avoid giving subcontractors projects they are not good at.	SubcontractorRelatedPreventionMatters	name
Having a training system/regime in place for subcontractors is needed in order to indoctrinate them in the ways of the company, e.g. control processes, tools and techniques, etc. (and they will have no excuses to say they don't know what you want).	SubcontractorRelatedPreventionMatters	name
Having more than one subcontractor for a particular trade/package to encourage healthy competition is needed.	SubcontractorRelatedPreventionMatters	name
Proper knowledge of contract during construction and referring the contract all the time is needed.	ContractImplementationRelatedPreventionMatters	name
Proper operation of contract machinery is needed.	ContractImplementationRelatedPreventionMatters	name
A consistent and complete project documentation should be maintained from start to finish.	ContractImplementationRelatedPreventionMatters	name
Good practice and coordination should be established during execution of works.	ContractImplementationRelatedPreventionMatters	name
Effective scheduling and rescheduling during execution of works is needed.	ContractImplementationRelatedPreventionMatters	name

Table A.1: Instance table of the delay analysis ontology (continued)

Instance name	Concept name	Attribute
Contractor should properly track progress of project via updated plan.	TrackingRelatedPreventionMatters	name
Contractor should collate and maintain adequate, relevant and contemporaneous information of the project.	TrackingRelatedPreventionMatters	name
Contemporaneous project schedules and updating should be used to keep the analysis objective and reliable.	TrackingRelatedPreventionMatters	name
As with creating and updating schedule, one must have a familiarity with scheduling terminology and be able to accurately interpret the data and results displayed by the schedule.	TrackingRelatedPreventionMatters	name
Updating the schedule periodically is needed to make it continue to reflect the contractor's as-built progress to-date and current as-planned schedule for performing the remaining work.	TrackingRelatedPreventionMatters	name
Maintaining proper job records on a timely manner is needed.	TrackingRelatedPreventionMatters	name
Programs should be get accepted and updated in time.	TrackingRelatedPreventionMatters	name
The work should be monitored closely by making inspections at appropriate times.	TrackingRelatedPreventionMatters	name
Owner's representative should ensure quality project work, project safety, and/or compliance with environmental regulations.	TrackingRelatedPreventionMatters	name
All lights, guards, fencing and watching for the protection of the works should be provided and maintained and the materials and equipment should be utilized therefore for the safety and convenience of the public or others.	TrackingRelatedPreventionMatters	name
Consultants should produce documentation properly undertaking design verifications, reviews and audits.	TrackingRelatedPreventionMatters	name
Consultants should improve their internal management practices by involving and providing a sense of ownership of the process.	TrackingRelatedPreventionMatters	name
Required information should be delivered to correct person in the right manner to avoid any late transmission of information.	TrackingRelatedPreventionMatters	name
The relationship between parties has to be preserved no matter since how long the relationship had established.	TrackingRelatedPreventionMatters	name
Owner should make site available at the right time.	OwnerRelatedPreventionMatters	name
Owner should provide continuous access to the site.	OwnerRelatedPreventionMatters	name
Owner should provide sufficient info in sufficient time to enable the contractor to carry out the works by the due completion date.	OwnerRelatedPreventionMatters	name
Owner should not interfere frequently during the execution and keep making major changes to the requirements.	OwnerRelatedPreventionMatters	name
Owner should work closely with the financing bodies and institutions to release the payment on schedule during construction.	OwnerRelatedPreventionMatters	name

Table A.1: Instance table of the delay analysis ontology (continued)

Instance name	**Concept name**	**Attribute**
Owner must make quick decisions to solve any problem that arise during the execution of work.	OwnerRelatedPreventionMatters	name
Owner should ensure that negotiation in relation to payment issue is carried out in proper manner during construction.	OwnerRelatedPreventionMatters	name
Owner should take certain action in emergency.	OwnerRelatedPreventionMatters	name
Contractor should timely carry out the directions of architect through change orders.	ChangeRelatedPreventionMatters	name
Focus is needed on minimization of change orders.	ChangeRelatedPreventionMatters	name
Timely responses to needs should be provided.	ChangeRelatedPreventionMatters	name
Changes should be dealt with when they occur involving all main participants.	ChangeRelatedPreventionMatters	name
All the relevant project parties should be notified of how they will be impacted and the schedule and cost implication of a change before going ahead with the change.	ChangeRelatedPreventionMatters	name
Owner's representative must manage changes and change order process.	ChangeRelatedPreventionMatters	name
Qualification of change orders is needed before signing-off to preserve the rights when risk of extra damages exists.	ChangeRelatedPreventionMatters	name
Ensuring the time and cost implication of a change is always determined and agreed before going ahead with the change whenever possible.	ChangeRelatedPreventionMatters	name
If a contractor submits a change request because of a design problem, the designer must take all necessary measures to ensure that its decisions are fair and impartial.	ChangeRelatedPreventionMatters	name
The basis for payment in advance should be agreed on before the accelerative measures are taken.	ChangeRelatedPreventionMatters	name
Change orders must be signed before starting doing these changes on site.	ChangeRelatedPreventionMatters	name
Provision/allocation of enough resources (labor, equipment, etc.) is needed to cope with a design change.	ChangeRelatedPreventionMatters	name
Design changes should be adequately highlighted and updated on all relevant project documentations (e.g. drawings, specifications, reports, etc.).	ChangeRelatedPreventionMatters	name
Ensuring prompt resolution to design change queries, issues and authorization requests is needed.	ChangeRelatedPreventionMatters	name
All design changes should be captured on a register with corresponding cost and schedule implications for discussion during project team meetings.	ChangeRelatedPreventionMatters	name
A design manager is needed where possible with responsibility for the management of the design change process and reviewing related information as it comes in.	ChangeRelatedPreventionMatters	name
No one should make a design change without the knowledge or authorization of the relevant project party, e.g. project manager.	ChangeRelatedPreventionMatters	name

Table A.1: Instance table of the delay analysis ontology (continued)

Instance name	Concept name	Attribute
Efficient analysis of the direct and indirect consequence (domino effect) of a design change on other activities or areas of the project is needed as one change can precipitate other changes.	ChangeRelatedPreventionMatters	name
Design changes should be reasonably timed when possible, e.g. late design changes may greatly impact the ability to control the project cost and schedule.	ChangeRelatedPreventionMatters	name
Freezing design at the appropriate stage of a project or implementing intermediate design freezes at various project stages depending on the type of contract is needed.	ChangeRelatedPreventionMatters	name
The risk register should not be solely kept in the corporate office but communicated to the construction management and site team as well.	ChangeRelatedPreventionMatters	name
The risk register should be reviewed at all relevant progress meetings including meetings with the site based team.	ChangeRelatedPreventionMatters	name
The risk register should be a live document that is updated regularly.	ChangeRelatedPreventionMatters	name
The relevant project parties should be swiftly informed if unforeseen circumstances affect the programme/lead-in times.	ChangeRelatedPreventionMatters	name
Constantly monitoring the progress and being open minded to improving the programme and cost plan is required as things become clearer and to other options available.	ChangeRelatedPreventionMatters	name
Integration of subcontractors into the site management team (where possible, practicable and feasible) is needed all through the course of the work.	ChangeRelatedPreventionMatters	name
The contractor should be notified as early as possible of any employer delays of which architect is aware.	DelayResponseRelatedPreventionMatters	name
Contractor should give reasonable notice of delay or any of claim in time to architect, contract administrator, engineer or project manager.	DelayResponseRelatedPreventionMatters	name
Contractor should immediately take reasonable steps to mitigate the effect in case of a delay as it is stated in contract.	DelayResponseRelatedPreventionMatters	name
Contractor should identify the causes of delay and relevant event, give particulars of the expected effects, estimate the extent and tell the story.	DelayResponseRelatedPreventionMatters	name
Contractor should establish the documentation of all delays and changes in writing in a timely manner.	DelayResponseRelatedPreventionMatters	name
Filing notice of potential claims is needed for preservation of rights.	ClaimingRelatedPreventionMatters	name
Proper devising of the documentation system for claims is needed.	ClaimingRelatedPreventionMatters	name
An overall comprehensive step-by-step procedure should be followed for tracking and managing the claims submitted by contractors.	ClaimingRelatedPreventionMatters	name
Claims should be submitted by closely following the steps stipulated in the contract conditions.	ClaimingRelatedPreventionMatters	name

Table A.1: Instance table of the delay analysis ontology (continued)

Instance name	Concept name	Attribute
All applicable notice requirements under the contract must be fulfilled before a contractor is entitled to compensation for a delay claim.	ClaimingRelatedPreventionMatters	name
Contractors should know their rights with the suspension of work and claiming for damages exactly and timely use them if needed.	ClaimingRelatedPreventionMatters	name
Once a claim has been presented, the owner and contractor should come to an agreement concerning the claim.	ClaimingRelatedPreventionMatters	name
Timely dispute resolution processes should be provided.	ClaimResponseRelatedPreventionMatters	name
Responding in time to contractor's claims and awarding for excusable delays is needed.	ClaimResponseRelatedPreventionMatters	name
Owner's representative should be able to evaluate time extensions and additional costs by properly maintaining a current CPM schedule and detailed performance records, and by seeking adequate information from the contractor	ClaimResponseRelatedPreventionMatters	name
Extensions of time should be dealt with as soon as possible after the delaying event is recognized leading to the requirement for interim assessments.	ClaimResponseRelatedPreventionMatters	name
If the analyst notes serious errors in the logic of the schedule, he or she should consider not accepting the contractor's schedule as a valid tool to measure the delays.	PreventionMattersDuringAnalysis	name
The analyst must not change the logic or durations to produce a schedule that seems more representative.	PreventionMattersDuringAnalysis	name
If the as-built schedule is complex, reconstruction of as-built schedule with the available information is required.	PreventionMattersDuringAnalysis	name
The validity of the schedule is subjective; therefore, the analyst should always seek help from a qualified scheduling consultant before making this determination.	PreventionMattersDuringAnalysis	name
If the schedule does not reflect the reality of the job progress, then it may be wiser to abandon the schedule and perform a delay analysis using the as-built approach.	PreventionMattersDuringAnalysis	name
Upon reviewing the CPM schedule, the analyst may question the validity of the durations assigned to specific activities based on his or her own knowledge of the project, estimating skills, and experience.	PreventionMattersDuringAnalysis	name
The delay analysis should rely on the contemporaneous project schedules as the basis of analysis to create objectivity as much as possible.	PreventionMattersDuringAnalysis	name
The analysis must accurately consider the contemporaneous information when the delays were occurring.	PreventionMattersDuringAnalysis	name
When a contemporaneous schedule is not available to measure critical project delays, the analyst should use an as-built analysis to identify the critical delay, which is based on an as-built diagram.	PreventionMattersDuringAnalysis	name
Schedules should not be created after the fact that: Creating schedules after the fact that for measuring delays should be prevented.	PreventionMattersDuringAnalysis	name

Table A.1: Instance table of the delay analysis ontology (continued)

The analyst should be familiar with the specific software used to create and update the schedules, given the different scheduling options available in each software package.	PreventionMattersDuringAnalysis	name
The analyst should gather all of the contractor's schedules throughout the duration of the project - the as-planned schedule and all subsequent schedule updates.	PreventionMattersDuringAnalysis	name
The analyst should get "electronic copies" - a copy of the computer file - for each of the schedules.	PreventionMattersDuringAnalysis	name
A review of project correspondence or as-built information near the time of the schedule revisions should assist the analyst in determining the causes.	PreventionMattersDuringAnalysis	name
The analyst should focus on determining the source and magnitude of all critical project delays without regard to the party responsible to achieve an objective analysis.	PreventionMattersDuringAnalysis	name
First the analyst should find what the delay is irrespective of the reliable party, determining the party responsible for this delay should be a separate task.	PreventionMattersDuringAnalysis	name
The analysis should account and identify for all project delays and savings throughout the duration of the project.	PreventionMattersDuringAnalysis	name
When assessing the contractor's entitlement to compensation for prolongation, the site overheads included in the tender should not be used.	PreventionMattersDuringAnalysis	name
For disruption ''the measured mile'' approach (i.e., comparing the same work in disrupted and undisrupted conditions) is suggested as the best way to handle it.	PreventionMattersDuringAnalysis	name